Elevating Efficiency and Sustainability in Large-Scale Coconut Oil Manufacturing through Progressive Strategies

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***Abstract*— Although Sri Lanka is known worldwide for producing premium coconut oil, small-scale growers face real challenges such as high production costs, limited access to foreign markets, and significant intermediary margins. This research proposes a web application as an affordable way to solve these problems. For coconut oil producers and distributors, the proposed application provides an easy-to-use platform that includes functionalities for quick notifications, effective order handling, and increased oil yield forecasting, as well as copra/oil quality measurement. The app also aims to improve coconut oil distribution, forecast demand and supply, and create a business-to-consumer marketplace. By empowering small-scale farmers with these tools, the app seeks to improve their financial results, expand access to international markets, and increase the income of small-scale producers by cutting out middlemen. Implementing this application will enable producers to get a fair price for their coconut oil, improve market penetration, and reduce transaction costs. The study suggests a new approach that could revolutionize Sri Lanka's coconut oil market and benefit producers and consumers worldwide.**

Keywords—predictive models, copra quality, oil yield prediction, quality measurement, supply-demand forecasting, digital transformation, economic prosperity.

I. Introduction

A. *Background*

Coconut cultivation is widespread across Sri Lanka, with coconut palms covering a considerable portion of the country's land. The coconut tree is often referred to as the "tree of life" in Sri Lanka due to the versatility and the multitude of products derived from the coconut. Sri Lanka exports a significant amount of coconut oil to various countries around the world. The country is known for producing high-quality virgin coconut oil (VCO), which is extracted from fresh coconut meat without undergoing chemical refining. Sri Lanka has numerous coconut oil processing facilities scattered across the country. These facilities process coconuts into oil through methods such as cold-pressing or expeller pressing to retain the oil's natural flavor and nutrients. Some larger facilities may also engage in refining processes to produce refined coconut oil. Sri Lankan coconut oil manufacturers adhere to strict quality standards to ensure that their products meet international requirements, which include compliance with food safety regulations and certifications such as ISO (International Organization for Standardization) and HACCP (Hazard Analysis and Critical Control Points).

Sri Lanka is the fourth-largest coconut producer as of 2021 [1] and, as Table 1 shows, the seventh-largest coconut oil producer as of 2019 [2]. Because the country has an abundance of coconut resources, Sri Lankans have an outstanding chance to increase the country's earnings by generating more coconut oil. Sri Lanka's economy depends heavily on coconut oil, but the sector hasn't made the most of contemporary technology to the fullest extent possible.

Table 1: Most Coconut Oil Produced Countries as of 2019 Source: Adapted from [Source: nationmaster website]

Rank	Country	2019 Production (Metric Tons)
1	Philippines	1,302,991
2	Indonesia	835,267
3	India	297,031
4	Vietnam	170,879
5	Mexico	130,484
6	Bangladesh	63,936
7	Sri Lanka	55,797
8	Malaysia	40,396
9	Mozambique	30,539
10	Thailand	27,256

Sri Lanka satisfies approximately 1.33% of the worldwide demand for coconut oil, totaling an export value of USD 62.7 million. The primary importers of coconut oil from Sri Lanka include the United States, Australia, Germany, Saudi Arabia, the United Kingdom, and the Netherlands [3].

The study endeavors to shed light on the nuanced interdependencies within the Sri Lankan coconut industry and explore avenues for resilient adaptation in the face of evolving environmental and market forces [4].

B. *Problem Statement*

In Sri Lanka's current coconut oil industry, there is a process based on human decisions, which is not efficient, and personal weaknesses can also cause disadvantages [5].

Figure 2 displays the difference between coconut oil imports and exports across various countries. Despite Sri Lanka's achievement as one of the top 10 coconut oil producers globally, the data reveals a concerning trend: Sri Lanka imports more coconut oil than it exports. To address this issue and boost export rates, there's a need for substantial changes in the current export process. It should be precise to move away from manual methods towards automated and faster processes. This transformation is essential for improving efficiency and sustainability in Sri Lanka's coconut oil industry.

