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RESEARCH ARTICLE

A cost analysis of coconut waste management through the formulation of saponin using the waste for chitosan chemical extraction for Nyior Gegor

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Abstract - Coconut waste, often overlooked as an environmental burden, holds significant potential for sustainable and economically viable applications. This study investigates the feasibility of transforming coconut waste into value-added saponin via chemical extraction for chitosan-related applications, with reference to Nyior Gegor. The research evaluates the economic viability of this approach by comparing conventional coconut waste management costs against the potential value generated through saponin production. The study considers the quantity, purity, and estimated market value of the extracted saponin to assess its potential contribution to waste valorisation and circular economy practices. From the experimental extraction, 5 g of saponin was obtained from coconut waste, with an estimated market value of RM 10.04 per gram—representing a total potential value of RM 50.20. The findings suggest that converting coconut husk into saponin offers greater economic potential than landfill disposal, creating opportunities for vendors and entrepreneurs to generate revenue from an otherwise discarded resource. However, the study has limitations, particularly its small-scale yield and reliance on estimated market values that may not reflect actual commercial returns. Additionally, the analysis does not fully account for large-scale production costs, raw material variability, processing requirements, market fluctuations, or long-term environmental impacts. Therefore, further research involving scaled-up extraction, a comprehensive life-cycle assessment, and validation of actual market demand is recommended. Overall, this study demonstrates the potential of coconut waste valorisation while highlighting the importance of ethical decision-making, research integrity, and transparent economic assessments in developing sustainable waste management solutions.

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1. Introduction

In coconut waste management and saponin formulation, strong governance, integrity, and ethical practices are essential to ensure sustainable, responsible operations. Nyior Gegor's approach to converting coconut waste into value-added products through chemical extraction must adhere to environmental regulations, occupational safety standards, and ethical research principles. Effective governance ensures that the waste management process is transparent, compliant with relevant laws, and minimises negative environmental impacts. Upholding integrity in cost analysis and experimental procedures promotes accurate data, honest reporting, and accountable decision-making. Ethically, the project reflects a commitment to circular economy principles by transforming agricultural waste into useful bioproducts, thereby reducing landfill burden and supporting community-based environmental stewardship. Embedding governance, integrity, and ethics within this initiative not only enhances operational credibility but also strengthens Nyior Gegor's reputation as a socially responsible and sustainable enterprise. In Malaysia, agricultural waste poses a pressing challenge because inadequate management practices lead to environmental degradation and resource loss. With the country's thriving agricultural sector, including palm oil production, coconut husk, and other agricultural activities, waste such as palm oil biomass and fruit peels has accumulated and become a significant concern that cannot be ignored. Previous research by Wan-Mohtar et al. (2023) showed that waste generated not only in Malaysia but across Asia can reach up to 1.3 billion tons. Imagine that each year our population keeps increasing at a steady pace; naturally, waste, especially agricultural waste, will also increase due to rising demand. Thus, sustainability has played a significant role in reducing agricultural waste. To implement sustainability measures to reduce agricultural waste, we must be creative. Often, there are many ways to turn waste into something useful and reintegrate it into society for another purpose. The most relevant waste that can be reused for other purposes is coconut waste. Most people already know that the coconut tree has many other functions, most of which support daily life applications such as crafting, food and beverage, and construction, all due to its physical properties. However, coconut husk's chemical properties also have uses, as it contains phytochemicals used in medicine, such as analgesics and anti-inflammatory agents. This is just one application of phytochemicals; they also contain other chemical compounds, such as saponins, alkaloids, flavonoids, catechins, epicatechins, and more. (Jose et al., 2014).

Among the many other chemical compounds in the family of phytochemicals, one of the most valuable chemical compounds is saponins. Saponins have been a focus in chemistry and biology, as this class of compounds is still being studied for its anticancer properties (Elekofehinti et al., 2021a). Imagine an anticancer compound found in agricultural waste. This would make coconut husk valuable, as cancer treatment research is still ongoing. If coconut husk itself can

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produce anti-cancer chemical compounds, surely its demand will increase, and local farmers can earn more profit by just selling coconut husks to cancer research institutions. Managing coconut waste, particularly the byproducts generated during disposal, is a major problem. This remains a major challenge in the industry. The most common disposal methods are often unsustainable, as most coconut husks, shells, and other parts are discarded or burned, contributing to environmental pollution. This traditional approach wastes valuable resources and creates environmental issues. Thus, more effective, efficient, and sustainable ways to utilise these coconut waste products must be implemented, potentially by transforming them into valuable commodities such as saponins, the chemical components produced in this experiment.

