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Growth Performance, Productivity, and Adaptability of Coconut (*Cocos nucifera*): A Mixed-Methods Review Across Environmental and Market Contexts

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ABSTRACT

Coconut tree productivity is often limited by the slow growth rate due to environmental stress and sub-optimal cultivation practices. This study examines the growth performance, productivity, and adaptability of coconut (*Cocos nucifera*) across diverse environmental and temporal contexts, providing additional insights into market stability and competitiveness. A mixed-methods approach was applied, integrating a systematic literature review with qualitative and quantitative analyses, as well as marketing data evaluation. Limitations include reliance on secondary data, a restricted sample of 15 countries, and inconsistencies in long-term yield and farm-level records. The results highlight substantial variability in coconut productivity, morphology, and biochemical composition. Molecular analysis shows a strong correlation between the number of heavy atoms and molecular weight, reflecting the complex composition of coconut-derived compounds, including fatty acids, sugars, and triglycerides. Variability is further influenced by cultivar type, maturity stage, and environmental conditions. In Malaysia, coconut cultivation demonstrates a declining planted area but relatively stable production, suggesting improved efficiency and management practices. The adoption of hybrid varieties, such as MATAG, among smallholders indicates strong potential to enhance yields and sustainability. Overall, coconut performance is shaped by genetic, environmental, and management factors, emphasizing the need for standardized data and improved cultivation strategies to support long-term industry sustainability.

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INTRODUCTION

Coconut (*Cocos nucifera*), a member of the palm family (Arecaceae), is a widely cultivated tropical crop originating from the Indo-Pacific and Indian Ocean regions. Commonly found along coastal areas such as the Malabar coast, coconut has adapted well to sandy soils and saline environments. Often referred to as the "tree of life," it plays a significant role in supporting livelihoods, cultural practices, and local economies, particularly among tropical and Austronesian communities that have long relied on its cultivation.

The coconut is highly valued for its diverse uses and economic importance. Its structural components, including the husk, shell, and flesh, serve multiple purposes ranging from food and beverages to industrial products such as coir and oil. Coconut oil is widely used

for its moisturizing and therapeutic properties, while coconut water and flesh contain essential nutrients, antioxidants, and bioactive compounds beneficial to human health. These multifunctional properties have contributed to the increasing global demand for coconut-based products across food, cosmetic, and health industries.

Despite its importance, coconut production faces numerous challenges that limit its productivity and sustainability. These include pest infestations, diseases such as bud rot and lethal yellowing, aging plantations, and the limited availability of high-quality planting materials. Furthermore, coconut trees exhibit slow growth rates and are highly influenced by environmental conditions, soil quality, and management practices. Such constraints hinder consistent yield performance and pose risks to long-term production stability.

Recent advancements have focused on improving coconut cultivation through biotechnology and sustainable practices. The use of molecular markers and hybrid varieties has enhanced breeding programs and genetic diversity, while improved nursery techniques, such as controlled rooftop systems, help optimize seedling growth under varying environmental conditions. Additionally, sustainable farming practices are being explored to address soil fertility issues, pest management, and efficient land use in coconut plantations.

However, there remains a lack of comprehensive and standardized information on the relationship between environmental factors, cultivation systems, and coconut productivity. This gap limits the ability to develop effective strategies for improving yield and adaptability. Therefore, this study aims to review and evaluate coconut cultivation systems to identify approaches that enhance growth performance, productivity, and adaptability under diverse environmental conditions.

Coconut is the essence of the sandy beach of the Malabar coast. The indigenous plant, where afloat means there is life. The germinated seed is for the expansion in size and growth. The visual and cross-section of the fruit hold the husk from within. The analogy of a hardened shell to the smoothness of the silky white flesh. Due to its extensive health guidelines for assisting clinicians and therapeutics for aromatherapy. The exclusive strategic location between the horticulture and plantation for the strategies to uphold their gross domestic product in the health industry.

