

ISTF2024

INTERNATIONAL SYMPOSIUM ON TROPICAL FRUITS

22-24 OCTOBER 2024
CORUS HOTEL, KUALA LUMPUR, MALAYSIA

Postharvest solutions, value addition, and waste management for sustainable tropical fruit value chains

EDITORS
Yacob Ahmad
Dorothy Chandrabalan

Main Organizer



Co-organizers



BRIN
BADAN RISET
DAN INOVASI NASIONAL



PROCEEDINGS

ISTF2024

**INTERNATIONAL SYMPOSIUM
ON TROPICAL FRUITS**

22-24 OCTOBER 2024

CORUS HOTEL, KUALA LUMPUR, MALAYSIA

Postharvest solutions, value addition, and waste management for sustainable tropical fruit value chains

EDITORS:

Yacob Ahmad

Dorothy Chandrabalan

Main Organizer



INTERNATIONAL TROPICAL FRUITS NETWORK

Co-organizers



**MALYSIAN AGRICULTURAL RESEARCH AND
DEVELOPMENT INSTITUTE**



DEPARTMENT OF AGRICULTURE, MALAYSIA



INSTITUTE OF FRUIT TREE RESEARCH, CHINA



**NATIONAL RESEARCH AND INNOVATION AGENCY
INDONESIA**

All reasonable efforts have been taken in the compilation and editing of the materials presented in this document. The views expressed herein are those of the presenters, panelists, and facilitators, and not necessarily those of the International Tropical Fruits Network (TFNet) and its members. Any companies, products from manufacturers, and technologies mentioned do not imply the endorsement or recommendation by TFNet.

eISBN 978-983-2532-19-4

© TFNet, 2025

This publication may not be reproduced or stored in a retrieval system without the prior written permission of TFNet. However, TFNet encourages the use and circulation of the information in this document. The information may be copied, downloaded, and printed for any non-commercial use, as long as TFNet is acknowledged as source and copyright holder, not as an endorser of any products or services.

Published by:
International Tropical Fruits Network (TFNet)
Box 334, UPM Post Office,
43400 Serdang, Selangor,
Malaysia.
Phone: +6017 234 1270
Website: www.itfnet.org
E-mail: info@itfnet.org

Layout by:
Christian Anthony T. Cangao

MESSAGE FROM THE CHAIRPERSON OF TFNET'S BOARD OF TRUSTEES



Distinguished guests, experts, and participants,

It is my honour to welcome you to the International Symposium on Tropical Fruits (ISTF) 2024. I extend warm greetings from the Ministry of Agriculture and Food Security, Malaysia, and express my sincere appreciation to the organisers and contributors who have made this Symposium possible.

The global tropical fruit industry has seen tremendous growth, but challenges such as postharvest losses, climate impacts, and sustainability concerns persist. According to the Food and Agriculture Organization of the United Nations (FAO), postharvest losses of tropical fruits are estimated at 32% globally, which underscores the importance of developing efficient solutions to reduce these losses and improve the resilience of fruit value chains.

For Malaysia, tropical fruits play a vital role in our agricultural sector and contribute significantly to the livelihoods of smallholder farmers. Our country is well-known for its high-quality tropical fruits like durian, pineapple, and mangosteen, which are increasingly sought after in international markets. However, postharvest losses, inefficient handling practices, and waste management issues continue to affect the full potential of our fruit sector.

Here in Malaysia, we have been proactive in seeking sustainable solutions. The Government has initiated several programmes aimed at reducing postharvest losses and promoting value addition. For instance, state agencies are working closely with smallholder farmers to adopt low-cost, scalable postharvest technologies. Innovations such as biodegradable packaging made from durian husks and the use of fruit waste to produce organic fertilisers and bioenergy are gaining momentum. These efforts not only help reduce environmental impact but also create new revenue streams for farmers, contributing to a more circular economy.

The theme of this year's Symposium, "Postharvest Solutions, Value Addition, and Waste Management for Sustainable Tropical Fruits Value Chains," reflects both global and local priorities. As Malaysia continues to push for innovations in these areas, this Symposium presents an invaluable platform for knowledge sharing, collaboration, and action. It brings together experts from across the globe, offering an opportunity to explore innovative strategies to reduce losses, increase value addition, and promote sustainability in the tropical fruit industry. I encourage all participants to actively engage, share ideas, and build networks. Together, through our collaborative efforts, we can ensure the long-term sustainability, resilience, and prosperity of the tropical fruit sector, both in Malaysia and globally.

Thank you.

H.E. DATUK SERI ISHAM BIN ISHAK
Chairperson of TFNet's Board of Trustees,
Secretary General, Ministry of Agriculture and Food Security, MALAYSIA

MESSAGE FROM THE VICE PRESIDENT OF GDAAS



On behalf of the Guangdong Academy of Agricultural Sciences, welcome to the International Symposium on Tropical Fruits (ISTF) 2024!

For agriculture to become more sustainable, it is essential to address the critical phases that occur after the harvest, as well as how to maximize the value derived from each crop. The journey from farm to market involves various challenges that require innovative solutions to reduce waste, increase product quality, and improve profitability. Tropical fruits demand careful handling, storage, and processing due to their perishable nature.

China recognizes the importance of postharvest solutions, value addition, and waste management in transforming tropical fruit value chains. By investing in research and development, we are enhancing techniques that preserve fruit quality, reduce losses, and extend shelf life. Moreover, adding value to tropical fruit products through processing and sustainable waste management practices not only boosts economic opportunities but also strengthens the resilience of the agricultural sector in the face of climate change and resource limitations.

This symposium provides a platform to explore and share research and strategies that can further enhance the postharvest handling, processing, and waste management of tropical fruits.

As we gather today, I encourage all participants to engage in meaningful discussions that will lead to tangible advancements in sustainable tropical fruit value chains.

I wish you all a fruitful and successful symposium.

DR. YI GANJUN
Vice President,
Guangdong Academy of Agricultural Sciences (GDAAS)

MESSAGE FROM THE DIRECTOR GENERAL OF MARDI



I am pleased to extend my warmest invitation to all participants of the International Symposium on Tropical Fruits 2024 (ISTF 2024), that will be co-organized by MARDI.

Our theme this year, “Postharvest Solutions, Value Addition, and Waste Management for Sustainable Tropical Fruit Value Chains,” reflects our commitment to enhancing the sustainability and resilience of the tropical fruit industry. To meet the challenges of the tropical fruit industry in Malaysia is a vital part of the agricultural landscape, contributing significantly to the economy and providing livelihoods for many.

However, to ensure its sustainability and growth, it is crucial to address postharvest challenges, enhance value addition, and implement effective waste management practices. By fostering collaboration among farmers, researchers, industry players, and consumers, we can enhance the resilience of this vital sector and ensure its growth for generations to come.

In this regard, the 2024 International Symposium on Tropical Fruits seeks to identify and address the challenges facing the tropical fruit industry and will focus on knowledge exchange around a more efficient postharvest management system linked to opportunities in waste management practices.

This symposium will serve as a crucial platform for researchers, industry experts, and stakeholders to exchange knowledge, share innovative practices, and collaborate on solutions that address the challenges within our sector. We believe that by working together, we can significantly improve postharvest practices, maximize value addition, and minimize waste, ultimately benefiting our communities and the environment.

Thank you.

DATO' DR. HJ. MOHAMAD ZABAWI BIN ABDUL GHANI
Director General
Malaysian Agricultural Research and Development Institute (MARDI)

MESSAGE FROM THE DIRECTOR GENERAL OF DOA, MALAYSIA



Greetings to all esteemed participants of the International Sustainable Tropical Fruits Forum (ISTF) 2024,

As co-organizers, we are thrilled to be part of this important forum that brings together thought leaders, industry experts, researchers, and innovators to address the pressing issues in the tropical fruit industry.

This year's theme, "Postharvest Solutions, Value Addition, and Waste Management for Sustainable Tropical Fruit Value Chains," is timely and highly relevant. The tropical fruit sector holds tremendous potential for both economic growth and sustainability, yet it faces a multitude of challenges, especially in managing postharvest losses, maximizing value addition, and minimizing waste. As we work to strengthen the tropical fruit value chains, it is essential to address these issues holistically.

At the Department of Agriculture Malaysia, we believe that innovation and collaboration are key drivers of sustainable development. Our nation is blessed with a rich variety of tropical fruits, and by leveraging advanced postharvest technologies, improving value-added processes, and adopting efficient waste management practices, we can create a more resilient, productive, and sustainable fruit industry. These efforts will not only reduce losses and waste but also unlock new opportunities for farmers, producers, and exporters to increase profitability while minimizing environmental impact.

Malaysia is committed to support sustainable agricultural practices that align with global goals, such as the UN's Sustainable Development Goals (SDGs), particularly in achieving food security, promoting sustainable agriculture, and fostering responsible production and consumption. As such, ISTF 2024 presents an ideal platform for us to share knowledge, exchange ideas, and collaborate on strategies that can advance the future of tropical fruit industries worldwide.

We are confident that this forum will inspire actionable solutions and innovative approaches to transform the tropical fruit sector into a model of sustainability and economic prosperity. We look forward to fruitful discussions and impactful collaborations that will shape the future of tropical fruit value chains.

Thank you, and welcome once again to ISTF 2024.

DATO' NOR SAM BINTI ALWI
Director General
Department of Agriculture Malaysia

MESSAGE FROM BRIN



Agriculture is the backbone of Indonesia with horticultural as major contributor to both the national economy and a source of livelihoods for millions of farmers who scattered throughout all islands in Indonesia. Especially, the tropical fruits like mango, banana, pineapple, mangosteen and durian are Indonesia's most valuable agricultural products that are appealing to local and international markets. The fruits are grown in all parts of the country, with important production areas being Sumatra, Java, Sulawesi and Kalimantan.

Indonesia has among the widest array of tropical fruits in the world, an asset not to be wasted; however, sustainability in the production and value chains is a primordial issue. Another important challenge that comes in this way is the postharvest management of these fruits, which affects directly on its quality, shelf life and market value. Along these national priorities, in a way the actions are being beefed up.



Developing research and innovation in the horticulture sector has become a major concern of the Indonesian government, through the National Research and Innovation Agency (BRIN). Research institutions like the Research Center of Horticulture are responding with creative post-harvest solutions to minimize by-product use and expand sustainable agriculture. These initiatives are backed by collaborative relationships with global networks such as TFNet, which serves as a platform for technical support, exchange of information, capacity building and promotion of best practices.



In Indonesia, Good Agricultural Practices (IndoGAP) for fruits have been enacted to produce high-quality, safe and sustainable commodities. These standards are being implemented across fruit-producing regions, ensuring that our fruits meet both domestic and international market requirements. In recent years, there has been a noticeable increase in tropical fruit exports from Indonesia, driven by improvements in quality management, certification, and value addition efforts.

We are thrilled to be collaborating with the International Tropical Fruits Network (TFNet) to host the International Symposium, on Tropical Fruits (ISTC) in 2024. The theme for ISTC 2024 focuses on "Enhancing the sustainability of fruit value chains through harvest solutions and waste management " aligning perfectly with our dedication to advancing the horticulture sector. This symposium serves as a platform, for researchers, industry professionals and government representatives to exchange ideas, address challenges and explore ways to fortify fruit value chains.

Greetings, to all participants of the ISTC 2024 from the Agricultural and Food Research Organization within BRIN! We believe that this symposium will play a role, in enhancing fruit cultivation techniques and ensuring sustainable post harvest practices. Greetings, to our colleagues from around the world! We wish for you to have an pleasant time at the symposium and join hands in securing an sustainable future, for tropical fruits that brings benefits to all involved.

DR. DWINITA WIKAN UTAMI
Head of Horticultural Research Center
Research Organization Agriculture & Food
National Research and Innovation Agency (BRIN)

MESSAGE FROM ACEO OF TFNET



On behalf of the International Tropical Fruits Network (TFNet), it is my honor to welcome all distinguished guests, key experts, and participants to the International Symposium on Tropical Fruits (ISTF) 2024. This year's theme, *'Postharvest Solutions, Value Addition, and Waste Management for Sustainable Tropical Fruit Value Chains'*, is particularly significant as it addresses critical areas in the tropical fruit sector that require immediate and sustained attention to ensure its long-term viability.

The tropical fruit industry is increasingly confronted by global challenges, including the adverse impacts of climate change, resource scarcity, and evolving consumer preferences. These challenges underscore the importance of focusing on the entire value chain, particularly in optimizing postharvest solutions, enhancing value addition, and minimizing waste. Addressing these critical issues offers substantial opportunities for improving the economic efficiency, environmental sustainability, and social benefits associated with tropical fruit production and distribution systems.

TFNet remains committed to fulfilling its mandate of promoting sustainable development across the tropical fruit sector. Through strategic international cooperation, TFNet facilitates the dissemination of research, best practices, and innovative solutions.

International fora such as the ISTF 2024 provide a critical platform for experts, researchers, and industry stakeholders to engage in evidence-based discussions, share the latest research, and form partnerships that will drive the tropical fruit industry forward. It is our hope that through this symposium, we will collectively contribute to a more resilient, efficient, and sustainable future for tropical fruits. I take this opportunity to also extend my sincere appreciation to our esteemed co-organizers—the Guangdong Academy of Agricultural Sciences (GDAAS), the Malaysian Agricultural Research and Development Institute (MARDI), the Department of Agriculture Malaysia (DOA), and the National Research and Innovation Agency of Indonesia (BRIN)—for their invaluable support in collaborating with TFNet to organize this symposium.

I hereby encourage all participants to actively engage and contribute to the success of this important symposium.

Thank you.

DR. DOROTHY CHANDRABALAN
Acting Chief Executive Officer,
International Tropical Fruits Network (TFNet)

TABLE OF CONTENTS

	Page
EXECUTIVE SUMMARY	01
LIST OF ABBREVIATIONS	03
PARTNERS/ORGANIZING COMMITTEE	04
SCIENTIFIC COMMITTEE AND SESSION CHAIRPERSONS	05
ABOUT ISTF 2024	06
SUMMARY OF THE SYMPOSIUM	08
SESSION 1. KEYNOTE PRESENTATIONS	
KEYNOTE 1: A SYSTEMS APPROACH FOR DEVELOPING RESILIENT, PROFITABLE TROPICAL FRUIT INDUSTRIES: A CASE STUDY <i>Muhammad Sohail Mazhar, Department of Industry Tourism and Trade & Charles Darwin University, Australia</i>	14
KEYNOTE 2: POSTHARVEST SOLUTIONS FOR MAJOR FRUITS IN THE DEVELOPING HUMID TROPICS <i>Guinevere I. Ortiz, The New Zealand Institute for Plant and Food Research Limited.....</i>	25
SESSION 2. POSTHARVEST SOLUTIONS AND PRACTICES TO MITIGATE LOSSES, ENCOURAGE VALUE ADDITION AND ENHANCE QUALITY FOR MARKETS	
THE USE OF EMERGING TECHNOLOGIES IN THE EXTRACTION TECHNIQUE OF FRUIT BY-PRODUCTS AS INGREDIENTS FOR THE FOOD INDUSTRY <i>Rosnah Shamsudin, Universiti Putra Malaysia, Malaysia</i>	26
ADVANCING VALUE-ADDED PRODUCTS FROM DRAGON FRUIT: A STUDY ON PROCESSING AND APPLICATIONS <i>Dihh T Tran, Vietnam National University of Agriculture, Vietnam</i>	38
CURRENT POST-HARVEST QUALITY AND TECHNOLOGY PRACTICES OF THE TROPICAL FRUIT INDUSTRY IN MALAYSIA <i>Lilynorfeshah Mohd. Shah, Department of Agriculture, Malaysia.....</i>	48
POSTHARVEST LOSSES OF TROPICAL FRUITS IN PACIFIC ISLAND COUNTRIES <i>Shalendra Prasad, Ministry of Agriculture & Waterways, Koronivia Research Station, Fiji ...</i>	65
LOW PROCESSING TECHNOLOGY FOR SMALL SCALE PROCESSOR FOR SUSTAINABLE TROPICAL FRUIT INDUSTRY IN INDONESIA <i>Setyadjit, National Research and Innovation Agency, Indonesia</i>	66
POSTHARVEST CHALLENGES OF TROPICAL FRUITS IN ARID AND SEMIARID REGIONS <i>Hassan M. Ali-Dinar, King Faisal University, Saudi Arabia</i>	67

	Page
POSTHARVEST PROCEDURE FOR MALAYSIAN DURIAN TO CHINA BY AIR SHIPMENT <i>Nur Azlin Razali, Malaysian Agricultural Research and Development Institute, Malaysia.....</i>	68
QUALITY ASSESSMENT OF COMMERCIAL DRIED BANANA PRODUCTS CONSUMED IN SULTANATE OF OMAN <i>Mohammed Al Rizeiqi, Sultan Qaboos University, Oman</i>	73
SUCCESSFUL APPLICATION OF POSTHARVEST TECHNOLOGY FOR EXPORTING MALAYSIAN FRESH JACKFRUIT TO CHINA <i>Nor Hanis Aifaa, Malaysian Agricultural Research and Development Institute, Malaysia. ..</i>	78
MEASURING POSTHARVEST LOSSES OF FRUITS IN MALAYSIA: INITIAL STEPS TOWARDS THE FOOD LOSS INDEX UNDER SDG 12.3.1.A <i>Wan Mohd Reza Ikwana Wan Hussin, Malaysian Agricultural Research and Development Institute, Malaysia</i>	84
SESSION 3: RECENT RESEARCH AND DEVELOPMENT INITIATIVES IN POSTHARVEST MANAGEMENT	
NON-DESTRUCTIVE MEASUREMENT TO PREDICT QUALITY AND THE USE OF PLASMA FINE BUBBLES FOR EXTENDING THE SHELF LIFE OF FRUITS <i>Y. Aris Purwanto, Institut Pertanian Bogor University, Indonesia</i>	94
EFFECTS OF EPIGALLOCATECHIN-3-GALLATE (EGCG) AND CYTOKININ ON POSTHARVEST ATTRIBUTES OF LITCHI FRUIT BY MODULATING ANTIOXIDANT ACTIVITY AND CHLOROPHYLL METABOLISM AFTER HARVEST <i>Hua Huang, Guangdong Academy of Agricultural Sciences, China</i>	95
ENZYMATIC BROWNING IN ARTOCARPUS ODORATISSIMUS (TERAP) AND ITS INHIBITION TREATMENTS UNDER COLD STORAGE CONDITION <i>Shiamala Devi Ramaiya, Universiti Putra Malaysia Sarawak, Malaysia</i>	96
EFFECTS OF CAPROALDEHYDE TREATMENT ON SHELF LIFE, PHYSICOCHEMICAL PROPERTIES, AND ANTIOXIDANT ACTIVITY OF D24 DURIAN (<i>DURIO ZIBETHINUS</i> L.) UNDER AMBIENT TEMPERATURE STORAGE CONDITION <i>Mohd Sabri Pak Dek, Universiti Putra Malaysia, Malaysia</i>	97
BROWNING OF JACKFRUIT (<i>ARTOCARPUS HETEROPHYLLUS</i> CV. J33) RIND DURING FRUIT DEVELOPMENT <i>Zhi Sin Tan, Universiti Putra Malaysia, Malaysia</i>	98
EFFECTS OF TORCH GINGER ESSENTIAL OIL ON PATHOGENS OF DRAGON FRUIT [<i>HYLOCEREUS POLYRHIZUS</i> (WEBER) BRITTON & ROSE] <i>Deng Xianzhu, Ningbo University, China</i>	99
TREE AGE AFFECTS THE VOLATILE COMPOUND PROFILE OF MUSANG KING DURIAN FRUIT <i>Eliwanzita Sospeter, Universiti Putra Malaysia, Selangor, Malaysia.....</i>	100

	Page
METABOLOMICS ANALYSIS REVEALED THE MECHANISM OF CHILLING INJURY DEVELOPMENT IN DURIAN FRUIT DURING LOW-TEMPERATURE STORAGE <i>Zhang Yuansho, Ningbo University, China</i>	101
SESSION 4. WASTE MANAGEMENT AND CIRCULAR BIOECONOMY	
WASTE MANAGEMENT IN GREAT GIANT FOODS <i>Fauzan Khumaidi, Great Giant Foods, Indonesia</i>	102
OHMIC HEATING-ASSISTED HYDRODISTILLATION OF ESSENTIAL OILS FROM MANDARIN CITRUS PEEL WASTE <i>Imro'ah Ikarini, Brawijaya University, Indonesia</i>	103
SESSION 5. PANEL DISCUSSION	109
SIDE EVENT: CARBON AND WATER FOOTPRINT MEASUREMENT IN TROPICAL FRUIT VALUE CHAINS María Hernández Lagana, Food and Agriculture Organization of the United Nations.....	112
LIST OF PARTICIPANTS	118

EXECUTIVE SUMMARY

The International Tropical Fruits Network (TFNet), in partnership with the Department of Agriculture Malaysia, the Malaysian Agricultural Research and Development Institute (MARDI), Indonesia's Research and Innovation Agency (BRIN), and the Guangdong Academy of Agricultural Sciences (GDAAS) in China, organized the International Symposium on Tropical Fruits 2024 (ISTF 2024) on 22-23 October at Corus Hotel, Kuala Lumpur, Malaysia.