Coconuts are often disposed of using traditional methods, but these approaches tend to generate low profits and waste valuable parts of the coconut. Chemical extraction methods, by contrast, offer a more efficient way to utilise coconut byproducts fully and could boost profit margins. Despite this potential, insufficient information exists on the costs and benefits of these two methods. This makes it hard to decide whether switching to chemical extraction is worth the investment. This study seeks to fill that gap by comparing the costs, profits, and overall economic impact of traditional disposal methods versus chemical extraction techniques. Local businesses are usually supplied with coconuts, which they then sell as food and beverages. However, after they sell the coconut's contents, the remaining shell becomes a burden for the local vendor, as they must remove the resulting waste. To remove the waste, they must pay for workers to dispose of it. If the waste product is not handled properly, they might also face summonses or court cases, which will further affect their business. Thus, for local business vendors, coconut waste byproducts have seemed like a burden, as they incur costs to dispose of the waste.

Ethics and research integrity are integral to assessing coconut waste valorisation and saponin extraction. The study adopts principles of transparency, objectivity, accountability, and responsible resource utilisation throughout the cost analysis and evaluation of extraction outcomes. All economic, environmental, and experimental findings should be reported accurately and without selective reporting or unjustified claims. Cost estimates, assumptions, extraction yields, purity levels, and potential market values should be clearly documented to enable appropriate interpretation and replication. Furthermore, claims regarding the environmental and financial benefits of converting coconut waste into value-added products should be supported by verifiable evidence. By incorporating these principles, the study seeks to ensure that the proposed waste management approach is not only economically and environmentally relevant but also ethically responsible and consistent with good research governance and integrity.

This research paper will focus entirely on experimental work to develop saponin from coconut waste using Soxhlet extraction to obtain saponin yield. This paper will also analyse the cost of developing saponin through Soxhlet extraction compared with managing coconut waste using traditional methods. Lastly, the project investigates potential markets for the extracted saponins and how this benefits local businesses. The research objectives are to utilise coconut waste by developing saponins via Soxhlet extraction, to conduct a cost analysis of profit margins between traditional methods of disposing of coconut waste and chemical extraction methods, and to determine the potential market and profitability of saponins produced from coconut waste for Nyior Gegor.

2. Literature Review

2.1 Saponin Properties

Saponins, named after the Latin word “sapo” for soap, are a class of naturally occurring glycosides. The history of saponins is a captivating tale of human interaction with the natural world. In ancient civilisations, society recognised saponins of certain plants for their soapy properties. Early cultures utilised saponin-rich plants for cleaning and incorporated them into traditional medicine for their various therapeutic effects. These properties arise from saponins, which act as surface-active agents, also known as surfactants. Surfactants help emulsify liquids and solids. These properties arise from amphiphilic molecules that have both hydrophilic (water-loving) and hydrophobic properties. This structure allows them to lower water's surface tension, creating a lather-like soap when stimulated as a self-defence mechanism. To know more details about saponins, they consist of glycoside molecules, which are sugar molecules (glycone) that are linked to another non-sugar molecule (aglycone).

Table 1

Source of Saponins

Categories	Types of plants
Legumes	Soybeans, beans, peas, Chickpeas
Lilies	Lilium lancifolium, Lilium pumilum, Lilium longiflorum, Lilium candidum, Lilium speciosum, Lilium tenuifolium
Soapwort family	Soapwort, quillaja bark, bouncing-bet, wild sweet William, and soapweed.
Ginseng family (Araliaceae)	Panax ginseng, Panax quinquefolius, Panax notoginseng.
Tree nut family	Horse chestnut, soapnut tree
Theaceae family	Camellia sinensis, Camellia oleifera.
Arecaceae family	Coconut Palm (cocos nucifera), Date Palm (Phoenix dactylifera) and Oil Palm (Elaeis guineensis)

Source: Rai et al. (2021)

Saponins usually derive from triterpenoid or steroid aglycones, which have promising medical applications, as they act as anti-inflammatory agents that can reduce inflammation internally or externally (Zhang et al., 2022). Saponins are

widely distributed throughout the plant kingdom, with over 100 plant families known to contain them. Table 1 shows saponin sources by plant type. The fact that saponins are found in almost all plants and marine creatures indicates that the use of saponins is wide-ranging. Saponins likely play an important role in flora and fauna, as these organisms may have evolved to use saponins to defend against insects or disease, or to compete with other plants for resources, which is why they have ecological significance.

