

Ecohusk Sustainable Coconut Fiber Disposables

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DOI: <https://doi.org/10.63163/jpehss.v4i1.1187>

Abstract

Now a days, many individuals are dependent on Styrofoam which is a type of polystyrene acknowledged for its high thermal protection, lightweight, and manufacturing convenience. Conversely, Styrofoam exhibits numerous challenges, as it has a negative impact on the environment as well as human health. Styrene, a chemical compound used to make Styrofoam contains carcinogenic agent that cannot be biodegraded. Therefore, this study provides insight into biodegradable and eco-friendly solution using coconut husk, an agricultural byproduct, often discarded as waste, repurposed into a high-value product, associated with waste reduction and a circular economy. To validate its efficiency, proximate analysis of ecohusk crockery was done which illustrates that it contains 1.088% moisture content at 140°C, while the ash content was 14.15%, fat content to be 0.247%, where as crude protein was 1.23%, and total carbohydrate content was assessed as 83.285. In addition, mechanical testing such as compression strength was observed 1-16Mpa, while burst strength test shown a rupture force of 2.5- 4.0 kg/cm², tensile strength test displayed that the crockery can bear a pressure of 15-25Mpa without distortion as well it exhibits no fractures when dropped. While the physical properties such as grammage and thickness were measured at 1.5 ±0.05 and 200g/m², indicating the product density with the opacity of 92%. The water leakage test showed no leakage for 3 hours and the water vapor transmission rate (WVTR) was measured 500g/m²/day. For the broader investigation physiochemical analysis was done in which the cobb test showed the water absorption of 30g/m², solubility of 22%, whereas the biodegradability test affirmed that it can degrade within 7 days. The next phase involved, uncovering a variety of test results of the DPPH, the antioxidant activity of ecohusk husk crockery is 28.97%, 41.74%, 56.97%, 71.70%, 89.37% at concentration of 2%, 4%, 6%, 8% and 10%. The studied data of total phenolic content (TPC) of crockery is 116.75 mg GAE/g and the total flavonoid content (TFC) of ecohusk crockery was reported 573.5 mg QE/g. As demand for greener alternatives grows, coconut husk crockery holds great promise for advancing the future of industries.

Keywords: Biodegradable, Ecofriendly, Polystyrene Replacement, Waste Utilization, Human Health, Packaging, Environmental Sustainability

Introduction

Plastic has emerged as a ubiquitous material in the packaging industry due to its advantageous properties, such as low cost, lightweight nature, and effective protective capabilities. These characteristics make plastic highly suitable for packaging applications in various industries, including food, cosmetics, and pharmaceuticals. The versatility of plastic allows it to preserve the integrity and quality of packaged products, extending their shelf life and reducing spoilage.

However, despite these benefits, the environmental impact of conventional plastics has become a critical concern. Plastic waste contributes substantially to environmental degradation. A review highlighted that since 1950, approximately 6.3 billion tonnes of plastics have been produced globally, with only 9% recycled and 12% incinerated; the remainder accumulates in landfills and natural habitats, leading to pollution. This issue has fueled the need for the development of alternative materials that are not only functional but also environmentally sustainable. Bio-based materials have emerged as a promising alternative to petrochemical-based plastics. These materials are derived from renewable biological resources, including agricultural by-products, food waste, and plant biomass, making them a viable solution to the environmental challenges posed by plastic waste [1]. As consumer preferences shift towards eco-friendly products, the demand for sustainable packaging solutions has significantly increased. Bio-based plastics are organic macromolecules synthesized or processed from biological sources, such as starch, cellulose, and natural fibers, and are gaining traction in the packaging industry as a more sustainable and biodegradable alternative to traditional plastics [2]. The growing public awareness of the harmful environmental consequences of petrochemical plastics has significantly heightened the demand for packaging materials that offer both reduced ecological footprints and enhanced biodegradability. Bio-based materials have the potential to meet these needs by minimizing carbon emissions, reducing environmental impact, and promoting sustainable practices throughout their lifecycle. Furthermore, bio-based packaging materials can provide key benefits such as maintaining essential barrier properties, preserving the product's freshness and shelf life, and offering an environmentally responsible end-of-life solution [3]. By using renewable resources in the manufacturing of bio-based plastics, the packaging industry can contribute to reducing the depletion of non-renewable resources and advancing global sustainability goals.

Among the various agro-industrial residues, coconut husk is gaining recognition as a promising material for sustainable packaging. Coconut husk is rich in lignocellulosic fibers, known for their strength, resilience, and biodegradability. These fibers can be transformed into various packaging items, providing a renewable and environmentally friendly alternative to conventional plastic packaging. The incorporation of coconut husk in packaging applications provides numerous benefits, including reduced reliance on petrochemical resources, enhanced biodegradability, and minimal environmental impact[4]. Additionally, the utilization of coconut husk contributes to waste reduction, as it is often discarded as a by-product of coconut processing, leading to the creation of additional waste that pollutes the environment. The environmental impact of food packaging has become a key concern in the context of a circular economy, where the emphasis is on decreasing waste and increasing sustainability. Coconut husk-based packaging materials have a lower environmental effect compared to traditional materials, giving a convincing rationale for their adoption in the industry. Key studies emphasize its potential for packaging with antimicrobial coatings, biodegradable paper, composites, and bioplastics. Coconut husk, high in polyphenols, provides a sustainable alternative to synthetic antimicrobials. Coconut husk packaging reduces environmental effect, which encourages industry use. Coconut husk is abundant and versatile, making it perfect for both industry and the environment[4]. From a health perspective, the use of coconut husk packaging eliminates the risks associated with conventional plastic packaging. Polystyrene and polyethylene-based packaging materials have been found to leach hazardous chemicals such as bisphenol A (BPA) and phthalates into food, posing risks of endocrine disruption and carcinogenicity . Coconut husk-based materials, being naturally derived and free from toxic additives, provide a safer alternative for food contact applications. Additionally, their inherent biodegradability ensures that they do not contribute to the growing problem of microplastic pollution, which has been detected in human tissues and major water sources worldwide [5].

Pakistan generates around 3.9 million tons of plastic waste each year, with a large percentage ending up in landfills, rivers, and the Arabian Sea. According to the United Nations Environment Programme (UNEP), only 9% of plastic garbage is recycled, with the rest of it contributing to environmental degradation. The abundance of microplastics in water bodies is concerning, and shifting to biodegradable alternatives such as coconut husk packaging can help alleviate the current crisis. Pakistan generates significant volumes of agricultural waste, such as coconut husks, which are frequently thrown or burned, contributing to air pollution and CO₂ emissions. Converting these husks into sustainable packaging materials decreases waste while also providing an environmentally beneficial alternative to polystyrene and plastic-based packaging.