The best way to have it on a shell. The outer part is the hardest to protect the flesh, and the coconut coir or fiber is the part for the drenching, and the oil can be used as a petroleum jelly. The petroleum jelly from coconut soothes and has a mild effect on the severity of a wound. The characteristics of the coconut for survival near the sea shore for the solo appearance. There is still a market for the coconut coir to survive in the market. The domestication of coconut (Cocos nucifera) showed how it arose from the tropics (Nayar, 2017). The origin of a coconut tree is within the palm family (Arecaceae) (Nayar, 2017). Geographically, there are dual places for the domestication, as in the Indo-Pacific origin and the Indian Ocean region (Nayar, 2017). Among the Austronesian community, who have built a cultivation of coconut trees (Nayar, 2017).

There is a deep rise in global demand for coconut, and the production is for palm senility, diseases, pests, and insufficient high-quality seedling material (Beveridge et al., 2022). The seed has a solid and liquid endosperm, which is a single cotyledon (Beveridge et al., 2022). Coconut apples share the same property as a notable antioxidant potential as they contain amount of vitamin C and mineral content (Preethi & Bukya, 2023). Thus, it is proposed to have more research on its health benefits and consumerism applications (Preethi & Bukya, 2023). Coconut water consisted of natural phytohormones that supported their growth and height (Undie et al., 2021). However, the wounds have triggered other sprouting (Undie et al., 2021). The coconut tree has many challenges, as there are key problems, as bud rot, lethal yellowing, and pest control (Tzec-Sima et al., 2022). Therefore, there should be an eco-friendly and sustainable of vital crops involving coconut plantations (Tzec-Sima et al., 2022).

The significance of a coconut tree is represented as the tree of life in its external value for economic and cultural benefits of an income, including increasing its production (Alrifai & Marcone, 2019). The challenges are to have a slow propagation rate, vulnerability to pests and diseases, and limited genetic diversity (Alrifai & Marcone, 2019). Therefore, biotechnology is utilized in molecular markers to assess genetic diversity, support breeding programs, and identify desirable traits (Alrifai

& Marcone, 2019). It is a rooftop nursery environment to allow temperature, humidity, light intensity, rainfall exposure, and wind to determine the mechanistic value in a coconut tree (Sulaiman et al., 2025). The coconut seedlings require a rooftop condition to increase in height, number of leaves, and stem girth (Sulaiman et al., 2025). Thus, these microclimatic responses affect the optimization of the rooftop nursery system for managing a coconut propagation as space is limited for an urban location setting (Sulaiman et al., 2025).

Coconut tree productivity is often limited by the slow growth rate due to environmental stress and sub-optimal cultivation practices. There is still an insufficient amount of information on how to specify environmental, soil, and other factors for the growth and productivity of coconut trees. Thus, these may put a halt to a coconut's progression in becoming the next cultivation season of an establishment in yield. Thus, the research gap is to address the missing link and information on alternative cultivation for high-density planting in a new cultivation era of the coconut tree. Therefore, the main aim is to review and evaluate cultivation systems for coconut trees to identify the approaches in growth performance, productivity, and adaptivity to different environmental conditions and other conditions.

LITERATURE REVIEW

Coconut is a vital crop that is traditionally grown in Fiji, providing food, income, and cultural diversity in a rural community (Lata & Osborne-Naikatini, 2025). However, the production has declined due to aging populations, inconsistent management practices, and limited adoption of modern technologies (Lata & Osborne-Naikatini, 2025). This paper explained how cover crops have become another cultivation for a coconut plantation (Dissanayaka et al., 2022). However, coconut plantations are synonymously related to low soil fertility, erosion, poor nutrient cycling, and inefficient land use (Dissanayaka et al., 2022). There is also a way to limit the weed growth to reduce other competing resources by using a herbicide (Dissanayaka et al., 2022).

Thus, the existing management practice originated in Central Maluku, where coconut farming has a major role in rural and local economic activity (Asthutiirundu et al., 2022). They have employed by analysing cultivation strategies and farming characteristics in order to improve productivity and sustainability (Asthutiirundu et al., 2022). There are also several key features included, such as a lack of reproducibility, a poor soil management system, inadequate space for pruning, and market barriers for farming investment (Asthutiirundu et al., 2022). This paper investigates the factors influencing a household's decision to their involved in coconut farming in Ghana for income generation, food security, and rural settings (Kwara et al., 2025). Therefore, it concludes that there are still socioeconomic disparities that increase the participation rate for coconut plantation to boost their economic activities (Kwara et al., 2025).