2.2 Applications of Saponins

The concentration and type of saponins in a plant can vary by plant part (leaves, roots, fruits) and even by environmental factors during growth. Thus, saponins offer many opportunities for future study, as their discovery has rapidly increased over the years. Saponins are not just part of plants but also key to the future, as their properties include toxicity, environmental safety, easy degradability when not in use, and stability across environmental ranges. In addition, their anti-cancer properties make them valuable, as research to find a cure for cancer is still ongoing. Throughout the years, saponin cancer treatments have been extensively researched as they have cytotoxic effects on cancer. Thus, there has been research to use saponins as a part of chemotherapy, as the component has low toxicity compared to the common radioactive treatments used in chemotherapy. With its cytotoxic effect, the component kills cancer cells by activating cell-death mechanisms, invading cancer cells and triggering self-destruction, also known as apoptosis. (Elekofehinti et al., 2021b) Based on the literature explored so far, saponins' pharmaceutical potential is broad and could transform the value of coconut husk from waste to wealth because of its anticancer properties. Figure 1 shows the mechanism of saponin-induced cell death. Saponins are also valuable for their surfactant properties, which can be applied in industry as surface-active agents. Table 2 compares saponins with other compounds as surface-active agents.

Figure 1

The cell death mechanism by Saponins

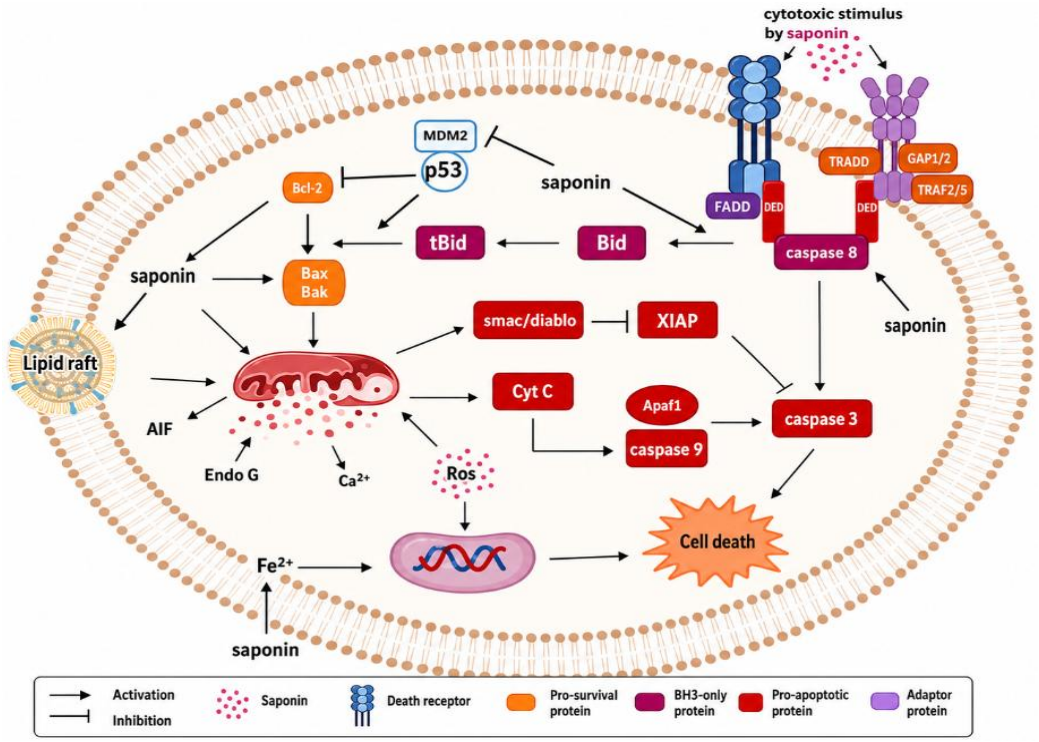


Table 2

Compares saponins with other compounds as surface-active agents

Factors	Inhibitors		
	Saponins	Lignosulfonates	Polymeric additives
Environmental Impact	Generally considered environmentally friendly and biodegradable.	Biodegradable but may contain sulphates, which can cause environmental concerns.	Environmental impact varies depending on the specific polymer used.
Surfactant Properties	Natural surfactant aid in emulsification and lubrication.	Limited surfactant properties. primarily used as dispersants and fluid loss control agents.	Primarily used for viscosity modification and fluid loss control.
Lubrication	Effective in enhancing lubrication due to their surfactant properties.	May have limited direct lubrication effects compared to saponins.	May contribute to lubrication indirectly by improving mud rheology and reducing friction.

