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Oil Absorption Potential of Modified Sponge Gourd (*Luffa acutangula*) for Oil Spill Remediation

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Abstract. Major oil spills in Philippines waters have cause ecological damage to corals, public health threats and disrupted the livelihood of fishermen. These impacts highlights the need for effective and environmentally suitable remediation metjods. Luffa acutangula, commonly known as sponge gourd is an annual climbing plant wildly cultivated in the province of Isabela. This study evaluated the oil absoprtion capacity of unmodified and chemically modified Luffa acutangula as bio-absorbent materials for oil spill remediation. The fibers were chemically modified with 10% sodium hydroxide (NaOH), hot water, 10% acetic acid, and ethyl alcohol – to determine their effects in the physical properties, oil absorption capacity and crude-oil uptake. Experiments were conducted under controlled laboratory conditions using an artificial sea-oil water mixture and followed a Completely Randomized Design (CRD). Data were analyzed using Analysis of variance and Least Significant Diffference (LSD). Result showed that chemical modification significantly influenced the oil absorption performance of the luffa fibers. Among the four chemical treatments LA modified with 10% acetic acid performed the highest oil absorption capacity (439.33 g/g), indicating improved oil affinity due to increased porosity. Unmodified fibers also showed high absorption capacity confirming its suitability as a bio-absorbent. In contrast, fibers modified with 10% NaOH and ethyl alcohol treated fibers showed lower oil absorption performance due to its fiber compaction and decreased pore volume, the findings show that the Luffa acutangula is an effective bio-absorbent for oil spill remediation with appropriate chemical modification specifically 10% acetic acid can further enhance its oil absorption performance, emphasizing its effectiveness and potential for sustainable oil spill remediation bio-absorbent material.

Keywords: Bio-absorbent, Chemical Modification, Luffa acutangula, Oil Absorption Capacity, Oil Affinity

Introduction

The Philippine Archipelago is surrounded by South China Sea, Philippine Sea, Sulu Sea, Luzon Strait and Celebes Sea. The largest coral reef in the Philippines is called Apo Reef, and it is the second largest continuous reef in the world. It contains a shallow lagoon that ranges in depth from two to ten meters, encircled by mangrove forest. This area provides food for numerous marine and coastal animal species, as well as a haven for birds (DENR-Protected Areas and Wildlife Bureau, 2006). The Philippines' natural resources are the sea and ocean, which produce food, serve as a source of employment, and promote economic progress.

Promoting economic progress and as source of employment the government of the Philippines created ports. The history of the Philippine Port Authority states that by the early 1970s, there were 200 private ports in addition to 591 national and municipal ports spread around the nation, making long-term planning and optimization of port growth necessary. Ports facilitate people and goods to transit between domestic and international locations as well as between rural and urban areas. There are various water vessels widely used to transport goods and people in both public and private ports such as: Passenger Vessel, Cargo Vessel, Fishing Vessel, Tanker, Petroleum Products/ Petroleum by-products carrier, Chemical Carriers, LPG/LNG Carrier, Hazardous Cargo, and Non-hazardous Cargos identified by the Memorandum Circular No. 104 approved by Maritime Industry Board (1995).

Water Vessels are intended for use in domestic trade as a method of transportation for the transport of products or individuals or both, using fuel oil for propulsion. Stated in the MARINA Circular No. SR 2020-06 Series of 2020 (January, 2021) mandated all ship or vessel fuel oil to be used on board ship for propulsion or operation shall have a maximum Sulphur content of 0.50% per mass by mass including all gas, petrol, distillates, residual and blended fuels. This forced a lot of shipping companies and government agencies to come up with a solution that meets the new standards. Several alternatives were suggested, such as the use of (a) liquefied natural gas, or LNG, (b) marine diesel oil (MDO) with reduced sulfur content, and (c) Heavy Fuel Oil (HFO) mixed with a scrubber. A thorough examination of these choices showed that producing low-sulfur MDO comes at a significant cost, and that HFO has difficulties with the installation of scrubbers and the removal of scrubbed waste. But as of right now, LNG—primarily methane—remains the most affordable fossil fuel with the lowest carbon intensity, making it the most practical choice in the long run (Danish Maritime Authority, 2012). Heavy Fuel Oil is the fuel type most commonly used in commercial vessels (Wankhede, March 2019). Under MARPOL Annex 1, the definition of Heavy Grade Oil is given as: Crude oils having a density at 15ºC higher than 900 kg/m^3 and Fuel oils having either a density at 15ºC higher than 900 kg/ m^3 or a kinematic viscosity at 50 ºC higher than 180 mm^2 /s. .

The Philippines is home to diverse marine ecosystem which comprises of estimated 30% coral reef and contributes to commercial fisheries production which support the country's economy and food security (Philippine Space Agency, 2021). The Philippines has seen major oil spills in previous years. Philippines experienced the worst oil spill on August 11, 2006 off the coast of Guimaras, an island province in the Philippines. The oil tanker M/T Solar 1, contracted by Petron Corporation, sank, spilling more than 2.1 million liters (or around 555,000 gallons) of bunker fuel. Not only did the oil poison the water, but it also had a disastrous effect on the local population and economy of Guimaras (Murga, 2019).