Themed "*Postharvest Solutions, Value Addition, and Waste Management for a Sustainable Tropical Fruits Value Chain*," the symposium brought together 70 participants from 11 countries, including researchers, policymakers, and industry stakeholders.

The symposium was officiated by Honourable Datuk Azah Hanim Ahmad, the Deputy Secretary General (policy) of the Ministry of Agriculture and Food Security, Malaysia. In her address, Datuk Azah highlighted the various challenges that are impacting the agriculture sector, including the tropical fruits industry, such as increasing cost of production, market access and productivity issues. Dr. Azah also said that postharvest losses and waste constitute main challenges and should be given close attention by impacted players along agricultural value chains. She also referred to the symposium's relevant theme, emphasizing the ongoing challenge of postharvest losses in agriculture, particularly in tropical fruits, particularly for producing countries.

A total of 22 papers were presented, covering topics ranging from postharvest solutions and best practices to recent postharvest research and development initiatives and waste management. Keynote speakers included Dr. Mohammad Sohail Mazhar from the Department of Plant Industries, Tourism and Trade, NT Australia, and Dr. Guinevere Ortiz from New Zealand's Plant and Health Institute. Additionally, invited and other speakers from China, Fiji, Malaysia, Indonesia, Oman, Sudan, Tanzania, and Vietnam contributed to the symposium. Besides presentations, there were 6 poster presentations.

The symposium focused on practical ways to reduce fruit losses after harvest, add value through better processing, and reduce waste across the tropical fruit supply chain. Presenters shared a variety of affordable and scalable innovations—ranging from improved storage, packaging, and transport systems to new ways of using fruit waste for added value. Keynote speakers from Australia and New Zealand emphasized whole-of-chain approaches and low-cost solutions that can be adapted to local needs.

Presentations throughout the symposium showcased success stories and lessons learned from across Asia and the Pacific. These included new export protocols for durian and jackfruit from Malaysia, practical tools to improve fruit quality in Vietnam and Indonesia, and strategies to address postharvest losses in small island nations like Fiji. Technologies such as cryogenic freezing, eco-friendly coatings, and solar-powered cold storage were also discussed as promising ways to reduce spoilage and expand market access.

A session focused on new research and innovations highlighted smart tools to non-invasive procedure to check fruit quality, natural treatments to reduce browning and spoilage, and eco-friendly disease control methods. Presenters also shared circular economy solutions that turn fruit waste into valuable products like compost, biopesticides, and biodegradable ingredients for use in food, cosmetics, and packaging.

The Q&A sessions revealed shared concerns across countries and participants. Participants inquired about the practicality of technologies, regulatory barriers, and farmer adoption. Highlights included questions on fruit maturity standards, low-cost processing for smallholders, traceability systems, and pest management in durian and banana. Presenters clarified the feasibility of lab-tested methods for industry use, acknowledged challenges in export logistics, and emphasized the need for further pilot

testing and data collection, especially among small-scale producers. The exchange highlighted strong interest in practical, cost-effective solutions with commercial potential.

Noting that big companies or advance producers can manage the postharvest losses better, members were requested shared their experience on how smallholders can be encouraged to adopt best postharvest practices, the panel discussion highlighted that postharvest losses are not necessarily as always reported to be 30 percent across the board. Postharvest management approaches vary according to a country's agricultural development, crop type and whether production is for the domestic or export markets or both. Solutions also vary according to the degree of involvement of private businesses, smallholders, and others. Generally, for many countries, increasing smallholder access to postharvest technologies requires an integrated, participatory approach that links research, infrastructure, policy, and grassroots engagement. Some key takeaways from the panel discussion are business or farmer approaches to mitigate issues, capacity building, government and institutional collaboration with the private sector, enhancing extension services and focusing on market and consumer preferences.

ISTF 2024 reaffirmed the importance of tackling postharvest losses through evidence-based, context-appropriate solutions that strengthen the entire tropical fruit value chain. Key recommendations emphasized investing in cold chain infrastructure, scalable and affordable postharvest technologies, improved packaging and handling, and promoting value addition from waste streams. Stakeholder training, quality assurance systems, and the adoption of low-cost, locally relevant interventions were seen as critical to enhancing marketability and reducing spoilage. The symposium also highlighted the importance of continuous R&D, smart technologies, and circular economy models, supported by strong policy frameworks and regional collaboration. Moving forward, deeper public-private partnerships and coordinated efforts are essential to build resilient, high-performing, and sustainable tropical fruit systems. As a side event, TFNet and the Food and Agriculture Organization of the United Nations (FAO) co-hosted a workshop on measuring carbon and water footprints in tropical fruit value chains. The session introduced tools and methods to help producers reduce their environmental impact and improve access to premium markets by becoming more resource-efficient and sustainable.

LIST OF ABBREVIATIONS

AE	Acid extraction
AI	Artificial Intelligence
CAE	Conventional acid extraction
CLP	Critical loss point
CRI	Crown Research Institute
DE	Degree of esterification
DKP	Durian Kampung Premium
DLE	Delay Light Emissions
DOA	Department of Agriculture
EAE	Enzymatic-assisted extraction
EGCG	Epigallocatechin-3-gallate
FAO	Food and Agriculture Organization
FNQ	Far North Queensland
HM	High methoxyl
IFR	Insidious fruit rot
IoT	Internet of Things
KLWM	Kuala Lumpur Wholesale Market
LDPE	Low-density polyethylene
LMP	Low-methoxyl pectin
MAE	Microwave-assisted extraction
MARDI	Malaysian Agricultural Research and Development Institute
MFC	Minimum fungicidal concentration
MIC	Minimum inhibitory concentration
NT	Northern Territory
OAE	Ohmic-assisted extraction
OAHD	Ohmic Assisted Hydrodistillation
PCC	Per capita consumption
PPO	Polyphenol oxidase
PFR	Plant and Food Research
RONS	Reactive oxygen and nitrogen species
SOP	Standard operating procedure
SPBT	Seed Verification Scheme
SSC	Soluble solids content
SWM	Selangor Wholesale Market
SW-NIR	Short-Wave Near-Infrared
TPC	Total phenolic content
TSS	Total Soluble Solids
TTA	Total Titratable Acidity
UAE	Ultrasound-assisted extraction
VOC	Volatile compounds
WAA	Weeks after anthesis

PARTNERS/ORGANIZING COMMITTEE

STEERING COMMITTEE

PATRON

H.E. Datuk Seri Isham bin Ishak

Secretary General, Ministry of Agriculture and Food, Security, Malaysia (TFNet Chairman)

MEMBERS

Dato' Dr. Mohamad Zabawi Abdul Ghani, Director General, MARDI, Malaysia

Dato' Nor Sam Binti Alwi, Director General, DOA Malaysia

Dr. Dwinita Wikan Utami, Head of Horticultural Research Center, BRIN, Indonesia

Dr. Yi Ganjun, Vice President, GDAAS, China

Dr. Dorothy Chandrabalan, Acting Chief Executive Officer, TFNet

Mr. Yacob Ahmad, Advisor, TFNet

MAIN ORGANIZING COMMITTEE

Dr. Dorothy Chandrabalan, Acting Chief Executive Officer, TFNet

Ms. Hariyatul Asni Abdul Rani, Administrative Officer, TFNet

Ms. Noor Ba'ah Abdol Said, Executive Assistant, TFNet

Mr. Christian Anthony T. Cangao, Information Officer, TFNet

Mr. Yacob Ahmad, Advisor, TFNet

SCIENTIFIC COMMITTEE AND SESSION CHAIRPERSONS

SCIENTIFIC COMMITTEE

Mr Yacob Ahmad, Advisor TFNet (Chair)

MEMBERS

Dr. Chunyu Li, Vice Director, Institute of Fruit Tree Research, GDAAS, China

Dr. Shalendra Prasad, Director, Research & Agriculture Scientific Services
Division, Ministry of Agriculture & Waterways, Fiji

Dr. Prakash Patil, Project Coordinator, IIHR-ICAR, India

Prof Dr. Phebe Ding, Senior Lecturer, University Putra Malaysia, Malaysia

Dr. Mohamad Roff Mohd. Noor, Board Expert Member, TFNet

Dr. Ellina Mansyah, Senior Researcher, Research Center for Horticulture. National
Research and Innovation Agency (BRIN), Indonesia

Prof. Dr. Yohanes Aris Purwanto, Senior Researcher, IBP University, Indonesia

Dr. Nguyen Thanh Hieu, Deputy Director, Southern Horticultural Research Institute
(SOFRI), Vietnam

Mr. Wan Reza Ikwan bin Wan Hussin, Deputy Director, MARDI, Malaysia

SESSION CHAIRPERSONS

SESSION 1: **Mr. Yacob Ahmad**
Advisor, International Tropical Fruits Network

SESSION 2: **Mr. Christopher Biai**
Department of Agriculture, Malaysia
Dr. Ellina Mansyah
National Research and Innovation Agency, Indonesia

SESSION 3: **Wan Mohd Reza Ikwan Wan Hussin**
MARDI, Malaysia

SESSION 4: **Dr. Shalendra Prasad**
Ministry of Agriculture, Fiji

PANEL DISCUSSION

MODERATOR **Yacob Ahmad**, International Tropical Fruits Network (TFNet)

PANELISTS **Dr. Mohammad Sohail Mazhar**,
Department of Agriculture and Fisheries, Northern Territory, Australia
Dr. Guinevere I. Ortiz
New Zealand Institute for Plant and Food Research, New Zealand
Dr. Dinh T Tran
Vietnam National University of Agriculture, Vietnam
Dr. Aris Purwanto
Institut Pertanian Bogor, Indonesia
Dr. Shalendra Prasad
Ministry of Agriculture, Fiji

ABOUT ISTF 2024

The Food and Agriculture Organization (FAO) reports a staggering statistic: over 30% of the food produced, roughly 1.3 billion tons annually, is lost or wasted from farm to fork. The UN's Sustainable Development Goals (SDGs) aim to halve global food waste by 2030. This target includes not just food waste at the consumer level but also losses that occur throughout the production and supply chain, especially after harvest (post-harvest losses). Post-harvest losses encompass both the quantity and quality of food lost within the system, impacting everything from harvesting, and processing, to storage, transportation, and ultimately reaching the consumer level. Improving post-harvest management and waste reduction in agriculture can further lead to higher economic and environmental gains (World Bank, 2018). Furthermore, the International Food Policy Research Institute (IFPRI) points out that addressing post-harvest losses can significantly contribute to poverty reduction and enhance the resilience of smallholder farmers (IFPRI, 2016)

The situation is particularly concerning for tropical fruits, where the FAO (2011) estimates post-harvest losses to be approximately 32% globally. Post-harvest losses in tropical fruits are influenced by several factors including inadequate handling, poor storage facilities, lack of access to modern technologies, and inefficiencies in the supply chain. Research has highlighted that simple interventions such as improved harvesting techniques and better storage conditions can reduce losses significantly. Furthermore, the literature indicates that integrating modern technologies such as cold chain logistics and controlled atmosphere storage can greatly enhance the shelf life and quality of tropical fruits.

Waste management in the tropical fruit industry also presents a critical challenge. Effective waste management not only helps in reducing losses but also in recovering valuable resources. Studies by the FAO (2013) and the International Trade Centre (ITC) (2014) emphasize the importance of implementing integrated waste management systems that can convert fruit waste into value-added commodities. For instance, byproducts from fruit processing can be used to produce value-added products like pectin, essential oils, and biogas. Thus, integrating advanced waste management practices in the tropical fruit value chains not only mitigate post-harvest losses but also unlocks new economic opportunities, promotes sustainability, and enhances the resilience of the agricultural sector.

The current state of the tropical fruit industry, marked by ongoing post-harvest and waste management challenges, sets the stage for the 2024 International Symposium on Tropical Fruits (ISTF 2024). ISTF 2024 seeks to address the critical issue of minimizing post-harvest losses, and waste, concurrently promoting effective waste management practices. The theme for this year, "Post-harvest solutions, value addition, and waste management for sustainable tropical fruit value chains," highlights the importance for industry stakeholders to consider these matters critically. The symposium aims to assess these challenges, foster discussions, and explore practical solutions that can be implemented by all.

AIM

The 2024 International Symposium on Tropical Fruits seeks to identify and address the challenges facing the tropical fruit industry and will focus on knowledge exchange around a more efficient postharvest management system linked to opportunities in waste management practices. Specifically, the symposium aims to:

Specifically, it aims to:

- i. Share the latest scientific research, technologies, and best practices on postharvest management in tropical fruits.
- ii. Assess new innovations within tropical fruits up and downstream supply/value chains to minimize losses.
- iii. Explore and identify knowledge gaps, research needs, and new opportunities in waste management applicable to tropical fruit stakeholders.
- iv. Share working examples and practical case studies that can be replicated by others.
- v. Establish networking among stakeholders.

THEMATIC AREAS

- i. Recent advances, technological innovations, and best practices in post-harvest management for tropical fruits.
- ii. Smart, innovative packaging and treatment solutions for maintaining quality and shelf life of tropical fruits.
- iii. Digital applications, IOT and logistical management in food loss measurement, product tracking and traceability.
- iv. Devices, instrumentations, robotics, and drones to determine fruit maturity and improve harvest efficiency.
- v. Opportunities in waste management for tropical fruits.
- vi. Research and practical solutions in bioproduct development from tropical fruit waste.
- vii. Valorisation of fruit waste biomass and circular bioeconomy.

TARGET PARTICIPANTS

- i. Value Chain Actors
- ii. Researchers and Academicians
- iii. Large- and Small-scale producers
- iv. Private Companies
- v. NGOs and Community Representatives
- vi. Government Officials and Policymakers

SUMMARY OF THE SYMPOSIUM

SESSION 1. KEYNOTE PRESENTATIONS

1. Keynote 1: Dr Muhammad Sohail Mazhar (Department of Agriculture and Fisheries) introduced a systems-based approach to reducing postharvest losses—currently exceeding 20% in Australia’s tropical fruit sector—while enhancing product value. His strategy connects production, handling, logistics, and markets through joint problem-solving involving all stakeholders in the value chain. The model incorporates technical, economic, and policy dimensions and has been applied across several fruit industries.

Q&A: No questions were raised during this session.

2. Keynote 2: Dr Guinevere I. Ortiz (Plant & Food Research, New Zealand) highlighted the significant post-harvest losses common to humid-tropical fruit chains and outlined a practical toolbox to curb them. Her recommended interventions span cultivar selection, cold-chain and ethylene management, plus low-cost upgrades in sanitation, handling, and packaging. Case studies on dragon fruit (Viet Nam), avocado (Kenya), and passionfruit (Vietnam) showed that high-pressure hot-water washing, 4–6 °C storage, strict dry-matter maturity standards, and weather-based harvest scheduling can dramatically cut losses and lift export returns. Dr Ortiz concluded that successful solutions in developing countries must be affordable, simple, and context-specific—built on value-chain collaboration, stakeholder training, and continuous adaptation.

Q&A: A participant requested clarification on the data analysis tool. Dr. Ortiz explained it was based on an existing model developed, though historical agricultural data was limited. Decisions were informed by available data on avocado from Kenya.

SESSION 2. POSTHARVEST SOLUTIONS AND PRACTICES TO MITIGATE LOSSES, ENCOURAGE VALUE ADDITION AND ENHANCE QUALITY FOR MARKETS

3. Prof. Ts. Dr. Rosnah Shamsudin (Universiti Putra Malaysia) explained how new technologies can turn large amounts of tropical fruit waste—such as from durian, jackfruit, banana, and cocoa—into useful products like dietary fibre, pectin, and other health-promoting ingredients. She highlighted environmentally friendly extraction methods, including microwave, ultrasound, enzymes, and high-pressure techniques, which are faster, more energy-efficient, and produce higher yields than traditional processes. By using these approaches, the food industry can reduce waste and pollution while creating valuable natural ingredients, supporting a more sustainable and circular bio-based economy.

Q&A: A participant asked whether the processed compounds had been tested commercially. Prof. Rosnah responded that while chemical analysis had been done in the lab, industry trials were still pending. Another attendee asked about uses for jackfruit peel. She noted that pectin extracted from jackfruit peel can be used as a vegan alternative to gelatin in baked goods.

4. Dr. Dinh Tran (Vietnam National University of Agriculture) shared the dilemma of Vietnam’s fruit industry which continues to face high postharvest losses largely attributed to weak marketing, poor transport, limited tools, and the perishable nature of fresh produce. To address this, he recommended practical solutions such as solar-powered refrigeration,

improved storage technologies, and better packaging, which can extend the shelf life of fruits like litchi and longan from just five days to over a month. He also highlighted the importance of quality grading, digital traceability (QR/RFID), and turning surplus produce into value-added products like jams, snacks, and fruit wine. Dr. Tran emphasized that adopting international quality standards and upgrading cold chain infrastructure are key to reducing losses, improving food security, and expanding access to export markets.

Q&A: Participants asked whether VietnamGAP was part of GlobalGAP; Dr. Tran clarified it was country-specific but traceability-enabled. On banana storage, he advised 13 °C for Cavendish but noted smaller varieties are more sensitive. Regarding export challenges, he confirmed that meeting protocols like heat treatment and traceability remains difficult for small farmers.