Pakistan is among the top ten most vulnerable countries to climate change. Traditional plastic production contributes to carbon emissions and global warming, whereas biodegradable, natural alternatives such as coconut husk packaging minimize environmental impact. The use of sustainable materials helps Pakistan meet its commitments to climate action and the UN Sustainable Development Goals (SDGs). Coconut husk packaging is both an environmental requirement and an economic opportunity for Pakistan. Pakistan may shift to a more sustainable and green economy by minimizing plastic pollution, utilizing agricultural waste, adhering to rules, and capitalizing on international demand. Increased research, legislative support, and industry adoption of coconut husk-based packaging can result in long-term environmental and economic advantages [6, 7].

Methods and Material

3.1 Acquisition of Raw Material

The raw material such as coconut husk was bought from a local vendor nearby Nazimabad, Karachi, the binders and other chemicals utilized for making sustainable packaging were provided by the premises. All the testing has been conducted in the centralized laboratories of Department of Food Science and Technology at Jinnah University for Women, Nazimabad, Karachi.

3.2 Product Preparation

Coconut husk was first ground into fine powder using a grinding machine (CYE2000AZW). The resulting powder was then sieved through 120-mesh sieves and stored in air tight zip-lock bags. The powder was subsequently soaked overnight in water and a sodium hydroxide solution. The soaked husk was then uniformly mixed with specific binders (Carboxymethylcellulose, Magnesium Stearate, Sorbitol, Chitosan, Corn Starch, Arabic Gum, and Xanthan Gum) and molded into desired shapes and coated with beeswax. Finally, the molded shapes were transferred to a drying oven (9053A) for 4 hours at 45°C.

3.3 Proximate Analysis of the Product

3.3.1 Total Moisture

Moisture content was determined using AACC (Method 44-15.02) of oven drying. It was assessed by placing 5 g of sample on a petri dish, followed by drying it in an oven at 140°C for 3 hours. Subsequently, it was transferred to a desiccator until it cooled slightly, after which it was weighed [8].

$$\text{Moisture Content (\%)} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100$$

Where,

Initial weight = weight of the sample before drying,

Final weight = weight of the sample after drying.

3.3.2 Crude Fat

Fat content was estimated AOAC official Method 948.22. A thimble was filled with around 5 g of the sample, which had been wrapped in filter paper. After which, 7 hours were spent on the extraction procedure, with pet ether serving as the solvent. The recovered material was then

used to compute the crude fat percentage[9].

$$\text{Crude Fat (\%)} = \frac{(W2 - W1)}{S} \times 100$$

Where,

W1 = Weight of empty flask (g),

W2 = Weight of flask and extracted fat (g),

S = Weight of sample.

3.3.3 Crude Protein

Protein content was estimated using Kjeldahl's method as described in Method 981.10 AOAC. The sample was placed into a digestion flask containing a catalyst such as CuSO_4 , alongside concentrated sulfuric acid (H_2SO_4). Once digestion was complete, the nitrogen in the protein was converted into ammonium sulfate. Subsequently, distilled water was added to dilute the mixture, followed by neutralizing the acidic solution with sodium hydroxide (NaOH) to release ammonia (NH_3). The digestion flask was then connected to a distillation apparatus to distill off the liberated ammonia into a known volume of boric acid (H_3BO_3) solution. Finally, the excess acid in the distillate was titrated using standardized hydrochloric acid (HCl) with an appropriate indicator such as methyl red [9].

$$\text{Crude Protein (\%)} = \frac{(V \times N \times E)}{W} \times 100$$

Where,

V = Volume of HCl used in titration (mL),

N = Normality of HCl,

E = Nitrogen equivalent (mg),

W = Weight of the sample (g).

3.3.4 Ash Content

Ash is an inorganic residue remaining after 5 g of coarse sample was placed in pre-weighed crucible and has been completely burnt at a temperature of 550°C for 4 hours in a muffle furnace that is based on AOAC Method tagged as 942.05 [10].

$$\text{Ash Content (\%)} = \frac{\text{Weight of ash}}{\text{Weight of sample}} \times 100$$

3.3.5 Total Carbohydrates

Carbohydrate content was estimated by using the following formula

$$\% \text{ Carbohydrates} = 100 - \% \text{ moisture} - \% \text{ protein} - \% \text{ lipid} - \% \text{ mineral}$$

3.3.6 pH

The pH of 3 mL of the ecohusk extract after treatment with NaOH was measured by using a pH meter by the Method marked as ASTM D 1293-95 [11].

3.4 Qualitative Phytochemical Analysis of the Product

The extract for phytochemical analysis was prepared by dissolving 5 g of sample in 20 mL of methanol which is then subjected to centrifuge at 1500 rpm for 15 minutes.

3.4.1 Detection of Alkaloids

Mayer's Test

The prepared extract of 2 mL was treated with two drops of Mayer's reagent added along the sides of the test tube. A white, creamy precipitate indicates the presence of alkaloids[12].

Dragendorff's Test

Red precipitates were produced when a few drops of Dragendorff's reagent were added to 2 mL of the prepared extract, indicating the presence of alkaloids in the sample[12].

Wagner's Test

To indicate the presence of alkaloids red brownish precipitates are formed when a few drops of Wagner's reagent are added to 2 mL of the prepared extract [12].

3.4.2 Detection of Carbohydrates

Molish Test

Prepared filtrate of 2 mL would treated with two drops of alcoholic solution of α -naphthol, and then concentrated sulfuric acid (1 mL) is added along the sides of the test tube slowly. The presence of carbohydrates is indicated with a violet ring [13].

Benedict's Test

The prepared extract of 2 mL was mixed with some drops of Benedict's reagent and heated in a water bath for 15 minutes. The presence of sugar is shown by the formation of a characteristic colored precipitate [13].

Fehling Test

Equal volumes of Fehling's solutions A and B are mixed with an equal volume of the filtrate of 2 mL while being boiled in a water bath for 15 minutes. A red precipitate formed signifies that sugar is present [14].

Detection of Protein and Amino acids

Biuret Test

One drop of 2% copper sulfate solution was added to 2 mL of filtrate, and then 1 mL of 95% ethanol and extra potassium hydroxide pellets are added. The presence of proteins is shown by the ethanolic layer turning pink [14].

Ninhydrin Test

Two drops of ninhydrin solution were added to 2 mL of filtrate. When amino acids are present, the color turns purple [15].