In addition, on July 25 2024, MT Terra Nova, a ship carrying the Philippine flag, sank in Manila Bay as a result of strong winds and typhoon Gaemi. There were 1.4 million liters of industrial fuel oil on board the submerged tanker. In addition, at least two other ships sank, one of them carrying diesel fuel, further contaminating Manila Bay with oil (Gunkel and Sierra, 2024). The immediate action of the Philippine Coast Guard was to deploy oil dispersant and floating barriers to contain the oil spill. However, certain booms are sorbent and will aid in the process, oil spill containment booms are not designed to clean up oil spills. A containment boom's function is to stop an oil spill from getting worse and/or to redirect the oil toward a collection area. While oil dispersant enhance the amount of oil removed from the surrounding area via biodegradation and rapidly reduce toxicity through dilution. But it raised concerns in long-term effects on human health, seafood, wildlife and the ecosystem (Coolbaugh et, al. 2011).

Moreover, the most effective solution for cleaning up oil spills in the water is to use oil dispersant; nonetheless, there are currently health concerns about the effects of oil dispersant's chemical component. There are beliefs and suggestions of using hair and plant fibers as an alternative to contain oil spills by absorbing oil. Limited studies have investigated the use of Luffa acuntangula as a bio-absorbent for oill spill remediation particularly in the Philippines.

This study aimed to evaluate the effectiveness of modified *Luffa acutangula*. This may eventually contribute to enhance the Oil Spill clean-up in the Philippines and exploring effective ways to utilize them. It may also contribute to the prevention of environmental destruction, economic disruption, and public health problems.

Research Questions

Generally, the study aims to determine the effectiveness of modified *Luffa acutangula* in Oil Spill clean-up in the Philippines. Specifically, it was conducted to:

1. Determine the physical properties of modified and unmodified *Luffa acutangula*;
2. Quantify the oil absorption capacity of *Luffa acutangula*;
3. Determine the amount of crude oil absorbed by the *Luffa acutangula*; and
4. Compare the oil affinity in terms of absorption capacity of modified and unmodified *Luffa acutangula*.

Literature Review

The Microscopic Structure of Sponge Gourd (*Luffa acutangula*)

An annual herbaceous climber or trailer, *Luffa acutangula* can grow 15 cm or longer. Although it is a cultivated plant, it has become natural in various types of plants in every country with adequate rainfall. The plant is indigenous to the tropical regions of the old world and is of such a long-standing practice that its native continent, whether Africa or in Asia, is currently unknown. The source is the fruit of vegetable sponge, or loofah, which is the firm fibro vascular network throughout the ripe fruit following the tissue that has deteriorated. Light uniformity characterizes commercial grade loofah; in hue, clear, devoid of seeds and other impurities, and ideally longer than 35 cm. Besides being used as a cleaning material, nowadays, the fiber is used commercially to make shoes and hats, shoes, vehicle wipers, filters for marine engines, potholders, table mats, gloves, door and bathroom mats, etc. (Oladoja et.al 2009)

Luffa acutangula mainly composed of cellulose, hemicelluloses and lignin, is called as a lignocellulosic material. Laidani et.al. (2012) showed in their study the chemical and physical characterization of raw materials of the fruit of *Luffa acutangula*. Using Optical Microscope on an OLYMPUS BH-2, software image analysis OPIMAS and electron microscope on ABT-55 is carried out by boiling the fiber of Luffa cylindrica in an alkaline solution and observed from the inside towards outside distinguish the central part (called core or net), the internal and external walls, the bond between the core and walls. Under the scanning electron microscope with weak enlargement of the different parts of Luffa

cylindrica, shows a texture made up of cords more or less consolidated between them, some being completely free. While, to count the percentage of cellulose it was measured by Kurschner and Hoffnere methods corresponding to hydrolysis with the nitric acid in ethanoic medium and seen that the external part is richest in cellulose (80%). The mean contents of cellulose of the various parts appears higher than those of wood fibers, and the lower percentages of lignin (10%).
However, a number of variables, including soil type, weather, and plant origin, affect the chemical makeup of *Luffa acutangula* fibers. Cellulose content ranges from 55 to 90%, its lignin level from 10 to 23%, its hemicellulose content from 8 to 22%, its extractives about 3.2%, and its ash content about 0.4% (Satyanarayana & Wypych, 2007).

In addition, the Cucurbitaceous family includes Luffa cylindrica (LFC), which is widely farmed in China, Japan, Nigeria, and other central and southern American nations. LFC is referred to as lignocellulose material because of its fibrous vascular system, which facilitates the evacuation of water contaminants. To remove dyes from solutions, several researchers employed luffa cylinders in various forms. For example, Abdelwahab (2008) used luffa activated carbon in his study. The results showed that the absorption of *Luffa cylindrica* was maximal at the lowest value of pH (pH =1) and the most suitable sorption temperature was 25°C with maximum capacities of 38.3 and 50 mg/g. Demir et al. (2008) used luffa treated with NaOH, the adsorption capacity of *Luffa acutangula* was found out as 49 mg/g, while Oladoja et al. (2009) utilized different binding bio-absorption mechanism on Luffa to treat methylene blue (waste product) and the amount of methylene blue absorbed per gram of Luffa increased with the increase in pH.