There is currently a lack of comprehensive systems for predicting country-specific demand, hindering effective planning and resource allocation in export-oriented industries. Additionally, there exists a gap in forecasting the profitability of potential export destinations, limiting strategic decision-making for future market expansions. Addressing these shortcomings through the development of advanced predictive analytics systems could significantly enhance the efficiency and competitiveness of international trade sectors.

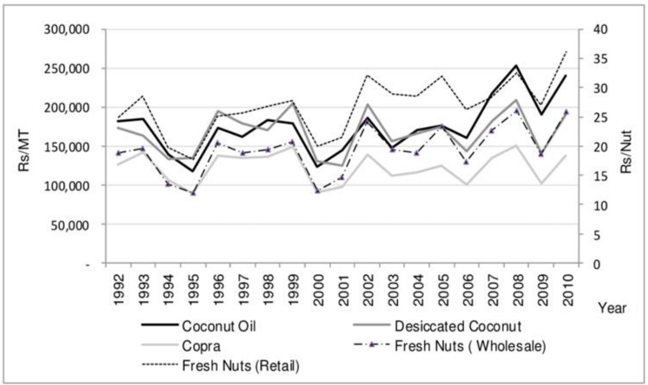


Figure 1: Local market prices of coconut kernel products (in 2012 real terms) (I USD = 130 RS)
Source: Adapted from Coconut Development Authority, 1970-2013

Predicting future coconut oil demand based solely on past export data may not provide accurate forecasts, as past data overlooks crucial factors such as the economic status, flooding count, and fire rate. While historical export analysis is valuable, analysis fails to capture the complexity of export determinants influenced by various economic indicators, market trends, geopolitical factors, and consumer behavior. Therefore, there is a need to explore how incorporating economic indicators and other relevant factors can improve the accuracy and reliability of coconut oil export predictions. This approach can lead to more informed decision-making and better market strategies for stakeholders in the coconut oil industry.

C. *Objectives*

The main goal of this research is to create a web application that combines cutting-edge technology, like predictive models and machine learning, to improve the sustainability and efficiency of large-scale coconut oil manufacturing. The application's goals are below mentioned.

1. Increase oil yield prediction and copra/oil quality measurement.
2. Improve coconut oil distribution.
3. Forecast the demand and the supply.
4. Create a business-to-consumer marketplace
5. Give small-scale farmers the tools they need to improve their financial results.

II. LITERATURE REVIEW

A. *Previous Work*

Numerous facets of coconut oil production and market dynamics have been studied in the past. Research has looked into supply and demand forecasting models, the link between imports and domestic supply, and the effect of economic issues like inflation on market demand. Nevertheless, not much research has been done expressly on Sri Lanka's coconut oil market and how it interacts with other international economic variables and local geographical disasters.

Limited research specifically addresses the coconut oil market in Sri Lanka and its interaction with global economic factors, indicating a gap in the literature that this study aims to fill [6].

Prior work on copra quality prediction has focused on classification models for agricultural products, including mold detection and quality assessment methods [7]. In the earlier study, every image of coconut oil was processed using an image processing methodology to identify contaminants, as shown in Figure 3's method of identifying items in coconut oil.

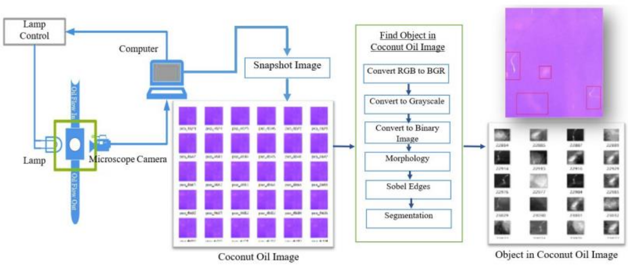
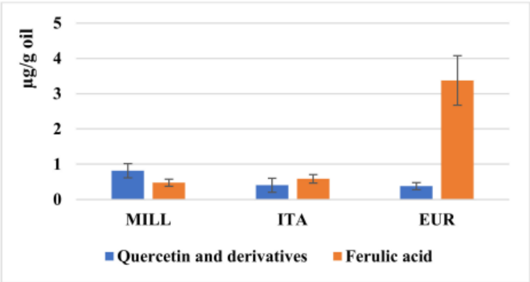