3.4.3 Detection of Flavonoids

Alkaline Reagent Test

A few drops of sodium hydroxide were added to 2 mL of the produced extract. When diluted acid was added, the color changed from bright yellow to colorless, indicating the presence of flavonoids[16].

Lead Acetate Test

A few drops of lead acetate solution were added to 2 mL of the extract. The presence of flavonoids is shown by the production of yellow precipitates[16].

3.4.4 Detection Of Phenols

A few drops of ferric chloride solution were added to 2 mL of produced extract for treatment. When phenols are present, a bluish-black coloration form [17].

3.4.5 Detection of Diterpenes

Copper acetate test

After dissolving 2 mL of prepared extract in 10 mL of water, three to four drops of copper acetate solution were added. There are diterpenes present when emerald green color forms [18]).

3.5 Mechanical Tests

3.5.1 Compression Test

Following (ASTM D642), a conditioned sample was placed between two platens and subjected to compressive forces until it failed. The maximum load the sample can bear has been recorded, which helps in determining the stacking strength of a sample.

$$\text{Compressive Strength} = \frac{\text{Maximum Load (N)}}{\text{Cross – Sectional Area (mm}^2\text{)}}$$

Where,

N = force applied to the sample at failure during the test,

mm² = area of the cup surface in contact with the load.

3.5.2 Bursting Strength Test

The bursting strength of the sample was determined according to (ASTM D774). In this test, a sample was conditioned, placed in a hydraulic device, and pressure was applied until the sample ruptured. The device measures the pressure required to burst the sample, and the result is then

recorded as the bursting strength, typically expressed in pounds per square inch (psi) or kilopascals.

3.5.3 Tensile Strength Test

The tensile strength of the biodegradable cups was determined using the method described by using a texture analyzer. This test determines the rupture resistance of a sample when a force is applied parallel to its surface. The grammage of the produced cups was initially determined by rolling them to a uniform thickness. The grammage figure was then entered into the tester's calibration board. Finally, the start button was clicked to show the tensile strength measurements for the various treatments in varying quantities.

$$\text{Tensile strength} = \frac{\text{Force}}{\text{Cross sectional area}}$$

3.5.4 Drop Test

To evaluate the durability of the sample cups, each cup was dropped from 0.8 meters onto a level cement floor. Upon the impact, the cups were thoroughly examined for any cracks, splits, or deformation. The drop test is an important early assessment of the strength of these molded cups. When a cup fractures due to a relatively minor impact force from a drop, it indicates that the bonds between the lignocellulosic fibers within the material are weak and quickly ruptured. This is an important result since, according to the standard, cups with cracks following a drop test are not appropriate for use as drinking cups .

3.6 Physical Testing

3.6.1 Grammage and Thickness

According to (ASTM D645), the grammage was determined by weighing a conditioned sample of a known area, and thickness was measured using a calibrated caliper .

$$\text{Grammage} = \frac{\text{Mass of the sample (g)}}{\text{Area of the sample (m}^2\text{)}}$$

3.6.2 Opacity

The opacity of the cup samples was measured using the method reported by using a spectrophotometer. The samples were cut into rectangles and placed in a cuvette, covering the entire width and length. A blank cuvette was used as a reference for the measurements. The opacity was then computed appropriately.

$$\text{Opacity} = \frac{\text{Abs}(600)}{X}$$

Where,

Abs600 = absorbance at 600 nm,

X = thickness of the relevant sample.

3.6.3 Water Vapor Transmission Rate

The Water Vapor Transmission Rate (WVTR) was measured by the Gravimetric Method (ASTM E96/E96M) it measures weight change due to water vapor passing through the cup in a controlled humidity environment. The result is typically expressed in g/m² .

$$\text{WVTR} = \frac{\Delta m}{A \cdot t}$$

Where,

Δm = Change in mass of water vapor (g),

A = exposed area of the cup (m²),

t = Time (hours).

3.6.4 Water Leakage Test

To determine the water resistance of the cup, the thickness of the beeswax coating was adjusted. The cups were covered with various thicknesses of beeswax, ranging from thin to heavier coatings, to determine how well each one prevented a leak. The cups were coated, then filled with water, and the time it took for water to leak through the cup was measured and recorded .

3.7 Physiochemical Analysis of the Product

3.7.1 Cobb Test

The Cobb sizing test was performed according to ASTM D646 where a sample were conditioned and then exposed to a specific quantity of water for a set period. Afterward, the water is removed, and the increase in weight is recorded. The amount of water absorbed is used to calculate the Cobb Value, expressed in grams per square meter (g/m^2).

$$\text{Cobb Value} = \frac{\text{Weight after absorption} - \text{Weight before absorption}}{\text{Area of the sample}}$$

3.7.2 Solubility

The solubility of the biodegradable cup sample in water was determined using the method published by author. To accomplish this, 20 mm × 20 mm strips were cut from the cup material (three samples total). These strips were dried at 105°C for 24 hours to establish their initial dry weight. After weighing, the samples were placed in a flask containing 80 mL of distilled water at 25°C and gently swirled for 1 hour. The samples were then removed and dried at 60°C until they reached a steady weight. Solubility was assessed by measuring the percent weight loss over 1 hour using the following formula.

$$\text{Solubility (\%)} = \left(\frac{X_i - X_f}{X_i} \right) \times 100$$

Where,

X_i = Initial weight of the dried sample

X_f = Final weight

3.8 Quantitative Analysis of The Product

3.8.1 Determination of Antioxidant Activity (DPPH)

For the evaluation of DPPH (1, 1-diphenyl-2-picrylhydrazyl) free radical scavenging activity, the procedure reported by [16] was followed. The sample were prepared by diluting 1 g of ecohusk with 25 mL of 99% methanol, the mixture was then centrifuged for 15 minutes at 1500 rpm and filtered. To do serial dilutions, two test tubes with 2 mL and 6 mL of the sample, respectively, were prepared. Methanol was then added to dilute the tubes to 10 mL, 200 μL and 600 μL were then taken out of each test tube and added into 3 mL of freshly made DPPH solution. Afterward, absorbance was measured at 517 nm using a UV/visible light spectrophotometer. Likewise, the absorbance of the control sample containing the equal content of DPPH reagent and solvent excluding extract was measured at the same wavelength. The DPPH value of each eco husk extract is represented as a percent reduction in DPPH radicals.[16]

$$\text{DPPH inhibition (\%)} = \frac{(A_s - A_c)}{A_c} \times 100$$

Where,

A_c = Absorbance of the control,

A_s = Absorbance of the tested sample.