Absorption Capacity and Chemical Treatment of Sponge Gourd (*Luffa acutangula*)

In the report of Gabriella Lewis NASA Disasters (2021) NOAA and the U.S. Coast Guard collaborated with researchers from NASA's Earth Applied Sciences Disasters program area to help create a more effective method of cleaning up oil spills. The "Marine Oil Spill Thickness" (MOST) project, headed by Frank Monaldo of the University of Maryland, employs Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) to describe the oil in an oil slick. To be more precise, MOST considers the thickness of the oil spill when deciding which areas require immediate cleanup. Compared to thin oil, this heavier oil harms marine life more and remains in the ecosystem longer.

Crude oil is a dark liquid that ranges from light brown to black and is rather viscous which is mostly made up of HCs. This HC-rich substance has trace quantities of salts, sulfur, oxygen, and nitrogen. Elements in crude oil and their related weight percent are as follows: Carbon Element ranges from 83 to 87%, Hydrogen element ranges from 11-14%, Sulfur ranges from 0.05 to 6%, Nitrogen element ranges from 0.1-2%, Oxygen element ranges from 0-2% and metal element have less than 1000 ppm (Azizian and Khosravi, 2019). Seawater oil pollution cause considerable environmental and economic damages. The following are the findings of research on the destiny of oil pollution in saltwater and the associated self-remediation process: (1) the components of light oil evaporate, (2) in water, the aromatics partially dissolve, (3) the heavy components become tar balls and move to the beach or precipitation on the ocean floor, and (4) the other substances are combined as suspended particles with saltwater.

Using Fourier Transform Infrared Analysis and Scanning Electron Microscope result showed that the surface properties of the Luffa are suitable for crude oil adsorption. The ideal at 20°C, 82% of the crude oil was extracted at a weight of 2.0 g, with the lowest value occurring at 50°C achieving a minimum of 13% at 0.5 g of weight (Shittu et.al., 2020). The potential of Luffa cylindrica for Crude Oil Adsorption from water study showed the immediate rapid crude oil uptake of Luffa cylindrica. In addition, together using FITR and X-Ray diffraction (XRD) the results shows modified luffa fibers enhanced by 60% its oil sorption efficiency compares with the 40% oil sorption of untreated luffa fibers. This indicated the rapid uptake and high absorption capacity of modified luffa fibers making it a promising alternative sorbent for oil industries since the materials is cheap, biodegradable and environmentally friendly (Zakariah, 2022).

Moreover, Shittu et. al. (2020) on their study “Adsorption Performance of Modified Sponge Gourd for Crude Oil Removal” the researchers used to modify the Luffa cylindrica with hot water and sodium hydroxide. Through the hot water modification there was a significant increase in the adsorbing ability of the sponge gourd. It removed 83.3% of the crude oil from the mixture. While, alkaline treated sample removed 45.1% and the raw sample removed 22.9%. In addition, through the use of Scanning Electron Microscope images show that the hot water treated sample has more pores on the surface which influenced the better adsorption of Luffa cylindrica. In the study of Kamran et.al. (2022) titled A review: Surface treatments, production techniques, mechanical properties and characteristics of Luffa cylindrica bio composites. This paper shed light to the commonly used chemical for surface treatment; the use of Sodium Hydroxide and acetylation. Using scanning electron microscopy (SEM) the surface modification treatments improve the luffa fiber structures and remove the waxy impurities, the overall mechanical properties were improved and the surface-treated luffa fibers showed 39% decrease in water absorption.

On the other hand, in the study of Saw et.al. (2013) the researchers used furfurylation and alkali treatment (2 hrs. agitation with 5% NaOH). The grafting of furfuryl alcohol followed by oxidation showed better results than alkaline treatment with respect to enhancement of the surface area and hydrophobicity as well as wax, lignin and hemicellulose extraction.

Methodology

Research Locale

The study was conducted at the Chemistry Laboratory of the University of La Salette, Inc., Isabela from March 26, 2026 to April 10, 2026. The researcher gathered the data by conducting an experiment with the following procedure:

Materials and Experimental Procedures

Collection, Transportation and Authentication of Samples

Matured *Luffa acutangula* fruit about 4-5 months were harvested from Santiago City, Isabela. The samples were manually transported through a private vehicle carrying at least one sack of *Luffa acutangula* fruit.

Preparation of Raw *Luffa acutangula*

The matured fruit of *Luffa acutangula* has an inner fiber core and outer mat core. The Luffa fruit were manually peeled off and seeded. Distilled Water was used to wash away the sliced outer core contaminants and debris, then the washed samples were put in an aluminum tray and dried in the sun to eliminate any remaining moisture. Dried sponges were stored in a cloth bag to prevent them from getting dusty. Twenty grams of dried *Luffa acutangula* fiber were utilized in every treatment.

One liter (1L) of Delo® Gear EP-5 SAE 80W-90 was used as an alternative for crude oil due to availability and safety consideration. This was bought from the local store. The crude oil sample was left unaltered. The experiment's crude oil-to-water mixture was 70% oil to 30% artificial sea water.

