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Absorption Studies of Some Agricultural Solid Wastes as Biosorbent for the Clean-up of Oil Spill

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Abstract: *Oil spills are a major environmental threat, causing ecological, economic, and health issues. Traditional cleanup methods like chemical dispersants, in-situ burning, and synthetic sorbents have drawbacks such as secondary pollution and high costs. This study investigates the use of agricultural solid wastes—pineapple leaves, pineapple peels, and oil palm empty fruit bunch (OPEFB)—as biosorbents for oil spill cleanup. The biosorbents were evaluated for their oil sorption capacities under different temperatures and contact times. The oil sorption capacity for the milled samples at 25 °C showed that the standard synthetic sorbent had the highest capacity, reaching 14.08 g/g, while pineapple leaves had a peak capacity of 7.92 g/g at 3 minutes before stabilizing around 5.5 - 6.0 g/g. Pineapple peel and OPEFB exhibited lower capacities of 1.30 g/g and 2.66 g/g, respectively. At 30 °C, the standard sorbent again had the highest capacity at 14.73 g/g, with pineapple leaves reaching 8.13 g/g, OPEFB at 3.02 g/g, and pineapple peels at 1.96 g/g. The reusability and recovery efficiency of these materials were also assessed, with pineapple leaves showing high reusability (90 ± 0.01%) and recovery efficiency (90 ± 1.35%) at 25°C. The study demonstrates the potential of pineapple leaves as a viable biosorbent for oil spill remediation, given their relatively high and consistent oil sorption capacity and reusability. Pineapple peel and OPEFB, while less effective, could be considered for low-cost or supplementary adsorption materials. Further research is recommended to optimize these biosorbents and explore their practical applications in varying environmental conditions.*

Keywords: *Pineapple leave, pineapple peel, oil palm empty fruit bunch, oil spill, sorption capacity*

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1.0 Introduction

Oil spills are a significant environmental hazard, leading to severe ecological damage, economic losses, and health risks. Traditional methods for oil spill cleanup include chemical dispersants, in-situ burning, and synthetic sorbents, which, while effective, often pose secondary environmental risks and high costs (Yap *et al*., 2019). Consequently, there is a growing interest in utilizing natural, biodegradable materials as sorbents for oil spill remediation. Agricultural solid wastes, such as pineapple peel, pineapple leaves, and palm oil empty fruit bunch (OPEFB), have emerged as potential candidates due to their abundance, low cost, and biodegradability (Adebajo *et al*., 2021;Choi & Cloud, 2019; Kelle. 2018; Kelle and Eboatu, 2018a,b).

Recent studies have explored the use of various agricultural wastes for oil sorption. For instance, Lim and Huang (2022) investigated the use of coconut coir and rice husk, finding that these materials demonstrated significant oil sorption capacities. Study conducted by Omar *et al*. (2023) showed that agricultural waste, specifically wheat straw modified via esterification with a hydrophobic benzoyl group, has proven to be an effective, eco-friendly, and economical biosorbent for oil spill cleanup. The modified wheat straw (Str-co-Benz) demonstrated high adsorption capacity, fitting well with the Langmuir adsorption model, and exhibited fast removal kinetics. Additionally, the resultant solid waste from the adsorption process can be repurposed as a fuel in industrial applications, underscoring its utility and sustainability. Report from the work published by Kumagai, *et al*. (2007) indicated that raw and refined (defiberized) Japanese Akita Komachi rice husks were pyrolyzed in a vacuum at 300–800 °C, with the refined husks showing superior adsorption capacity, particularly for B-heavy oil, adsorbing more than 6.0 g of oil with minimal water uptake. The refining process significantly enhances the oil adsorption capacity, whereas carbonization time has a minor effect, indicating that the residual fluid components in the carbonized rice husks play a critical role in oil adsorption, more so than their porosity. Yousaf *et al*. (2021) also observed that orange peel has a high oil sorption capacity that supported its usefulness in oil spill cleanup. Updated research data showed that most agricultural wastes functions most effectively in the removal of oil and other contaminants because of their potential to provide significant adsorption surface (Umoren and Utin, 2024). Adsorption in this context is defined as a separation process for the removal of contaminant through selective attraction to a surface (Eddy *et al*., 2023; Eddy *et al*., 2024a-c)

Despite these advancements, a gap exists in the comprehensive evaluation of the oil sorption capacities of different agricultural wastes, especially under varying environmental conditions. Most studies have focused on a single type of waste or specific temperature and contact time settings. There is limited comparative analysis of different agricultural wastes under a range of operational conditions, which is crucial for determining the most effective and versatile biosorbent. Furthermore, the influence of different factors such as oil type, salinity, and biodegradability over multiple cycles of use has not been extensively studied (Ghaly *et al*., 2019; Rezaei *et al*., 2022).

The aim of this study is to evaluate and compare the oil sorption capacities of pineapple peel, pineapple leaves, and OPEFB under different temperatures and contact times. By systematically analyzing the performance of these natural biosorbents, this research seeks to identify the most efficient material for oil spill cleanup and provide insights into optimizing their use. Additionally, this study aims to assess the reusability and oil recovery efficiency of these materials, contributing to the development of sustainable and eco-friendly solutions for oil spill remediation. This research will also explore the impact of multiple factors such as oil viscosity, water salinity, and biodegradability over repeated cycles of use, providing a comprehensive understanding of the practical applications and limitations of these agricultural wastes as oil sorbents. A bridge for the existing knowledge gap, provide the present study, which is aimed at advancing the field of oil spill remediation and promote the use of sustainable and environmentally friendly materials. The outcomes of this research could significantly contribute to reducing the environmental impact of oil spills and enhancing the efficiency of oil spill response strategies.