Further, this paper explores the coconut industry transition toward a circular economy model for a wide range of products, including food, oil, water, fibre, charcoal, timber, and by-products (Udumann et al., 2025). It is a review of the diversity of coconut's multipurpose uses for their traditional, nutritional, and industrial applications (Joshi et al., 2025). It is summarised that coconut is a versatile, health-promoting, and industrially invaluable crop (Joshi et al., 2025). This paper reviews the design and efficiency of a coconut peeling machine for coconut processing and reducing labour intensity (Ingle et al., 2022). However, there is still a need for a cost-effective, safe, and efficient coconut peeling machine adopted in regions where coconut is a major crop (Ingle et al., 2022).

This study explores coconut peel as an alloy with cement to enhance soil properties for construction and other engineering notable discoveries (Rojas & Vidal, 2025). The agricultural waste, such as a coconut peel to improve soil strength, reduce environmental impact, sustainable construction mechanism (Rojas & Vidal, 2025). Besides improving soil strength, combining waste valorization to enhance structural performance (Rojas & Vidal, 2025). This paper reviews the nutritional balance, processing technologies, and product development (Nirmalaruban et al., 2025). It can either be a food or an industrial crop (Nirmalaruban et al., 2025). For instance, coconut milk is rich in mineral extracts for an antioxidant property (Nirmalaruban et al., 2025). Thus, a coconut has highly versatile and nutritionally rich resources for consumer health by developing strategies at its economic potential (Nirmalaruban et al., 2025).

This study examines the multifaceted significance of coconut (Cocos nucifera) across economic, social, and environmental sectors for considering it as a vital crop in tropical regions (Alouw et al., 2025). Thus, the challenges are ageing plantations, climate change impacts, pests and diseases, and limited technological adoption (Alouw et al. 2025). This study examines the global prospect of coconut (Cocos nucifera) as an economic crop of fair trade in a rural livelihood (Johnson et al., 2024). There are value-added products for tropical countries, such as raw nuts and processed products, as the key source of employment (Johnson et al., 2024). Therefore, it is found that coconut has a strong potential as a high-value crop depending on sustainable management and technological innovation (Johnson et al., 2024).

Coconut (*Cocos nucifera*) plays a vital role in supporting rural livelihoods, food security, and economic development across tropical regions; however, its productivity and sustainability are increasingly challenged by aging plantations, poor soil management, pest and disease pressures, and limited adoption of modern technologies. Previous studies have highlighted issues such as declining production, inefficient land use, and socioeconomic barriers affecting farmer participation, alongside the need for improved cultivation practices, including the use of cover crops and better resource management strategies. In addition, while coconut demonstrates high versatility in food, industrial applications, and emerging circular economy models, there remains a gap in integrating these innovations with sustainable farming systems and technological advancements. Therefore, this study aims to evaluate and synthesize existing coconut cultivation practices, management strategies, and value-added innovations to identify effective approaches for improving productivity, sustainability, and economic potential. Specifically, the study seeks to examine the influence of environmental, agronomic, and socioeconomic factors on coconut production, while exploring opportunities for technological adoption and resource optimization to support long-term industry development.

MATERIALS AND METHODS

This paper conducts a systematic literature review on growth performance, productivity, and adaptivity of coconut (Cocos nucifera) across different timelines and geographical boundaries. There is also a marketing data analysis to provide market-relevant insights into supply stability, product quality, and competitive advantage. For a time record, a sustainably vital crop combines productivity, environmental resilience, market stability, and socioeconomic benefits. This study employed a mixed-methods research design by integrating qualitative and quantitative assessments of the comprehensive evaluation of coconut growth performance, productivity, and adaptivity across different cultivation systems and environmental conditions. However, there is an insufficient amount of data and information on yield records, variability in management practices, the long growth cycle of the coconut, and difficulty in measuring the aging of the coconut population in the region itself. Therefore, a standardized and thorough detail record of the data is also reported to avoid any inconsistencies in the information.