3.8.2 Determination of TPC

The TPC assay called the Folin-Ciocalteu (FC) method, is a well-established procedure that oxidizes phenolic compounds using the FC reagent. At 760 nm, the reaction produces a blue-colored reduced FC reagent and the intensity of the blue color corresponds to the amount of phenolics in the sample (Sánchez-Rangel et al., 2013). A 0.6 mL extract was placed in a test tube and mixed with 0.6 mL of distilled water. Next, 0.2 ml of Folin-Ciocalteu (FC) reagent was added, and the mixture was allowed to stand for 5 minutes. After this, 1 ml of 8% sodium carbonate solution was added, and the final volume was adjusted to 3 mL with distilled water. The solution was incubated for 30 minutes, and its absorbance was measured at 765 nm using a UV-visible spectrophotometer (model Genesys-5). Results were expressed as mg of gallic

acid equivalent (GAE) per gram of dry weight. Total phenolic compounds of extract in gallic acid equivalent (GAE) were then calculated.

$$\text{TPC (mg GAE/g sample)} = \frac{(C \times V)}{m}$$

Where,

C = Concentration of the standard

V = Volume of the standard solution used in mL,

m = Mass of the sample in grams.

3.8.3 Determination of TFC

The aluminum chloride colorimetric assay was used to determine the total flavonoid content [16]. Subsequently, 1 mL of the extract was taken in a test tube and mixed with 0.3 mL of 5% sodium nitrite solution. After five minutes, 0.6 mL of 10% aluminum chloride (AlCl₃) solution was added and left for another six minutes. Finally, 2 mL of 1 M sodium hydroxide solution and 2.1 mL of distilled water were added. The absorbance was recorded immediately at 510 nm using a UV/visible light spectrophotometer. Quercetin was used as standard. The calibration curve was plotted using standard quercetin.

$$\text{TFC (mg QE/g sample)} = \frac{(C \times V)}{m}$$

Where,

C = Concentration of the standard solution

V = Volume of the standard solution used in mL,

m = Mass of the sample in grams.

3.9 Biodegradability Test

The sample's biodegradation was assessed by burying 5 × 5 cm sections in moist sand. The average temperature was 34 °C, and seawater with an average pH of 7.4 was used to keep the sand wet. The samples were observed for its degradation every 12 hours .

3.10 Microbiological Analysis of Ecohusk Crockery

Microbial analysis of the ecohusk sample was carried out using the streak plate method . Primarily, an extract of the ecohusk sample was prepared, from which 0.1 mL was streaked onto Nutrient Agar, Eosin Methylene Blue (EMB) Agar, Sabouraud Dextrose Agar (SDA), and Mannitol Salt Agar (MSA) plates using a sterile wire loop. The plates were then incubated at 37°C for 1–2 days. Colony counts were performed to calculate the Colony-Forming Units per gram (CFU/g), providing critical insights into the microbial load present in the ecohusk.

3.11 Sensory Evaluation of Ecohusk Crockery

Sensory evaluation of the ecohusk was conducted by using a 9-point hedonic rating scale, where parameters like appearance, color, texture, odor, and overall acceptability were arbitrated by untrained judges wherein the highest score was coded as 'like extremely', and the lowest score was coded as 'dislike extremely'.

3.12 Shelf-Life evaluation of Ecohusk Crockery

The shelf life of ecohusk cup was studied at room temperature for 30 days using a hedonic rating scale. Sensory parameters like color, aroma, texture, appearance, and overall acceptability were assessed at 5-day intervals.

Result and Discussion

Coconut husk biodegradable crockery was developed and analyzed to assess its physical, mechanical and thermal properties. Various tests such as proximate analysis including pH, moisture content, ash content, crude protein, crude fat, total carbohydrate, qualitative phytochemical analysis of the product for alkaloids, protein, flavonoid, phenols, carbohydrate, diterpenes; mechanical test such as compression test, edge crush test, water resistant test, tensile strength test, drop test , opacity, water leakage, cobb test, solubility, biodegradability, grammage & thickness test, quantitative phytochemical testing through in-vitro methods including the determination of DPPH (2,2-diphenyl-1-picrylhydrazyl), TPC (total phenolic content), TFC

(total flavonoid content), and microbial testing for the detection of E coli, fungi were performed to determine the suitability of coconut husk crockery.

4.1 Proximate Analysis of the Product

After performing the testings on the product, the desired results were obtained for different aspects defined below in (Table 2).

4.1.1 Total Moisture Content

In present study the Moisture content of coconut husk based biodegradable crockery was determined to be 1.088% at 140 °C, which suggests greater resistance to degradation and enhanced stability. This finding contrasts with the research by Rana et al. (2023), for biodegradable plates made from wheat bran which exhibited higher moisture content of 4.3%. Similarly, Thagunna et al. (2023), found 4.8% moisture content in edible cutlery made from a blend of wheat flour, finger millet, and rice flour, which also suggests higher moisture retention compared to coconut husk-based cups. The coconut husk-based cups offer moisture resistance, positioning them as a more durable alternative for longer-term use.

4.1.2 Crude Fat

The fat content of coconut husk biodegradable crockery was found to be 0.247%, indicating a minimal fat composition. However, different studies have contradicted each other findings. reported a fat content of 3.7% whereas the study on biodegradable plates made from wheat bran and resultant atta by author, observed the fat content $3.86\% \pm 0.075$ moreover these results are higher than the ongoing study thus focus on lightweight and biodegradable application. A similar study by, focusing on the properties of coconut husk and fiber, reported $0.56 \pm 0.05\%$ of fat content.

4.1.3 Crude Protein

The coconut husk biodegradable disposable regarding the protein content showed a measurement of 1.23% which is consistent with previous research on coconut-based material. This result is slightly higher than the $1.12 \pm 0.03\%$ crude protein for coconut husk observed by (Selamat et al, 2022). These results were in contrast to who found $0.46 \pm 0.03\%$ protein in coconut shell likely due to composition of the materials and processing method.

4.1.4 Ash Content

After conducting the research, the estimation of ash content of coconut husk packaging was calculated 14.15% indicating significant mineral composition thus contributing to structural strength and strong durability. Ongoing results, however, were in contrast to those of, who reported $1.71 \pm 0.05\%$ ash. On the other hand, also reported 9.0% ash content in coir dust.

4.1.5 Total Carbohydrate

The coconut husk packaging exhibited a high total carbohydrate content of 83.29%. This abundance of carbohydrates is typical of lignocellulosic materials like coconut husk, which are rich in cellulose and hemicellulose. Such a composition makes the material well-suited for biodegradable disposable applications. This result contrasts with the findings of, who reported a carbohydrate content of $52.56\% \pm 0.3\%$.