2.3 Saponin in Coconut

According to Mazaya et al. (2020), coconut shell contains phytochemicals such as saponins, tannins, and steroids. Malaysia also has abundant coconut resources, which makes saponin extraction relatively cheap. However, different coconuts yield varying amounts of saponins for extraction. Thus, a pre-test is essential before conducting the experiments to ensure resources are not wasted. Thus, the coconuts that are typically found in Malaysia, which are Mawar, Matang and Pandan, became a point of interest to determine the amount of saponins that will be extracted. Additional peer-reviewed research supports the broader potential of coconut residues for value creation, while also showing that applications and economic outcomes depend on the type of residue and conversion process. Reviews describe coconut waste as a potential feedstock for bio-based products and environmental applications, but identify scale-up, processing infrastructure, and techno-economic validation as continuing challenges (James & Yadav, 2021; Vieira et al., 2024; D'Almeida & de Albuquerque, 2025). These studies support investigating coconut husk as a resource; however, they do not establish that saponin can be commercially recovered from the specific Nyior Gegor feedstock at the yield or price assumed in this case study.

2.4 Case Study of Nyior Gegor Sdn. Bhd.

Nyior Gegor Sdn. Bhd is a food and beverage hawker in Kuantan, Pahang. The store is famous for selling coconut milkshakes. The company is estimated to have 2,500 regular customers, with 2500 customers a month. The demand for coconuts has also helped the company grow. However, as demand for coconuts increases, the coconut waste produced by the hawker has also increased. The company must pay a ransom of RM 140 per week. The store owner is committed to disposing of the coconut husk every week for 2 main reasons. First, coconut waste occupies too much space. Without proper waste management, the store would not operate optimally. In addition, coconut waste tends to become foul and emit unpleasant odours if not handled properly (Jangchud et al., 2007). Due to the store's humidity and damp environment, this likely increases the risk of the coconut waste becoming mouldy, which could cause health and safety issues. However, disposing of the waste every week has also become a burden for the store as it can cost up to RM 560 a month. Figure 1 shows the store's locations. Therefore, this project is intended to help the store address the weekly waste disposal issues it has faced. In addition, this research paper will suggest which potential market the company should sell coconut husk to in order to earn additional income.

Figure 2

Nyior Gegor Sdn. Bhd.



The choice of Soxhlet extraction is consistent with established solvent-extraction approaches for recovering plant compounds. Nevertheless, published reviews emphasise that extraction yield and compound identification depend on solvent selection, operating conditions, and the analytical method used for quantification (Cheok et al., 2014; Chemat et al., 2012, 2019). For waste-valorisation studies, economic comparisons should also state system boundaries and assumptions transparently; environmental benefits should not be inferred from potential revenue alone without a life-cycle assessment (Geissdoerfer et al., 2017; Dominguez Aldama et al., 2023).

3. Methodology

This research paper will focus on experimental methods for extracting saponins. The extracted saponins will be analysed based on their development cost relative to the disposal cost of coconut waste by Nyior Gegor Sdn. Bhd. The other method

used for analysis is a quantitative approach to calculating the production costs of the extracted. Figure 3 shows the overall experimental flowchart. Table 3 lists the materials used in this study. The study utilised coconut husk samples and several other chemicals. Saponins were extracted from these husks using the Soxhlet method with 99% denatured ethanol as the solvent. Saponins were re-extracted using n-butanol with a filter funnel. Table 4 lists the equipment used for sample extraction and formulation.