This study adopts a mixed-methods research design to evaluate the growth performance, productivity, and adaptivity of coconut (*Cocos nucifera*) across different geographical regions and time periods. The research integrates both qualitative and quantitative approaches to provide a comprehensive understanding of coconut cultivation systems under varying environmental conditions. This design allows for a holistic assessment of agronomic performance while also capturing broader socioeconomic and market-related dimensions.

A systematic literature review was conducted to gather relevant secondary data from published journals, reports, and academic sources. The review focused on key themes such as yield performance, environmental adaptability, cultivation practices, and technological advancements in coconut production. Sources were selected based on their relevance, credibility, and coverage across multiple regions and timelines to ensure a balanced and comparative analysis.

In addition to the literature review, marketing data analysis was performed to examine market trends related to supply stability, product quality, and competitive advantage. This component aimed to link production performance with market dynamics, highlighting how coconut functions as a sustainable crop that contributes to economic resilience and industry development.

However, several limitations were identified, including insufficient and inconsistent yield data, variability in management practices, and challenges associated with the long growth cycle of coconut palms. Furthermore, difficulties in assessing the aging population of coconut trees across regions were noted. To address these issues, efforts were made to standardize data collection and reporting, ensuring consistency and reliability in the analysis.

RESULTS AND DISCUSSION

It is a study with a limited sample of only 15 out of 97 countries (Naik, 2017). Therefore, it is not representative of global diversity and must be handled with caution (Naik, 2017). Since it is secondary data, there is no information on farm-level practices for the adoption of any improvement in the cultivation of the coconut. Thus, this study covers a large time span of 30 years and includes many major coconut-producing countries (Narmadha & Karunakaran, 2022). Further, a compound growth rate is appropriate for long-term trends (Narmadha & Karunakaran, 2022). However, there are inconsistencies for a stagnant average (Narmadha & Karunakaran, 2022). COCONUT is a collection database of natural products represented by small molecules produced by living organisms that have bioactive compounds (Sorokina et al., 2021). There are altogether 721,011 unique coconuts with stereochemistry prepared for the internal molecular features, to produce organisms and taxonomy (Sorokina et al., 2021).

The lightest molecular weight of the coconut is at 1, and the heaviest is at 1071. The data extracts information on the chemical composition of a coconut for its medicinal value properties. It is to analyse the natural products contained within a coconut. The high molecular weight was attributed to the water content and macromolecules, which consisted of fats, lipids, and carbohydrates, consumed in daily dietary intake. By weight, a coconut contains several natural products, including major fatty acids, sugars, and carbohydrates, as well as antioxidant properties. However, the overall density is lighter for the coconut to stay afloat in the middle of the ocean. There is a strong correlation between heavy atom count and the molecular weight of all the coconuts. A coconut is not a single molecule but is made of millions of different molecules. The heavier the atoms, the higher the molecular weight. It holds well for fatty acids, triglycerides, sugars, and amino acids.

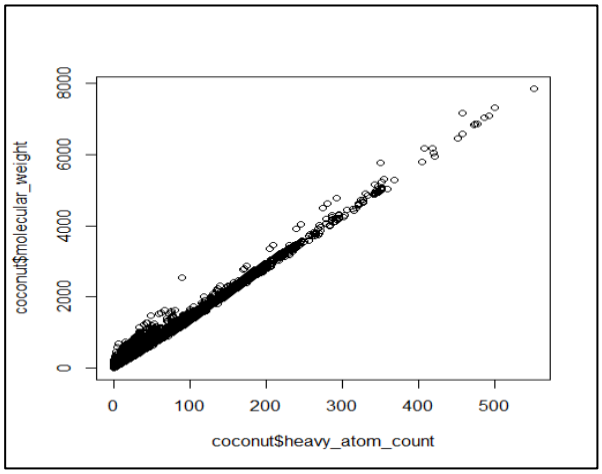


Figure 1: The Scatterplot Between Total Heavy Atom Count and Molecular Weight of Coconut Data.

It uses representative natural products found in coconut, such as fatty acids, sugars, phenolics, and triglycerides, which are chemically accurate approximations to prove the strength of the relationship between total atom heavy count and molecular weight of a coconut. There is a comparison study between two improved parent cultivars for Rennell Island Tall and West Africa Tall were harvested at different maturity stages (Kouadio et al., 2023). Thus, both cultivar and maturity stage significantly influenced most morphological characteristics (Kouadio et al., 2023).