2.0. Materials and Methods

2.1. Materials

Crude oil was obtained from Shell Development Company, Port Harcourt, Nigeria. Polypropylene conventional synthetic sorbent used as standard was purchased from McHill Company, Port Harcourt, Nigeria.

2.2. Sample Collection

Pineapple leave and pineapple peel were collected from fruit sellers in Wuse market, Abuja, Nigeria. Oil palm empty fruit bunch (OPEFB) was sourced from local palm oil producers in Akwanga, Nassarawa state, Nigeria.

2.3. Sample Preparation

Pineapple leave, pineapple peel and oil palm empty fruit bunch (OPEFB) were thoroughly washed with water to remove dirt and dried under the sun for 3weeks. The samples were divided into two portions; one portion was milled to a mesh size of 1.12 mm while the other portion was mashed into a sponge – like biomass using laboratory mortar and pestle. Each portion of the sample was stored in properly labelled sample containers.

2.4. Sample Analysis

200 ml of water was poured into a 500 ml beaker and 200 ml of crude oil was added to the water. The less dense oil was dispersed on the water. 1g of sample and synthetic sorbent were each placed on different sieve net and introduced into different crude oil and water mixture and allowed to contact with the crude oil for 1,2, 3,4,5,6,7,8,9 and 10 minutes respectively. At the end of each contact time, the sieve net was removed from the crude oil on water and allowed to drip for 5 mins. The sample was carefully and thoroughly removed from the sieve net and weighed. Absorbed water in sample or standard was determined using Karl Fischer technique described in ASTM D1533-00 (ASTM Standard,2005). The amount of oil recovered from the sample and standard and the reusability of the materials was determined by squeezing out the absorbed oil, after which the sample was reweighed (Hilario *et al*., 2019; Abdelwahad,2014). The experiment was performed at 25 ° C and 30° C for the milled and mashed samples. The oil sorption capacity of the samples and standard was calculated as the weight gain which implies the weight of absorbed oil per unit weight of sample (Wan *et al*., 2015), obtained according to equation 1 below (Abdelwahad,2014)

$$Q_a = \frac{M_b - M_a - M_c}{Ma} \quad (1)$$

where Q_a (g) = oil sorption capacity, M_b = mass of sample or standard after sorption

M_a = mass of sample or standard before sorption and M_c = mass of water absorbed

Reusability and oil recovery efficiency of the materials was calculated as resorption capacity obtained as the ratio of the resorption mass to the initial absorption mass (Hilario *et al*., 2019), determined as weight difference between weight of sample or standard after oil sorption and weight of sample after squeezing plus weight of water recovered per initial sorption mass. The recovery efficiency was expressed in percentage based on equation 2

$$Q_r = \frac{M_b - Md - M_r}{M_i} \quad (2)$$

where Q_r (g) = reusability/recovery efficiency, M_b = mass of sample or standard after sorption M_d = mass of sample or standard after squeezing, M_r = mass of water recovered and M_i = initial sorption mass

3.0. Results and Discussion

The provided plot shows the oil adsorption capacity of four samples (PL, PP, OPEFB, and

Std) over a 10-minute period. The trend lines for each sample are as follows: PL (Pineapple Leaf): The oil adsorption capacity starts at 6.2 g/g and peaks at around 7.92 g/g at 3 minutes. After 4 minutes, it declines and stabilizes around 5.5 - 6.0 g/g. PP (Pineapple Peel): This sample shows a consistently low oil adsorption capacity, starting at 1.17 g/g and slightly increasing to around 1.30 g/g by the 10th minute. OPEFB (Oil Palm Empty Fruit Bunch): The oil adsorption capacity remains relatively low and stable at around 2.29 g/g initially, with a slight increase to approximately 2.66 g/g by the 10th minute. Std (Standard): The standard sample shows the highest oil adsorption capacity, starting at 9.86 g/g and increasing steadily to 14.08 g/g at the 8th minute, before slightly declining to 13.01 g/g by the 10th minute. Table 1 provides the detailed oil sorption capacity values for each sample at specific time intervals. The mean and standard deviation for each sample are also given: PL: 6.23 ± 1.09 g/g, PP: 1.22 ± 0.107 g/g, OPEFB: 2.33 ± 0.599 g/g, Std: 12.63 ± 1.451 g/g. The standard sample (Std) consistently demonstrates the highest oil adsorption capacity throughout the experiment, significantly outperforming the other samples. Pineapple leaf (PL) exhibits moderate oil adsorption capacity, with a peak at 3 minutes before stabilizing at a lower value. Pineapple peel (PP) has the lowest oil adsorption capacity, with minimal changes over time. OPEFB shows slightly higher capacity than PP but remains relatively low compared to PL and Std. The standard sample has the highest mean oil adsorption capacity (12.63 g/g) with a relatively high standard deviation (1.451), indicating variability in adsorption efficiency over time. PL also shows variability (standard deviation of 1.09), which might be due to the nature of the material or experimental conditions. PP and OPEFB show lower variability, indicating more consistent adsorption capacities, although at lower levels compared to Std and PL. The high oil adsorption capacity of the standard sample suggests it is the most effective for oil spill remediation. Pineapple leaf could be a potential alternative for oil adsorption given its moderate capacity and availability. Pineapple peel and OPEFB, while less effective, could still be considered for low-cost or supplementary adsorption materials, especially in less severe spill scenarios. The study reveals significant differences in oil adsorption capacities among the tested samples, with the standard sample showing superior performance. Pineapple leaf also presents a promising option due to its moderate adsorption capacity. Further optimization and cost-benefit analyses are recommended to explore the practical applications of these materials in real-world oil spill remediation.