5. Dr. Lilynorfeshah Mohd Shah (Department of Agriculture Malaysia) gave an overview of Malaysia's durian industry, which produced 455,000 tonnes in 2022, with most consumed locally. She described a standardized post-harvest process that includes harvesting, quality checks, and packaging, and highlighted new technologies like cryogenic freezing with liquid nitrogen, automated pulp processing, and durian paste production. Her analysis pointed out strengths such as 45 certified packing facilities with traceability systems but also noted challenges like the short 36-hour export window, quality issues, and climate-related risks. She identified opportunities in promoting premium local varieties and developing agrotourism. To compete in high-end export markets, she stressed the need for more consistent quality through broader use of postharvest technologies.

Q&A: When asked how small farmers can ensure durian quality, she noted that smallholders can be trained to meet standards, and that proper landscape management can reduce climate-related risks.

6. Dr. Shalendra Prasad of Fiji's Ministry of Agriculture & Waterways reported that post-harvest fruit losses in Fiji reach 20–50 %, varying by crop and local conditions. Losses spike on remote islands where storage and transport infrastructure remain unfavorable. Key drivers include an inadequate cold chain, limited awareness of good post-harvest practices, and unreliable logistics. Dr. Prasad called for an integrated response—upgrading infrastructure, expanding farmer education, deploying appropriate technologies, and encouraging community collaboration. He also urged investment in R&D to breed varieties that tolerate transport and storage stresses, highlighting that supportive policies are essential to build a resilient post-harvest ecosystem.

Q&A: He confirmed that papaya disease is limited to Phytophthora in the Sunrise Solo variety. Regarding price volatility, Fiji currently operates on an open market system but provides government support for infrastructure.

7. Dr. Setyadjit (Indonesian Agency for Agricultural Research and Development) discussed simple, low-cost processing technologies to support small-scale tropical fruit processors in Indonesia. He emphasized that processing helps stabilize fresh fruit prices and provides a use for fruits that don't meet market standards. Focusing on mango as a key example, he outlined current processing practices and stressed the importance of strengthening links between producers and processors. His recommendations included improving farming practices to ensure steady supply, establishing systems to connect all actors in the value chain, and expanding successful research-based solutions to regions with more challenging production conditions.

Q&A: No questions were raised

8. Dr. Hassan Ali-Dinar (King Faisal University, Saudi Arabia) shared some of the postharvest challenges of tropical fruits produced in arid and semi-arid regions —characterised by scarce water and extreme heat. These agroclimatic extremities often compound post-harvest fruit losses through pests, improper harvesting and handling techniques, inadequate cold-chain infrastructure, weak marketing channels, and limited grower know-how. To build a resilient value chain, he urged regional collaboration, adoption of stress-tolerant cultivars and appropriate technologies, investment in packing and cold-storage facilities, development of organised market centres, use of treated wastewater for irrigation, and continuous farmer training and knowledge transfer.

Q&A: A question was raised on salinity issues. Dr. Dinar confirmed it is a major concern but can be managed with protective measures for plants.

9. Ms. Nur Azlin Binti Razali (MARDI) shared Malaysia's air-freight protocol for exporting fresh durian to China. Although Malaysia is the world's third-largest durian exporter, it holds just 0.26% of China's market compared to Thailand's 95%, despite having high production and domestic consumption. To improve competitiveness, MARDI developed a detailed postharvest process that includes pre-cooling, special packaging, and cold storage to keep the fruit fresh and reduce pest risks. The use of thin, low-density plastic packaging helps extend shelf life. Ms. Nur Azlin estimated that this combined packaging and cold-chain approach could reduce postharvest losses and increase export earnings by about 5% annually, especially as export volumes grow enough to make sea freight more viable.

Q&A: To a query on pests, she explained on possible correlation between mealy bugs and ants, though more research is needed. To a question if Malaysian durian be harvested earlier for export purposes, speaker explained that in Malaysia, durians are typically not harvested by hand but allowed to drop naturally from the tree, signaling full ripeness. While this results in sweeter fruit, it shortens shelf life. Harvesting the fruit earlier—before it falls—and storing it at 14 °C allows it to ripen gradually, extending shelf life and making it more suitable for export.

10. Dr. Mohammed H. AlRizeiqi (Sultan Qaboos University) examined the safety and quality of four Indian dried-banana brands commonly sold in Oman. His study tested for bacteria, mould, and yeast, and checked whether the products met Codex and Gulf (GSO) standards for hygiene, moisture content, labeling, preservatives, and coloring. While overall bacterial levels were within safe limits, one brand had excessive Enterobacteriaceae and another exceeded the acceptable mould and yeast levels. Three brands met the recommended moisture range, but one had higher-than-allowed moisture at 29%. Although there were noticeable differences in color, none posed a safety risk. Dr. AlRizeiqi concluded that solar drying is a safe, energy-efficient method suitable for Omani banana varieties and produces dried products that appeal to local preferences.

Q&A: He reported that Oman grows four banana varieties, including Cavendish.

11. Ms. Nor Hanis Aifaa Binti Yusoff (MARDI) discussed Malaysia's progress in exporting J33 jackfruit to China, highlighting the rise in exports while noting that challenges like short shelf life and diseases such as black rot still affect competitiveness. After the Fresh Jackfruit Export Agreement with China was signed in April 2023, she explained the key requirements, including farm registration, pest management, and hygiene standards. She also described postharvest practices used to maintain fruit quality. A taste test showed that jackfruit treated with EONature coating was well received by Chinese consumers. She concluded that this coating, combined with strong cold-chain systems, could reduce spoilage, meet China's safety standards, and

help expand exports to new markets like Beijing—if Malaysia maintains steady supply and competitive pricing.

Q&A: Speaker confirmed that the variety used was honey jackfruit, coated with sodium benzoate. Export destinations include the Middle East, Singapore, and Australia (processed).

12. Mr. Wan Mohd Reza (MARDI) presented findings from a study conducted with FAO-UN under the SDG 12.3.1 Food Loss Index, which measured pineapple and watermelon losses in several Malaysian states. The study found that most pineapple losses occurred during harvesting, while for watermelon, significant losses happened during handling at wholesale markets. Losses tended to build up along the entire supply chain. Based on the findings, he recommended expanding the survey to include more crops, making food loss data part of national statistics, and combining regular loss monitoring with farmer training and affordable postharvest technologies to help reduce waste more effectively.

Q&A: Questions focused on data consistency and gaps. Speaker explained that the small sample size allowed for better monitoring and pre-tested questionnaires helped reduce bias. Participants recommended expanding sample sizes and including pre-harvest data for a more complete picture.

SESSION 3. RECENT RESEARCH AND DEVELOPMENT INITIATIVES IN POSTHARVEST MANAGEMENT

13. Prof. Dr. Aris Purwanto (IPB University) presented two practical innovations to reduce losses and improve quality in tropical fruit supply chains. The first was a portable device that uses near-infrared light and links to a smartphone to check ripeness and internal quality of mangoes and citrus on-site, helping farmers make better harvest decisions. The second was a fruit-washing method using plasma fine bubbles to reduce microbes and extend shelf life without chemicals. He also highlighted similar techniques, such as ozone-treated water to control postharvest disease in papaya. These tools show promise for safer, cleaner fruit handling and meeting export standards, though more work is needed to scale them up for wider use.

Q&A: No questions were raised

14. Dr Hua Huang (ITFRI, China) presented strategies for tackling litchi's rapid post-harvest browning, which is linked to pericarp phenols, energy imbalance and membrane damage. His experiments showed that treatments with epigallocatechin-3-gallate (EGCG) and the cytokinin forchlorfenuron (CPPU) delayed pericarp browning.

Q&A: To prevent lychee from browning, speaker explained that including leaves during storage reduces water loss, while double packaging helps extend shelf life.

15. Dr. Shiamala Devi Ramaiya (UPM, Bintulu Campus, Malaysia) shared her study on the browning in terap (*Artocarpus odoratissimus*) and methods to keep the fruit fresh for a longer period as a ready-to-eat product. Her research looked at how browning-related enzymes and natural compounds changed during storage and evaluated two anti-browning treatments—NatureSeal® and a dip made of ascorbic acid, citric acid, and calcium chloride—under cold storage, both with and without packaging. The results showed that the ascorbic acid-based dip was especially effective in preventing browning for up to one month, while preserving the fruit's appearance and quality. This approach offers a practical solution for extending shelf life and reducing postharvest losses in fresh-cut terap.

Q&A: *She clarified that browning was measured over four days, pre-harvest treatments weren't part of the study*

16. Ms. Tan Zhi Sin (UPM, Malaysia) explored the causes of rind browning in the Malaysian J33 jackfruit during fruit development, which can affect appearance and market value—especially during long transport and poor handling. Her study looked at how natural compounds, enzymes, and stress signals in the rind changed at 2, 4, 8, and 12 weeks after flowering. The findings showed that browning is caused by a mix of oxidative stress and enzyme activity. Based on this, she recommended harvesting the fruit around 12 weeks after flowering to maintain rind quality for long-distance shipping.

Q&A: *She confirmed browning begins around 1-2 weeks after flowering during cell division but said mid-stage development wasn't covered in her study.*

17. Ms. Deng Xianzhu (Ningbo University) presented her research on using torch ginger (*Etilingera elatior*) essential oil as a natural treatment to control postharvest diseases in dragon fruit. She identified two common fungi responsible for fruit decay—*Bipolaris cactivora* and *Fusarium incarnatum*. Laboratory tests showed that the essential oil was effective in stopping the growth of *F. incarnatum* at lower concentrations than *B. cactivora*, which required higher doses. While *B. cactivora* was more sensitive during its growth stage, its spores were more difficult to eliminate. The study suggests that torch ginger essential oil could be a promising, eco-friendly alternative to chemical treatments for managing fungal infections in dragon fruit.

Q&A: *No questions raised*

18. Ms. Eliwanzita Sospeter (UPM Malaysia) shared a study on how the age of Musang King durian (MKD) trees influences the fruit's aroma. By comparing durians from young (5-9 years), middle-aged (10-15 years), and older trees (over 15 years), the research found distinct aroma profiles linked to tree age. Fruits from younger trees had more sweet and fruity notes, while those from older trees contained stronger, sulfur-like compounds. These findings may help in identifying the age of durian trees based on fruit aroma, which could be useful for quality control and marketing.

Q&A: *She stated that it's not possible to gauge fruit source from age of tree. A comment was made about the influence of soil fertility.*

19. Ms. Zhang Yuansuo (Ningbo University) presented findings on how cold storage affects the quality of Monthong durian. Storing the fruit at 5 °C, instead of 15 °C, helped delay splitting by reducing water loss and ethylene production. However, this lower temperature also led to chilling injury, seen in early signs of tissue damage after six days. The study identified over 130 compounds that changed in response to cold stress, linking them to plant stress and membrane protection processes. Ms. Zhang concluded that while colder storage can help extend shelf life, the risk of chilling injury must be carefully managed to maintain fruit quality.

Q&A: *A question was raised on ethylene-related stress responses*

SESSION 4. WASTE MANAGEMENT AND CIRCULAR BIOECONOMY

20. Mr. Fauzan Khumaedi (Plantation Advisor & Head of R&D, Great Giant Foods, Indonesia) shared his company's circularity approach, which converts plantation waste into useful products like compost, vermicompost, biochar, and biopesticides. Other by-products are used for cattle feed, while valuable compounds like bromelain are extracted. They also developed liquid organic fertiliser (LOB 2.0) using beneficial microbes, and tested maggot oil as a natural fruit-wax coating. Field trials showed that compost improved soil health and yields, biochar boosted plant growth, and the fertiliser mix supported bigger fruits. LOB 2.0 helped root development and nutrient absorption, while maggot oil reduced weight loss and mould, extending shelf life. This initiative shows how waste can be reused to boost productivity and move large-scale pineapple farming closer to zero waste.

Q&A: He noted that 20 tons/ha of biochar can be produced from cassava and banana waste, and while economic returns match chemical fertilisers, the main benefit is soil regeneration.

21. Ms. Imro'ah Ikarini (BRIN, Indonesia) shared a sustainable method to turn citrus peel waste into useful products by combining essential oil extraction with cellulose recovery. Her team used a more energy-efficient technique called ohmic-heating hydrodistillation, which significantly cut processing time and energy use while increasing oil yield compared to traditional methods. The remaining peel was then processed into citrus-based cellulose, a biodegradable thickening agent suitable for use in food, cosmetics, pharmaceuticals, and bioplastics. She emphasized the benefits of this approach, including time and energy savings, added value, and reduced environmental impact, while noting that the best method depends on the raw material, production scale, and intended use.

Q&A: To a query on the type of citrus waste used, she confirmed using mandarin peel for the study. She added that the economic feasibility analysis has yet to be undertaken.

KEYNOTE PRESENTATIONS

A SYSTEMS APPROACH FOR DEVELOPING RESILIENT, PROFITABLE TROPICAL FRUIT INDUSTRIES: A CASE STUDY

Jashanpreet Kaur^{1,4}, Muhammad Sohail Mazhar^{1,2}, Ray Collins³ and Zora Singh⁴

¹Department of Agriculture and Fisheries, Northern Territory Government of Australia.

²Faculty of Science and Technology, Charles Darwin University, Australia.

³The University of Queensland, Australia.

⁴Horticulture, Edith Cowan University, Australia

Supply chain disruptions, increasingly competitive markets and changing consumer preferences are drivers of postharvest losses exceeding 20 per cent in Australian tropical fruit industries. At the same time, the provenance of Australian grown products is highly valued in both domestic and international markets. Tackling the multiple causes of postharvest losses in tropical fruit industries while enhancing product value is a multi-faceted challenge that has technological, social and economic dimensions. This may explain why the RD&E efforts of tropical horticulture organizations in Australia, central and Southeast Asia and the Pacific, are increasingly based on systems approaches to dealing with the challenges of meeting the needs and aspirations of local and global consumers, including broader challenges such as waste management, resource scarcity and climate change adaptation. At the individual product level, for example, systems-based research has created the ability to predict yield, fruit quality and shelf life, results that can be applied to improving supply chain efficiency and lowering costs, while delivering greater value to retailers and consumers. At the sectoral level, Australia's National Food Waste Strategy (2017), which aims to reduce food waste by 50% by 2030, establishes a food waste hierarchy based on circular uses of food products that would otherwise be lost, including reuse (e.g. food rescue donations), recycling (e.g. composting) and reprocessing (e.g. conversion to pharmaceuticals and nutraceuticals). Currently, Australian researchers are exploring the recovery of edible and inedible portions of tropical fruits that would otherwise be wasted, to transform them into higher-value commercial products. For individual fruits and for the sector as a whole, adopting a systems-based approach to RD&E can deliver win-win outcomes for growers, processors, wholesalers, distributors, retailers and most importantly, consumers. Applying a value chain perspective is one systems-based approach to RD&E that can incorporate all stakeholders from production to consumption, integrate inputs from multiple disciplines, address complex problems at different scales, and incorporate regulatory and policy influences on system behaviour.

1. INTRODUCTION

In Australia, horticulture is the third largest agricultural industry (Hort Innovation, 2023) with total production of 2.65 million tonnes in 2022-23 (Hort Innovation, 2024). The total production value of Australian horticulture in 2022-23 increased by 2.8% to AUD 16.3 billion, including a substantial increase of 12.6% in fruit production (Hort Innovation, 2024). The value of horticultural production is projected to reach a record high of AUD 17.8 billion in 2024-25

National Food Waste Strategy (2017). [National Food Waste Strategy: Halving Australia's Food Waste by 2030 \(dceew.gov.au\)](https://www.dccew.gov.au)

(Winarata, 2024). Increasing the value of production can result in increasing output volumes and higher prices for export-oriented sectors (Winarata, 2024).

The Australian tropical fruit industry is highly diversified, with around 60 fruit species in commercial or semi-commercial production in the tropical and subtropical areas of northern Australia, specifically the Northern Territory (NT) and Far North Queensland (FNQ) (Owens, 2021). Australian tropical fruit research, development and extension (RD&E) is driven by federal, state, and territory governments, along with significant contributions from universities, growers and other value chain stakeholders. Australian federal government agencies include AgriFutures, the Australian Centre for International Agricultural Research, Hort Innovation and various Cooperative Research Centres (Mazhar, Norris, Attenborough, van't Hag, Robson, Sinha & Walsh, 2022).

This paper presents a case study of a systems-based approach to production, postharvest and marketability of jackfruit (*Artocarpus heterophyllus* Lam.), a tropical fruit crop with significant growth potential (Owens, 2021). Jackfruit produces the largest edible fruit in the world (Figure 1) (Kaur, Singh, Shah, Mazhar, Hasan & Woodward, 2024a). Owing to its resemblance with shredded meat, jackfruit has gained popularity alongside the rise in veganism (Mistry, George & Thomas, 2020). Jackfruit is one of the five emerging tropical fruit crops identified in AgriFuture's RD&E strategic plan and has been recognised as a priority crop for investment, research and development support (Owens, 2021).



Figure. 1 Cauliflorous bearing habit in jackfruit

Significant growth in jackfruit production has been attributed to strong market demand for both fresh and value-added products (Owens, 2021), with total value of Australian jackfruit production reported as AUD 2.09 million in 2020 (Norris, Hag, Su, Attenborough, Buckingham, Perry, & Marcsik, 2021), and expected to increase to AUD 5-10 million by 2025 (AgriFutures, 2024). This paper reflects key elements of Australia's strategic approach to tropical fruit RD&E, highlighting nutritional quality evaluation, maturity assessment, storage life optimisation and postharvest quality management of jackfruit.

2. KEY RD&E FOCAL AREAS FOR JACKFRUIT INDUSTRY DEVELOPMENT

2.1 Fruit quality evaluation of jackfruit genotypes

Successful new tropical fruit industries ultimately rely on the acceptability and profitability of products that are relatively new to markets and consumers. The wide natural genetic variability

that typically characterises unimproved fruit varieties can be both an opportunity and an impediment in identifying selections that have market and economic potential. Early screening of genotypes is an essential first step for the successful establishment of new industries.

Jackfruit is highly heterozygous and cross-pollinated tree with a significant genetic variation within the population (Kaur, Singh, Mazhar, Afrifa-Yamoah, & Woodward, 2024b). As a result, there are several jackfruit genotypes in Australia and worldwide, providing extensive opportunities for crop improvement through selection. Characterising this variability from economic and market perspectives is necessary for identifying genotypes accurately and developing effective breeding programmes. Moreover, evaluation, characterisation and documentation of the genotypes assist in genetic conservation, management of landraces and supporting future breeding programmes. Whilst DNA markers are believed to be most reliable, as these are independent of environmental effects (Sharif, Jaskani, Naqvi, & Awan, 2019), physicochemical traits are mostly fixed in trees and are rarely influenced by ecological parameters, hence the characterisation of these traits serves as a dependable tool for diversity evaluation in fruit trees (Din, Jaskani, Naqvi, & Awan, 2020). This case study analyses the physicochemical characteristics of jackfruit genotypes to initially identify the diversity within the species (Figure 2). Given the increasing current interest in production, marketing and consumption of jackfruit, it is essential to align the distinctive characteristics of current genotypes with crop improvement and breeding program objectives (Nakintu, Olet, Andama, & Lejju, 2019). Characterisation of genotypes based on morphological and biochemical parameters is reported as an initial phase in genetic conservation of underutilised crops by classifying genotypes with similar traits (Din, et al., 2020). Because fruit quality is influenced by the complex interaction of genetic and environmental factors, it has been suggested that genotype assessment should be specific to each growing region (Radunić, Špika, Ban, Gadže, Díaz-Pérez, & MacLean, 2015). While previous research has evaluated the physicochemical characteristics of fruit from different jackfruit growing regions (Jagadeesh, Reddy, Swamy, Gorbai, Hegde, Raghavan, 2007; Youssef & Khalil, 2020; Balamaze, Muyonga, & Byaruhanga, 2019), there is a lack of research on assessment of fruit morphological and biochemical characteristics of jackfruit genotypes grown in Australia.