Figure 3
Overall methodology

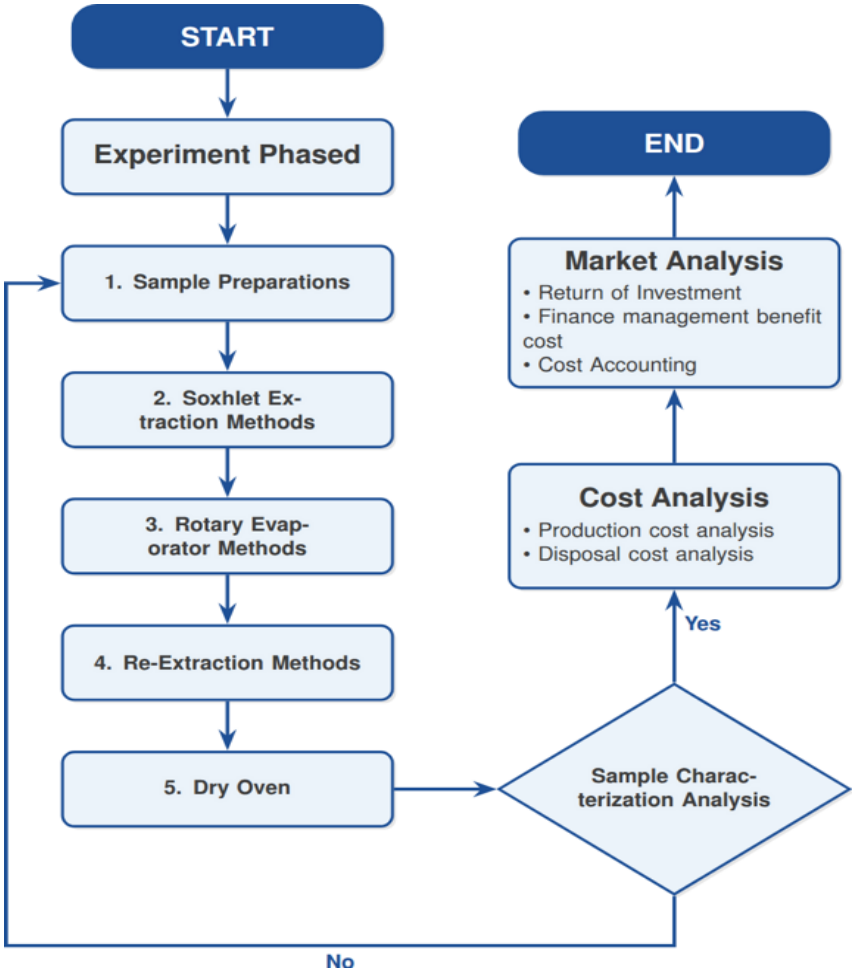


Table 3
List of materials

Materials	Function
Coconut Husk	Raw samples used for extraction
n-Butanol	Re-extraction process of saponins using a filter funnel.
99% denatured ethanol	Extraction solvent of saponin.

Table 4
List of apparatus

Apparatus	Function
Electronic Blender	To blend the sample into smaller pieces.
Electronic Balancer	To measure the mass of samples.
Soxhlet Extractor	To extract saponins from the samples.
Heating Mantle	To heat a round-bottom flask during the Soxhlet Extraction process.
Rotary Evaporator	To concentrate the solution and remove alcohol from the solution.
Separating Funnel	To separate the aqueous solution residue using butanol.
Hot Air Oven	To dry the samples at a constant temperature.
FTIR	To determine the saponin characterisation
GCMS	To determine the saponin characterisation

3.1 Saponin Extraction Methods

The coconut husk is collected from the nearest hawker stall that sells coconuts. The coconut is then cleaned using running water. After cleaning, the coconut is shredded into smaller pieces using a machete. Once the coconut husk is cut into small pieces, it is placed in the hot-air oven to dry for a day. The next day, the dried coconut husk sample is smashed into a fine powder using an electric grinder. Figure 4 shows the preparation of coconut powder. Once the coconut powder is formed, the extraction process is then started by using a Soxhlet extractor. Place around 30 g of coconut husk powder in the Soxhlet extractor along with 150 ml of 90% denatured ethanol. The experiment is then started by heating the heating mantle to 100°C for 6 hours. After 6 hours, a liquid saponin sample is obtained. The obtained sample is then placed in a separating funnel and filtered with n-butanol to obtain a concentrated saponin solution. After filtration, the sample is placed in a rotary evaporator to remove butanol. After removing the butanol, the concentrated sample is dried in an oven at 50 °C for 1 day. After 1 day, a dried saponin sample is obtained. Figure 5 shows the saponin extraction process.

Figure 4

Preparations of coconut powder



3.2 Characterisation of Extracted Saponins

Once the dried, extracted saponin is obtained, the sample is characterised to confirm that the compound is a saponin. In this project, 2 characterisation methods are used: Fourier Transform infrared spectroscopy (FTIR) to determine the sample's chemical composition, and Gas chromatography–mass spectrometry (GC-MS) to quantify the toxic chemical compound in the sample. Figure 6 shows the 2 characterisation methods. After drying, the extracted saponin is obtained and analysed, and a cost analysis is conducted based on the sample yield. Table 5 shows the yield of the saponin extracted.