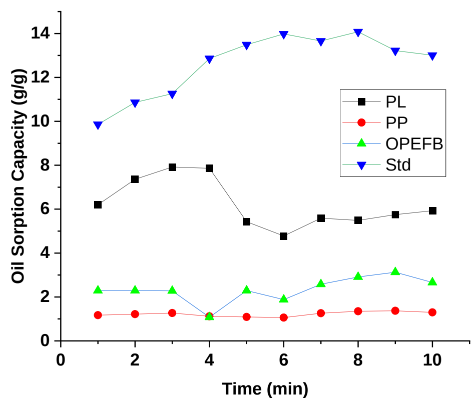

Fig 1: Variation of adsorption capacity of different adsorbents with period of contact 25 ^{o}C

Fig. 2(a and b) illustrates the variation of adsorption capacity for reusability and recovery efficiency of four samples (PL, PP, OPEFB, and Std) over a 10-minute period under reusability test. The reusability values for the samples over time are as follows: PL ranges from 0.88 to 0.92, with a mean of 0.90 ± 0.01; PP ranges from 0.76 to 0.95, with a mean of 0.90 ± 0.06; OPEFB ranges from 0.62 to 0.97, with a mean of 0.87 ± 0.10; Std ranges from 0.81 to 0.90, with a mean of 0.86 ± 0.03. The recovery efficiency percentages over time are: PL ranges from 88% to 92%, with a mean of 90 ± 1.35%; PP ranges from 76% to 95%, with a mean of 90 ± 5.71%; OPEFB ranges from 62% to 97%, with a mean of 87 ± 10.44%; Std ranges from 81% to 90%, with a mean of 86 ± 2.75%.

The plot and the table reveal the following findings: Pineapple leaf (PL) shows high and consistent reusability and recovery efficiency, indicating its potential as a reliable material for repeated oil adsorption cycles. Pineapple peel (PP) also exhibits high reusability and recovery efficiency, although with greater variability, suggesting it might be suitable for oil adsorption but could have performance inconsistencies. OPEFB has a wider range of reusability and recovery efficiency values, with some significantly lower points, particularly at the 6th minute, which might indicate structural or compositional weaknesses affecting its performance under certain conditions. The standard sample (Std) shows consistent but relatively lower reusability and recovery efficiency compared to PL and PP, suggesting it is effective but might not maintain performance as well in repeated use compared to the other materials.

The observed sample indicate that while all samples show potential for reusability and recovery, Pineapple leaf appears to be the most stable and reliable material, followed by Pineapple peel with some variability, and OPEFB showing the most fluctuation in performance. Further research and optimization may help improve the consistency and effectiveness of these materials for practical oil adsorption applications.

Fig. 3 shows the variation of adsorption capacity with time for four samples (Pineapple leave (PL), Pineapple peel (PP), OPEFB, and Standard) at 30°C over a 10-minute period. The oil sorption capacity values for the samples over time are as follows: Pineapple leave (PL) ranges from 5.46 g to 8.13 g, with a mean of 6.92 ± 0.832 g. Pineapple peel (PP) ranges from 1.25 g to 1.96 g/g, with a mean of 1.51 ± 0.241 g/g. OPEFB ranges from 2.48 g to 3.02 g/g, with a mean of 2.72 ± 0.200 g. Standard ranges from 10.01 g to 14.73 g, with a mean of 13.04 ± 1.633 g.

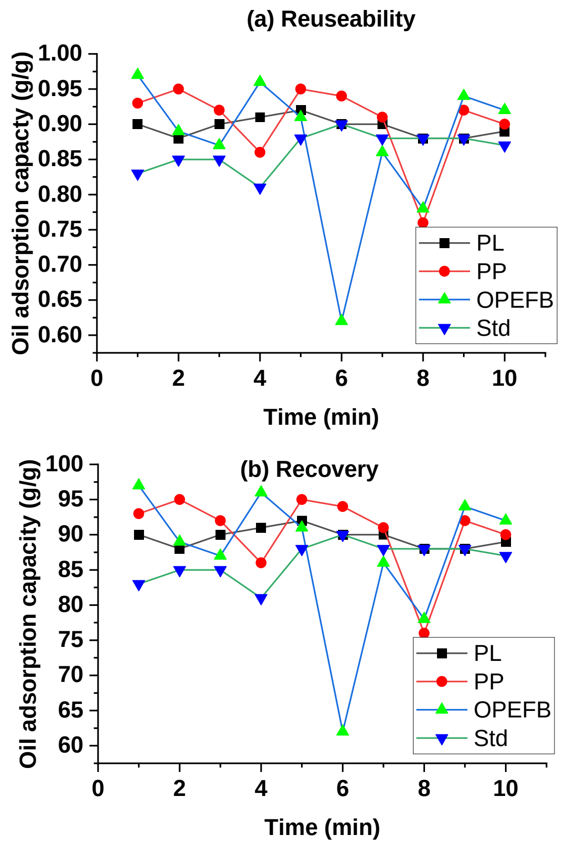

Fig. 2: Variation of adsorption capacity for (a) reusability and (b) recovery efficiency (%) of milled samples and standard at 25 ° C

The plot and the table reveal the following findings: Pineapple leave (PL) shows a relatively high and stable oil sorption capacity, with a peak at 8.13 g/g at the 8th minute, indicating its effective oil adsorption capability at 30°C. Pineapple peel (PP) exhibits lower oil sorption capacity, with minimal variation over time, suggesting its limited effectiveness compared to PL and Standard. OPEFB has a moderate oil sorption capacity with slight fluctuations, indicating it could be useful for oil adsorption but is not as effective as PL or Standard. The standard sample (Std) consistently demonstrates the highest oil sorption capacity, peaking at 14.73 g at the 8th minute, which highlights its superior performance in oil adsorption at 30°C.