Figure 2. Different parts of jackfruit (a) pulp (b) seeds (c) arils or bulbs (d) rag (e) core (f) peel

Adopting a systematic approach to genotype characterisation is foundational in building new fruit industries that are economically viable. This research project characterises twelve different jackfruit genotypes, including germplasm accessions and seedling selections, to identify the unique characteristics of each genotype and ascertain their processing and market suitability.

2.2 Mineral profiling of jackfruit genotypes

The nutritional importance of fruits and vegetables in modern diets is beyond question (Slavin & Lloyd, 2012). Understanding the nutritional composition of a minor fruit such as jackfruit, helps to communicate its health benefits not only to consumers but also to other members of the value chain who may be considering investing in its production, processing or marketing.

Within the nutritional composition of fruit, minerals play a crucial role (Soetan, Olaiya, & Oyewole, 2010). Evaluation of fruit mineral composition among various genotypes is an additional measure of overall variability and a basis for assessing each genotype's contribution to the diets of potential consumers. While mineral profiling of different fruit crops including mangoes (Ma, Xu, Zhou, Wu, & Wang, 2019), citrus (Czech, Zarycka, Yanovych, Zasadna, Grzegorzczak, & Kłys 2020) and persimmons (Mir-Marqués, Domingo, Cervera, & de la Guardia, 2015) has been conducted, little is known of the complete mineral profile of different jackfruit genotypes. This research trial aims to evaluate the composition of 25 different mineral elements in jackfruit genotypes and to quantify how much each genotype contributes towards the recommended dietary allowance or adequate intake of the respective mineral element. The mineral elements are being quantified using ion chromatography, inductively coupled plasma optical emission spectroscopy and inductively coupled plasma mass spectrometry (Figure 3).

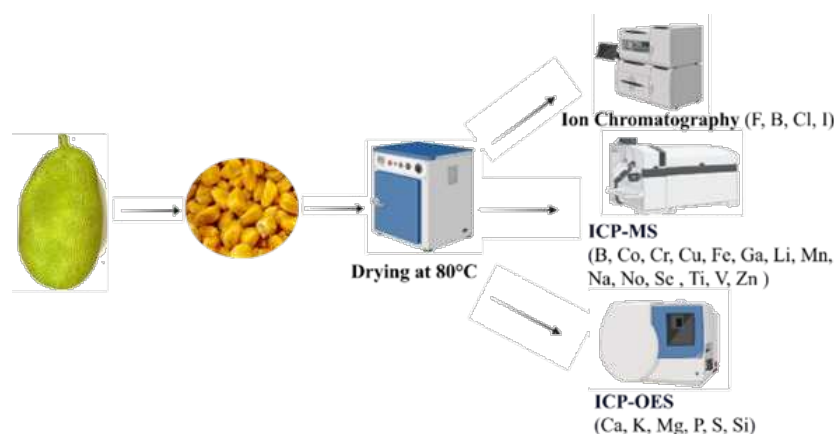


Figure 3. Mineral composition analysis in jackfruit pulp using ion chromatography, inductively coupled plasma-mass spectrometry, and inductively coupled plasma-optical emission spectrometry

2.3. Assessment of jackfruit maturity

Being able to produce a new fruit crop with the quality characteristics valued by consumers is an essential building block of new industry development. However, those parts of the system that are between the fruit on the tree ready for harvest, and the retail outlet where the fruit becomes available to consumers, are equally critical to the performance of the whole value chain. Indeed, the performance of these postharvest elements of the chain can make or break a new fruit industry.

The effective management of postharvest factors begins with pre-harvest factors. The maturity stage at harvest is one of the most critical factors affecting fruit quality (Zhao, Zhu, Hou, Pan, Shi, & Li, 2021). Jackfruit is harvested at different stages of maturity depending upon its potential usage. Being a climacteric fruit, maturity at harvest is a major factor affecting its ripening, quality and storage life. Understanding changes in fruit physicochemical characteristics during maturity and ripening can facilitate the optimisation of fruit harvest and handling practices (Moradinezhad, Setayesh, Mahmoodi, & Khayyat, 2016). Examining the characteristics of jackfruit genotypes at different maturity stages can also assist in determining the best stage for use of jackfruit in different processed products (Amin, Ahamad, & Rahim, 2022). Moreover, the evaluation of fruit characteristics during maturation has practical implications for the development of equipment for handling and processing of jackfruit (Rana, Pradhan, & Mishra, 2018). Various studies have been conducted to evaluate the effects of harvest maturity on fruit quality in different growing regions of jackfruit (Saha, Islam, & Mola, 2016; Ranasinghe & Marapana, 2019; Shamlu, Heeba, Jose, & Nisha, 2019). However, the impact of the fruit maturity stage at harvest on fruit physicochemical characteristics and textural attributes has not yet been evaluated in jackfruit genotypes grown in Australia. To help address this knowledge gap, this research project examines the changes in fruit quality characteristics along with cell wall polysaccharides and fruit softening enzymes in fruit of two jackfruit genotypes harvested at four different maturity stages (Figure 4).

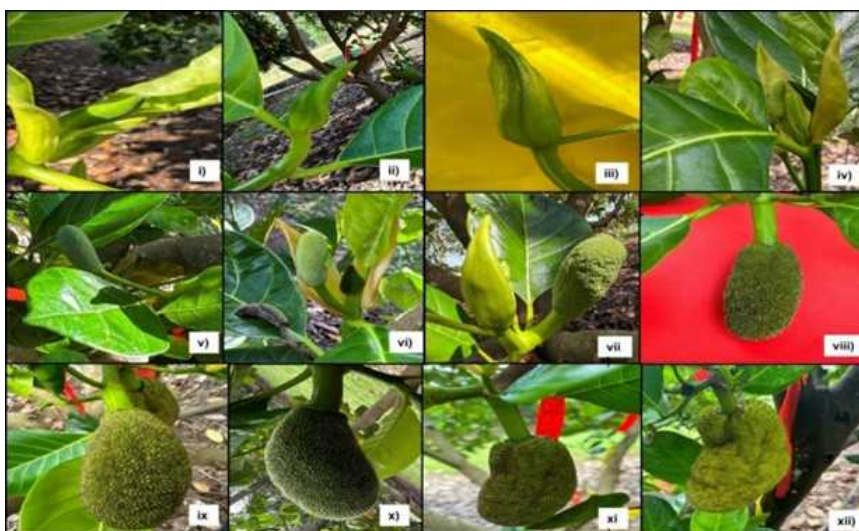


Figure 4: Different stages of flower development in jackfruit i) Growth of bearing footstalk; ii, iii) swelling of female bud; iv) Bracts separating; v) End of bract separation and female spike clearly visible; vi) Growth of female spike; vii) Maturation of female spike; viii) Stigma at peak receptivity; ix, x) Pollination complete; xi) Fruit set; xii) Beginning of syncarp growth

In practice, the harvesting stage of jackfruit is assessed by a range of indicators including change in skin colour, days from flowering to fruit maturity, flattening of spines, production of jackfruit odour, yellowing of last leaf on stalk, decrease in spine density and dull hollow tapping sound (Haq, 2006; Ranasinghe, Maduwanthi, & Marapana, 2019). An increase in the proportion of fruit edible portions to non-edible portions is also used to assess the harvest maturity of jackfruit (Elevitch & Manner, 2006). However, all these maturity indicators vary depending on the climatic conditions and genotype and there is no standardised practice for judging the maturity of jackfruit. From an economic and marketing point of view, it is important to standardise the assessment of harvesting time of jackfruit to ensure optimal quality to the consumer, to extend storage life and meet market demand throughout the harvest season. In

this project, the harvest maturity of jackfruit is being evaluated by examining the relationship between traditionally used fruit maturity indicators (production of dull-hollow tapping sound, increase in spine flatness and decrease in spine density) and the reflectance and fluorescence values recorded by Rubens scanner (Figure 5).



Figure 5. Jackfruit maturity assessment using Rubens scanner

2.4. Postharvest storage life extension

The ability to extend the storage life of a fruit without appreciable loss of quality ensures marketability and consumer access over more than just the fruit's harvest season. In terms of industry development, availability over an extended period adds to the attractiveness of fruit not only to consumers but also to other members of the value chain, such as producers, wholesalers and retailers.

Jackfruit is a perishable fruit crop owing to its intrinsic characteristics and textural attributes (Mondal, Remme, Mamun, Sultana, Ali, & Mannan, 2013). The climacteric nature of jackfruit leads to increased postharvest ethylene production and respiration, significantly impacting the storage life of fruit (Kaur, et al., 2024a). Jackfruit is susceptible to postharvest conditions such as flesh browning and softening, decay and fruit flavour loss (Prathibha, Vasudeva, Sadananda, & Suresha, 2019). The fruit also tends to lose moisture during extended storage, leading to build up of reactive oxygen species which ultimately reduce the capacity of antioxidants to neutralise free radicals (Maalekuu, Tuvia-Alkalai, Shalom, Fallik, Elkind, Jenks, & Goodwin, 2005). Extended storage also results in cell wall degradation due to demethylation, de-esterification and disintegration of cell wall polysaccharides via the action of fruit softening enzymes (Cao, Qu, Ma, Ba, Ji, Meng, Lei, & Wang, 2021). Because of the range and severity of these postharvest conditions, combined with a lack of standardised postharvest and storage practices, jackfruit has remained an unexploited fruit crop (Kaur, et al., 2024a). It is estimated that about 70% of total jackfruit production is lost due to improper pre- and postharvest management practices (APAARI, 2012). In Australia, the geographical location of jackfruit production areas requires long-distance transportation to reach large consumer markets in capital cities (Baker, 2023). Consequently, for jackfruit industry development it is essential to investigate innovative methods to alleviate postharvest losses and preserve the overall quality of jackfruit during extended storage life. The increasing environmental and health concerns have prompted the exploration of eco-friendly methods for maintaining the quality of fruit and vegetables (Davarynejad, Zarei, Nasrabadi, & Ardakani, 2015). Melatonin as a natural, food-safe and environmentally friendly compound shows potential as a postharvest treatment (Ze, Gao, Li, Yang, & Jiang, 2021). Given the effectiveness of melatonin in maintaining fruit quality through modulation of antioxidant potential and oxidative stress (Madebo, Zheng, & Jin, 2021)

this research project aims to evaluate the effects of postharvest dip application of melatonin on overall fruit quality, storage life, antioxidant potential and oxidative stress of jackfruit during cold storage (Figure 6).

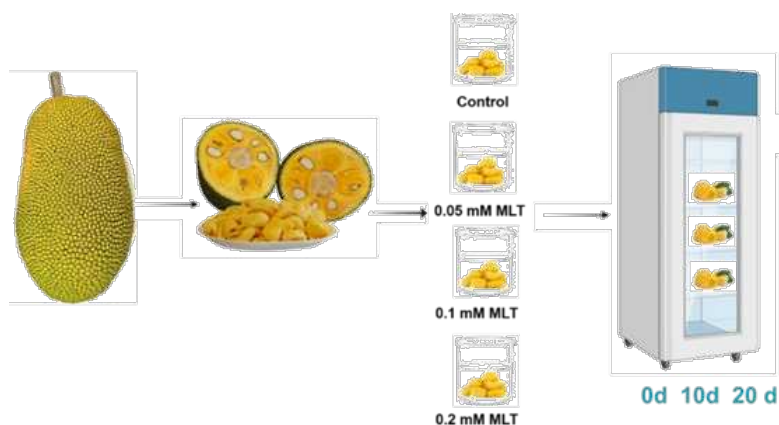


Figure 6. Dipping of jackfruit arils in different concentrations of melatonin for shelf-life extension

3. FUTURE DIRECTION

In line with the National Food Waste Strategy of Australia and the principles of the Food Waste Hierarchy illustrated in Figure 7, the outcomes of the research outlined in the sections above will collectively contribute to reducing waste at multiple levels of the hierarchy: by improving fruit harvest timing, minimising losses due to fruit quality degradation, extending storage life and ultimately by focusing on understanding and delivering value to the end consumer.

In future, the aim is to build on this foundation by exploring strategies to minimise waste and add value through reprocessing and improved postharvest management practices, working towards alignment with sustainable food system goals. In the short term, research will focus on value-added products and valorisation of the inedible parts of jackfruit. National and international collaborations, as well as engagement with leading institutions and industry partners both locally and globally, can provide opportunities to utilise their diverse expertise and technologies, and most importantly, to validate the economic potential of jackfruit with commercial value chain partners. Such collaboration aligns with the research initiatives of the Australian and global sustainability goals, aiming to develop feasible solutions that reduce food waste.

Future initiatives will also focus on creating strong research and development collaboration through multiagency and multidisciplinary forums. At the same time, engaging experts from the biophysical and social sciences will be necessary to develop the integrative, systems based approach that is crucial to addressing the complex RD&E challenges of new industry development for a crop such as jackfruit. Finally, cross sector cooperation will ensure that research outcomes are validated and grounded in real-world commercial contexts, enhancing research impacts and contributing to the development of economically and environmentally sustainable practices that benefit the development of the jackfruit industry, and through it, benefit horticulture nationally and internationally.

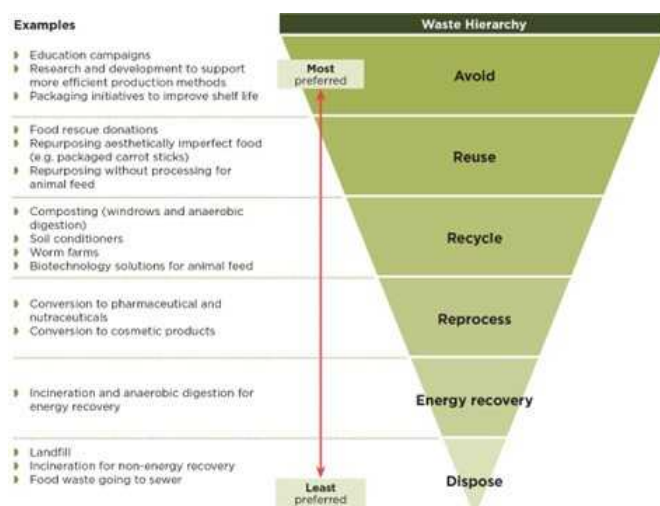


Figure 7. Food waste hierarchy: Strategic framework under Australia’s National Food Waste Strategy, 2017 (Commonwealth of Australia, 2017)

4. CONCLUSION

The tropical fruit industry is a vital and dynamic component of Australian horticulture, with significant prospects for both economic development and improved environmental sustainability. The systems based approach outlined in this paper emphasises the importance of integrating research, industry practices and strategic collaboration to ensure long-term profitability and resilience. Maintaining a focus on creating and delivering value to the end consumer is an essential element of this approach. If successful, the benefits flow not only to growers, consumers and other members of the value chain, but they also contribute to the broader goals of global food security and sustainability. Collaboration among researchers, industry stakeholders and policymakers also aims to ensure that outcomes and recommendations are rigorous, grounded and adaptable to changing circumstances. In future, this jackfruit case study may serve as an exemplar by promoting national and international collaboration and adopting an integrative multidisciplinary framework for supporting innovation and ensuring the sustainable growth of tropical fruit industries. The wider value of this case study lies in the ability of other industries to extract models and lessons that can enhance resilience, help to meet domestic and global demand and contribute meaningfully to advancing sustainable horticultural practices.

REFERENCES

AgriFutures. (2024). *Identifying new revenue opportunities for the jackfruit industry*. Agrifutures Australia. <https://agrifutures.com.au/emerging-industries>

Amin, I., Ahamad, R., & Rahim, A. (2022). Characterization of fruits of eleven accessions of jackfruit. *International Journal of Chemical Studies*, 10 (2), 4-10. <https://doi.org/10.22271/chemi.2022.v10.i2a.12171>

APAARI. (2012). *Jackfruit improvement in the Asia-Pacific region- A status report*. Asia-Pacific Association of Agricultural Research Institutions, Bangkok, Thailand. https://www.apaari.org/wp-content/uploads/downloads/2012/10/Jackfruit-A-Success-Story_31-8-2012.pdf

Baker, D. (2023). *Technology mapping for the Australian jackfruit industry*. AgriFutures Australia. https://assets-global.website-files.com/5f4f19737a6ae318c84e362c/64507ddbf5e89543045359ad_AF123%20REPORT%20Jackfruit%20%204_02_2023.pdf