Table 5

Yield of extracted saponins

Concentration of the denatured ethanol (%)	Mass of coconut husk powder (g)	Time of extraction (hr)	Yield of extracted saponin (g)	Yield of extracted saponin (%
90	30	6	5	16.6

Figure 5

Process of obtaining extracted Saponins

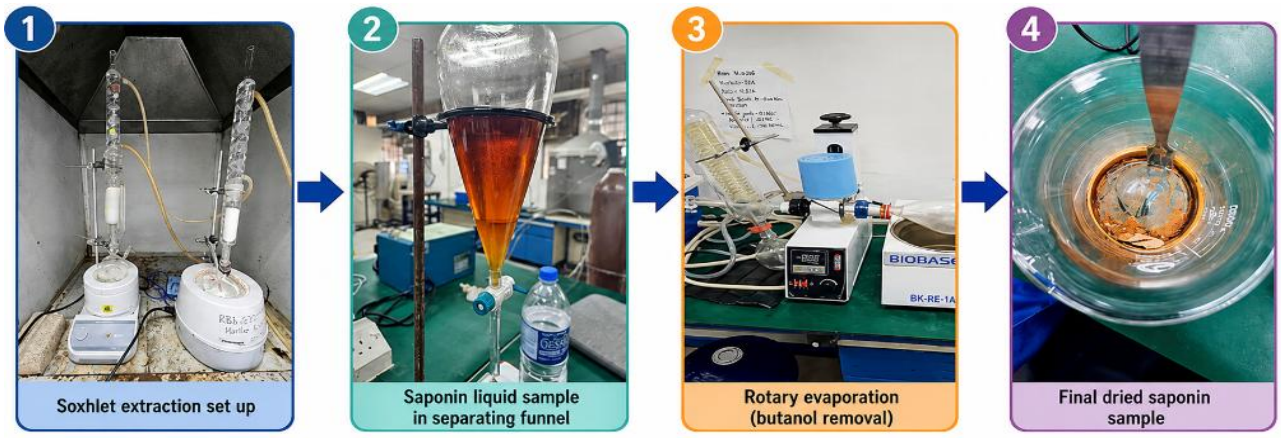
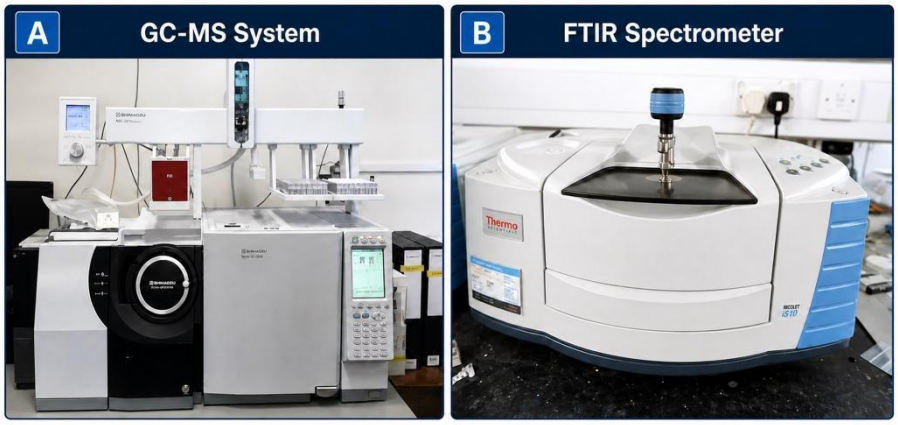


Figure 6
Methods of characterisation from left to right (GCMS, FTIR)



4. Results and Discussion

4.1 Cost Analysis for Saponin Extraction Development

Table 5 shows that with 30 grams of coconut powder, 5 grams of extracted saponin can be produced, with denatured ethanol at 90% and an extraction time of 6 hours held constant throughout the experiment. To produce the extracted saponins, the following materials were used, with prices listed in Table 6.

Table 6
Usage of materials with pricing

Volume of denatured ethanol (mL)	Price of 1L denatured ethanol (RM1)	Volume of butanol (mL)	Price of 1L butanol (RM)
120	152	30	1065.6

Calculation steps for the cost of production for extracted Saponins are shown below:
Production cost = Cost of raw material + Cost of labour + Cost of overhead

- Cost of raw material
- Price for 120 mL of Ethanol: 0.12 L × RM 152 = RM 18.24
- Price for 30 mL of Butanol: 0.03 L × RM 1065.6 = RM 31.97

Labour and overhead costs are considered RM 0 because the experiments are conducted at UMPSA facilities. Thus, the cost of Production is RM 50.21/5 g of saponin extracted and RM 10.04/g. At the market price, commercial saponin is sold at RM 362.00/10 g and RM 36.2/g. By comparing the total price of saponin extracted at UMPSA, the extracted saponin is RM 26.16 cheaper compared to the commercial-grade saponin, although both saponins have similar chemical compounds.