The study reveals significant differences in oil sorption capacities among the tested samples at 30°C, with the standard sample showing the highest performance, followed by Pineapple leave, OPEFB, and Pineapple peel. Pineapple leave presents a promising option due to its relatively high and stable sorption capacity. Pineapple peel and OPEFB, while less effective, could still be considered for low-cost or supplementary adsorption materials. Further optimization and cost-benefit analyses are recommended to explore the practical applications of these materials in real-world oil spill remediation at varying temperatures.

The provided data includes a comprehensive analysis of the oil adsorption capacity, reusability, and recovery efficiency of various samples, including Pineapple leave (PL), Pineapple peel (PP), OPEFB, and a standard (Std) sample, at 30°C. Fig. 3 illustrates the variation of adsorption capacity with time, while Fig. 4 and Table 4 detail the reusability and recovery efficiency over a 10-minute period.

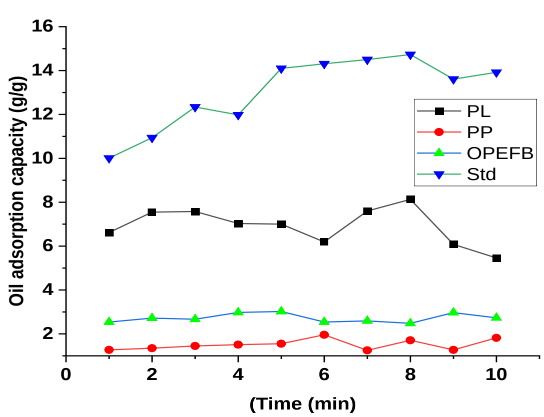

Fig. 3: Variation of adsorption capacity with time for Milled Samples and Standard at 30 °C

The oil sorption capacity values over time for the samples are as follows: Pineapple leave (PL) ranges from 5.46 g/g to 8.13 g/g, with a mean of 6.92 ± 0.832 g/g. Pineapple peel (PP) ranges from 1.25 g to 1.96 g/g, with a mean of 1.51 ± 0.241 g/g. OPEFB ranges from 2.48 g/g to 3.02 g/g, with a mean of 2.72 ± 0.200 g. Standard ranges from 10.01 g to 14.73 g/g, with a mean of 13.04 ± 1.633 g/g.

From Fig. 3, we observe that pineapple leave (PL) has a relatively high and stable oil sorption capacity, peaking at 8.13 g at the 8th minute, indicating its effective oil adsorption capability at 30 °C. Pineapple peel (PP) exhibits lower oil sorption capacity, with minimal variation over time, suggesting its limited effectiveness compared to PL and Standard. OPEFB shows a moderate oil sorption capacity with slight fluctuations, indicating it could be useful for oil adsorption but is not as effective as PL or Standard. The standard sample (Std) consistently demonstrates the highest oil sorption capacity, peaking at 14.73 g/g at the 8th minute, highlighting its superior performance in oil adsorption at 30 °C (Fig. 4). The reusability values for each sample are as follows: Pineapple leave (PL) ranges from 0.88 to 0.93, with a mean of 0.90 ± 0.015; Pineapple peel (PP) ranges from 0.70 to 0.98, with a mean of 0.88 ± 0.090; OPEFB ranges from 0.83 to 0.95, with a mean of 0.87 ± 0.042; Standard ranges from 0.84 to 0.90, with a mean of 0.86 ± 0.022. The recovery efficiency percentages over time are as follows: Pineapple leave (PL) ranges from 88% to 93%, with a mean of 90 ± 1.577%; Pineapple peel (PP) ranges from 70% to 98%, with a mean of 88 ± 9.077%; OPEFB ranges from 83% to 95%, with a mean of 87 ± 4.27%; Standard ranges from 84% to 90%, with a mean of 86 ± 2.213%.

From Fig. 4 (a and b), we observe that Pineapple leave (PL) shows high and consistent reusability and recovery efficiency, indicating its potential as a reliable material for repeated oil adsorption cycles at 30°C. Pineapple peel (PP) also exhibits high reusability and recovery efficiency but with greater variability, suggesting its performance might be less predictable under repeated use. OPEFB has moderate reusability and recovery efficiency, with some fluctuations, indicating it could be a viable option but might have performance inconsistencies. The standard sample (Std) demonstrates relatively lower but consistent reusability and recovery efficiency, suggesting it is effective but may not maintain performance as well in repeated use compared to PL and PP.

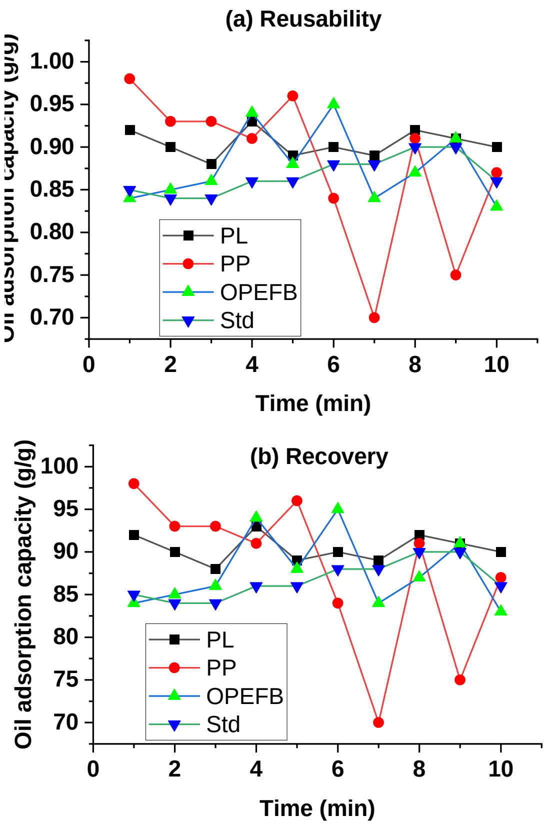

Fig. 4: Variation of oil adsorption capacity with time representing (a) reusability and (b) recovery efficiency (%) of milled samples and standard at 30 °C