By using Robust Regression, the data contain outliers, heavy-tailed noise, or measurement errors. Thus, it is useful when some coconut samples are mismeasured, the measurement equipment drifts, and there is a need for a line-based model. In biochemical measurements, there are skewed errors and heterogeneous samples. Coconut samples vary widely in terms of maturity, moisture content, oil composition, and lignan content. Coconuts are not uniform, as there are different cultivars in production for more standardized sizes and quality of the product, as the pest or disease controls checklists seem to go on endlessly (Seethapathy et al., 2025). The disease resistance depends relentlessly on the topographical measurements of the coconut plantation sites, as the pest management control is on the verge of Science (Seethapathy et al., 2025).

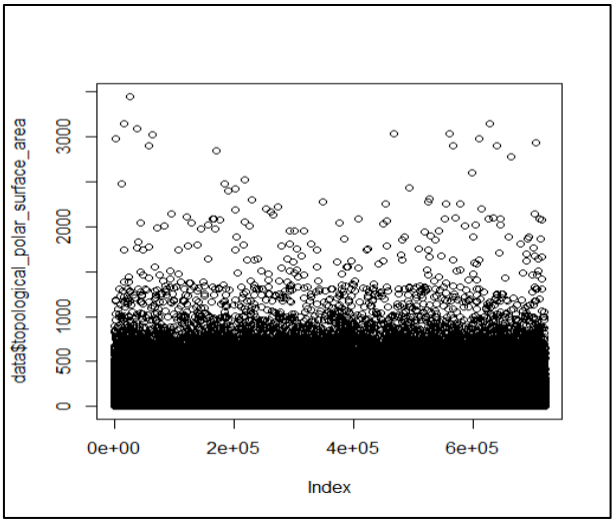


Figure 2: Variability of Topological Polar Surface Area of Coconut (N=721 011).

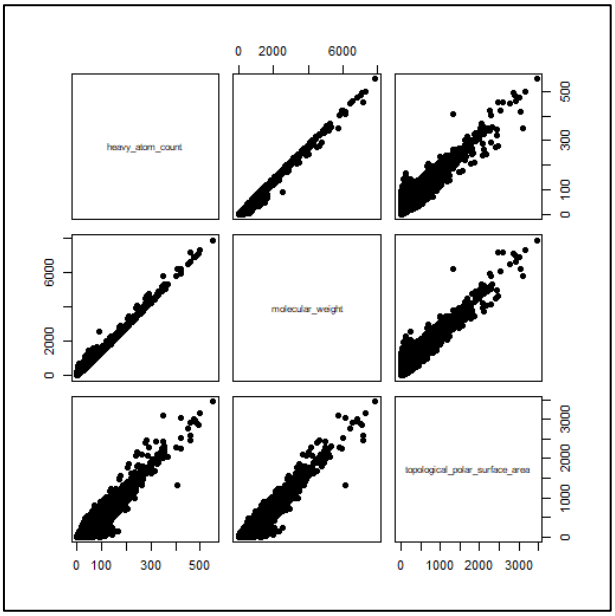


Figure 3: Scatter Plot of Heterogeneity in Morphological Data for Coconuts.

Based on Figures 2 and 3, coconuts are single molecules, chemical compositions contain coconut-derived compounds (fatty acids, triglycerides, and sugars). From a narrow perspective, molecular weight and heavy atom count are strongly linearly correlated. Most coconut lipids have many low topological polar surface areas, and because they are more represented in a long chain of hydrocarbons and a single carboxyl. Thus, after a variability in mixed compound classes, none of these properties is correlated linearly. Topological polar surface area is for the bioavailability of coconut polar atoms, including oxygen, nitrogen, and hydrogen (Islam et al., 2024). It reviews on coconut derivatives nutritional, biochemical, and bioactive properties (Islam et al., 2024).

Table 1: Area and Amount of Production of Coconuts in Malaysia.