- Balamaze, J., Muyonga, J. H., & Byaruhanga, Y. B. (2019). Physico-chemical characteristics of selected jackfruit (*Artocarpus heterophyllus* Lam.) varieties. *Journal of Food Research*, 8(4), 11-22. <https://doi.org/10.5539/jfr.v8n4p11>
- Cao, S., Qu, G., Ma, C., Ba, L., Ji, N., Meng, L., Lei, J., & Wang, R. (2021). Effects of melatonin treatment on the physiological quality and cell wall metabolites in kiwifruit. *Food Science and Technology*, 42, e85421. <https://doi.org/10.1590/fst.85421>
- Commonwealth of Australia. (2017). *National Food Waste Strategy: Halving Australia's food waste by 2030*. <https://www.dcceew.gov.au/sites/default/files/documents/national-food-waste-strategy.pdf>
- Czech, A., Zarycka, E., Yanovych, D., Zasadna, Z., Grzegorzczak, I., & Kłys, S. (2020). Mineral content of the pulp and peel of various citrus fruit cultivars. *Biological Trace Element Research*, 193, 555-563. <https://doi.org/10.1007/s12011-019-01727-1>
- Davarynejad, G. H., Zarei, M., Nasrabadi, M. E., & Ardakani, E. (2015). Effects of salicylic acid and putrescine on storability, quality attributes and antioxidant activity of plum cv. 'Santa Rosa'. *Journal of Food Science and Technology*, 52, 2053-2062. <https://doi.org/10.1007/s13197-013-1232-3>
- Din, S., Jaskani, M. J., Naqvi, S. A., Awan, F. S., 2020. Diversity and divergence in domesticated and wild jamun (*Syzygium cumini*) genotypes of Pakistan. *Scientia Horticulturae*, 273, 109617. <https://doi.org/10.1016/j.scienta.2020.109617>
- Elevitch, C. R., & Manner, H. I. (2006). *Artocarpus heterophyllus* (jackfruit). *Species Profiles for Pacific Island Agroforestry*, 10, 1-25. <https://agroforestry.org/free-publications/traditional-tree-profiles>
- Haq, N. (2006). Fruits for the future: jackfruit (*Artocarpus heterophyllus*). In J. T. Williams, R. W. Smith, & Z. Dunsiger (Eds.), *Crops for the Future* (pp. 102-140). Southampton Centre for Underutilized Crops.
- Hort Innovation (2023). Annual Report 2022/23. <http://www.horticulture.com.au/annual-report-portal>
- Hort Innovation (2024). Australian Horticulture Statistics Handbook 2022/23.
- Jagadeesh, S. L., Reddy, B. S., Swamy, G. S. K., Goral, K., Hegde, L., Raghavan, G. S. V. (2007). Chemical composition of jackfruit (*Artocarpus heterophyllus* Lam.) selections of Western Ghats of India. *Food Chemistry*, 102(1), 361-365. <https://doi.org/10.1016/j.foodchem.2006.05.027>
- Jaskani, M. J., & Khan, I. A. (2021). Horticulture: An Overview. In A. S. Khan & K. Ziaf (Eds.). *Horticulture: Science & Technology*. (pp 3-22). University of Agriculture, Faisalabad.
- Kaur, J., Singh, Z., Mazhar, M. S., Afrifa-Yamoah, E., & Woodward, A. (2024b). Variability in fruit quality traits of tropical Australian jackfruit (*Artocarpus heterophyllus* Lam.) genotypes. *Scientia Horticulturae*, 338, 113771. <https://doi.org/10.1016/j.scienta.2024.113771>
- Kaur, J., Singh, Z., Shah, H. M. S., Mazhar, M. S., Hasan, M. U., & Woodward, A. (2024a). Insights into phytonutrient profile and postharvest quality management of jackfruit: A review. *Critical Reviews in Food Science and Nutrition*, 64(19), 6756-6782. <https://doi.org/10.1080/10408398.2023.2174947>
- Ma, X. W., Xu, W. T., Zhou, Y. G., Wu, H. X., & Wang, S. B. (2019). Analysis of the mineral composition in fruit pulp of 53 mango genotypes. *Acta Horticulturae*, 1244, 215-220. <https://doi.org/10.17660/ActaHortic.2019.1244.32>
- Maalekuu, K., Tuvia-Alkalai, S., Shalom, Y., Fallik, E., Elkind, Y., Jenks, M. A., & Goodwin, M. S. (2005). Characterization of physiological and biochemical factors associated with postharvest water loss in ripe pepper fruit during storage. *Journal of American Society for Horticultural Science*, 130(5), 735-741.
- Madebo, M. P., Zheng, Y., & Jin, P. (2022). Melatonin mediated postharvest quality and antioxidant properties of fresh fruits: A comprehensive meta analysis. *Comprehensive*

- Reviews in Food Science and Food Safety*, 21(4), 3205-3226. <https://doi.org/10.1111/1541-4337.12961>
- Mazhar, M. S., Norris, A., Attenborough, E., van't Hag, L., Robson, A., Sinha, P., & Walsh, K. (2022). Tropical fruit research, development, and extension in Australia. *Proceedings of the international symposium on tropical fruits, 2021*. International Tropical Fruits Network.
- Mir-Marqués, A., Domingo, A., Cervera, M. L., & de la Guardia, M. (2015). Mineral profile of kaki fruits (*Diospyros kaki* L.). *Food Chemistry*, 172, 291-297. <http://dx.doi.org/10.1016/j.foodchem.2014.09.076>
- Mistry, M., George, A., & Thomas, S. (2020). Alternatives to meat for halting the stable to table continuum—an update. *Arab Journal of Basic and Applied Sciences*, 27(1), 324-334. <https://doi.org/10.1080/25765299.2020.1807084>
- Mondal, C., Remme, R. N., Mamun, A. A., Sultana, S., Ali, M. H., & Mannan, M. A. (2013). Product development from jackfruit (*Artocarpus heterophyllus* Lam.) and analysis of nutritional quality of the processed products. *Journal of Agriculture and Veterinary Science*, 4(1), 76-84.
- Moradinezhad, F., Setayesh, F., Mahmoodi, S., & Khayyat, M. (2016). Physicochemical properties and nutritional value of jujube (*Ziziphus jujuba* Mill.) fruit at different maturity and ripening stages. *International Journal of Horticultural Science and Technology*, 3(1), 43-50.
- Nakintu, J., Olet, A. E., Andama, M., & Lejju, J. B. (2019). Ethno-varieties and distribution of jackfruit tree (*Artocarpus heterophyllus* Lam.) in Uganda: implications for trade, food security and germplasm conservation. *East African Journal of Science, Technology and Innovation*, 1 (1), 27-51. <http://ir.must.ac.ug/xmlui/handle/123456789/723>
- Norris, A., Hag, L. V., Su, C., Attenborough, E., Buckingham, E., Perry, O., & Marcsik, D. (2021). Processing jackfruit into ready-to-eat products and ingredients. *AgriFutures Australia*. <https://www.agrifutures.com.au/related-projects/processing-jackfruit-into-ready-to-eat-products-and-ingredients>
- Owens, G. (2021). Australian emerging tropical fruits strategic RD&E plan. *AgriFutures Australia*. <https://www.agrifutures.com.au/wp-content/uploads/2021/12/21-151.pdf>
- Owens, G. (2021). Australian emerging tropical fruits strategic RD&E plan. *AgriFutures Australia*. <https://www.agrifutures.com.au/wp-content/uploads/2021/12/21-151.pdf>
- Prathibha, S. C., Vasudeva, K. R., Sadananda, G. K., & Suresha, G. J. (2019). Effect of pretreatment and packaging on quality of fresh cut jackfruit (*Artocarpus heterophyllus* Lam.) bulbs. *International Journal of Chemical Studies*, 7, 1697-1700.
- Radunić, M., Špika, M. J., Ban, S. G., Gadže, J., Díaz-Pérez, J. C., & MacLean, D. (2015). Physical and chemical properties of pomegranate fruit accessions from Croatia. *Food Chemistry*, 177, 53-60. <https://doi.org/10.1016/j.foodchem.2014.12.102>
- Rana, S. S., Pradhan, R. C., & Mishra, S. (2018). Variation in properties of tender jackfruit during different stages of maturity. *Journal of Food Science and Technology*, 55, 2122-2129.
- Ranasinghe, R. A. S. N., Maduwanthi, S. D. T., & Marapana, R. A. U. J. (2019). Nutritional and health benefits of jackfruit (*Artocarpus heterophyllus* Lam.): a review. *International Journal of Food Science*, 2019, 4327183. <https://doi.org/10.1155/2019/4327183>
- Ranasinghe, R. A. S., & Marapana, R. A. U. J. (2019). Effect of maturity stage on physicochemical properties of jackfruit (*Artocarpus heterophyllus* Lam.) flesh. *World Journal of Dairy and Food Sciences*, 14(1), 17-25. <http://dx.doi.org/10.5829/idosi.wjdfs.2019.17.25>
- Saha, M. G., Islam, M. N., & Molla, M. M. (2016). Determination of harvest maturity of jackfruit. *Bangladesh Society for Horticultural Science*, 2, 23-36.
- Shamla, L., Heeba, S., Jose, N., & Nisha, P. (2019). Change in chemical composition during maturation of *Artocarpus heterophyllus* and its effect on acrylamide formation in deep fried jackfruit chips. *Journal of Food Processing and Preservation*, 43(9), e14099. <https://doi.org/10.1111/jfpp.14099>

- Sharif, N., Jaskani, M. J., Naqvi, S. A., Awan, F. S., 2019. Exploitation of diversity in domesticated and wild ber (*Ziziphus mauritiana* Lam.) germplasm for conservation and breeding in Pakistan. *Scientia Horticulturae*, 249, 228-239. <https://doi.org/10.1016/j.scienta.2019.01.041>
- Slavin, J. L., & Lloyd, B. (2012). Health benefits of fruits and vegetables. *Advances in Nutrition*, 3(4), 506-516. <https://doi.org/10.3945/an.112.002154>
- Soetan, K. O., Olaiya, C. O., & Oyewole, O. E. (2010). The importance of mineral elements for humans, domestic animals and plants: A review. *African Journal of Food Science*, 4(5), 200-222.
- Winarta, T. (2024). Horticulture. *Australian Bureau of Agricultural and Resource Economics and Sciences*. <https://www.agriculture.gov.au/abares/research-topics/agricultural-outlook/horticulture#value-of-production-to-reach-a-record-high>
- Youssef, M., & Khalil, O. A. (2020). Morphological, chemical and molecular variations among some jackfruit landraces. *Assiut Journal of Agricultural Sciences*, 51(1), 102-113.
- Ze, Y., Gao, H., Li, T., Yang, B., & Jiang, Y. (2021). Insights into the roles of melatonin in maintaining quality and extending shelf life of postharvest fruits. *Trends in Food Science & Technology*, 109, 569-578. <https://doi.org/10.1016/j.tifs.2021.01.051>
- Zhao, Y., Zhu, X., Hou, Y., Pan, Y., Shi, L., & Li, X. (2021). Effects of harvest maturity stage on postharvest quality of winter jujube (*Zizyphus jujuba* Mill. cv. Dongzao) fruit during cold storage. *Scientia Horticulturae*, 277, 109778. <https://doi.org/10.1016/j.scienta.2020.109778>
- Zoroddu, M. A., Aaseth, J., Crisponi, G., Medici, S., Peana, M., & Nurchi, V. M. (2019). The essential metals for humans: a brief overview. *Journal of Inorganic Biochemistry*, 195, 120-A129. <https://doi.org/10.1016/j.jinorgbio.2019.03.013>

POSTHARVEST SOLUTIONS FOR MAJOR FRUITS IN THE DEVELOPING HUMID TROPICS – THE PLANT & FOOD RESEARCH EXPERIENCE

Guinevere I. Ortiz¹, Allan B. Woolf¹, Nguyen Van Phong², Nguyen Khanh Ngoc¹, Nguyen Van Tung², Nguyen Duy Duc⁴, San Tram Anh⁴, Nguyen Trong Minh Khiem⁴, Phu Cao Ngoc³, Manh Hung Phung³, Karmun Chooi¹, Vu Thi Phuong Thanh¹, Stephanie Montgomery¹, Suzie M. Newman¹

¹The New Zealand Institute for Plant & Food Research, Auckland, New Zealand

²Southern Horticultural Research Institute, My Tho, VietNam

³Northern Mountainous Agriculture and Forestry Science Institute

⁴Sub-Institute for Agricultural Engineering and Post-harvest Technology, Ho Chi Minh, VietNam

The developing tropics face unique challenges in ensuring the quality and shelf life of major fruits due mainly to inadequate infrastructure, poor transportation, and limited access to technology. This presentation will explore practical postharvest solutions aimed at extending the shelf life and enhancing the quality of major fruits in these regions drawing on our experiences at Plant & Food Research and our ongoing international development efforts in Southeast Asia, Africa and the Pacific around postharvest management and value chain.

We will delve into the importance of proper handling, storage, and packaging techniques to minimize damage and maintain quality as well as practical solutions for complex problems. Cold chain management strategies will be discussed as a critical component in preserving the quality of fruits by controlling temperature throughout the supply chain, especially in tropical climates. The presentation will highlight our work on dragon fruit and passionfruit in Viet Nam, and avocado in Kenya.

The New Zealand Institute for Plant and Food Research (PFR) is a New Zealand government-owned Crown Research Institute (CRI). Its long history of undertaking professional scientific research to aid agriculture and horticulture in New Zealand dates to the early 1900s. One of the key aspects of PFR's work is its international development efforts, where it collaborates with organizations and partners around the world to address agricultural challenges and improve food security.

ORAL PRESENTATIONS

THE USE OF EMERGING TECHNOLOGIES IN THE EXTRACTION TECHNIQUE OF FRUIT BY-PRODUCTS AS INGREDIENTS FOR THE FOOD INDUSTRY

Rosnah Shamsudin^{1,2}, Satria Bhirawa Anoraga^{1,3}, Muhammad Hazwan Hamzah⁴, Arifin Dwi Saputro⁵, Suzannah

¹Department of Process and Food Engineering, Faculty Engineering, Universiti Putra Malaysia, 43400, Serdang, Selangor, Malaysia

²Institute of Plantations Studies, Universiti Putra Malaysia, 43400, Serdang, Selangor, Malaysia

³Department of Veterinary and Bioresources Technology, Vocational College, Universitas Gadjah Mada, 55281, Yogyakarta, Indonesia

⁴Department of Biological and Agricultural Engineering, Universiti Putra Malaysia, 43400, Serdang, Selangor, Malaysia

⁵Departement of Agricultural and Biosystems Engineering, Universitas Gadjah Mada, 55281, Yogyakarta, Indonesia

⁶Cocoa Innovation and Technology Centre, Malaysian Cocoa Board, 71800, Negeri Sembilan, Malaysia

rosnahs@upm.edu.my

Tropical fruits such as durian, jackfruit, banana, and cacao generate substantial amounts of peel waste, with more than half of this biomass often discarded. Improper disposal of such waste poses environmental and health risks. However, these by-products can serve as valuable resources for producing food additives. In particular, fruit peels present a promising alternative for commercial pectin production, a compound in high demand globally due to its health benefits and functional properties. Increasing interest in natural plant-based ingredients drives research into utilizing fruit waste, supported by emerging technologies that enhance extraction methods. These technological advancements reduce energy consumption, promote renewable resources and alternative solvents, and ensure the production of high-quality, safe extracts and products. In addition to improving the efficiency of biomass recovery, such technologies align with environmental and health objectives. Fruit by-products can be extracted to provide ingredients rich in phenolic compounds, which offer various bioactive properties, including antioxidants, antimicrobial, anticancer, and antidiabetic effects. Moreover, they hold potential for applications in food packaging, thereby contributing to food safety and quality. The valorization of fruit by-products into functional ingredients offers a sustainable solution to waste management and can improve nutrition, food quality, and food safety. This approach also aligns with efforts to enhance the sustainability and efficiency of the agricultural industry, emphasizing the broader impact of utilizing waste from tropical fruit processing through innovative extraction technologies.

Keywords: By-products, Extraction, Food applications, Fruit waste, Valorization.

1. INTRODUCTION

The food industry generates a substantial number of by-products, including fruit peels, seeds, and pomace, which are often discarded as waste (Ayele et al., 2024). These residues contribute to environmental concerns, particularly in developing countries where efficient waste management systems are lacking (Prokic et al., 2022). However, many of these by-products contain valuable bioactive compounds, such as pectin, that have significant applications in food and pharmaceutical industries (Nirmal et al., 2023; Ritika et al., 2024). Extracting and utilizing these compounds can help minimize food waste while enhancing sustainability in food processing (Belkheiri et al., 2021a). The concept of waste valorization aligns with the principles of a circular economy, where food waste is converted into high-value ingredients instead of being disposed of as landfill waste (Sundarraaj & Ranganathan, 2017).

Pectin is a structurally complex polysaccharide widely used as a gelling, thickening, and stabilizing agent in food formulations (Barrera-Chamorro et al., 2025). It plays an essential role in manufacturing jams, fruit-based beverages, dairy products, and confectioneries (Chandel et al., 2022). Beyond its functional applications, the pectin has been recognized for its bioactive properties, including cholesterol-lowering effects and potential prebiotic benefits that promote gut health (Soomro et al., 2024). Due to these diverse applications, there is growing interest in developing sustainable methods for extracting pectin from fruit by-products to meet the increasing demand in the food industry (Maran et al., 2017).

Conventional acid extraction (CAE) is the most used method for pectin extraction due to its simplicity and cost-effectiveness (De Laet et al., 2024). However, this approach has several limitations, including low extraction yields, excessive use of strong acids, high energy consumption, and degradation of pectin quality (Adimas & Abera, 2023). The disposal of acidic waste also raises environmental concerns, necessitating alternative methods that improve efficiency and sustainability (Agarwal & Pandey, 2023). As a result, researchers have explored various emerging extraction technologies that can enhance pectin yield while reducing environmental impact.

Recent advancements in extraction techniques have introduced alternative methods such as microwave-assisted extraction (MAE), ultrasound-assisted extraction (UAE), enzymatic-assisted extraction (EAE), and ohmic-assisted extraction (OAE) (Gumustepe et al., 2023; Hennessey-Ramos et al., 2021; Sharma et al., 2022; Wongkaew et al., 2020). These innovative approaches have demonstrated higher extraction efficiency, shorter processing times, and improved functional properties of extracted pectin compared to conventional methods. Additionally, these techniques align with green chemistry principles by reducing the need for excessive chemical solvents and energy consumption (Maran et al., 2017).

One of the most significant applications of pectin is fruit jam production, where it functions as a key gelling agent to achieve the desired texture and consistency (Lara-Espinoza et al., 2018; Roman-Benn et al., 2023). Pectin interacts with sugar and acid to form a stable gel network, ensuring a smooth and firm structure in jams (Said et al., 2023). The use of pectin enhances the spreadability and mouthfeel of fruit jams while improving their overall stability during storage (Alam et al., 2024; Garg et al., 2019). Low-methoxyl pectin (LMP) is particularly beneficial in low-sugar and sugar-free jam formulations, as it forms gels in the presence of calcium ions rather than requiring high sugar concentrations (Muñoz Almagro et al., 2022). This makes LMP an ideal choice for producing reduced-calorie fruit jams while preserving their natural color and bioactive compounds, such as anthocyanins and phenolics, which contribute to antioxidant

properties. As consumer demand for healthier food products increases, pectin derived from fruit by-products offers a natural and sustainable alternative for developing high-quality fruit-based products (Poiana et al., 2013).

This review aims to provide a comprehensive analysis of emerging extraction technologies for obtaining pectin from fruit by-products. It highlights the advantages and limitations of these novel techniques compared to conventional methods and discusses their potential applications in the food industry. By examining these advancements, this review contributes to the ongoing efforts to develop sustainable and efficient pectin extraction processes that align with global food industry demands and environmental sustainability goals (Sundarraaj et al., 2020).

2. PECTIN CHARACTERISTICS

Pectin, a complex polysaccharide, plays a vital role in various industries, particularly in food production. It serves as an essential additive with a global demand of approximately 45,000 tons per year, growing at an annual rate of 4–5% (Raji et al., 2017; Suleiman et al., 2025). Pectin is primarily found in plant cell walls, especially in fruits, where it contributes to cell adhesion (Anoraga, et al., 2024; Liew et al., 2016). According to Adetunji et al. (2017), pectin consists of long chains of α -D-galacturonate units linked by α -(1 \rightarrow 4) glycosidic bonds. The main pectic structure also contains 2–3% L-rhamnose units, which are connected to galacturonate units via β -(1 \rightarrow 2) and β -(1 \rightarrow 4) linkages (Ridley et al., 2001; Satapathy et al., 2020).