4.1.6 pH

The average pH of the disposable crockery stayed within the range 6.8-7.5 tend to have slightly acidic to neutral pH. This pH range ensured the material is stable, non-reactive with food and beverage also resistant to microbial contamination. A study reported pH pf biodegradable container made of walnut shell powder within the range of 6.61-6.35.

Table 1: Proximate Analysis of the Product

Parameters	Value %
Ph	6.8-7.5 \pm 0.25
Moisture	1.088 \pm 1.35
Ash content	14.15 \pm 0.75
Crude fat	0.247 \pm 1.69
Crude protein	1.23 \pm 0.84
Total carbohydrate	83,285 \pm 1.75

4.2 Qualitative Phytochemical Analysis of the Product

Qualitative test was conducted on coconut husk biodegradable disposable to determine the presence of various bioactive compounds, including protein, flavonoids, phenolic compounds, alkaloids and carbohydrates, most of the positive results indicates that product is rich in phytochemical. After performing test, the product has achieved desired results from different methods shown in (Table 3).

4.2.1 Detection of Alkaloids

The study demonstrated positive (+ve) results in the Mayer's and Wagner test, whereas negative (-ve) results were observed in Dragendroff's test. These findings partially align with Sumarni et al. (2020), who reported the presence of alkaloids using multiple detection method. However, the negative result in Dragendroff's test contrasts with their observation of uniformly positive results across various alkaloid detection test. Similarly, Kibria et al. (2018), observed positive results for the detection of alkaloids.

4.2.2 Detection of Carbohydrates

Carbohydrates were assessed using three methods, Fehling's test resulted in negative (-ve) detection, while the Benedicts and Molish test showed positive (+ve) result. This study is supported by Kibria et al. (2018), where presence in detection of carbohydrate was noticed.

4.2.3 Detection of Protein /Amino Acid

Proteins were not detected in the sample, as indicated by negative (-ve) results in both the biuret and ninhydrin tests. This finding contrasts with research of Selamat et al. (2022), who reported the presence of protein. Therefore, the absence of protein in coconut husk packaging aligns with the findings of low protein content in those part of coconut husk used.

4.2.4 Detection of Diterpenes

In the copper acetate test for the detection of diterpenes positive (+ve) results were observed. This is consistent with findings from Hasan et al. (2021), affirmed diterpenes content in coconut husk extracts. The present study confirms the presence of diterpenes in coconut-based materials.

4.2.5 Detection of Flavonoids

In the current study, flavonoids were detected using alkaline reagent test which showed negative (-ve) results while lead acetate test yielded positive (+ve) results. This indicated that specific types of flavonoids may be present, which react positively with lead acetate but are undetectable with alkaline reagents. These findings partially contrast with those reported by Haryanti et al. (2023), who observed positive results for flavonoids using both test in coconut husk extracts. The discrepancy in results may be due to difference in sample type.

4.2.6 Detection of Phenolic Compound

Detection of phenolic compound in coconut husk disposable showed positive (+ve) results. These findings supported by Valadez-Carmona et al. (2016), who reported that fresh coconut husk contains significant number of phenolic compounds. These studies support the current findings, indicating that coconut husk fiber is a rich source of phenolic compound, which may contribute to their antioxidant and antibacterial activities.

Table 2: Qualitative Phytochemical Analysis of the Product

S.No	Tests	Observation
1	Detection Of Alkaloids	
	Mayers Test	++
	Wagner's Test	+++
	Dragendroff's Test	-
2	Detection Of Carbohydrate	
	Molish Test	+++
	Fehling's Test	-
	Benedicts Test	+++
3	Detection Of Protein/Amino Acid	
	Ninhydrin Test	-
	Biuret Test	-
4	Detection Of Diterpenes	
	Copper acetate Test	++
5	Detection Of Flavonoid	
	Alkaline Reagent Test	-
	Lead Acetate Test	+++
6	Detection Of Phenols	
	Iodine Test	+++

4.3 Mechanical Test

A series of mechanical tests was performed on the coconut husk biodegradable disposable to assess its structural integrity and performance under various stress conditions. These tests included compression testing to evaluate the material's response to compressive loads, bursting strength testing to determine its resistance to internal pressure, tensile strength testing to measure its ability to withstand tensile forces, and drop testing to simulate potential impact scenarios. The results of these analyses, presented in (Table 4).

4.3.1 Compression Test

Packaging materials made from coconut husks give excellent structural durability, with a compression strength of 12–16 MPa. Their performance stands out as being extremely competitive when contrasted with other materials.

Bagasse pulp has a 14.89 MPa compression strength (Thakker et al., 2025). This resemblance shows that materials made from coconut husks are equally durable and appropriate for uses requiring load-bearing capacity. Conversely, spoons made of soy protein isolate combined with morning glory stem fiber, which has a compression load of only 0.008–0.01 MPa (Choeybunditet et al., 2022), show much lower values. Compared to coconut husk, these materials are less appropriate for high-strength applications.

4.3.2 Bursting Strength

Coconut husk disposable cups exhibit a burst strength range of 2.5–4.0 kg/cm², which demonstrates notable resistance to rupture under applied pressure. This strength is attributed to the combined use of CMC, Arabic gum, and corn starch, which enhance fiber cohesion and structural integrity.

For instance, a study by Rahul et al. (2023) on biodegradable cups made from pomegranate peel powder reported bursting strength values ranging from 4.37 to 5.18 kg/cm², depending on the specific formulation used. Buxoo et al. (2020) analyzed burst index values for cups made from pineapple peels and hemp. Their findings showed a maximum burst index of 75.2 kPa for a 40:60 hemp pineapple peel blend. Overall, while the burst strength of coconut husk cups is slightly lower than other formulations, their sustainable composition and use of binders like Arabic gum and corn starch make them a competitive and eco-friendly option for disposable products.

4.3.3 Tensile Strength

Compared to other biodegradable materials, coconut husk disposables exhibit exceptional durability with a 15–25 MPa tensile strength. According to Thakker et al. (2025), they function similarly to bagasse pulp, which has a tensile strength of 15.51 MPa. The stronger structure and bonding of coconut husk fibers are demonstrated by the significantly lower tensile strength of pomegranate peel-based cups, which have a tensile strength of 0.56 MPa (Rahul et al., 2023). With a tensile index of 3.30 Nm/g (Buxoo et al., 2020), the hemp-pineapple peel composite also fails, demonstrating that coconut husk improves the material's strength and distribution. Coconut husk fibers provide rigidity, while binders like chitosan and xanthan gum improve inter-fiber bonding and flexibility.