4.2 Cost Analysis for Disposal of Coconut Waste for Nyior Gegor

The cost of disposing of coconut husk for Nyior Gegor was calculated to compare waste disposal with using the waste to develop useful by-products. According to the owner, the store can generate between 2,000 and 2,350 coconuts' worth of waste. The total weight of the coconut waste is estimated at 2.4 tons. Table 7 shows the weekly disposal cost of coconut waste. The waste generated by Nyior Gegor costs RM 140/week to dispose of. Thus, in a week, a total of 600 kg of coconut waste, or roughly 588 kg, has been disposed of in the landfill. According to Anugrah (2022), 1 coconut can produce up to 0.35 kg of cocopeats. Thus, to calculate the profit lost from saponin production, the coconut husk disposal costs are calculated as follows.

Table 7
Disposal cost of coconut waste

Expenditure	Cost, RM
Labour	70
Petrol Fee	10
Packaging Fee	10
Landfill Fee	50
Total	140

Loss of cocopeats resulting from disposal: 0.35 kg × 588 = 205.8 kg. 0.03 kg of cocopeats can generate 0.0005 kg of extracted saponins.
Loss of saponin extraction due to disposal of coconut husk: 205.8 kg ×0.0005 kg 0.03 kg =3.43 kg

The cost of extracted saponin is RM 10.04 /g Total saponin profit lost due to disposal of coconut husk: 3430 g × RM 10.04 = RM 34,437.20. At the end of the analysis, Nyior Gegor incurred a loss of RM 34,437.20 from saponin extraction due to the disposal of coconut waste in a landfill. Not only did Nyior Gegor lose the opportunity to profit, but it also suffered a loss of RM 140 per week, totalling RM 560. In total, Nyior Gegor Sdn. Bhd has lost about RM 34,997.20/ month in saponin production.

4.3 Finance Management Analysis for Nyior Gegor Coconut Waste Management Business

The company has missed the opportunity to gain RM 34,997.20/month. Thus, the company is interested in entering the coconut waste management business. However, it is very important to make a financial analysis before starting a business. In this section, the company's financial management analysis will be conducted through revenue analysis and financial metrics. This approach uses quantitative analysis and quantitative methods. Table 8 shows the financial reports for the 1st quarter of 2024. Based on Table 8, the company remains in positive cash flow for the 1st quarter of 2024 because revenue exceeds operating costs. Table 9 shows the company's cash flow for the 1st quarter.

Table 8
Financial analysis reports of Nyior Gegor in 2024

Month	Coconut waste	Cocopeat yield (g)	Revenue (RM)	Operating costs (RM)
January	2350	916.5	3,666	1,904.67
February	2650	1033.5	4,134	1,904.67
March	2100	819.0	3,276	1,904.67

Table 9
Net profit/ loss table

Month	Revenue (RM)	Operating costs (RM)	Net profit/loss (RM)
January	3,666	1,904.67	+ 1,761.33
February	4,134	1,904.67	+ 2,229.33
March	3,276	1,904.67	+ 1,371.33
Total	11,076	3,809.40	+ 5,361.99

Since the company has revenue of RM 5,361.99. Thus, the Financial Management analysis proceeds to examine operating costs. In this section, all the costs and revenue used for the manufacturing of the coconut byproduct are stated clearly as follows:

i) Operational costs = Labour Costs + Utilities + Maintenance Costs + Equipment Costs
   - Labour Costs (1 worker at RM 9.50, 6 days a week, 6 hours a day): RM 9.50 × 6 hours/day × 6 days/week × 4 weeks/month = RM 1,368/week.
   - Electricity Fees: RM 120 - Marketing Fee: RM 200
   - Maintenance Fee: RM 1,300/6 Month = RM 216.70/ Month
   - Operational costs: RM 1,368 + RM 120 + RM 200 + RM 216.70 = RM 1,904.70

ii) Revenue Analysis for Monthly Production and Sales
   - Production
     a) Cocopeat produced in 1 coconut: 0.35 kg
     b) Monthly Average Production: (2350 + 2650 + 2100) × 0.35 kg = 2485 kg
   - Revenue:
     a) Selling price of cocopeat in Malaysia: RM 4/kg
     b) Monthly Revenue: 2485 kg × RM 4 = RM 9,940
     c) Once the Revenue analysis is complete, the break–even analysis is conducted to determine the point at which total revenue equals total costs.

