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DIGITAL TWIN-ENABLED RESILIENT COCONUT SUPPLY CHAINS

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DECLARATION

I declare that this is my own work and this thesis/dissertation does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other University or Institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text. I retain the right to use this content in whole or part in future works (such as articles or books).

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Date: 09/01/2026

The above candidate has carried out research for the ~~PhD/MPhil~~/Masters thesis/dissertation under my supervision. I confirm that the declaration made above by the student is true and correct.

Name of Supervisor: Prof. Niles Perera

Signature of the Supervisor:

Date: 09/01/2026

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ABSTRACT

Agricultural supply chains are increasingly exposed to complex and interdependent risks, yet risk management in perennial crop systems remains largely reactive. This research addresses this gap by developing a Digital Twin (DT)-enabled model to enhance resilience in the Sri Lankan coconut supply chain, with a specific focus on production-stage risks. Three objectives guide the study: (1) identify the critical production risks influencing coconut yield, (2) design a comprehensive DT framework for proactive risk management, and (3) implement and validate a functional DT model capable of early risk detection and mitigation. Structured content analysis of recent literature and semi-structured interviews with domain experts from prominent national institutions were employed to identify and priorities production risks. These were classified into three primary categories: weather and climate variability, pests and diseases, and soil conditions. Building on these insights, a Digital Twin framework was developed using Azure Digital Twins, integrating physical asset representation, data ingestion, virtual modeling, analytics, and decision support services. Historical yield, meteorological data train a Bi-directional Long Short-Term Memory (BiLSTM) model for district-level coconut yield prediction. Soil data was analyzed and incorporated as input to the model as a risk indicator. The model achieved strong performance, with an R^2 of 0.9387 and a MAPE of 2.31% on test data, demonstrating its capability to capture nonlinear and lagged relationships between environmental drivers and yield outcomes. The research contributes theoretically by extending Digital Twin and resilience concepts into agricultural supply chains through a structured, scalable framework for perennial crops. Practically, it delivers a decision support tool that enhances visibility, supports proactive interventions, and informs policy and resource allocation for the coconut sector. Overall, this study demonstrates the feasibility and value of DT-based, data-driven resilience strategies for securing the performance and sustainability of coconut supply chains in an increasingly uncertain environment.

Keywords: Digital Twin, Agricultural Risk, Risk Management, Resilience Supply Chain, Coconut Production.

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LIST OF ABBREVIATIONS

Abbreviation	Description
ADT	Azure Digital Twins
ADTE	Azure Digital Twin Explorer
AFSC	Agricultural and Food Supply Chain
AI	Artificial Intelligence
API	Application Programming Interface
ASC	Agricultural Supply Chain
BiLSTM	Bi-directional Long Short-Term Memory
CCB	Coconut Cultivation Board
CDA	Coconut Development Authority
CEC	Cation Exchange Capacity
CRI	Coconut Research Institute
CSC	Coconut Supply Chain
DT	Digital Twin
DTDL	Digital Twin Definition Language
DUL	Drainage Upper Limit
GCS	Google Cloud Storage
GDP	Gross Domestic Product
LSYM	Long Short-Term Memory
MAE	Mean Absolut Error
MAPE	Mean Absolut Percentage Error
ONNX	Open Neural Network Exchange
RMSE	Root Mean Squared Error
RNN	Recurrent Neural Networks
SHAP	SHapley Additive exPlanations
XGBoost	Extreme Gradient Boosting

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