Pectin dissolves in water, enabling it to disperse in aqueous solutions. When highly diluted, it behaves as a Newtonian fluid, but at moderate concentrations, it exhibits pseudoplastic (non-Newtonian) behavior (Pancerz et al., 2021). The viscosity of a pectin solution depends on factors such as equivalent weight and degree of esterification (DE) (Arias et al., 2021). Based on DE, pectin is categorized as either high methoxyl (HM) or low methoxyl (LM), which determines its functional applications. The Food and Agriculture Organization (FAO) specifies that pectin used in food applications should contain at least 65% galacturonic acid (GalA). Additionally, pectin's gelling capacity is often evaluated based on its equivalent weight (Torres-Gallo et al., 2022). HM pectin has more than 50% esterified galacturonic acid units, which requires high sugar concentrations (>55%) and a low pH (≤ 3.5) for gel formation (Wang et al., 2016). Due to these properties, HM pectin is widely used in traditional jams, jellies, and preserves to achieve a firm gel structure. In contrast, LM pectin has less than 50% esterified galacturonic acid units (Liew et al., 2016). It forms gels in the presence of divalent cations over a broader pH range (2.0–6.0) without requiring high sugar concentrations. This makes LM pectin suitable for low-sugar or sugar-free products, dairy applications, and fruit preparations for yogurt (Khubber et al., 2021).

Pectin has diverse applications in the food and pharmacy industry, serving as an emulsifier and stabilizer in products such as jams, jellies, and frozen foods (Anoraga, Shamsudin, Hamzah, Sharif, & Saputro, 2024). Recently, it has gained attention as a functional ingredient in low-calorie foods, where it is used as a fat or sweetener substitute (Mierczyńska et al., 2015). Beyond the food sector, pectin's unique structural and biological properties have led to its use in pharmaceutical and biotechnology industries. It has been utilized in the production of biodegradable films, plasticizing agents, paper alternatives, and foamed materials (Moreira et al., 2024).

3. EXTRACTION TECHNIQUE

a. Acid extraction

Acid extraction (AE) is a widely used method for pectin extraction from plant materials, including fruit peels. The process involves treating the matrix of plant materials in a dilute acid solution, such as hydrochloric or sulfuric acid, under controlled temperature and time conditions to hydrolyze the pectin and release it from the cell walls (Belkheiri et al., 2021b; Voragen et al., 2009). AE remains a preferred technique due to its ease of process control, relatively low cost, and moderate energy requirements (Das & Arora, 2021). The choice of acid plays a critical role in maintaining the quality and functionality of the extracted pectin. Zhang et al. (2024) compared organic and mineral acids for extracting pectin from dragon fruit peels and found that oxalic acid (an organic acid) yielded 20.14%, whereas hydrochloric acid (a mineral acid) at 0.03 M produced a lower yield of 14.96%. These findings align with those of Seixas et al. (2014), who reported that mineral acids can degrade pectin and contribute to environmental concerns. AE typically operates under specific extraction conditions, including time, temperature, and pH. The process is commonly conducted at temperatures between 70°C and 90°C (Vieira et al., 2024), while the pH of the extraction medium is typically maintained between 1.5 and 3.0 to optimize pectin solubility and prevent excessive degradation (Belkheiri et al., 2021).

b. Emerging Technologies of Extraction

Microwave-assisted extraction (MAE) is an advanced technique that employs microwave energy to enhance the release of bioactive compounds, including pectin, from plant matrices. As a non-ionizing radiation, microwaves operate at frequencies between 300 MHz and 300 GHz, with industrial applications commonly using 0.915 and 2.450 GHz (Barba et al., 2016; Mumtaz et al., 2022). The extraction mechanism relies on dielectric heating, where microwaves interact with polar molecules, inducing ionic conduction and dipole rotation. This interaction generates rapid internal heating, which disrupts plant cell walls, thereby facilitating the solubilization and diffusion of pectin into the extraction solvent (Marić et al., 2018). MAE is considered an advanced extraction method due to its ability to improve pectin yield, quality, and efficiency compared to conventional approaches. It aligns with green chemistry principles by reducing solvent usage, minimizing energy consumption, and lowering extraction waste (Cheriyana et al., 2025; Ling Wen Xia et al., 2024). Studies indicate that MAE can increase pectin yield by up to 60% while using less energy than traditional acid hydrolysis (Gavahian et al., 2021). Additionally, it limits the use of strong acids, enabling the recovery of high-purity pectin with minimal chemical degradation (Adetunji et al., 2017).

Ultrasound-assisted extraction (UAE) is a non-conventional method that employs high-frequency sound vibrations to facilitate the release of bioactive compounds, including pectin, from plant cell walls. The mechanism of UAE is based on acoustic cavitation, in which ultrasonic waves generate microscopic bubbles within the extraction medium (Bucur et al., 2023; Shen et al., 2024). The expansion and collapse of these bubbles create localized high pressure and temperature, disrupting the plant cell structure (Zahari et al., 2020). This process generates mechanical shear forces that increase cell wall permeability, allowing pectin to diffuse into the solvent. Additionally, the shock waves and microjets produced during cavitation enhance solvent penetration, further improving pectin recovery (Tomé Constantino & Garcia-Rojas, 2020). UAE offers several advantages over traditional pectin extraction methods. It significantly enhances pectin yield while reducing extraction time, as evidenced by citric acid extraction from grape pomace, which yielded 32.3% pectin at pH 2 and 75°C (Minjares-Fuentes et al.,

2014). Moreover, UAE operates at lower temperatures, minimizing thermal degradation and preserving the functional integrity of pectin (Gavahian et al., 2021). This method also aligns with green extraction principles, as it requires less solvent, reducing chemical waste and making the process more environmentally sustainable (Kumar et al., 2020).

Ohmic-assisted extraction (OAE) is an advanced thermal technique that applies electrical conductivity to generate uniform heat within a food matrix. This process involves passing an electric current through the material, inducing volumetric heating via Joule's law, which enhances mass transfer efficiency and shortens extraction time (Gavahian et al., 2019). Unlike conventional thermal methods, OAE ensures rapid and uniform heating, preventing localized overheating and minimizing thermal degradation of pectin, thus preserving its functional properties (Saberian et al., 2017). The efficiency of OAE depends on parameters such as voltage gradient, temperature, extraction time, and the electrical conductivity of the medium (Gumustepe et al., 2023). Hassanloofard et al. (2024) demonstrated that applying a voltage gradient of 15 V/cm at 90°C for 30 minutes significantly improved pectin yield and esterification degree compared to conventional extraction methods. OAE provides several advantages, making it a promising alternative for pectin extraction. It operates at lower temperatures and requires shorter processing times, preserving the structural integrity and bioactivity of pectin (Rawat et al., 2024). Additionally, its volumetric heating mechanism eliminates the need for excessive solvent use, promoting a more sustainable and energy-efficient extraction process (Goksu et al., 2022). Studies have also reported enhanced emulsifying properties, viscosity, and flow behavior of pectin extracted via OAE, broadening its applications in the food and pharmaceutical industries (Saberian et al., 2017). As an environmentally friendly technique, OAE aligns with sustainable extraction principles by reducing energy consumption, minimizing solvent waste, and enhancing efficiency (Talha et al., 2024). Unlike conventional acid hydrolysis, which generates chemical waste, OAE provides a cleaner alternative while maintaining high pectin quality (Rownaghi & Niakousari, 2024). Its controlled heating mechanism prevents excessive degradation, resulting in pectin with higher purity and enhanced its functional properties, rendering it appropriate for use in the food, pharmaceuticals, and nutraceuticals (Saberian et al., 2018).

Enzyme-assisted extraction (EAE) is an environmentally friendly technique that employs specific enzymes, such as cellulases, hemicellulases, and pectinases, to hydrolyze plant cell wall components and enhance pectin release (Stanek-Wandzel et al., 2024). Unlike conventional acid hydrolysis, EAE operates under mild conditions, reducing degradation and improving pectin yield and quality (Marić et al., 2018). The efficiency of EAE depends on factors such as enzyme type, concentration, reaction time, pH, and temperature (Dikmetas et al., 2024). Enzymes such as polygalacturonase and pectinesterase directly break down pectin structures, while cellulases and hemicellulases degrade surrounding cell wall components to improve pectin solubilization (Adetunji et al., 2017b). EAE offers several advantages over conventional methods. It enhances pectin yield while preserving its functional properties, making it a sustainable alternative (Nova et al., 2024). The process also reduces energy consumption by operating at lower temperatures, which minimizes equipment corrosion and eliminates the need for waste neutralization (Marić et al., 2018). However, the high cost of enzymes and the complexity of optimizing reaction conditions remain challenges for large-scale implementation (Picot-Allain et al., 2020).

4. APPLICATION OF PECTIN FROM VARIOUS SOURCES ON FRUIT JAMS

Fruit jam is a semi-solid gel produced by cooking fruit, sugar, and pectin to achieve a thick

consistency that holds its shape upon cooling. It typically contains at least 40% fruit and has a sugar content exceeding 65% (Davis, 2023). The European Union Council's 2004/84/EC regulations define jam as a pectin-gelled mixture of sugar, fruit pulp or purée, and water (Javanmard & Endan, 2010). In thermally processed jams, pectin concentrations generally range around 1%, though this may vary depending on national regulations. While no strict limits are imposed on pectin content by food regulatory bodies, high-pressure processed jams have been formulated with pectin concentrations of up to 10% (Dervisi et al., 2001). The interaction between pectin, sugar, and acidity ensures proper gel formation, with fruit fibers enhancing the texture (Javanmard & Endan, 2010).

Low-methoxyl pectin (LMP) forms gels in the presence of calcium ions rather than requiring high sugar concentrations, making it suitable for low-sugar jam formulations. This allows for stable gel formation while maintaining a lower calorie profile, meeting consumer demand for healthier alternatives (Muñoz Almagro et al., 2022). Additionally, LMP interacts with anthocyanin pigments through ionic and hydrogen bonding, stabilizing these compounds and preserving the vibrant colors and bioactive properties of jams. Compared to high-methoxyl pectin (HMP), LMP-based formulations better retain antioxidant compounds such as phenolics and anthocyanins, enhancing both the nutritional value and visual appeal of the final product (Poiana et al., 2013).

Research on pectin derived from various plant sources has highlighted its critical role in determining jam quality, particularly in terms of color, texture, stability, and sensory attributes. Studies show that LMP and low-methoxyl amidated pectin (LMAP) are especially effective in low-sugar and reduced-calorie jams due to their ability to form gels with minimal sugar content when combined with calcium ions (Kopjar et al., 2009; Poiana et al., 2013). These pectins also improve anthocyanin and phenolic retention, ensuring better color stability and antioxidant properties throughout processing and storage (Poiana et al., 2013).

In mango jams, citrus peel-derived pectin enhanced textural consistency and sensory acceptability compared to commercial pectin. The natural pectin provided stronger gel formation and improved total soluble solids (TSS) stability during storage, reinforcing its role in shelf-life extension (Mukhtar et al., 2022). Similarly, sunflower-derived LMP facilitated the formulation of low-sucrose strawberry jams with rheological properties comparable to commercial alternatives, demonstrating its suitability for healthier jam formulations (Muñoz-Almagro et al., 2022).

In pineapple jams, a pectin concentration of 5% resulted in optimal consistency, improved vitamin C retention, and desirable sensory attributes (Chalchisa et al., 2022). Meanwhile, pomegranate peel-derived pectin served as an effective gelling agent, yielding jams with physicochemical and sensory properties comparable to or better than those formulated with commercial pectin (Abid et al., 2018). Additionally, reduced-calorie sorrel jams formulated with LMP achieved the desired gelation and sensory characteristics, underscoring the importance of LMP in developing specialized jam products (Broomes & Badrie, 2014).

5. CONCLUSION

Emerging extraction technologies provide a sustainable approach to utilizing fruit by-products while enhancing pectin recovery for the food industry. This review highlights the advantages of microwave-assisted extraction (MAE), ultrasound-assisted extraction (UAE), ohmic-assisted extraction (OAE), and enzyme-assisted extraction (EAE) over conventional acid extraction,

including higher yield, reduced processing time, and improved sustainability. These methods align with green chemistry principles, minimizing chemical use and supporting circular economy practices. Pectin plays a vital role in fruit jam production by improving texture, stability, and sensory properties. Low-methoxyl pectin (LMP) enables the formulation of low-sugar and reduced-calorie jams while preserving bioactive compounds such as anthocyanins and phenolics. Its functional properties meet growing consumer demand for healthier alternatives. Future research should focus on optimizing these technologies for large-scale applications and exploring new uses for pectin beyond food, including pharmaceuticals and biodegradable packaging. Advancing sustainable extraction methods will enhance food quality, safety, and environmental responsibility.

ACKNOWLEDGEMENT

The authors would like to thank Universiti Putra Malaysia for providing support and facilities for this research through Grant Putra GP-IPS No. GP-IPS/2023/9748700.

REFERENCES

- Abid, M., Yaich, H., Hidouri, H., Attia, H., & Ayadi, M. A. (2018). Effect of substituted gelling agents from pomegranate peel on colour, textural and sensory properties of pomegranate jam. *Food Chemistry*, 239, 1047–1054. <https://doi.org/10.1016/j.foodchem.2017.07.006>
- Adetunji, L. R., Adekunle, A., Orsat, V., & Raghavan, V. (2017). Advances in the pectin production process using novel extraction techniques: A review. *Food Hydrocolloids*, 62, 239–250. <https://doi.org/10.1016/J.FOODHYD.2016.08.015>
- Adimas, M. A., & Abera, B. D. (2023). Valorization of fruit and vegetable by-products for extraction of pectin and its hydrocolloidal role in low-fat yoghurt processing. *LWT*, 189, 115534. <https://doi.org/10.1016/j.lwt.2023.115534>
- Agarwal, C., & Pandey, A. K. (2023). Remediation and recycling of inorganic acids and their green alternatives for sustainable industrial chemical processes. *Environmental Science: Advances*, 2(10), 1306–1339. <https://doi.org/10.1039/D3VA00112A>
- Alam, M., Dar, B. N., & Nanda, V. (2024). Hydrocolloid-based fruit fillings: A comprehensive review on formulation, techno-functional properties, synergistic mechanisms, and applications. *Journal of Texture Studies*, 55(4). <https://doi.org/10.1111/jtxs.12861>
- Anoraga, S. B., Shamsudin, R., Hamzah, M. H., Sharif, S., & Saputro, A. D. (2024). Cocoa by-products: A comprehensive review on potential uses, waste management, and emerging green technologies for cocoa pod husk utilization. *Heliyon*, 10(16), e35537. <https://doi.org/10.1016/j.heliyon.2024.e35537>
- Anoraga, S. B., Shamsudin, R., Hamzah, M. H., Sharif, S., Saputro, A. D., & Basri, M. S. M. (2024). Optimization of subcritical water extraction for pectin extraction from cocoa pod husks using the response surface methodology. *Food Chemistry*, 459(June), 140355. <https://doi.org/10.1016/j.foodchem.2024.140355>
- Arias, D., Rodríguez, J., López, B., & Méndez, P. (2021). Evaluation of the physicochemical properties of pectin extracted from *Musa paradisiaca* banana peels at different pH conditions in the formation of nanoparticles. *Heliyon*, 7(1). <https://doi.org/10.1016/J.HELIYON.2021.E06059>
- Ayele, A., Masi, C., Abda, E. M., & Korsá, G. (2024). Wastes from Fruits and Vegetables Processing Industry for Value-Added Products. In *Value Added Products From Food Waste* (pp. 127–146). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-48143-7_7
- Barba, F. J., Zhu, Z., Koubaa, M., Sant'Ana, A. S., & Orlíen, V. (2016). Green alternative methods for

- the extraction of antioxidant bioactive compounds from winery wastes and by-products: A review. *Trends in Food Science & Technology*, 49, 96–109. <https://doi.org/10.1016/j.tifs.2016.01.006>
- Barrera-Chamorro, L., Fernandez-Prior, Á., Rivero-Pino, F., & Montserrat-de la Paz, S. (2025). A comprehensive review on the functionality and biological relevance of pectin and the use in the food industry. *Carbohydrate Polymers*, 348, 122794. <https://doi.org/10.1016/j.carbpol.2024.122794>
- Belkheiri, A., Forouhar, A., Ursu, A. V., Dubessay, P., Pierre, G., Delattre, C., Djelveh, G., Abdelkafi, S., Hamdami, N., & Michaud, P. (2021a). Extraction, characterization, and applications of pectins from plant by-products. *Applied Sciences (Switzerland)*, 11(14). <https://doi.org/10.3390/app11146596>
- Belkheiri, A., Forouhar, A., Ursu, A. V., Dubessay, P., Pierre, G., Delattre, C., Djelveh, G., Abdelkafi, S., Hamdami, N., & Michaud, P. (2021b). Extraction, Characterization, and Applications of Pectins from Plant By-Products. *Applied Sciences* 2021, Vol. 11, Page 6596, 11(14), 6596. <https://doi.org/10.3390/APP11146596>
- Broomes, J., & Badrie, N. (2014). Effects of Low-Methoxyl Pectin on Physicochemical and Sensory Properties of Reduced-Calorie Sorrel/ Roselle (*Hibiscus sabdariffa* L.) Jams. *The Open Food Science Journal*, 4(1), 48–55. <https://doi.org/10.2174/1874256401004010048>
- Bucur, M.-P., Radulescu, M.-C., Radu, G. L., & Bucur, B. (2023). Cavitation-Effect-Based Treatments and Extractions for Superior Fruit and Milk Valorisation. *Molecules*, 28(12), 4677. <https://doi.org/10.3390/molecules28124677>
- Chalchisa, T., Zegeye, A., Dereje, B., & Tolesa, Y. (2022). Effect of Sugar, Pectin, and Processing Temperature on the Qualities of Pineapple Jam. *International Journal of Fruit Science*, 22(1), 711–724. <https://doi.org/10.1080/15538362.2022.2113598>
- Chandel, V., Biswas, D., Roy, S., Vaidya, D., Verma, A., & Gupta, A. (2022). Current Advancements in Pectin: Extraction, Properties and Multifunctional Applications. *Foods*, 11(17), 2683. <https://doi.org/10.3390/foods11172683>
- Cheriyān, B. V., Karunakar, K. K., Anandakumar, R., Murugathirumal, A., & Kumar, A. S. (2025). Eco-friendly extraction technologies: A comprehensive review of modern green analytical methods. *Sustainable Chemistry for Climate Action*, 6, 100054. <https://doi.org/10.1016/j.scca.2024.100054>
- Das, I., & Arora, A. (2021). Kinetics and mechanistic models of solid-liquid extraction of pectin using advance green techniques- a review. *Food Hydrocolloids*, 120(February), 106931. <https://doi.org/10.1016/j.foodhyd.2021.106931>
- Davis, M. (2023). Fruits Jams: Food and Agriculture Organization of the United Nations. *Encyclopedia of Toxicology, Fourth Edition: Volume 1-9*, 4, V4-769-V4-772. <https://doi.org/10.1016/B978-0-12-824315-2.00835-6>
- De Laet, E., Bernaerts, T., Mikhalski, M., & Van Loey, A. M. (2024). Kinetic study of a conventional and ultrasound-assisted extraction of pectin from different plant-based side streams: Impact on pectin extraction yield, purity and molecular pectin structure. *LWT*, 205, 116522. <https://doi.org/10.1016/j.lwt.2024.116522>
- Dervisi, P., Lamb, J., & Zabetakis, I. (2001). High pressure processing in jam manufacture: effects on textural and colour properties. *Food Chemistry*, 73(1), 85–91. [https://doi.org/10.1016/S0308-8146\(00\)00289-2](https://doi.org/10.1016/S0308-8146(00)00289-2)
- Dikmetas, D. N., Devecioglu, D., Özunal, Z. G., Demiroz, A., Yavuz, E., Sirkeci, C. B., Karbancioglu-Guler, F., & Kahveci, D. (2024). From waste to remedy: Extraction and utilization of food waste-derived bioactive components in wound healing. *Trends in Food Science & Technology*, 145, 104347. <https://doi.org/10.1016/j.tifs.2024.104347>
- Garg, S., Ghosh, P., Rana, S. S., & Pradhan, R. C. (2019). Preparation and Quality Evaluation of Nutritionally Enriched Jam Made from Blends of Indian Blackberry and Other Fruits.