Year	Planted Area (ha)	Production (Tonnes)
2022	79412	517983
2023	85400	464000

Based on Table 1, the planted area of coconut in 2023 was measured at 84,500 hectares. The production amount totaled 464,000 tonnes. In five years of a term per annum, the compound annual growth of 0.48% for the stabilization growth of the land specified for coconuts only. Among smallholders, this could influence the overall production and supply stability of coconuts. They have a mapping effect on several distribution systems of coconut production in Malaysia. As mentioned before, there has been a shrinking cultivation area for lucrative crops and housing areas. The demographic aging shows less inclination to coconut farming.

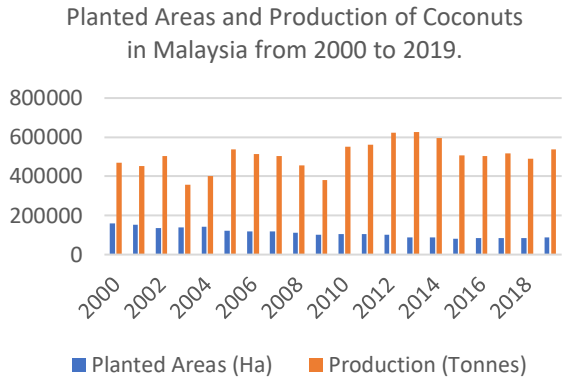


Figure 4: Planted Areas and Production of Coconuts in Malaysia from 2000 until 2019.

In 2016, there is a representative midpoint that emphasizes the total planted area at 84,609 hectares, and the amount of production is at 504,772 tonnes of metric for an average yield of 5.97 tonnes per hectare. Over time, there is a declination drastically changes in their strategy control to have a sudden slope from 120,000 ha to 85,000 from 2005 to 2016. The contraction of the planted area has created a new home

for lucrative crops or other land uses. The amount of production has fluctuated from 539,000 in 2005 to 379,000 in 2009, but then recovered in 2010 until 2016 to reach a range of 500,000 to 625,000 tonnes annually. At the end of 2019, the production was at 536,606 metric tonnes. Therefore, there is a partial gain in yield (productivity) or more efficient harvesting or management on the remaining planted land.

According to the 2021 industry summary on the coconut sector in Malaysia, the total planted area with coconut in 2020 was 85,630 hectares, and total production was reported at 542,000 metric tonnes (Ariff et al., 2020). The study aims to assess the acceptance of the hybrid coconut seed variety MATAG, which was conducted in two districts: Bagan Datoh, Perak, and Bachok, Kelantan. This is because these districts have the highest number of smallholders (7,087 in Bagan Datoh and 7,144 in Bachok) (Man & Shah, 2020). Among the 200 respondents (100 from Bagan Datoh and 100 from Bachok), the growers showed a positive awareness of the attitude toward MATAG (Man & Shah, 2020). It is widely accepted that hybrid seed is another viable alternative for a successful coconut plantation (Man & Shah, 2020). Its main objective was to produce an F1 hybrid seedling from a cross between female Kopyor Sinumpur Yellow Dwarf (KSYD) and male Kopyor Sinumpur Tall (KST) parents, are the resulting seedlings are true to type (genuine hybrids) using both morphological and molecular genetic analysis (Sisunandar et al., 2025). Further, it demonstrates a robust protocol combining conventional breeding with modern molecular verification to produce true-to-type seedlings (Sisunandar et al., 2025).

CONCLUSIONS

This study highlights several important findings regarding coconut productivity and sustainability. First, despite a decline in planted areas due to competition from more lucrative crops and alternative land uses, coconut production has shown relative stability, with fluctuations followed by recovery, indicating improved efficiency in harvesting and management practices. Second, the adoption of hybrid varieties such as MATAG demonstrates strong potential to enhance yield, resilience, and uniformity, supported by advances in breeding techniques and molecular verification. Third, coconut remains a valuable economic crop with significant contributions to smallholder livelihoods, particularly through improved planting materials and cultivation strategies.

However, the study is limited by its reliance on secondary data, inconsistencies in long-term production records, and a lack of detailed farm-level information. Additionally, variations in management practices and environmental conditions may affect the generalizability of the findings. Therefore, future research should focus on standardized data collection, technological adoption, and sustainable cultivation approaches to further strengthen the coconut industry.

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