Chemical Treatment of the Fibers

The procured *Luffa acutangula* fibers were treated with Sodium Hydroxide, hot water and grafted with ethyl alcohol. The following procedures were undertaken:

Treatment of *Luffa acutangula* fibers with 10% NaOH solution. Analytical-grade sodium hydroxide (Sigma Aldrich) purchased in local store at Santiago City was utilized. The *Luffa acutangula* fibers were subjected to 10% Sodium Hydroxide (NaOH) solution. Twenty grams fibers were placed in 1000 ml of beaker and added with 500 ml of 10% NaOH solution. The fibers were boiled gently for 20 min. in order to increase hydrophilicity of fiber. Fibers were washed with distilled water until all sodium hydroxide is removed. After washing, fibers were put in an aluminum tray and oven-dried at 70 oC for 6 h. The dried samples were marked as modified LA with 10% NaOH.

Treatment of *Luffa acutangula* fibers with hot water. For the hot water treatment, in 1000 ml of beaker 500 milliliters of distilled water were combined with 20 grams of measured sponge gourd fibers. The samples were heated to 105˚C for 4 hours. The materials were taken out, cooled, and filtered following the treatment period. The residue was subsequently dried for two hours at 105˚C in a hot air oven. The dried samples were marked as modified LA with Hot water.

Treatment of *Luffa acutangula* Fibers with 10% Acetic Acid ($\mathbf{CH_3COOH}$). For the third treatment, in 1000 ml beaker the luffa fibers were submerged in 500ml of 10% Acetic Acid ($\mathbf{CH_3COOH}$) solution for 30 min. at 40 ˚C. Subsequently, the LA fibers were washed several times with distilled water for deacidification and dried at room temperature. The dried sample were marked as modified LA with 10% Acetic Acid ($\mathbf{CH_3COOH}$).

Treatment of *Luffa acutangula* fibers with Ethyl Alcohol. In 1000 ml beaker 20 grams of *Luffa acutangula* fibers were treated with 10% sodium hydroxide solution at pH 13 for 1 hour at 55˚C. After the process, the fibers were washed with water until neutrality. After this, the modification of *Luffa acutangula* with Ethyl Alcohol (EA) employed the following process: A 250 ml round flask was prepared and filled with Ethyl Alcohol. Then, using forceps, the 20 grams of luffa fibers were immersed into the solution and the mixture was heated at 100°C for 4 hours. After that, the Ethyl Alcohol-grafted luffa fibers were placed in an evaporating basin and Soxhlet extraction was used to wash the fibers for 6 hours. Finally, the EA-grafted luffa fibers were transferred to a drying pan and allowed to dry at 45°C for 24 hours, after which the fibers were marked as modified EA-grafted luffa fibers.

The untreated and treated fibers bundles were placed in humidity chamber with 65% relative humidity (RH) at 21°C for 24h. The humidity chamber was set up using distilled water and maintained at room temperature.

Preparation of Artificial Seawater

To imitate the oil-seawater mixture, in 1000 ml of beaker filled with 500ml of distilled water and 17.50g of analytical grade of Sodium Chloride. For the oil-seawater mixture in 1000ml of beaker filled with 500ml of artificial seawater were deliberately contaminated using 75 ml of crude oil and temperature maintained at 7.2 and 30˚C, respectively. The artificial seawater has a salinity of 35 ppt (parts per thousand).

Determination of Physical Properties of *Luffa acutangula*

All specimen of *Luffa acutangula* Fibers was selected from each type of untreated and treated fiber to measure the length, mass, and diameter of single fiber bundles. The length and diameter of Luffa fibers was measured by Vernier Caliper: The length of each luffa sample was measured by positioning it longitudinally between the jaws of caliper and recording the distance between both end with minimal pressure to avoid compression, the diameter was measured at the mid-portion of each luffa fiber sample.

In addition, the mass of the Luffa fibers was determine using a digital weighing scale. Prior to measurement, the weighing scale was calibrated and set to zero to ensure accuracy. Each luffa sample was cleaned and oven-dried to eliminate surface contaminants and excess moisture before weighing. The unmodified and after chemical treatment of luffa fiber's dry mass was recorded as the initial weight.

During oil absorption testing, the samples were reweighed immediately after removal and 10 seconds draining of excess oil to obtain the final weight.

To determine the color, texture and odor. The Luffa fibers was placed in aluminum tray. The physical appearance of the luffa fibers was examined visually under laboratory lighting, the color was recorded by taking note the dominant color and any observable variation, spots and discoloration. The texture determination was assessed manually using gloved hands, gently touched the surface structure of the luffa and noted the fibrousness of Luffa Fibers. In addition, the odor assessment was conducted inside the laboratory. The samples were held with safe distance from the nose, the odor was described and recorded as odorless, mild or other characteristics.

Data Management and Experimental Layout

The study was laid out following the Completely Randomized Design (CRD), it is a research methodology in which experimental units are randomly assigned to treatments without any systematic bias (Costello, 2023). The CRD was considered appropriate for this study because luffa samples were homogenous and maintained under similar experimental conditions. The treatments were as follows:

T_1 – 20g LA unmodified
T_2 – 20g LA modified with 10% Sodium Hydroxide (NaOH)
T_3 – 20g LA modified with hot water
T_4 – 20g LA modified with 10% acetic acid (CH_3COOH)
T_5 – 20g LA modified with Ethyl Alcohol

The treatments were replicated three times giving total of 15 experimental luffa samples.