- International Journal of Fruit Science*, 19(1), 29–44. <https://doi.org/10.1080/15538362.2018.1536872>
- Gavahian, M., Chu, Y. H., & Farahnaky, A. (2019). Effects of ohmic and microwave cooking on textural softening and physical properties of rice. *Journal of Food Engineering*, 243, 114–124. <https://doi.org/10.1016/J.JFOODENG.2018.09.010>
- Gavahian, M., Mathad, G. N., Pandiselvam, R., Lin, J., & Sun, D. W. (2021). Emerging technologies to obtain pectin from food processing by-products: A strategy for enhancing resource efficiency. *Trends in Food Science & Technology*, 115, 42–54. <https://doi.org/10.1016/J.TIFS.2021.06.018>
- Goksu, A., Duran, G., Çilingir, S., Çevik, M., & Sabanci, S. (2022). Performance evaluation of pectin extraction from grapefruit peel powder by ohmic heating. *Journal of Food Processing and Preservation*, 46(10). <https://doi.org/10.1111/jfpp.16813>
- Gumustepe, L., Kurt, N., Aydın, E., & Ozkan, G. (2023). Comparison of ohmic heating and microwave assisted extraction techniques for avocado leaves valorization: Optimization and impact on the phenolic compounds and bioactivities. *Food Science & Nutrition*, 11(9), 5609–5620. <https://doi.org/10.1002/fsn3.3556>
- Hassanloofard, Z., Zandi, M., Gharekhan, M., Ganjloo, A., & Roufegarinejad, L. (2024). Novel Green Method for Enhancing the Extraction Efficiency of Bioactive Compounds: Falcaria vulgaris Extract. *Journal of Food Biochemistry*, 2024(1). <https://doi.org/10.1155/2024/9974099>
- Hennessey-Ramos, L., Murillo-Arango, W., Vasco-Correa, J., & Astudillo, I. C. P. (2021). Enzymatic Extraction and Characterization of Pectin from Cocoa Pod Husks (*Theobroma cacao* L.) Using Celluclast® 1.5 L. *Molecules*, 26(5). <https://doi.org/10.3390/MOLECULES26051473>
- Javanmard, M., & Endan, J. (2010). A Survey on Rheological Properties of Fruit Jams. *International Journal of Chemical Engineering and Applications*, 31–37. <https://doi.org/10.7763/IJCEA.2010.V1.6>
- Khubber, S., Chaturvedi, K., Thakur, N., Sharma, N., & Yadav, S. K. (2021). Low-methoxyl pectin stabilizes low-fat set yoghurt and improves their physicochemical properties, rheology, microstructure and sensory liking. *Food Hydrocolloids*, 111, 106240. <https://doi.org/10.1016/J.FOODHYD.2020.106240>
- Kopjar, M., Piližota, V., Tiban, N. N., Šubarić, D., Babić, J., Ačkar, D., & Sajdl, M. (2009). Strawberry jams: Influence of different pectins on colour and textural properties. *Czech Journal of Food Sciences*, 27(1), 20–28. <https://doi.org/10.17221/95/2008-cjfs>
- Kumar, M., Tomar, M., Saurabh, V., Mahajan, T., Punia, S., Contreras, M. del M., Rudra, S. G., Kaur, C., & Kennedy, J. F. (2020). Emerging trends in pectin extraction and its anti-microbial functionalization using natural bioactives for application in food packaging. *Trends in Food Science and Technology*, 105(June), 223–237. <https://doi.org/10.1016/j.tifs.2020.09.009>
- Lara-Espinoza, C., Carvajal-Millán, E., Balandrán-Quintana, R., López-Franco, Y., & Rascón-Chu, A. (2018). Pectin and Pectin-Based Composite Materials: Beyond Food Texture. *Molecules*, 23(4), 942. <https://doi.org/10.3390/molecules23040942>
- Liew, S. Q., Ngoh, G. C., Yusoff, R., & Teoh, W. H. (2016). Sequential ultrasound-microwave assisted acid extraction (UMAE) of pectin from pomelo peels. *International Journal of Biological Macromolecules*, 93, 426–435. <https://doi.org/10.1016/J.IJBIOMAC.2016.08.065>
- Ling Wen Xia, F., Supri, S., Djamaludin, H., Nurdiani, R., Leong Seng, L., Wee Yin, K., & Rovina, K. (2024). Turning waste into value: Extraction and effective valorization strategies of seafood by-products. *Waste Management Bulletin*, 2(3), 84–100. <https://doi.org/10.1016/j.wmb.2024.06.008>
- Maran, J. P., Priya, B., Al-Dhabi, N. A., Ponmurugan, K., Moorthy, I. G., & Sivarajasekar, N. (2017). Ultrasound assisted citric acid mediated pectin extraction from industrial waste of

- Musa balbisiana. *Ultrasonics Sonochemistry*, 35, 204–209. <https://doi.org/10.1016/j.ultsonch.2016.09.019>
- Marić, M., Grassino, A. N., Zhu, Z., Barba, F. J., Brnčić, M., & Rimac Brnčić, S. (2018). An overview of the traditional and innovative approaches for pectin extraction from plant food wastes and by-products: Ultrasound-, microwaves-, and enzyme-assisted extraction. *Trends in Food Science & Technology*, 76, 28–37. <https://doi.org/10.1016/J.TIFS.2018.03.022>
- Mierczyńska, J., Cybulska, J., Pieczywek, P. M., & Zdunek, A. (2015). Effect of Storage on Rheology of Water-Soluble, Chelate-Soluble and Diluted Alkali-Soluble Pectin in Carrot Cell Walls. *Food and Bioprocess Technology*, 8(1), 171–180. <https://doi.org/10.1007/s11947-014-1392-9>
- Minjares-Fuentes, R., Femenia, A., Garau, M. C., Meza-Velázquez, J. A., Simal, S., & Rosselló, C. (2014). Ultrasound-assisted extraction of pectins from grape pomace using citric acid: A response surface methodology approach. *Carbohydrate Polymers*, 106, 179–189. <https://doi.org/10.1016/j.carbpol.2014.02.013>
- Moreira, M. N. de L., Moreira, F. K. V., & Prata, A. S. (2024). Effect of adding micronized eggshell waste particles on the properties of biodegradable pectin/starch films. *Journal of Cleaner Production*, 434, 140229. <https://doi.org/10.1016/j.jclepro.2023.140229>
- Mukhtar, S., Mohamed, H. I., Qazi, I. M., Basit, A., Javed, H., Shah, S. T., Ibrahim, A., Aziz, I., Ali, F., & Kaleemullah. (2022). Impact of pectin extracted from selected citrus fruit peel on overall quality of mango jam. *Journal of Food Measurement and Characterization*, 16(6), 4847–4859. <https://doi.org/10.1007/s11694-022-01576-y>
- Mumtaz, S., Rana, J. N., Choi, E. H., & Han, I. (2022). Microwave Radiation and the Brain: Mechanisms, Current Status, and Future Prospects. *International Journal of Molecular Sciences*, 23(16), 9288. <https://doi.org/10.3390/ijms23169288>
- Muñoz Almagro, N., Garrido Galand, S., Taladrid, D., Moreno Arribas, M. V., Villamiel, M., & Montilla, A. (2022). Use of natural low methoxyl pectin from sunflower by products for the formulation of low sucrose strawberry jams. *Journal of the Science of Food and Agriculture*, 102(13), 5957–5964. <https://doi.org/10.1002/jsfa.11948>
- Nirmal, N., Khanashyam, A., Mundanat, A., Shah, K., Babu, K., Thorakkattu, P., Al-Asmari, F., & Pandiselvam, R. (2023). Valorization of Fruit Waste for Bioactive Compounds and Their Applications in the Food Industry. *Foods*, 12(3), 556. <https://doi.org/10.3390/foods12030556>
- Nova, P., Cunha, S. A., Costa-Pinto, A. R., & Gomes, A. M. (2024). Chemical and Antioxidant Properties of Solvent and Enzyme-Assisted Extracts of *Fucus vesiculosus* and *Porphyra dioica*. *Marine Drugs*, 22(7), 319. <https://doi.org/10.3390/md22070319>
- Pancerz, M., Kruk, J., Łukasiewicz, M., Witek, M., Kucharek, M., Jaschik, J., & Ptaszek, A. (2021). Red currant pectin: The physicochemical characteristic of pectin solutions in dilute and semi dilute regimes. *Food Hydrocolloids*, 113, 106420. <https://doi.org/10.1016/j.foodhyd.2020.106420>
- Picot-Allain, M. C. N., Ramasawmy, B., & Emmambux, M. N. (2020). Extraction, Characterisation, and Application of Pectin from Tropical and Sub-Tropical Fruits: A Review. *Food reviews international*, 38(3), 282–312. <https://doi.org/10.1080/87559129.2020.1733008>
- Poiana, M.-A., Munteanu, M.-F., Bordean, D.-M., Gligor, R., & Alexa, E. (2013). Assessing the effects of different pectins addition on color quality and antioxidant properties of blackberry jam. *Chemistry Central Journal*, 7(1), 121. <https://doi.org/10.1186/1752-153X-7-121>
- Prokic, D., Stepanov, J., Curcic, L., Stojic, N., & Pucarevic, M. (2022). The role of circular economy in food waste management in fulfilling the United Nations' sustainable development goals. *Acta Universitatis Sapientiae, Alimentaria*, 15(1), 51–66. <https://doi.org/10.2478/ausal-2022-0005>
- Raji, Z., Khodaiyan, F., Rezaei, K., Kiani, H., & Hosseini, S. S. (2017). Extraction optimization and physicochemical properties of pectin from melon peel. *International Journal of*

- Biological Macromolecules*, 98, 709–716. <https://doi.org/10.1016/j.ijbiomac.2017.01.146>
- Rawat, S., Pavithra, T., & Sunil, C. K. (2024). Citrus byproduct valorization: pectin extraction, characterization, and research advances in biomaterial derivation for applications in active film packaging. *Discover Food*, 4(1), 149. <https://doi.org/10.1007/s44187-024-00238-w>
- Ridley, B. L., O'Neill, M. A., & Mohnen, D. (2001). Pectins: structure, biosynthesis, and oligogalacturonide-related signaling. *Phytochemistry*, 57(6), 929–967. [https://doi.org/10.1016/S0031-9422\(01\)00113-3](https://doi.org/10.1016/S0031-9422(01)00113-3)
- Ritika, Rizwana, Shukla, S., Sondhi, A., Tripathi, A. D., Lee, J.-K., Patel, S. K. S., & Agarwal, A. (2024). Valorisation of fruit waste for harnessing the bioactive compounds and its therapeutic application. *Trends in Food Science & Technology*, 144, 104302. <https://doi.org/10.1016/j.tifs.2023.104302>
- Roman-Benn, A., Contador, C. A., Li, M.-W., Lam, H.-M., Ah-Hen, K., Ulloa, P. E., & Ravanal, M. C. (2023). Pectin: An overview of sources, extraction and applications in food products, biomedical, pharmaceutical and environmental issues. *Food Chemistry Advances*, 2, 100192. <https://doi.org/10.1016/j.focha.2023.100192>
- Rownaghi, M., & Niakousari, M. (2024). Assessing physicochemical characteristics of a shear-thinning polysaccharide mucilage extracted from marshmallow root (*Althaea officinalis* L.) by an ohmic heating system. *International Journal of Biological Macromolecules*, 277, 134274. <https://doi.org/10.1016/j.ijbiomac.2024.134274>
- Saberian, H., Hamidi-Esfahani, Z., Ahmadi Gavlighi, H., & Barzegar, M. (2017). Optimization of pectin extraction from orange juice waste assisted by ohmic heating. *Chemical Engineering and Processing: Process Intensification*, 117(September 2016), 154–161. <https://doi.org/10.1016/j.cep.2017.03.025>
- Said, N. S., Olawuyi, I. F., & Lee, W. Y. (2023). Pectin Hydrogels: Gel-Forming Behaviors, Mechanisms, and Food Applications. *Gels*, 9(9), 732. <https://doi.org/10.3390/gels9090732>
- Satapathy, S., Rout, J. R., Kerry, R. G., Thatoi, H., & Sahoo, S. L. (2020). Biochemical Prospects of Various Microbial Pectinase and Pectin: An Approachable Concept in Pharmaceutical Bioprocessing. *Frontiers in Nutrition*, 7. <https://doi.org/10.3389/fnut.2020.00117>
- Seixas, F. L., Fukuda, D. L., Turbiani, F. R. B., Garcia, P. S., Petkowicz, C. L. de O., Jagadevan, S., & Gimenes, M. L. (2014). Extraction of pectin from passion fruit peel (*Passiflora edulis* f. *flavicarpa*) by microwave-induced heating. *Food Hydrocolloids*, 38, 186–192. <https://doi.org/10.1016/j.foodhyd.2013.12.001>
- Sharma, P., Osama, K., Gaur, V. K., Farooqui, A., Varjani, S., & Younis, K. (2022). Sustainable utilization of Citrus limetta peel for obtaining pectin and its application in cookies as a fat replacer. *Journal of Food Science and Technology*. <https://doi.org/10.1007/s13197-022-05424-1>
- Shen, C., Chen, W., Aziz, T., Khojah, E., Al-Asmari, F., Alamri, A. S., Alhomrani, M., Cui, H., & Lin, L. (2024). Drying kinetics and moisture migration mechanism of yam slices by cold plasma pretreatment combined with far-infrared drying. *Innovative Food Science & Emerging Technologies*, 95, 103730. <https://doi.org/10.1016/j.ifset.2024.103730>
- Soomro, M. A., Khan, S., Majid, A., Bhatti, S., Perveen, S., & Phull, A. R. (2024). Pectin as a biofunctional food: comprehensive overview of its therapeutic effects and antidiabetic-associated mechanisms. *Discover Applied Sciences*, 6(6), 298. <https://doi.org/10.1007/s42452-024-05968-1>
- Stanek-Wandzel, N., Krzyszowska, A., Zarębska, M., Gębura, K., Wasilewski, T., Hordyjewicz-Baran, Z., & Tomaka, M. (2024). Evaluation of Cellulase, Pectinase, and Hemicellulase Effectiveness in Extraction of Phenolic Compounds from Grape Pomace. *International Journal of Molecular Sciences*, 25(24), 13538. <https://doi.org/10.3390/ijms252413538>

- Suleiman, J., Shamsudin, R., Hamzah, M. H., Basri, M. S. M., & Jimoh, K. A. (2025). Extraction optimization and characterization of durian (*Durio zibethinus*) rind pectin extracted by subcritical water. *Food Chemistry*, 474(January), 143123. <https://doi.org/10.1016/j.foodchem.2025.143123>
- Sundarraaj, A. A., & Ranganathan, T. V. (2017). A Review-Pectin from Agro and Industrial Waste. *International Journal of Applied Environmental Sciences*, 12(10), 1777–1801. <http://www.ripublication.com>
- Talha, M., Khalid, S., Maan, A. A., Tanveer, N., Khan, M. K. I., Asif, M., Arif, S., & Sarwar, A. (2024). Ohmic assisted extraction: a sustainable and environment friendly approach to substitute conventional extraction methods. *Food Reviews International*, 40(10), 3508–3529. <https://doi.org/10.1080/87559129.2024.2366841>
- Tomé Constantino, A. B., & Garcia-Rojas, E. E. (2020). Modifications of physicochemical and functional properties of amaranth protein isolate (*Amaranthus cruentus* BRS Alegria) treated with high-intensity ultrasound. *Journal of Cereal Science*, 95, 103076. <https://doi.org/10.1016/j.jcs.2020.103076>
- Torres-Gallo, R., Bayuelo-Bonilla, S., Carpio-Ortiz, L., Barreto-Rodríguez, G., & Tirado, D. F. (2022). High-Intensity Ultrasound-Assisted Extraction of Pectin from Mango Wastes at Different Maturity. *International Journal of Food Science*, 2022, 1–7. <https://doi.org/10.1155/2022/4606024>
- Vieira, D. R. R., da Silva, V. R., & Spier, M. R. (2024). Extraction of high methoxyl pectin from unripe waste Ponkan mandarine (*Citrus reticulata* Blanco cv. Ponkan) with an eco-friendly solvent. *International Journal of Biological Macromolecules*, 258, 128663. <https://doi.org/10.1016/j.ijbiomac.2023.128663>
- Voragen, A. G. J., Coenen, G. J., Verhoef, R. P., & Schols, H. A. (2009). Pectin, a versatile polysaccharide present in plant cell walls. *Structural Chemistry*, 20(2), 263–275. <https://doi.org/10.1007/S11224-009-9442-Z/TABLES/1>
- Wang, W., Ma, X., Jiang, P., Hu, L., Zhi, Z., Chen, J., Ding, T., Ye, X., & Liu, D. (2016). Characterization of pectin from grapefruit peel: A comparison of ultrasound-assisted and conventional heating extractions. *Food Hydrocolloids*, 61, 730–739. <https://doi.org/10.1016/j.foodhyd.2016.06.019>
- Wongkaew, M., Sommano, S. R., Tangpao, T., Rachtanapun, P., & Jantanasakulwong, K. (2020). Mango Peel Pectin by Microwave-Assisted Extraction and Its Use as Fat Replacement in Dried Chinese Sausage. *Foods*, 9(4), 450. <https://doi.org/10.3390/foods9040450>
- Zahari, N. A. A. R., Chong, G. H., Abdullah, L. C., & Chua, B. L. (2020). Ultrasonic-Assisted Extraction (UAE) Process on Thymol Concentration from *Plectranthus Amboinicus* Leaves: Kinetic Modeling and Optimization. *Processes*, 8(3), 322. <https://doi.org/10.3390/pr8030322>
- Zhang, X., Chen, X., Dai, J., Cui, H., & Lin, L. (2024). Edible films of pectin extracted from dragon fruit peel: Effects of boiling water treatment on pectin and film properties. *Food Hydrocolloids*, 147, 109324. <https://doi.org/10.1016/j.foodhyd.2023.109324>

ADVANCING VALUE-ADDED PRODUCTS FROM DRAGON FRUIT: A STUDY ON PROCESSING AND APPLICATIONS

Than Thi Huong¹, Tran Thi Dinh^{1*}, Maarten L.A.T.M. Hertog², Bart Nicolai^{2,3}, Koen Dewettinck⁴

¹Vietnam National University of Agriculture, Faculty of Food Science and Technology, Hanoi, Vietnam

²KU Leuven, BIOSYST-MeBioS, B-3001 Leuven, Belgium

³Flanders Centre of Postharvest Technology, B-3001 Leuven, Belgium.