The study reveals significant differences in oil sorption capacities, reusability, and recovery efficiency among the tested samples at 30°C. Pineapple leave (PL) appears to be the most stable and reliable material for oil adsorption, followed by Pineapple peel (PP) with some variability, and OPEFB showing moderate and slightly inconsistent performance. The standard sample, while effective, shows lower reusability and recovery efficiency compared to the other materials. Further research and optimization may help improve the consistency and effectiveness of these materials for practical oil adsorption applications at varying temperatures.

Fig. 5 presents data includes a detailed analysis of the oil sorption capacity of mashed samples and a standard at 25°C. Fig. 5 illustrates the variation of adsorption capacity with time for these samples.

The oil sorption capacity values over time for the samples are as follows: Pineapple leave (PL) ranges from 5.50 g/g to 8.81 g/g, with a mean of 6.82 ± 0.976 g/g. Pineapple peel (PP) ranges from 0.81 g/g to 1.38 g/g, with a mean of 1.02 ± 0.182 g/g. OPEFB ranges from 1.77 g to 3.35 g/g, with a mean of 2.64 ± 0.577 g. Standard ranges from 9.86 g/g to 14.08 g/g, with a mean of 12.63 ± 1.451 g/g. From Fig. 5, we observe that Pineapple leave (PL) has a relatively high and consistent oil sorption capacity, peaking at 8.81 g/g at the 5th minute, indicating its effective oil adsorption capability at 25°C. Pineapple peel (PP) exhibits a lower oil sorption capacity with minimal variation over time, suggesting its limited effectiveness compared to PL and the standard. OPEFB shows a moderate oil sorption capacity with some fluctuations, indicating it could be useful for oil adsorption but is not as effective as PL or the standard.

The standard sample consistently demonstrates the highest oil sorption capacity, peaking at 14.08 g/g at the 8th minute, highlighting its superior performance in oil adsorption at 25°C. The study reveals significant differences in oil sorption capacities among the tested mashed samples at 25°C. Pineapple leave (PL) appears to be the most stable and reliable material for oil adsorption, with consistent and relatively high performance over time. Pineapple peel (PP) shows lower oil sorption capacity, indicating its limited effectiveness for oil adsorption applications. OPEFB has moderate oil sorption capacity with some variability, suggesting it could be a viable option but may have performance inconsistencies.

The standard sample demonstrates the highest oil sorption capacity, highlighting its effectiveness in oil adsorption applications at 25 °C.

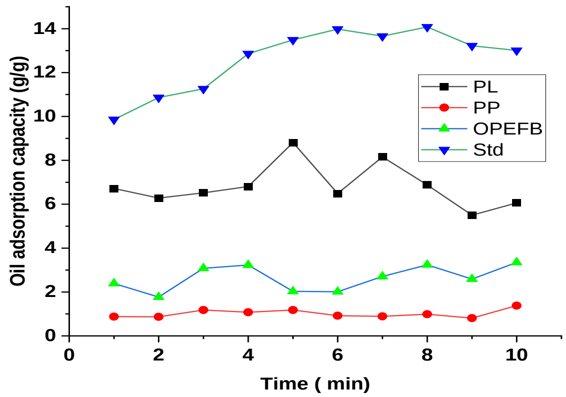

Fig. 5: Variation of oil adsorption capacity of Mashed Samples and Standard with time at 25 ° C

Further research could explore the potential for optimizing these materials to improve their oil sorption capacities and consistency, making them more effective for practical oil adsorption applications. The data provides valuable insights into the comparative performance of these materials, which could inform future developments in oil adsorption technologies.

Fig. 6 shows plots demonstrating reusability and recovery efficiency (%) of mashed samples and standard at 25 ° C. From Fig. 6, it is evidence that the potential of using mashed agricultural waste materials, specifically pineapple leaves and pineapple peels, as effective biosorbents for oil spill cleanup. The performance of these biosorbents is compared to a standard synthetic sorbent**.** The mashed pineapple leaves exhibited moderate reusability, with some variability across cycles. The decline in reusability at certain points suggests that structural degradation or oil saturation might occur over repeated use. The mashed pineapple peels showed high reusability, maintaining consistent performance over multiple cycles. This indicates that pineapple peels are robust and can retain their sorption capacity better than pineapple leaves and the standard synthetic sorbent.

The standard sorbent demonstrated high initial reusability but showed significant variability over time, suggesting that it may be prone to quicker degradation or loss of efficiency compared to the biosorbents. The recovery efficiency of mashed pineapple leaves was moderate, with noticeable fluctuations. This suggests that while pineapple leaves can be reused, their efficiency in oil recovery decreases over time. Pineapple peels had a high recovery efficiency, indicating that they can effectively recover oil over multiple cycles. This makes them a strong candidate for sustainable oil spill cleanup. The standard synthetic sorbent showed variability in recovery efficiency, which might be due to structural or chemical changes after repeated use.