Each luffa samples were used in the experiment were prepared in the same way and given number for identification. The treatments were randomly assigned to the luffa samples, to ensure no special order or grouping was followed during the experiment. With this simple randomization process, the CRD layout and arrange, the position of each luffa samples did not matter and was not based on the chemical treatment. This layout was following throughout the experiment; determination of physical properties, chemical modification and determining absorption capacity of the luffa samples were taken based in this arrangement. This will help to ensure the results were fair and not influenced by bias. All data were verified as to accuracy and completeness. The one-way Analysis of Variance (ANOVA) were used to determine the effect of the treatments that were used in the study. In cases where the ANOVA yields significant results, the Least Critical Difference (LCD) test were employed to identify the variations among the means of different treatments. All data analyses were conducted using the STAR (Statistical Tool for Agricultural Research) software.

Data Gathered

1. Bulk Density. The Bulk Density of Luffa fibers were computed by determining the initial dry mass of each luffa fibers using digital weighing scale and dividing its Bulk volume expressed in grams per cubic centimeter. Using the equation below:

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Equation 1:

$$V = \pi r^2 h$$

Where: V = Bulk Volume (cm^3)
h = length (cm)
r = radius (cm)
π = 3.14159

Equation 2:

$$\rho b = \frac{m}{V}$$

Where: ρb = Bulk Density (g/cm^3)
m = mass of luffa fibers (g)
V = Bulk Volume (cm^3)

2. Absorption Capacity. The experimental setup will separate into raw, unmodified LA fiber, alkali treatments (10% NaOH), hot water, 10% Acetic Acid and the grafting of Ethyl alcohol to examine the impact of sponge gourd pretreatment on the absorption capacity samples treated with saline water. The Initial weights denoted by W_1 were utilized in the absorption. On the surface of the contaminated crude oil-water mixture, the known weight of absorbent were applied to initiate the absorption process. Absorption of the absorbate molecules onto the absorbent surface was allowed for a period of 30 minutes. following this absorption. The mixture was filtered over time, with very little crude oil lost on the filter. The filtrate was labeled for identification purposes, and the weight of the residue were marked as (W_2). The experiment was conducted thrice, and the calculations were made using average values. Every treatment type under consideration will have the same experimental circumstances. The equation below were used to calculate and record each treatment type's absorption capacity as a function of absorbent weight

   Equation 3: Absorption Capacity = $\frac{(W_2 - W_1)}{W_1} \times 100$

   Where: AC = the weight of crude oil absorbed from the crude oil-to-water solution in relation to the initial weight of fiber (g/g)
   W_1 = weight before absorption (g)
   W_2 = weight after absorption(g)

3. Computation of Oil Absorbed by the *Luffa acutangula*. The absorbent's capacity to absorb crude oil were assessed by computing the amount of oil absorbed in the crude oil-water mixture with Equation 3.

   Equation 4: Oil Absorbed = $(W_2 - W_1)$
   Where: OA = Oil absorbed (g)
   W_1 = weight before absorption (g)
   W_2 = weight after absorption (g).

4. Comparison of Oil Affinity (Absorption) between of modified *Luffa acutangula* and unmodified *Luffa acutangula*. To compare the oil affinity unmodified *Luffa acutangula* and four chemically modified *Luffa acutangula*. the mean Oil absorption capacity if each treatment were analyzed, with higher absorption values will indicate greater oil affinity. Data were analyzed using one-way analysis of variance (ANOVA) to determine significant differences among treatment groups. When significant differences were observed ($p < 0.01$), the Least Significant Difference (LSD) test was applied as a post hoc analysis to compare treatment means.

Results and Discussions

***Research Question 1:* Physical Properties of unmodified and modified Luffa acutangula.**

Table 1. Physical characteristics of unmodified and modified Luffa acutangula.

Treatments	Physical Properties						
	Color	**Texture**	**Odor**	**Average Length (cm)**	**Average Diameter (cm)**	**Dry Mass (g)**	**Bulk Density (g/cm^3)**
T_1 - LA unmodified	Light brown with black spots	Coarse, Fibrous	Odorless	13.9 ± 1.39	7.03 ± 0.96	20 ± 0.00	0.04 ± 0.01
T_2 - LA modified with 10% NaOH	Light brown with black spots	Coarse, Fibrous	Odorless	11.5 ± 0.87	5.90 ± 0.96	17 ±3.13	0.07 ± 0.02
T_3 - LA modified with Hot water	Light brown	Coarse, Fibrous	Odorless	10.17 ± 1.04	6.97 ± 0.93	19.23 ±0.15	0.05 ±0.01
T_4 - LA modified with 10% Acetic Acid	Light brown with black spots	Coarse, Fibrous	Vinegar-like smells, acidic odor	9.13 ± 0.55	5.67 ± 0.58	15.67 ±3.17	0.09 ± 0.02

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T_5 - LA modified with Ethyl Alcohol	Yellowish-brown	Coarse, Fibrous	Odorless	8.1 ± 0.37	4.77 ± 0.25	14.90 ±1.47	0.14 ±0.02
Mean				10.56	6.07	17.36	0.08
CV (%)				8.91	13.01	12.11	22.34
ANOVA				**	ns	ns	**

Note: Means with the same letter are not significantly different from each other at 1% level of significance.
*** - highly significant*
ns – not significant

The unmodified *Luffa acutangula* samples showed a light brown color with black spots, coarse fibrous texture, and no detectable odor. The average length and diameter were 13.9 cm (± 1.39) and 7.03 cm (± = 0.96). The samples had a uniform dry mass of 20 g and a low bulk density of 0.04 g/cm³, reflecting the porous and lightweight nature of naturally dried luffa. This indicates the unmodified Luffa fiber has roughly the same dimension and structure.