4.3.4 Drop Test

Table 3: Mechanical Testing of the Product

Property	Results
Compression Strength (Mpa)	12-16
Burst Strength (kg/cm ²)	2.5-4.0
Tensile Strength (Mpa)	15-25

Coconut husk cups are a strong option for biodegradable tableware because of their remarkable drop resistance. The cups' strong fiber bonding and structural integrity were seen when they were dropped from a height of 0.8 meters onto a cement floor without splitting, cracking, or deforming.

When compared to Devatha et al. (2021), the SU and SG cups showed their limitations under higher impacts, remaining intact up to 0.7 m before cracking at 0.9 m. On the other hand, coconut husk cups outperformed SU and SG cups, withstanding a height of 0.8 m without suffering any damage. In contrast to the Buxoo et al. (2020) study, orange composite cups failed the drop test at 0.8 m, displaying cracks that show a weaker bond between lignocellulosic fibers. Coconut husk cups, on the other hand, showed noticeably stronger fiber-to-binder adhesion and remained intact under the same circumstances.

4.4 Physical Testing

The coconut husk biodegradable disposable underwent a series of physical tests to determine key material properties. These included measurements of grammage and thickness, evaluation of opacity, water leakage, and determination of the water vapor transmission rate (WVTR). The results of these tests are presented in (Table 5).

4.4.1 Grammage and Thickness.

According to the study by (Tingirikari, Manthena, & Ramasamy, 2024), the grammage of coconut leaves was 181.5 g/m^2 , which is less than the 200 g/m^2 estimated grammage of coconut husk disposables. This implies that the husk of the coconut might be thicker or denser than the leaf, which could provide more strength and durability. In contrast, banana sheets had the highest grammage (247.61 g/m^2) in their study, which is much higher than that of coconut husk and coconut leaf. This suggests that banana sheets may be more durable but are probably heavier and less flexible. However, compared to coconut husk, coconut leaf, or banana sheet, banana leaf had the lowest grammage (95.9 g/m^2), making it significantly lighter and perhaps more flexible but less durable.

The sturdy structure of coconut husk crockery is attributed to its thickness of $1.5 \pm 0.05 \text{ mm}$. The coconut husk crockery was slightly thicker, according to Buxoo et al. (2020), who discovered that a hemp: pineapple composite cup had a thickness of $1.416 \pm 0.158 \text{ mm}$. Better durability and adaptability to various applications could result from this extra thickness. However, compared to the constant thickness of coconut husk, the average thickness of 10 ALS (Areca Leaf Sheath) samples was between 1.00 mm to 1.08 mm (Jong, Yong, & Jaafar, 2020).

4.4.2 Opacity

The opacity of the coconut husk disposables was measured 92%, demonstrating a significantly higher light-blocking ability compared to results reported in similar studies. In the research by Deshmukh et al. (2024) reported significantly lower opacity values, with a control sample achieving only 3.0171. This difference highlights the substantial influence of coconut husk fibers, which provide a natural and effective barrier to light transmission due to their inherent density and lignin content.

In comparison, the findings of Sinha et al. (2011), the highest opacity value observed was 99.6% in a sample containing 22% coal ash and 78% rice straw pulp. Although slightly lower, the prepared coconut husk material still exhibits high opacity, indicating a dense structure with efficient light-blocking properties.

4.4.3 Water Vapor Transmission Rate

Coconut husk tableware gives moderate water vapor transmission resistance (WVTR) of approximately $500 \text{ g/m}^2/\text{day}$. Insights from Ismaili et al. (2014) found that the lowest WVTR of $21.98 \text{ g/m}^2/\text{day}$ was achieved with $3.34\text{--}0.6 \text{ g}$ of rice bran wax and $5.5\text{--}10 \text{ g}$ of whey protein isolate. Coconut husk tableware does not match these performance levels but provides natural, eco-friendly moisture resistance that balances functionality with biodegradability.

4.4.4 Water Leakage Test

Coconut husk cups exhibit moderate water resistance, retaining water for 24 minutes before leaking. Roasted sorghum cups, for example, can hold cold water for more than an hour and hot water for more than 30 minutes at 80°C (Devatha et al., 2023). Compared to coconut husk cups, this exhibits a higher water-holding capacity and greater physical resilience. Pomegranate peel cups containing glycerol and xanthan gum exhibit noticeably greater water resistance and can hold water for four hours. (Rahul et al., 2023). Although coconut husk cups function fairly well overall, they might need extra coatings or treatments to match the superior water resistance found in other biodegradable materials.

Table 4: Water Leakage Test

Property	Results
Thickness (mm)	1.5±0.05
Grammage (g/m²)	200
Opacity (%)	92
Water Leakage (min)	24
WVTR (g/m²/day)	500

4.5 Physicochemical Analysis of the Product

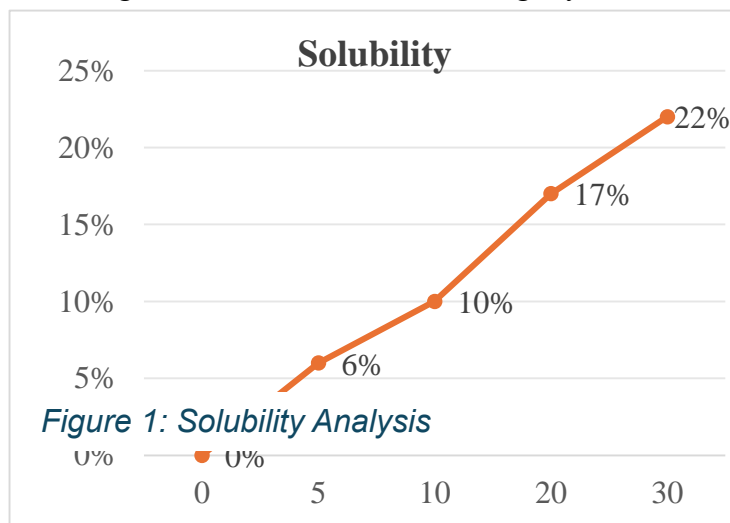
Physicochemical analyses were performed on the coconut husk biodegradable disposable to characterize its interaction with liquids and its degradation behavior. The Cobb test was used to determine the material's water absorption capacity. Solubility tests were conducted to assess the material's breakdown in various solvents. Biodegradability testing was performed to evaluate the rate and extent of decomposition under controlled environmental conditions. The results of these analyses, presented in (Table 6).