Figure 2: Object image acquisition in coconut oil
Source: Adapted from [7]

The existing coconut oil yield forecasting mainly revolves around agronomic practices and crop yield estimation. While some studies have explored predictive modeling techniques for crop yield, few have specifically addressed coconut oil yield prediction in the context of Sri Lanka.

Coconut oil quality prediction focuses primarily on laboratory testing and chemical analysis methods. While these approaches provide valuable insight into oil quality, they are often time-consuming and resource-intensive. Figure 6 displays the polyphenol content, which is frequently regarded as a quality indicator, in each of the three clusters.



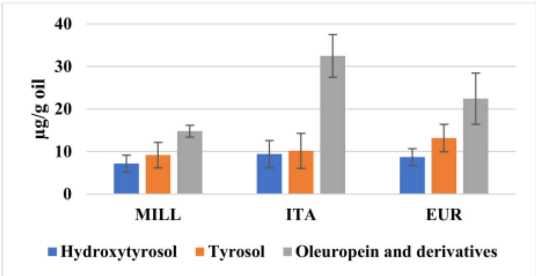


Figure 3: Average values of the main polyphenolic components in the three main clusters (MILL, ITA, and EUR)
Source: Adapted from [7]

B. *Gaps in the Literature*

Previous research in the coconut oil sector has mostly concentrated on human decision-making processes and conventional techniques. Research on the use of cutting-edge technology, like machine learning and predictive models, to enhance market results and streamline production processes is lacking. This disparity emphasizes the necessity for creative solutions catered to the special requirements and features of the coconut oil sector in Sri Lanka.

Research "The Coconut Industry: A Review of Price Forecasting Modeling in Major Coconut Producing Countries" focuses on analyzing past global coconut oil prices and forecasting future prices based on a single variable, which highlights a significant limitation in current methodologies. By neglecting to incorporate various critical parameters such as production levels, market demand, climatic variables, peak seasons, and the economic status of coconut-producing countries, the forecasting model fails to capture the comprehensive array of factors influencing coconut oil prices. This narrow approach overlooks the intricate interplay between these variables, potentially leading to less accurate predictions and a limited understanding of the underlying drivers shaping coconut oil market dynamics. Consequently, there exists a notable research gap in the failure to integrate multiple parameters into the forecasting framework, which could significantly enhance the predictive capabilities and robustness of coconut oil price forecasts.

A significant gap in research, "THE COCONUT INDUSTRY IN SRI LANKA: AN ANALYSIS OF GOVERNMENT INTERVENTION MEASURES," is the lack of studies that predict the best amount of coconut oil to produce to help with inflation in Sri Lanka. Even though coconut oil is very important in Sri Lanka and inflation can be a problem, there haven't been many studies looking at how coconut oil production levels can help control inflation. Figuring out the right amount of coconut oil to produce could be really helpful for Sri Lanka's government and businesses. If the facts that how much coconut oil to make to meet demand without making prices go up too much are known, it could help policymakers make better decisions to deal with inflation.

Another noticeable gap in current research is the absence of studies predicting the optimal distribution of coconut oil to each country to maximize profits. Despite the global demand for coconut oil and its importance as a commodity in various countries, there is a lack of research specifically focusing on determining the most profitable distribution levels for different markets. Understanding how much coconut oil should be distributed to each country to achieve the desired profits could offer valuable insights for producers, exporters, and policymakers alike. By identifying the distribution strategies that yield the highest returns, such research could inform more effective decision-making processes and resource allocation strategies in the coconut oil industry.