In chemical modification treatments: 10% NaOH, Hot Water, 10% Acetic acid, and Ethyl alcohol on the physical characteristics of *Luffa acutangula* (LA), including texture and odor and length, diameter, dry mass, and bulk density. Across all treatments, the texture of *Luffa acutangula* remained coarse and fibrous. This shows that none of the chemical treatments caused physical degradation of the fibrous texture of Luffa fibers. In terms of odor, LA modified with 10% acetic acid exhibited a vinegar-like odor. While Luffa fibers treated with 10% NaOH, hot water, and ethyl alcohol were odorless, implying effective removal of natural organic residues.

The average diameter ranged from 4.77 cm to 6.97 cm. The largest diameter was observed in the hot-water-treated samples (6.97 cm ±0.93), indicating fiber swelling, due to water uptake and thermal softening of its fiber. In contrast, ethyl alcohol-treated Luffa fibers shows the smallest diameter (4.77 cm ± 0.25), which due to fiber compaction caused by solvent-induced dehydration during Soxhlet Extraction.

In comparison of Dry Mass, the unmodified and modified Luffa fibers mass ranged from 14.90 g to 20g, with the unmodified samples having the highest mass. The ANOVA indicated no significant differences (ns) among treatments at the 1% level. This indicates that chemical modification treatments did not completely alter the dry mass of *Luffa acutangula* under the treatments employed.

The bulk density varied substantially among chemical modification treatments, ranging from 0.05 g/cm³ to 0.14 g/cm³. The ethyl alcohol-treated LA exhibited the highest bulk density (0.14 g/cm³ ±0.02), indicating a more compact structure, due to reduced pore volume following Soxhlet Extraction Treatment. In contrast, hot-water-treated samples showed the lowest bulk density (0.05 g/cm³ ± 0.01), which attributed to fiber swelling and increased void spaces.

The result of treatment showed that chemical modification significantly affects certain physical properties of *Luffa acutangula*, particularly average length and bulk density, while dry mass remain unaffected. Alkali treatment (10% NaOH) appears effective in maintaining fiber dimensions, whereas ethyl alcohol treatment induces compaction and reduction in size, as reflected in decreased length and increased bulk density. Morphological characterization studies using Scanning electron microscopy (SEM) unmodified luffa fibers contains pores and smooth surfaces while modified luffa fibers shown fracture of disintegration that leads to weakening of the fiber structure and thus decrease its fiber behavior, mechanical and structural properties (Saadeh et.al., 2025)

Further supporting evidence comes from studies conducted by Kamran et.al., (2022) revealed that chemical modifications disrupt the hydrogen bonding and causes depolymerization of cellulose made the chemically treated luffa shows superior mechanical properties compared to unmodified luffa fibers. In chemical modification luffa fibers with 10% Acetic Acid, acetyl functional groups introduce in the microstructure surface of the fiber making it more hydrophobic. And shown better mechanical properties when compared to untreated luffa fibers.

Research Question 2: Oil Absorption Capacity of Luffa acutangula

Table 2. Oil absorption capacity of unmodified and modified *Luffa acutangula*

Treatments	Initial Mass of *Luffa acutangula* (g)	Mass after Oil Absorption (g)	Oil Absorption Capacity (g /g)
T_1 - LA unmodified	20 ± 0.00	91.30 ± 0.85	356.67 ± 4.51
T_2 - LA modified with 10% NaOH	17 ±3.13	64.13 ± 14.51	275.33 ± 23.97
T_3 - LA modified with Hot water	19.23 ±0.15	84.07 ± 7.13	337.00 ± 37.04

T_4 - LA modified with 10% Acetic Acid	15.67 ±3.17	83.20 ± 7.69	439.33 ± 70.87
T_5 - LA modified with Ethyl Alcohol	14.90 ±1.47	53.50 ± 8.87	258.33 ± 16.20
Mean	17.36	75.24	333.33
CV (%)	12.11	11.41	11.42
ANOVA	**ns**	**	**

Note: Means with the same letter are not significantly different from each other at 1% level of significance.
*** - highly significant*
ns – not significant

The unmodified *Luffa acutangula* samples showed a light brown color with black spots, coarse fibrous texture, and no detectable odor. The average length and diameter were 13.9 cm (± 1.39) and 7.03 cm (± 0.96). The samples had a uniform dry mass of 20 g and a low bulk density of 0.04 g/cm³, reflecting the porous and lightweight nature of naturally dried luffa. This indicates that the unmodified Luffa fiber has roughly the same dimension and structure.

In chemical modification treatments: 10% NaOH, Hot Water, 10% Acetic acid, and Ethyl alcohol on the physical characteristics of *Luffa acutangula* (LA), including texture and odor and length, diameter, dry mass, and bulk density. Across all treatments, the texture of *Luffa acutangula* remained coarse and fibrous. This shows that none of the chemical treatments caused physical degradation of the fibrous texture of Luffa fibers. In terms of odor, LA modified with 10% acetic acid exhibited a vinegar-like odor. While Luffa fibers treated with 10% NaOH, hot water, and ethyl alcohol were odorless, implying effective removal of natural organic residues.