4.5.1 Cobb Test

The Cobb test value for coconut husk crockery, 30 g/m^2 in 30 minutes, highlights their superior resistance to water absorption compared to other biodegradable materials. Biodegradable tableware made from paddy straw and pine needles shows significantly higher Cobb values, ranging from 338.3 ± 1.5 to $406.7 \pm 1.5 \text{ g/m}^2$ (Gupta et al., 2023). These values indicate moderate to high water absorption, making such materials less ideal for liquid-heavy applications compared to coconut husk disposables. In contrast, Bagasse-molded pulp tableware, with Cobb values ranging from $15\text{--}20 \text{ g/m}^2$, demonstrates slightly better water resistance, likely due to the addition of moisture repellents (Liu et al., 2018).

4.5.2 Solubility Analysis

The structural integrity of biodegradable disposables under long-term liquid exposure is an important factor in determining their suitability for holding, serving, and preserving beverages such as milk, juice, or water. The maximum solubility observed after 15 minutes was 22%. A study by Chauhan et al. (2024) presented slightly conflicting results, where the maximum solubility recorded after 30 minutes was 31%. Conversely, another study by Hanani et al. (2018) reported a comparable solubility range of 2.07% to 23.88%. The current study found a direct correlation between immersion time in water and solubility percentage. While the hydrophobic nature of coconut husk fibers contributed to their low solubility, the presence of hydrophilic binders like CMC and Arabic gum weakened the structure slightly.



4.5.3 Biodegradability Test

Coconut husk disposables degraded completely after 7 days. Each sample was gradually disintegrated and started decaying within 4 to 5 days. The cellulose and hemicellulose components of the husk degrade rapidly into simple sugars. In contrast, lignin, due to its complex structure, is more resistant and requires specialized enzymes such as lignin peroxidase for breakdown. Hazra and Sontakke (2023) observed that their cutlery, developed using a blend of ragi, sorghum, and wheat flour and fortified with ginseng root powder, fully degraded in 4 to 5 days. Similarly, Iqbal et al. (2022) reported that cutlery from wheat, rice, and sorghum-based flour degraded within 5 to 7 days. In contrast, Kumbhar and Masali (2020) documented that spoon manufactured from moringa husk powder required 20 days to achieve complete degradation.

Table 5: Physiochemical Analysis of Crockery

Property	Results
Cobb Test (g/m ² in 30 minutes)	30
Solubility (%)	22
Degradation Time (day)	7

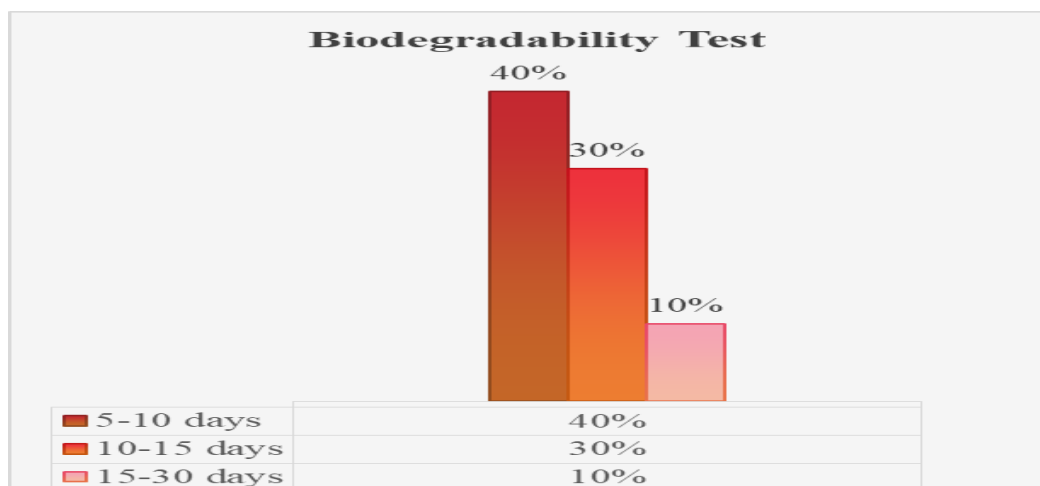


Figure 3: Biodegradability Test

4.6 Quantitative Phytochemical Analysis of the Product

Quantitative analysis was performed to determine the composition of phytochemical and antioxidant activity of product using spectrophotometer. Total phenolic content (TPC) was assessed using Folin-ciocalteu reagent (FRC), which determines the total phenolic compound. Total flavonoid (TFC) was determined using aluminum chloride. Antioxidant activity was evaluated using DPPH (2, 2-diphenyl-1-picrylhydrazyl), which measures the ability of the product to scavenge free radicals. These analyses provide valuable information. The results are presented in (Table 7 and 8).

4.6.1 Antioxidant Activity by DPPH Method

The antioxidant activity of coconut husk crockery in the present study was found to be 28.97%, 41.74%, 56.97%, 71.70%, and 89.37% at concentration of 2%, 4%, 6%, 8% and 10%, respectively. However, results observed by Wahab et al. (2023), affirmed that as concentration increases % inhibition of DPPH also increases, reaching close to 90-100% inhibition at the highest concentration.

Table 6: Antioxidant Activity by DPPH Method

Antioxidant Activity DPPH with Respective Concentration	VALUE %
2ml	28.97%
4ml	41.74%
6ml	56.97%
8ml	71.70%
10ml	89.37%

4.6.2 Total Phenolic Content (TPC)

In the present study, the total phenolic content (TPC) of coconut husk packaging was determined to be 116.75 mg GAE/g. These results are significantly higher than those reported in previous studies. For instance, Haryanti et al. (2023), reported TPC of coconut coir extracts range from 9.54 to 85.33 mg GAE/g, depending on the age of the coconut and the solvent used. Another study by Nor et al. (2023), evaluated the phenolic content of coir extracts, the coir powder recorded a TPC of 848.46 mg GAE/g. The substantial differences observed in the present study could be attributed to variations in the extraction methods, solvent used, and environmental or geographical factors, which influence the phenolic content

4.6.3 Total Flavonoid Content (TFC)

The total flavonoid content (TFC) in the coconut husk disposable was found to be 573.5 mg QE/g. This value is in contrast with the findings observed by Nor et al. (2023), who reported much lower levels of TFC in coconut coir, ranging from 0.51 to 1.57 mg QE/g. Similarly, Wahab et al. (2023) observed TFC value of 8.4 mg QE/g, which is considerably lower than the value observed in present study.