Justification for Current Study

The goal of the current project is to close the gaps that have been found by creating a web application that uses cutting-edge technology to improve the sustainability and efficiency of large-scale coconut oil production. The suggested application aims to optimize manufacturing procedures, enhance quality assessment, and provide improved market access for small-scale producers by combining machine learning algorithms and predictive models.

III. METHDOLOGY

1) *Supply And Demand Predictive Model*

The methodology for forecasting coconut oil exports involves a systematic approach that combines data collection, preprocessing, forecast modeling, and application. This approach is designed to build a comprehensive model that predicts export volumes, identifies optimal distribution strategies, and improves decision-making for stakeholders in Sri Lanka's coconut oil industry.

The first step in the methodology is data collection, which forms the basis of the predictive model. Data has been collected from multiple sources, including historical export data from Sri Lanka to various countries, economic indicators such as inflation rates, currency exchange rates, and compound annual growth rates (CAGR), as well as climate and environmental data related to natural disasters. Like floods and forest fires that have affected coconut production. Additionally, global market trends and trade agreements are included to provide a complete picture of factors affecting coconut oil exports.

After data collection, the preprocessing phase is crucial to ensuring data quality and reliability. This phase involves data cleaning to handle missing values, outliers, and inconsistencies. Feature engineering is then applied to convert categorical variables such as country names and industry types into numerical formats using techniques such as one-hot coding. Moreover, relevant characteristics are designed to capture economic growth trends, seasonal effects, and the impact of natural disasters. The dataset is divided into training and testing subsets to evaluate the performance of the model on unseen data.

For predictive modeling, multiple techniques are used to build a robust export forecasting system. Logistic regression is used to forecast coconut oil prices, leveraging historical price data, economic indicators, and market trends. Using One-vs-Rest (OvR) and One-vs-One (OvO) strategies for effective multiclass classification, a multiclass logistic regression model is implemented to predict the countries to which coconut oil should be distributed. Additionally, a random forest regression model is developed to predict the optimal export volume for each country based on features such as inflation rates, number of exporters, disaster impact data, and historical export volumes.

Models are rigorously evaluated and optimized to ensure their accuracy and reliability. Evaluation metrics such as mean absolute error (MAE), mean square error (MSE), and R-squared values are used to assess model performance. Cross-validation methods are used to verify that the models generalize well to new data, and hyperparameter tuning is performed using methods such as grid search or random search to optimize the performance of the models.

The final step in the methodology is to deploy the prediction model to a web-based platform. The platform allows users to enter various parameters, such as inflation rates, export prices, and market demand, to get export forecasts. To improve transparency and usability, the platform integrates explanatory AI (XAI) tools such as SHAP (SHAPley Additive Explanations), which provide insight into how various factors influence export forecasts. This deployment ensures that the forecast model is not only accurate but also accessible and actionable for decision-makers in the coconut oil industry.

2) *Copra Quality Predictive Model*

The initial phase of the study involved the systematic collection and processing of a qualitatively classified set of different copra images. The database was developed in collaboration with research institutes, agricultural experts, and coconut processing facilities, ensuring a broad representation of copra at various stages and quality levels.

Each image is meticulously tagged and preprocessed to facilitate accurate model training. This preprocessing included standardization techniques to ensure uniformity of image dimensions and quality, critical to the effectiveness of the Convolutional Neural Network (CNN) model employed in this research.

A CNN's overall architecture is shown in Figure 5, which includes the following layers: input, convolutional, pooling, output, rectified linear unit (ReLU), and softmax.