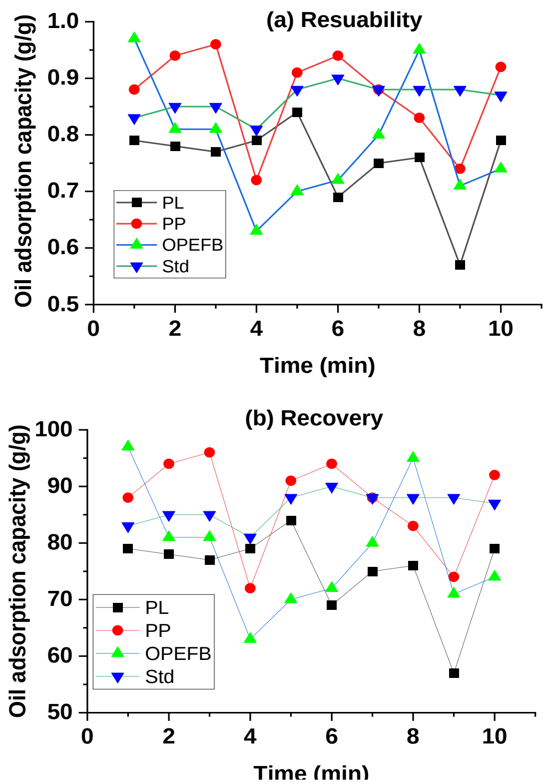

Fig. 6: Variation of oil adsorption capacity with time representing (a) reusability and (b) recovery efficiency (%) of mashed samples and standard at 25 ° C

Fig. 7 shows Oil Sorption Capacity of Mashed Samples and Standard at 30 ^{o} C. The oil sorption capacity of mashed pineapple leaves, pineapple peels, and a standard synthetic sorbent at 30°C was assessed over ten different contact times. Pineapple leaves exhibited a variable sorption capacity, ranging from a low of 4.93 g/g at 7 minutes to a high of 8.92 g/g at 9 minutes, with a mean capacity of 6.62 ± 1.429 g/g. This variability suggests that while pineapple leaves can absorb a considerable amount of oil, their efficiency is inconsistent across different contact times. In contrast, mashed pineapple peels consistently showed lower oil sorption capacities, ranging from 0.77 g/g at 10 minutes to 1.37 g/g at 4 minutes, with a mean of 0.95 ± 0.167 g/g. This indicates that while pineapple peels can absorb oil, their capacity is significantly lower and more stable than that of pineapple leaves.

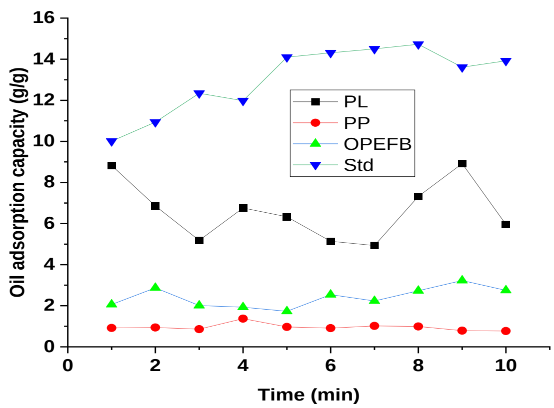

Fig. 7: Oil Sorption Capacity of Mashed Samples and Standard at 30 ^{o} C

The standard synthetic sorbent demonstrated the highest and most consistent oil sorption capacities across all contact times, ranging from 10.01 g/g at 1 minute to 14.73 g/g at 8 minutes, with a mean of 13.04 ± 1.633 g/g. This high and stable performance underscores the efficiency of synthetic sorbents compared to the natural biosorbents tested.

OPEFB (oil palm empty fruit bunch) also showed a relatively stable oil sorption capacity, though lower than the synthetic sorbent, with values ranging from 1.73 g/g at 5 minutes to 3.23 g at 9 minutes, averaging 2.40 ± 0.486 g/g. In Fig. 8 (a and b), the reusability and recovery efficiency of mashed pineapple leaves, pineapple peels, OPEFB, and a standard synthetic sorbent were evaluated at 30°C over ten different contact times. The reusability of pineapple leaves ranged from 0.75 to 0.85, with a mean of 0.80 ± 0.032. This suggests moderate consistency in reusability across different contact times.

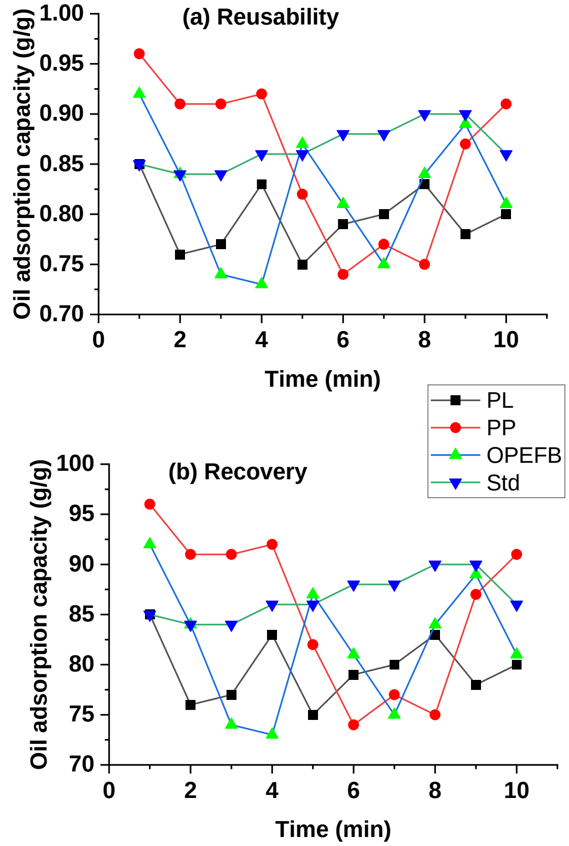

Fig. 8: Variation of oil adsorption capacity with time representing (a) reusability and (b) recovery efficiency (%) of mashed samples and standard at 30 ^{o} C

Pineapple peels showed slightly higher reusability values, ranging from 0.74 to 0.96, with a mean of 0.86 ± 0.079, indicating a relatively higher and more variable reusability. OPEFB displayed reusability values between 0.73 and 0.92, with a mean of 0.82 ± 0.064, reflecting moderate consistency and performance. The standard synthetic sorbent demonstrated consistently high reusability, ranging from 0.84 to 0.90, with a mean of 0.86 ± 0.022, indicating stable and reliable reusability performance.