Table 7: In-Vitro Analysis of Coconut husk crockery

In-Vitro Analysis	Observation
Total Phenolic Content (TPC)	116.75 mg GAE/g
Total Flavonoid Content (TFC)	573.5 mg QE/g

4.7 Microbiological Analysis of Ecohusk Crockery

Through Microbial analysis of disposable crockery, it was observed that 2.1×10^3 CFU/mL on Nutrient Agar and 7.1×10^3 CFU/mL on Sabouraud Dextrose Agar, and no growth on Mannitol Salt Agar or Eosin Methylene Blue Agar. These studies align with research related to disposable

food contact materials. For instance, a study by Hladíková et al. (2015), on paper-based food contact materials with recycle fiber found total bacterial counts ranging from 5.0×10^1 to 1.2×10^5 CFU/mL with higher contamination another study by Sood et al. (2019), reported microbial growth with total bacterial count ranging from 1.3×10^2 to 6.1×10^3 CFU/mL.

Table 8: Microbial Analysis of coconut husk crockery

Agar medium	Observation	Interpretation
Sabouraud Dextrose Agar (SDA)	7.1×10^3 cfu/mL	Fungal growth observed
Mannitol Salt Agar (MSA)	0 cfu/mL	No halotolerant species detected
Eosin Methylene Blue Agar (EMBA)	0 cfu/mL	No gram-negative bacteria observed
Nutrient Agar (NA)	2.1×10^3 cfu/mL	General bacteria growth observed

4.8 Sensory Evaluation of Ecohusk Crockery

Sensory analysis is conducted to assess the organoleptic properties of coconut husk crockery. These evaluations involve human panelists who assess sensory attributes such as appearance, texture, color, and aroma. Panelist 1 reported an overall acceptability score of 7, panelist 2 gave score of 9, panelist 3 rated it 7, panelist 4 gave score of 8 and panelist 5 rated it at 8 (figure 5).



Figure 4: Sensory Evaluation of Ecohusk Crockery

Sensory Analysis Of Coconut Husk Crockery

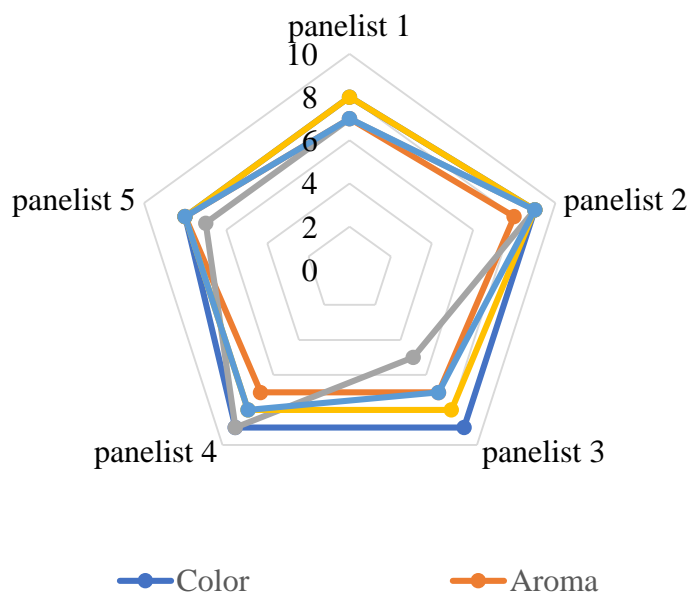


Figure 5: Sensory Analysis of Coconut Husk Crockery

4.9 Shelf Life evaluation of Ecohusk Crockery

The shelf life study demonstrated that product remained stable and maintained acceptable quality over a period of 30 days at room temperature the results presented in figure 6 indicated no significant changes during storage. This study contrast with the research by George et al. (2023), which indicate shorter shelf life for wheat bran biodegradable tableware, as wheat is bran is more susceptible to microbial growth.

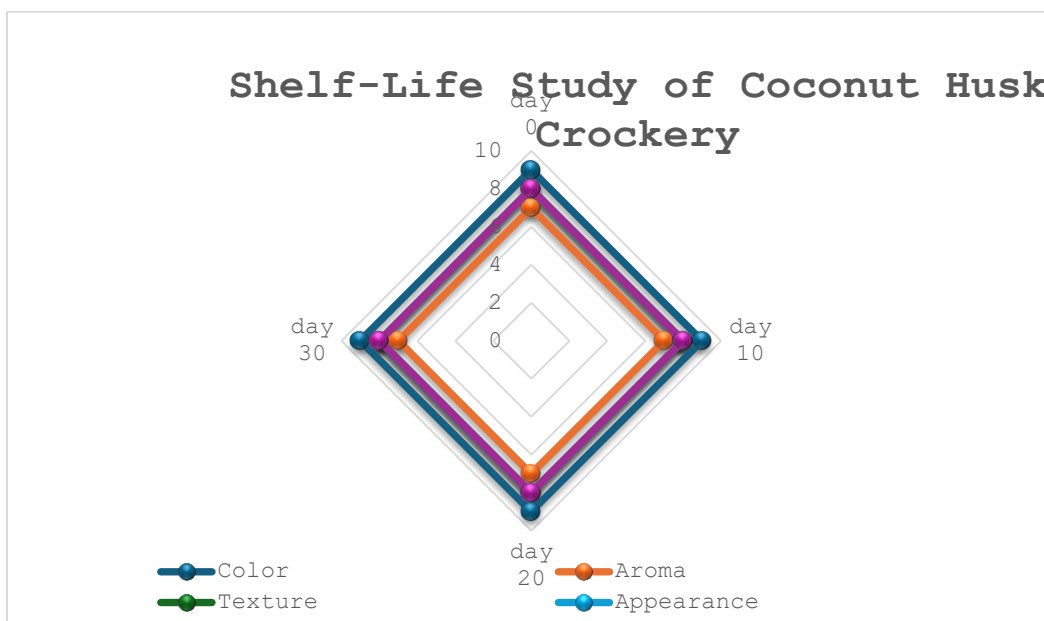


Figure 6: Shelf-Life Study of Coconut Husk Crockery

Conclusion

EcoHusk is an environmentally friendly, biodegradable crockery made from coconut husk, designed for durability, functionality, and sustainability. It exhibits strong antioxidant and antimicrobial properties due to its bioactive compounds, including flavonoids, alkaloids, and phenols. The product has excellent structural integrity, with high compression (1-16 MPa) and tensile strength (15-25 MPa), ensuring its resistance to mechanical stress. It is moisture-resistant, with a low moisture content of 1.088%, and can withstand water exposure for up to three hours without leakage. EcoHusk is highly biodegradable, breaking down naturally within seven days without leaving harmful residues. Its antioxidant activity increases with concentration, highlighting its potential health benefits. Microbial analysis confirms its safety, as it is free from harmful pathogens. Additionally, EcoHusk retains its quality for 30 days, making it a viable and sustainable alternative to conventional disposable crockery.

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