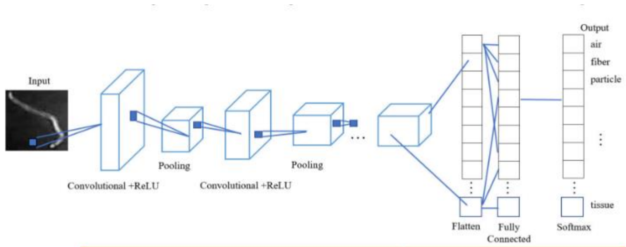


Figure 4: CNN architecture
Source: Adapted from [5]

After data collection, the development of the copra quality prediction model began. A Convolutional Neural Network (CNN) is constructed and consists of input, convolutional, pooling, Rectified Linear Unit (ReLU), and softmax layers, each designed to systematically extract and analyze the features of copra images. CNN was trained using the preprocessed data set, and the model was able to classify copra quality into three categories: good, medium, and poor. The use of RGB image processing techniques further enhanced the model's ability to detect subtle differences in copra quality.

The trained model was then integrated into the CocoClarity Mobile App, allowing for real-time copra quality assessment. Users can capture images of copra using the app and process the images through CNN to predict quality levels, providing instant and reliable feedback that is critical to optimizing coconut oil production.

A user-centric interface was developed to facilitate seamless interaction between end users and the copra quality prediction model in the mobile application. Established regular feedback loops with industry experts and stakeholders to iterate the model and improve the user experience. This iterative refining process ensures that the application remains relevant and practical for large-scale coconut oil producers, thereby supporting both the efficiency and sustainability of the industry.

3) *The Oil Product Estimator*

The Oil Production Estimator is an ‘ultra moderate’ research project for mechanizing coconut oil production through the utilization of modern artificial intelligence approaches. Organized at its core, the project will focus on the usage of algorithms and other model-based approaches to optimize the set production process, making it more efficient in terms of yields and resource consumption.

The process starts with an effective process of data gathering; this is a vital process in the success of the project. This includes an assumption of different data, for example historical yield data together with current yield data, and other factors in the external environment that may in one way or another affect yield. Historical data creates a reference point that outlines trends that have occurred in the past, while current data enables one to make changes and forecasts that are possibly the most accurate since they are made at the time when they are being made. Even weather conditions, type of soil, or even market demand can also influence the growth of coconuts and, in turn, the production of coconut oil. From this vast database, the various predictive models for IT service management are developed.

The research then focuses on the development of two key predictive models: two of them are a random forest model and a decision tree model. It is a formula-based model that predicts the quantity of coconut input that is required and the time taken to produce the desired oil output in Random Forest. This model is especially useful because of its ability to deal with a great number of indicators and owing to its stability to overtraining, which allows predicting outcomes depending on several factors. On the other hand, the decision tree model is used to forecast the oil yield, more particularly from kurutu, which is a co-product during coconut oil production. This model is used due to its ability to give the specifics of what went on in the decision-making process to arrive at that yield.

One of the essential components of the methodology is the creation of a current yield tracking system. The data taken each time is compiled with previous data to develop individual coconut files. These profiles are crucial since they give a clear performance of each coconut within the production process so as to be in a position to make a better estimate and control. It also has features that allow the assessment of factors from outside and their impact on the productivity of the systems.

The optimization is one of the methodology's crucial parts, and distinctive algorithms are designed for every method. These algorithms are supposed to optimize the production process to ensure that loss is almost eradicated and production is boosted. Taking into account the data collected and the forecasts of the models, optimization algorithms can propose that course of action that would enhance the results of the production. For instance, they may recommend a change in the pattern of picking or the alteration of the practices that come into the process depending on what the expected yield is and what it would take to achieve it.

The other notable feature of the research is the dissemination of the results and the findings of the researcher. In this regard, the work features a stable data analysis and visualization part. Managers and analysts thus employ different graphs and charts to express the idea that may otherwise be complicated to untangle and give meaning to. For instance, when using the line charts, one is able to compare between the coconut input and the outlay of the oil over some time and reach conclusions that might not be noticeable. Pie charts are employed in presenting the use of coconut by-products on the impression as to how different portions of coconut are useful. Bar charts are also used to present the impact of the various external factors in the production of oil, hence indicating which factors affect yield most.