Regarding recovery efficiency, pineapple leaves exhibited values between 75% and 85%, with a mean of 80% ± 3.272%. Pineapple peels had recovery efficiencies ranging from 74% to 96%, with a mean of 86% ± 7.974%, showcasing a wider variation but generally higher efficiency. OPEFB showed recovery efficiency values from 73% to 92%, with a mean of 82% ± 6.480%, indicating moderate consistency. The standard synthetic sorbent had recovery efficiency values between 84% and 90%, with a mean of 86% ± 2.213%, reflecting high and stable recovery efficiency.

Overall, the results indicate that while mashed pineapple peels exhibit higher reusability and recovery efficiency compared to pineapple leaves and OPEFB, the standard synthetic sorbent consistently outperforms the natural biosorbents in both reusability and recovery efficiency. This highlights the superior and reliable performance of synthetic sorbents in applications requiring repeated use and high recovery efficiency.

The oil sorption capacity results from this study show that polypropylene, as the standard, outperforms pineapple leave, pineapple peel, and OPEFB at both 25 and 30 °C. This finding is consistent with the observations of Choi and Cloud (1992), who reported varying efficiencies of natural sorbents, and Dong *et al*. (2015), who highlighted effective oil sorption by structured natural sorbents like cattail fibers. El-Gheriany and Ahmad El-Saqa (2020) also provided insights into the performance of fruit-based sorbents, which can help contextualize the results of pineapple peel in this study. The superior oil sorption capacity of polypropylene can be attributed to its oleophilic and hydrophobic properties, as discussed by Zamparas *et al*. (2020), which are more effective compared to the hydrophilic nature of cellulose-based materials like pineapple leaves and peel.

The effect of temperature on oil sorption observed in this study shows increased sorption at 30°C, with pineapple leave, pineapple peel, and OPEFB all showing improved performance compared to 25°C. This aligns with Abdelwahab *et al*. (2016), who noted that higher temperatures enhance oil sorption due to decreased oil viscosity, and Khalifaa *et al*. (2021), who observed similar trends with increasing temperature until a certain point. These results confirm that elevated temperatures facilitate better oil penetration into sorbent materials, which is especially beneficial for milled samples with greater surface area.

The comparison of particle size effects reveals that milled samples demonstrate higher oil sorption than mashed samples, corroborating findings by Bayat *et al*. and Husseine *et al*., who reported that smaller particle sizes improve oil sorption capacity due to increased surface area and more binding sites. This is consistent with the greater efficiency of milled samples observed in this study, as their larger surface area allows for better oil contact and absorption. The observed rapid increase in oil sorption with contact time, reaching a maximum at about 5 minutes before stabilizing, is consistent with the results reported by Abdelwahab *et al*. (2016) and Khalifaa *et al*. (2021). This rapid sorption capacity indicates that the materials used in this study are effective for quick response in oil spill clean-up situations.

Finally, the reusability and oil recovery efficiency of these samples, ranging from 0.75 to 0.90 for reusability and 75% to 90% for oil recovery efficiency, suggest that the materials can be effectively reused and that a significant portion of the absorbed oil can be recovered. These findings align with similar studies, demonstrating the practical utility of our sorbents for oil spill clean-up and recycling purposes.

4.0 Conclusion

The study reveals significant differences in oil adsorption capacities among the tested samples, with the standard sample demonstrating the highest performance across various conditions. Pineapple leaf shows a promising potential as an effective and reliable oil adsorbent due to its relatively high and stable adsorption capacity and consistent reusability and recovery efficiency. Pineapple peel and OPEFB, while less effective, could still be considered for low-cost or supplementary adsorption materials, especially in less severe spill scenarios. The results suggest that further optimization and cost-benefit analyses are recommended to explore the practical applications of these materials for oil spill remediation in the real world.

We also recommend further studies to optimize the preparation and application conditions of pineapple leaf adsorbent to maximize its oil adsorption capacity. There is need to perform a comprehensive cost-benefit analysis to evaluate the economic feasibility of using pineapple leaf and other tested adsorbents for large-scale oil spill remediation. Also, a the implementation of field trials to assess the practical performance and environmental impact of using these natural adsorbents in real-world oil spill scenarios as well as the modifications of the materials to enhance the adsorption efficiency and reusability. Finally, we also recommend the evaluation of the sustainability and environmental impact of sourcing and utilizing these natural materials, concerning influencing factors such as availability, biodegradability, and ecological footprint.

5.0 References

Abdelwahad, R. (2014). Oil spill removal from water by corn stalk; factors affecting sorption process. *International Journal of Environmental Waste Manageament*, 16(, 4, pp. 281-289.

Al-Majed, A. A., Adebayo, A. R., & Hossain, M. E. (2012). A sustainable approach to controlling oil spills. *Journal of Environmental Management*, 113C, pp. 213–227.

ASTM, D1533-00, *Annual Book of ASTM Standards*, vol. 10.3, American Society of Testing and Materials, Philadelphia, 2000.

Choi, H., & Cloud, R. M. (1992). Natural sorbents in oil spill cleanup. *Environmental Science and Technology*, 26, pp. 772–776.

Dong, T., Xu, G., & Wang, F. (2015). Oil spill Cleanup by structured natural sorbents made from cattail fibers, *Industrial Crops and Products*, 76, pp. 25–33.