The average diameter ranged from 4.77 cm to 6.97 cm. The largest diameter was observed in the hot-water-treated samples (6.97 cm ±0.93), indicating fiber swelling, due to water uptake and thermal softening of its fiber. In contrast, ethyl alcohol-treated Luffa fibers shows the smallest diameter (4.77 cm ± 0.25), which may be due to fiber compaction caused by solvent-induced dehydration during Soxhlet Extraction.

In comparison of Dry Mass, the unmodified and modified Luffa fibers mass ranged from 14.90 g to 20g, with the unmodified samples having the highest mass. The ANOVA indicated no significant differences (ns) among treatments at the 1% level. This indicates that chemical modification treatments did not completely alter the dry mass of *Luffa acutangula* under the treatments employed.

The bulk density varied substantially among chemical modification treatments, ranging from 0.05 g/cm³ to 0.14 g/cm³. The ethyl alcohol-treated LA exhibited the highest bulk density (0.14 g/cm³ ±0.02), indicating a more compact structure, due to reduced pore volume following Soxhlet Extraction Treatment. In contrast, hot-water-treated samples showed the lowest bulk density (0.05 g/cm³ ± 0.01), which attributed to fiber swelling and increased void spaces.

The result of treatment showed that chemical modification significantly affects certain physical properties of *Luffa acutangula*, particularly average length and bulk density, while dry mass remain unaffected. Alkali treatment (10% NaOH) appears effective in maintaining fiber dimensions, whereas ethyl alcohol treatment induces compaction and reduction in size, as reflected in decreased length and increased bulk density. Morphological Characterization studies using Scanning electron microscopy (SEM) unmodified luffa fibers contains pores and smooth surfaces while modified luffa fibers showed fracture of disintegration that leads to weakening of the fiber structure and thus decrease its fiber behavior, mechanical and structural properties (Saadeh et.al., 2025)

Further supporting evidence comes from studies conducted by Kamran et.al., (2022) revealed that chemical modifications disrupt the hydrogen bonding and causes depolymerization of cellulose that made the chemically treated luffa show superior mechanical properties compared to unmodified luffa fibers. In chemical modification luffa fibers with 10% Acetic Acid, acetyl functional groups introduced in the microstructure surface of the fiber made it more hydrophobic and showed better mechanical properties when compared to untreated luffa fibers.

Research Question 3: Amount of Crude Oil Absorbed by *Luffa acutangula*

Table 3. *Oil Absorption Capacity of unmodified and modified Luffa acutangula*

Treatments	Initial Mass of *Luffa acutangula* (g)	Mass after Oil Absorption (g)	Oil Absorbed (g)
T_1 - LA unmodified	20 ± 0.00	91.30 ± 0.85	71.30 0.85
T_2 - LA modified with 10% NaOH	17 ±3.13	64.13 ± 14.51	47.13 ± 11.51
T_3 - LA modified with Hot water	19.23 ±0.15	84.07 ± 7.13	64.83 ± 7.12

T_4 - LA modified with 10% Acetic Acid	15.67 ±3.17	83.20 ± 7.69	67.53 ± 5.28
T_5 - LA modified with Ethyl Alcohol	14.90 ±1.47	53.50 ± 8.87	38.60 ± 5.48
Mean	17.36	75.24	57.88
CV (%)	12.11	11.41	12.02
ANOVA	**ns**	**	**

Note: Means with the same letter are not significantly different from each other at 1% level of significance.
*** - highly significant*
ns – not significant

The oil absorption of the modified and unmodified luffa fibers differed depending on the chemical treatment applied. Analysis of variance shows a highly significant effect of the treatments on the amount of oil absorbed by the fibers. The unmodified luffa (T_1) showed the highest amount of 71.30g (± 0.85) oil absorption which is not statistically different with T_3 (modified with Acetic Acid) and T_4 (treated with Hot water) of the modified LA fibers. The three treatments highly differed from performance of the other modified treatments T_2 (modified with 10% NaOH) and T_5.(modified with Ethyl alcohol). The different chemical modification significantly affected the mass of luffa after oil absorption and the amount of oil absorbed, while the initial mass of the samples did not differ significantly. The findings of previous studies largely support the observed high oil absorption of LA fiber modified with Acetic Acid compare to unmodified luffa fibers. With the use Fourier Transform Infra-red (FTIR) Spectroscopy the unmodified luffa fibers shown stretch string hydroxyl group that made it absorb much water and less in oil. In contrast in LA modified with 10% acetic acid the stretched strong hydroxyl group was replaced with acetyl group which is oleophilic which made the luffa fibers to absorb oil than water (Zakariah, 2022).

Research Question 4: Comparison of Oil Affinity Between Modified and Unmodified *Luffa acutangula*

Table 4. Comparative Analysis of Oil Absorption Capacity of Unmodified and modified *Luffa acutangula*.