Once again, the reasoning has been presented as following the methodology: In the last point, the author evaluates the prospects of the given predictive models as well as the whole system. It includes the verification of the models for accuracy, testing of the optimization algorithms for optimization, and lastly, the capability of deploying the system on a production line. Documentation also creates another side of the methodology because everything should be described thoroughly and easily for other subjects to comprehend.

4) Coconut Oil Quality Predictive Model

For the purpose of accomplishing its goals, the research process for creating the live coconut quality measurement function uses a methodical approach that incorporates knowledge from multiple fields. First, thorough data collection varied library of photos of coconut oil with matching quality labels is required for this. is the first step in the procedure. Building a varied library of photos of coconut oil with matching quality labels is required for this. Access to such data is facilitated by collaboration with laboratories, research institutes, and producers of coconut oil, which guarantees its representativeness across various quality features and production settings.

Following that, focus shifts to the creation of the model, where a convolutional neural network (CNN) is painstakingly created and trained to predict quality based on images. CNN employs deep learning techniques to extract relevant information and forecast the quality of coconut oil photos based on machine learning and image analysis knowledge [8]. To guarantee the effectiveness and precision of the model, this stage necessitates a thorough comprehension of machine learning principles as well as the characteristics of coconut oil.

In this study, we predicted coconut oil quality using key parameters: moisture content, free fatty acid (FFA) levels, peroxide value, and color. A convolutional neural network (CNN) model analyzed visual features from sample images, capturing subtle quality indicators, while a decision tree classifier processed the quantitative data. This hybrid approach leveraged both visual and structured data, significantly improving prediction accuracy. Our results showed that combining CNN and Decision Tree methods provided a comprehensive and reliable assessment of coconut oil quality, making it an effective tool for industrial quality control.

IV. Results

A. Findings

The research also highlights the role of the application in oil yield prediction and copra/oil quality measurement. With tools that provide data-driven insights, manufacturers can make informed decisions about production cycles and distribution quantities, leading to higher product quality and yields. By interacting with the export statistics, manufacturers can predict the demand of the coconut oil buying country with the explainable AI and analyze important factors. This improvement in production results is critical to maintaining the premium status of coconut oil in Sri Lanka.

By enabling manufacturers to streamline operations and optimize their supply chains, the app reduces dependence on middlemen, thereby lowering production costs. This optimization not only increases the efficiency of resource allocation but also reduces waste, contributing to overall cost savings.

Additionally, the app's integration into a business-to-consumer (B2C) marketplace greatly expands market access for small-scale manufacturers. This feature allows manufacturers to bypass traditional middlemen by reaching both domestic and international markets directly. By facilitating direct sales, the platform increases profit margins for manufacturers and enhances their competitiveness in the global market.

V. Discussion

A. Interpretation of Results

Predictive models for measuring oil yield and quality enable producers to make data-driven decisions that optimize production cycles and increase product quality. This capability is particularly important in maintaining Sri Lanka's reputation for producing premium coconut oil, as it ensures consistency in the quality of the final product. The ability to accurately forecast demand and supply positions producers to better align their production with market needs, reduce the risk of overproduction or shortages, and stabilize prices.

Moreover, the integration of a business-to-consumer (B2C) marketplace within the app expands market access for small-scale producers, allowing them to bypass intermediaries and engage directly with domestic and international customers. This direct market access not only increases profit margins but also empowers manufacturers by giving them more control over pricing and distribution.

The study also underscores the importance of using technology to address inefficiencies in the current export process. By automating key aspects of production and distribution, the app reduces reliance on human decision-making, which is prone to errors and inefficiencies.

Limitations

The quality and availability of the data, which may affect the predictive models' accuracy and generalizability, is one of the study's drawbacks. To ensure the web application's efficacy and relevance, ongoing updates and cooperation with industry stakeholders are also necessary for its implementation.

VI. Conclusion

A. Future Work

To guarantee the application's continued performance and applicability, updates to the data repository, live coconut oil quality prediction, coconut oil distribution sector prediction, and ongoing cooperation with industry stakeholders can be suggested.

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