$$Break-even\ analysis = \frac{Fixed\ costs}{Selling\ price - Variable\ costs}$$

   - Fixed Costs: RM1,904.67
   - Average Cost per Coconut = Variable Costs / Units: RM 1.50/kg
   - Selling Price: RM 4/kg
   - Break-Even Analysis = 761.87 kg/month

The analysis above shows that to break even, the company must sell cocopeat at RM 4/kg, totalling 762 kg/month, with operational costs of RM 1,904.67. Nyior Gegor has produced more than 2000 coconuts per month. Thus, this business can help the company generate profit if it performs consistently. To confirm the data, another analysis can be conducted: the Benefit-Cost Ratio (BCR). The Benefit-Cost Ratio is a profitability analysis that compares the present value of project benefits to its costs. Thus, this analysis is suitable as an indicator for entrepreneurs to measure business profitability. The analysis of the Benefit-Cost Ratio is as follows:

$$Benefit - cost\ ratio = \frac{Total\ revenue}{Total\ costs}$$

- Total Revenue: RM 9,940.00
- Total Costs: RM 3,809.40

Benefit-Cost Ratio = 2.61. Since the Benefit–Cost Ratio is 2.61 (>1), the coconut waste management business will help Nyior Gegor Company generate profit as long as coconut production does not fall below 761.87 Kg/Month.

5. Conclusions

This study examined the potential of converting coconut waste, particularly coconut husk, into value-added saponin as an alternative to conventional landfill disposal. The findings indicate that coconut waste can be transformed into a potentially valuable resource rather than being treated solely as an environmental burden. The extraction process yielded 5 g of saponin, with an estimated market value of RM10.04 per gram, representing a potential gross value of RM50.20. The economic analysis further suggests that converting coconut husk into saponin may provide greater economic potential than disposing of the waste in landfill. This approach could therefore create opportunities for vendors and entrepreneurs to generate additional economic value while contributing to more sustainable waste management practices. These findings matter because they could support the circular economy by recovering and reusing coconut waste. Converting waste into value-added products may reduce dependence on conventional disposal methods, promote resource efficiency, and create opportunities for local entrepreneurship. The findings also highlight the importance of ethical and integrity-based approaches in evaluating sustainability initiatives. Report economic and environmental benefits transparently and support them with reliable evidence, particularly when making claims about profitability and environmental advantages.

The specific contribution of this pilot study is the combined reporting of a laboratory extraction yield and a case-specific comparison with the vendor's stated waste-disposal costs. The experiment produced 5 g of extract from 30 g of coconut-husk powder (a reported yield of 16.6%); this is an experimental result for the tested conditions, not yet evidence of commercial-grade saponin purity, scalable production, or realised profit. These distinctions are important when interpreting waste-valorisation results and planning further techno-economic and life-cycle assessment (Cheok et al., 2014; Dominguez Aldama et al., 2023).

Nevertheless, several limitations should be acknowledged. The relatively small quantity of saponin obtained limits the generalisability of the findings to large-scale commercial production. Furthermore, the estimated value of RM10.04 per gram may vary according to market conditions, product purity, quality, and demand. The analysis may also not fully capture all costs associated with large-scale production, including chemicals, labour, energy, equipment, transportation, and waste treatment. Therefore, the estimated value should not necessarily be interpreted as net profit. Future research should investigate larger-scale extraction, optimise extraction conditions, and improve saponin yield and purity. Comprehensive cost-benefit and life-cycle assessments should also be conducted to evaluate both economic and environmental performance. Further research should examine market demand, commercial scalability, and the feasibility of adoption by local vendors and entrepreneurs. Such research would strengthen the evidence for developing coconut waste valorisation as an economically viable, environmentally responsible, and ethically sound circular economy practice.

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Declaration of Competing Interest

The author declares no conflicts of interest.

Credit Authorship Contribution Statement

Chiew Kah Heng: Methodology; Analysis; Data curation; Writing-original draft
Norwazli Abdul Wahab: Conceptualisation; Visualisation; Verification; Supervision; Write- review & revise

Availability of Data and Materials

The data supporting this study's findings are available on request from the corresponding author.

Ethics Declarations

This study did not involve human participants or animals. Ethical approval was therefore not required.

Generative Artificial Intelligence Declarations

The authors claim that artificially intelligent-assisted technologies, such as generative AI, were not used to generate content, ideas, or theories. We have just utilised AI to enhance readability and refine the language. This was used with extreme human control and oversight. The authors take full responsibility for reviewing and approving the content.

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