Eddy, N. O., Garg, R., Garg, R., Garg, R., Ukpe, R. A. & Abugu, H. (2024a). Adsorption and photodegradation of organic contaminants by silver nanoparticles: isotherms, kinetics, and computational analysis. Environ Monit Assess, 196, 65, https://doi.org/10.1007/s10661-023-12194-6.

Eddy, N. O., Garg, R., Ukpe, R. A., Ameh, P. O., Gar, R., Musa, R., , Kwanchi, D., Wabaidur, S. M., Afta, S., Ogbodo, R., Aikoye, A. O. & Siddiqu, M. (2024b). Application of periwinkle shell for the synthesis of calcium oxide nanoparticles and in the remediation of Pb^{2+}-contaminated water. Biomass Conversion and Biorefinery, DOI: 10.1007/s13399-024-05285-y.

Eddy, N. O., Jibrin, J. I., Ukpe, R. A., Odiongenyi, A., Iqbal, A., Kasiemobi, A. M., Oladele, J. O. & Runde, M. (2024c). Experimental and Theoretical Investigations of Photolytic and Photocatalysed Degradations of Crystal Violet Dye (CVD) in Water by oyster shells derived CaO nanoparticles (CaO-NP), Journal of Hazardous Materials Advances, 13, 100413, https://doi.org/10.1016/j.hazadv.2024.100413

Eddy, N. O., Ukpe, R. A., Ameh, P., Ogbodo, R., Garg, R. & Garg, R. (2023). Theoretical and experimental studies on photocatalytic removal of methylene blue (MetB) from aqueous solution using oyster shell synthesized CaO nanoparticles (CaONP-O). Environmental Science and Pollution Research, https://doi.org/10.1007/s11356-022-22747-w.

El-Gheriany, I. A., & Ahmad El-Saqa, F. (2020). Oil spill sorption capacity of raw and thermally modified orange peel waste. *Alexandria Engineering*, 59, pp. 925–932.

Ghaly, A. E., Ananthashankar, R., Alhattab, M., & Ramakrishnan, V. V. (2019). Oil spills in oceans: An overview of spill causes, environmental and health impacts, and regulations. Journal of Environmental Management, 91, pp. 1875–1889.

Hilario, A. N., Fernandez, E. A., Contreras, E. M., & Medina, M. A. (2019). Oil spill removal from water by corn stalk; factors affecting sorption process. *International Journal of Environmental Waste Management*, 16, 4, pp. 281-299. .

Kelle, H. I. (2018). Mopping of crude oil and some refined petroleum products from the environment using sawmill factory waste: adsorption isotherm and kinetic studies. Journal of Applied Sciences and Environmental Management, 22, 1, pp. 34–40.

Kelle, H. I., & Eboatu, A. N. (2018a). Determination of the viability of chicken feather as an oil spill clean-up sorbent for crude oil and its lower fractions. Journal of Applied Sciences and Environmental Management, 22, 2, pp. 267–273.

Kelle, H. I., & Eboatu, A. N. (2018b). Evaluation of coconut husk sorbent for cleanup of petroleum contaminated environments. *Journal of Chemical Society of Nigeria*, 43, 1, pp. 36–49.

Kumagai, S., Noguchi, Y., Kurimoto, Y., & Takeda, K. (2007). Oil adsorbent produced by the carbonization of rice husks. *Waste Management, 27*(4), 554-561. https://doi.org/10.1016/j.wasman.2006.04.006.

Omar, B. M., Abdelgalil, S.A., Fakhry, H. et al. (2023). Wheat husk-based sorbent as an economical solution for removal of oil spills from sea water. Sci Rep 13, 2575, https://doi.org/10.1038/s41598-023-29035-8.

Rezaei, M., Ashrafi, M., & Keshavarz, A. (2022). Effects of oil spills on marine and coastal environments: A review. *Marine Pollution Bulletin*, 140, pp. 335–342.

Umoren, F. J & Utin, M. C, (2024). Resource recovery from maize wastes; synthesis and characterization of silicon oxide nanoparticles. *Communication in Physical Sciences*, 11, 3, pp. 576-588.

Wan, C., Lu, Y., Cao, J., Sun, Q., & Li, J. C. (2015). Preparation, characterization and oil adsorption properties of cellulose aerogels from four kinds of plant materials via NaOH/PEG aqueous solution. Fibers and Polymers, 16, 2, pp. 302–307.

Yap, C. L., Gan, S., & Ng, H. K. (2019). Evaluation of natural adsorbents for oil spill cleanup in aqueous environment. *Environmental Science and Pollution Research*, 26, 7, pp. 6381–6393.

Yousaf, Z., Khan, K. U., Ali, R., Bilal, M., & Iqbal, H. M. N. (2021). Orange peel-derived activated carbon as an efficient biosorbent for oil spill cleanup. *Journal of Cleaner Production*, 291: 125217.

Zamparas, M., Tzivras, D., Dracopoulos, V., & Loannides, T. (2020). Application of sorbents for oil spill cleanup focusing on natural-based modified materials: A review. Molecules, 25, 19, : 4522. https://doi.org/10.3390/molecules25194522

Compliance with Ethical Standards Declaration

Ethical Approval

Not Applicable

Competing interests

The authors declare that they have no known competing financial interests

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Availability of data and materials

Data would be made available on request.

Authors Contribution

Kelle, H.I. designed the study, Kelle, H.I., Chukwu, M.N, Timothy, R.A and Iduseri, E.O. sampled the materials and performed the laboratory analysis. Kelle, H.I. wrote the manuscript, Chukwu, M.N, Iduseri, E.O. and Ogoko, E. C proofread and edited the manuscript.