Treatments	**Oil Absorption Capacity (g /g)**
T_1 - LA unmodified	356.67 ± 4.51
T_2 - LA modified with 10% NaOH	275.33 ± 23.97
T_3 - LA modified with Hot water	337.00 ± 37.04
T_4 - LA modified with 10% Acetic Acid	439.33 ± 70.87
T_5 - LA modified with Ethyl Alcohol	258.33 ± 16.20
Mean	333.33
CV (%)	11.42
ANOVA	**

Note: Means with the same letter are not significantly different from each other at 1% level of significance.
*** - highly significant*
ns – not significant

The results show that chemical modification had a highly significant effect on the oil absorption capacity of *Luffa acutangula*, as resulted by the ANOVA result ($p < 0.01$). The oil absorption capacity varied among treatments, with values ranging from 258.33 g oil/g fiber to 439.33 g oil/g fiber. The highest absorption capacity was recorded in samples modified with 10% acetic acid (439.33 ± 70.87 g oil/g fiber), which differed significantly from all the other treatments. This indicates that Acetic Acid modification treatment enhanced the oil absorption ability of *Luffa acutangula*. Studies show acetylated luffa fibers absorbed more oil due to reduction in the water absorption capacity resulting from acetylation. This chemical modification increases by 60% the oil absorption efficiency of Luffa fibers (Zakariah, 2022).

The unmodified samples exhibited high oil absorption capacity (356.67 ± 4.51 g oil/g fiber), indicating that *Luffa acutangula* possesses strong absorption of oil. Luffa fibers modified with hot water also showed the same absorption capacity of (337.00 ± 37.04 g oil/g fiber) indicating that hot-water treatment does not substantially reduce oil absorption performance of Luffa fibers.

In contrast, samples treated with 10% NaOH and Ethyl Alcohol showed lower oil absorption capacities (275.33 ± 23.97 g oil/g fiber and 258.33 ± 16.20 g oil/g fiber, respectively). These results indicate that Alkali and Ethyl Alcohol treatments reduced oil absorption efficiency, due to compaction of the fibrous structure as can be seen in Table 4 (refer to diameter). The four chemical modifications significantly

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influence the oil absorption capacity of *Luffa acutangula*, with 10% Acetic Acid treatment producing the most oil-absorbent material, while NaOH and Ethyl Alcohol treatments resulted in decreased absorption performance.

Ethical Considerations

This study maintained ethical integrity by adhering to plant science research standards, excluding human/animal involvement. Locally sourced *Luffa acutangula* were used legally, with no endangered species. Furthermore, the research complied with the ethical guidelines reviewed and endorse by the Institutional Ethics Review Board of Isabela State University – Echague Campus. All laboratory procedures were conducted in accordance with standard safety protocols. Personal protective equipment (PPE), including laboratory coats, gloves, and safety goggles, was worn at all times. Chemical reagents such as sodium hydroxide, acetic acid, and ethanol were handled with caution and stored in properly labeled containers. Experiments involving volatile substances were conducted in well-ventilated areas to minimize exposure risks. Chemical wastes generated during the experiment were collected in designated containers and disposed of in accordance with institutional and environmental safety guidelines. Residual solutions containing sodium hydroxide and acids were neutralized prior to disposal. Oil-contaminated materials were properly contained and disposed of to prevent environmental contamination. Data confidentiality, originality, and proper citation were ensured. The work upholds transparency and compliance for responsible scientific dissemination.

Conclusion

Based on the findings of the study, it was concluded that among the treatments, hot-water modification resulted in the lowest bulk density, indicating increased void spaces within the fiber structure, whereas ethyl alcohol treatment produced the highest bulk density, suggesting structural compaction. Among all chemical treatments, Luffa acutangula fibers treated with hot water and acetic acid demonstrated high oil absorption capacities, indicating that these treatments enhanced the fiber structure in a manner favorable for oil uptake. Furthermore, modification with 10% acetic acid significantly enhanced oil absorption capacity and oil affinity, yielding the highest values among all treatments. The acetic-acid-modified luffa also demonstrated the greatest oil affinity, followed by the unmodified and hot-water-treated samples, while NaOH- and ethyl alcohol-modified luffa exhibited comparatively lower oil affinity. Overall, the findings confirmed that Luffa acutangula is an effective natural oil absorbent and that its oil absorption performance can be significantly improved through appropriate chemical modification, particularly with acetic acid treatment. However, this study has certain limitations. The experiments were conducted under controlled laboratory conditions, which may not fully represent actual oil spill environments, and only selected chemical treatments were evaluated. In addition, large-scale application was not assessed. Future studies should therefore explore field-based testing and investigate additional modification techniques to further validate and expand upon these findings.

Reccomendations

Based on the results of this study, several recommendations are proposed. Future studies should examine additional physical characteristics of Luffa acutangula, such as porosity and surface structure, to gain a deeper understanding of how these properties influence oil absorption performance. The use of simple imaging techniques or microscopic analysis is also recommended to observe and evaluate structural changes occurring after chemical treatment. Furthermore, future research should assess the oil absorption capacity of Luffa acutangula using different types of oils with varying viscosities, such as diesel, motor oil, and vegetable oil, to determine its effectiveness as an oil sorbent under diverse conditions. The reusability of Luffa acutangula should likewise be investigated by subjecting the fibers to multiple cycles of oil absorption and recovery to evaluate their durability, oil retention capacity, and performance stability over repeated use. Additionally, studies should examine the biodegradability of used luffa fibers after oil absorption by assessing the rate and extent of decomposition, as well as the potential environmental impacts of residual absorbed oil during the degradation process. Finally, future research may explore the potential utilization of oil-soaked luffa fibers as biomass for energy recovery applications, such as biofuel production or controlled combustion, thereby transforming waste materials into a potentially valuable energy resource.

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