⁴Department of Food Technology, Safety and Health, Ghent University, Ghent, Belgium

ttdinh@vnua.edu.vn

Vietnam, as a leading producer of dragon fruit, faces significant challenges in postharvest losses, quality degradation, and sustainability. Developing value-added products from dragon fruit presents an effective solution to these issues while meeting growing consumer demand for health-oriented and innovative food products. This study investigated the potential of dragon fruit as a raw material for value-added products, focusing on white-fleshed dragon fruit wine, red-fleshed dragon fruit jam, and soy yogurt enriched with fruit jam. By optimizing production processes and ingredient formulations, this research demonstrates the potential to improve product quality, increase economic value, and promote sustainability in the dragon fruit industry in Vietnam.

Keywords: Processing technology; dragon fruit wine; fruit jam; soy yogurt.

1. INTRODUCTION

Vietnam is one of the world's leading producers of dragon fruit, with an annual output of approximately 1.2 million tons. Despite this, the country faces significant challenges, including high postharvest losses, quality degradation, and sustainability concerns. These losses not only reduce market supply, leading to higher prices, but also have significant social and environmental impacts, as resources like labor, water, land, and energy are used to produce, process, and transport fruits that are not consumed. Addressing these challenges is critical for ensuring the long-term viability of Vietnam's dragon fruit industry.

Developing value-added products from dragon fruit offers a promising solution to reduce postharvest losses and promote sustainable production. Dragon fruit, with its attractive color, high nutritional values, and antioxidant properties, is an excellent raw material for the food processing industry (Le Bellec et al., 2006; Sabbe et al., 2009). It has been widely utilized in products such as sweets, ice cream, pastries, wine demonstrating its versatility and appeal to health-conscious consumers (Gunaseena et al., 2007).

This study focuses on the development of innovative dragon fruit-based products, including white-fleshed dragon fruit wine, red-fleshed dragon fruit jam, and soy yogurt enhanced with dragon fruit jam. White-fleshed dragon fruit wine is a novel product that combines a distinctive flavor profile with the efficient use of lower-grade fruits, reducing postharvest losses and increasing economic value. Similarly, red-fleshed dragon fruit jam responds to the growing demand for functional and health-focused foods. Its nutrient-rich composition and appealing characteristics make it a versatile ingredient for various culinary applications. Soy yogurt, a popular plant-based product, offers numerous nutritional benefits, including enhanced

absorption of isoflavones and antioxidants, improved flavor, and increased nutritional value compared to soy milk (Chien et al., 2007; Weng et al., 2023). As there is growing in consumer interest in plant-based diets, soy yogurt has gained broader acceptance and market potential, particularly in the Asia-Pacific region. Combining soy yogurt with dragon fruit jam presents an opportunity to create a unique, nutritionally enriched product with improved sensory attributes, aligning with evolving consumer preferences (Santos et al., 2014). These products aim to address consumer demand for unique, health-oriented, and sustainable food options while diversifying the applications of dragon fruit in the market, contributing to the sustainable development of Vietnam’s agriculture industry.

2. MATERIALS AND METHODOLOGY

2.1. Materials

White dragon fruits and assam apple for making wine, red dragon fruit, apple and passion fruit for making jam were grown in the Northern areas in Vietnam.

For making wine, two commercial yeast strains Oenoferm® Freddo and Oenoferm®Veltliner were cultured for fermentation.

2.2. Experimental design

2.2.1. Effects of some technological factors on dragon fruit wine quality

This study investigated the effects of dragon fruit and apple juice mixtures, yeast type, and final sugar content on wine quality, as outlined in Table 1. The process began with extracting juice from white dragon fruit and assam apple, followed by enzymatic treatment with pectinase and cellulase to enhance yield. The juice was filtered, blended in specific ratios, and adjusted to 24% soluble solids content (SSC) with sucrose. To prevent spoilage and oxidation, the must was mildly pasteurized. Activated yeast strains were added to the cooled must for a two-stage fermentation. The first stage occurred at 15°C until the desired sugar level was reached, followed by a second stage at 5°C to stabilize quality. After fermentation, the wine was vacuum-filtered and bottled. Main parameters, including SSC, sugar content, acidity, alcohol content, total polyphenols, and antioxidant capacity, were monitored throughout fermentation, and sensory quality was assessed on the final product.

Table 1. Experimental design for factors influencing fermentation of dragon fruit wine

Treatment	Dragon fruit juice (%)	Asssam apple juice (%)	Final sugar content (%)	Yeast type
T1	70	30	3	Oenoferm Freddo
T2	70	30	0	Oenoferm Veltliner
T3	80	20	3	Oenoferm Freddo
T4	80	20	1.5	Oenoferm Veltliner
T5	90	10	3	Oenoferm Freddo
T6	90	10	0	Oenoferm Veltliner

2.2.2. Effects of ingredients, acidity, and SSC on the quality of dragon fruit jam

This study optimized the mixture of dragon fruit, apple, and passion fruit, along with acidity and SSC levels in the final jam product, as indicated in Table 2 and Table 3. To prepare the jam, red dragon fruit, apple, and passion fruit were processed into puree and juice. The fruit pulps were blended in specified ratios, mixed with sugar at a 70%:30% puree-to-sugar ratio, and combined with citric acid and 0.7% pectin. The mixture was concentrated at 70°C to achieve the desired SSC, then packaged and pasteurized at 85°C for 15 min. The optimal jam formulation was determined by assessing acidity, betacyanin content, and sensory quality.

Table 2. Experimental design for determining optimal ingredients for jam

Treatment	Dragon fruit juice (%)	Apple juice (%)	Passion fruit juice (%)
T7	100	0	0
T8	70	10	20
T9	70	20	10
T10	80	0	20
T11	80	20	0
T12	80	10	10
T13	90	0	10
T14	90	10	0

Table 3. Experimental design for determining optimal acid addition and SSC of jam

Treatment	Acid addition (%)	SSC (%)
T15	0.6	45
T16	0.5	40
T17	0.6	45
T18	0.5	50
T19	0.7	40
T20	0.7	50

2.2.3. Effects of fruit jam addition on quality of soy yogurt

After optimizing dragon fruit jam production, varying levels of jam (5%, 10%, 15%, and 20%) were incorporated into soy yogurt to enhance its quality. The preparation of soy yogurt involved soaking soybeans in water (26–28°C) for 3 h, blanching at 85°C for 5 min, and grinding with water (1:6 ratio) at 80°C. The resulting soy milk was filtered, sucrose added to reach SSC of 16%, homogenized, and pasteurized at 90°C for 10 min. After cooling, it was inoculated with lactic acid bacteria, packaged, and fermented at 43°C for 8 h. The yogurt was then stabilized at 4°C for 12 h. A 15% layer of dragon fruit jam was added on top, and the final product was refrigerated until consumption. Sensory and nutritional evaluations were conducted to determine the optimal jam addition level.

2.3. Analytical methods

2.3.1. Soluble solids content

SSC was determined using a digital refractometer (Atago Co., Ltd, Tokyo, Japan).

2.3.2. Sugar content

The sugar content was measured using DNS method described by King et al (2001).

2.3.3. Titratable acidity

Titrate acidity was determined by titrating the solutions with 0.1 N NaOH (Merck Millipore, Darmstadt, Germany) using an Orion pH meter to the endpoint of 8.2. Titratable acidity was converted to malic acid equivalent.

2.3.4. Total phenolic content

Total phenolic content (TPC) was determined spectrophotometrically by Folin-Ciocalteu's reagent according to the method of Lim et al. (2007).

2.3.5. Antioxidant capacity

Antioxidant capacity was determined by the DPPH free radical scavenging assay. Trolox was used as standard. Scavenging activity on DPPH free radicals by must and wine was measured according to the method of Tarbart et al (2009).

2.3.6. Alcohol content

The alcohol content in sample was determined from the difference between the water and must or wine boiling points by using an ebulliometer (Dujardin-Salleron, France).

2.3.7. Betacyanin content

Betacyanins contents in wine was determined using a spectrophotometric analysis as method described by Herbach et al. (2007).

2.3.8. Nutritional composition analysis

The protein, lipid, and carbohydrate content in the soy yogurt were determined according to TCVN (Vietnamese Standards) procedures. Protein content was determined using the Kjeldahl method as described in TCVN 8125:2015. Total carbohydrate content was determined according to TCVN 7033:2002. Lipid content was determined following the procedure outlined in TCVN 6688-3:2000.

2.3.9. Sensory evaluation

A preference test was used to evaluate the sensory quality of the final wine, jam and soy yogurt. The samples were evaluated by 60 panellists using a 9-point Hedonic scale (1 = dislike extremely and 9 = like extremely).

A ranking test was conducted to differentiate within dragon fruit jam samples and soy yogurt flavored with dragon fruit jam samples. Panelists were asked to rank the samples based on specific attributes: overall quality for the jam, and texture, color, flavor, and overall quality for the soy yogurt. They were instructed to taste each sample and rank them in ascending order for each attribute, from the most preferred (highest number) to the least preferred (least number), corresponding to the number of samples provided.

2.4. Data analysis

Statistical differences among treatments were estimated from the ANOVA test at the 5% level of significance for all parameters evaluated. The differences between means were determined by Tukey's multiple comparison test. Sensory attributes were evaluated by calculating the average ranking score for each experimental formulation, and differences in ranking scores were assessed using the Friedman test with a significance level of $P = 0.05$.

3. RESULTS AND DISCUSSION

3.1. Changes of wine quality attributes during fermentation

Changes of wine quality attributes during fermentation are shown in Figures 1 A-F. The SSC of all treatments decreased significantly during fermentation, particularly in the early stages (Figure 1A). The treatments with Oenoferm Vetliner yeast (T2, T4, T6) showed a faster decline in SSC compared to those fermented with Oenoferm Freddo yeast (T1, T3, T5). This suggests that Oenoferm Vetliner was more effective in utilizing nutrients in the must. Furthermore, the SSC reduction was slower in treatments with 70%:30% and 80%:20% juice ratios (dragon fruit:assam apple), indicating that these ratios provided more favorable fermentation conditions. The rapid decrease in SSC during the main fermentation stage is attributed to the active growth and metabolism of yeast at the optimal temperature (15°C). The slowdown in SSC reduction during the secondary fermentation stage (5°C) is likely due to the exhaustion of nutrients and the lower temperature inhibiting yeast activity.

Sugars are the substrates of fermentation, during this process, sugars are transformed into alcohol and other compounds by yeast. Sugar content is an important parameter, its value determined the time of fermentation, type of wine, as well as the potential alcohol. As expected, the sugar concentration decreased as fermentation progressed in agreement with the fall in SSC (Figure 1B). In the first two days, sugar reduction was slow due to yeast adaptation to the juice environment. However, in the subsequent ten days, sugar levels dropped rapidly, particularly in the T4 treatment, where the sugar content decreased from 20.9% to 6.4%. The sugar reduction slowed down during the secondary fermentation phase. The sugar concentration in the final products was adjusted according to experiment design by controlling fermentation time and temperature fermentation. The residual sugar in treatments T1, T3, T5 were 3% and that in treatment T4 was 1.5%. The treatments T2 and T6 had no sugar residue.

The alcohol content increased along the fermentation as yeast converted sugar into alcohol. All treatments reached alcohol content between 14.5% and 15.6% after 60 days of fermentation (Figure 1C). According to Kosseva (2015), the amount of alcohol in fruit wine usually ranges from 5% to 15%. Therefore, the alcohol contents of the wines in this experiment were favourable for consumption. Compared to the results of Nguyen Phuoc Minh (2014) who also studied on production of wine from red dragon fruit, the alcohol levels in this experiment were higher.

Acidity is an important indicator that has a great influence on the taste and quality of the finished wine. Changes of acidity are shown in Figure 1D indicated that acidity increased slightly during fermentation due to the production of organic acids as byproducts of yeast metabolism. At the end of fermentation, T1 and T2 treatments had the highest acidity, reaching 0.68%, while T6 treatment had the lowest acidity, about 0.54%. The increase was generally observed in the initial days of the main fermentation stage and stabilized during the secondary fermentation. This pattern is explained by the abundance of nutrients and lower alcohol concentration in the early stages, promoting acid production.

The total phenol content of dragon fruit wine in this study ranged from 320 to 740 mg GAE/L, with treatments containing a higher proportion of Assam apple juice (T1, T2) exhibiting the highest total polyphenol levels (Figure 1E). This indicates that these juice mixtures serve as substantial sources of polyphenols. However, these values were relatively lower in comparison with the other published research which shown a great variation in the total phenolic values of berry wines that range between 592 and 2651 mg GAE/L. (Kosseva, 2016). It was also observed that the total polyphenol content decreased during fermentation, particularly in the final stage. This decline can be attributed to the degradation of phenolic compounds, their interactions with other wine components such as proteins, and oxidation reactions. Such a reduction may affect the wine's bitterness, astringency, and antioxidant properties.

Antioxidant capacity showed an initial increase, peaking around day 10, followed by a gradual decrease throughout the fermentation process (Figure 1F) The decrease in antioxidant capacity aligns with the reduction in total polyphenol content, as polyphenols are major contributors to the antioxidant properties of wine. However, other substances like organic acids and vitamins also contribute to the antioxidant capacity.

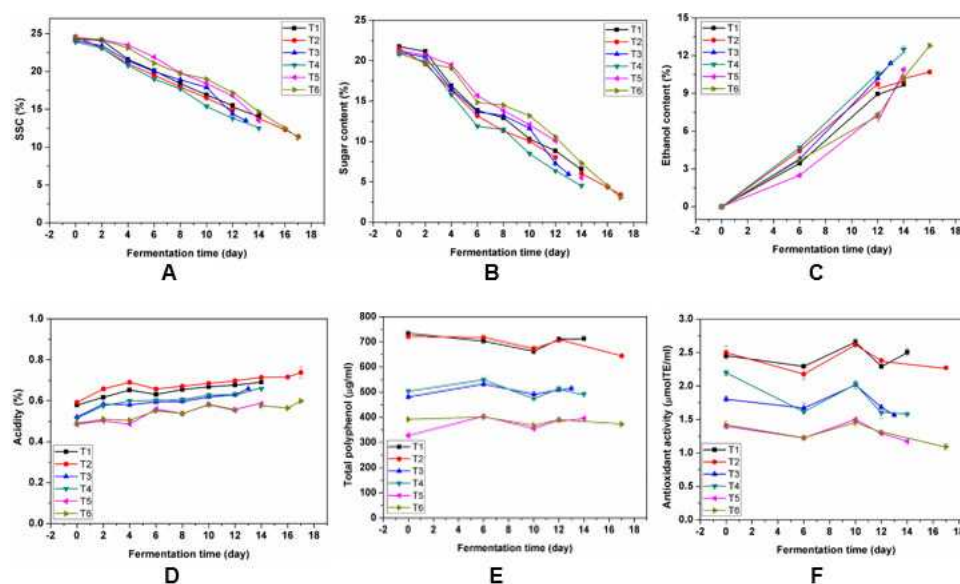


Figure 1. Changes of SSC (A), sugar content (B), ethanol content (C), acidity (D), total polyphenol content (E), and antioxidant activity (F) during wine fermentation

Sensory evaluation was conducted to assess consumer preferences for the wine quality. A panel of 60 individuals evaluated the wine using a 9-point Hedonic scale, rating overall quality of wines. The highest sensory scores were obtained for T3 (7.08), which used 80% dragon fruit juice and 20% assam apple juice, fermented with Oenoferm Freddo yeast and a final sugar

content of 3%. T2 received the lowest sensory scores, highlighting the significant impact of yeast strain and residual sugar content on wine quality. The Oenoferm Freddo yeast produced wines of better sensory quality compared to Oenoferm Vetliner (Figure 2).

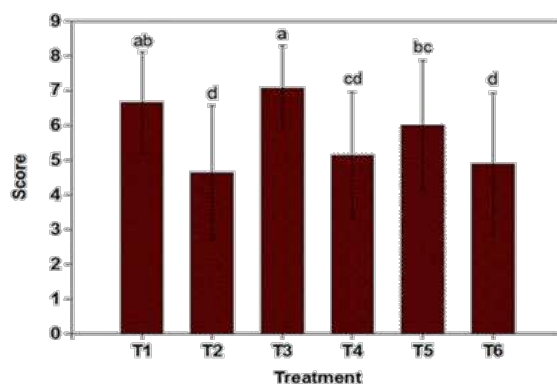


Figure 2. Sensory evaluation on overall quality of dragon fruit wine

3.2. Development of dragon fruit jam flavoring with apple and passion fruit

Another option to transform fresh dragon fruit into highly added value product is to making fruit jam. Therefore, in this study, we optimized the formulation of dragon fruit jam by investigating the impact of fruit ratios, acid addition, and total soluble solids content on its quality.

Different jam formulation were prepared by mixing different ratios of dragon fruit, apple, and passion fruit according to the experimental design. The results presented in Table 4 indicate that the ratio of dragon fruit, apple, and passion fruit significantly influenced both the sensory quality and the betacyanin content, a compound with high antioxidant activity, in the jam. Formulations containing 10-20% passion fruit received higher sensory ratings compared to those without this fruit. Among the tested formulations, the ratio of 70%:20%:10% (dragon fruit:apple:passion fruit) achieved the highest sensory score of 5.4. Conversely, formulations lacking passion fruit or with minimal apple content scored lower; for instance, the 90%:10%:0% (dragon fruit:apple:passion fruit) formulation received the lowest sensory score of 3.91. Notably, the inclusion of apple improved the sensory score, highlighting the positive impact of both passion fruit and apple on the product’s flavor. Thus, the 70%:20%:10% (dragon fruit:apple:passion fruit) ratio is considered the most favorable for jam production.

Table 4. Quality of dragon fruit jam with different fruit mixing ratios

Treatment	Average ranking score
T7	4.6
T8	5.4
T9	4.6
T10	4.2
T11	4.0
T12	4.97
T13	4.65
T14	3.91

Note: The sensory score column of the ranking test shows the consumer preference for the jam: the highest sensory score means the most preferred, and the higher the sensory score, the greater the preference (maximum is 8 points corresponding to 8 samples).

In addition to the suitable fruit blending ratio, the balance of sweetness and acidity in the jam significantly influences consumer preference. The results of the jam's quality assessment, considering acid addition and final SSC, are presented in Table 5. It is clearly observed that acid addition and final SSC significantly influenced the quality of the finished jam at a significance level of $\alpha = 0.05$. While a lower SSC of 40% initially showed promise, it resulted in inadequate gelling and was deemed unsuitable. An SSC of 50% enhanced sweetness and preserved betacyanin content but was considered too sweet for modern consumer preferences. The formulation with an SSC of 45% and 0.6% acid addition was selected as optimal, striking a balance between desirable sensory attributes, product stability, and consumer health. This formulation achieved a harmonious sweet-and-sour flavor while maintaining a relatively high betacyanin content (53.73 mg/kg).

Table 5. Quality of dragon fruit jam with different acid addition ratios and final SSC

Treatment	Acidity content (%)	Betacyanin content (mg/kg)	Average ranking score
T15	1.3	47.52	3.55
T16	1.21	55.91	4.17
T17	1.36	53.73	3.35
T18	1.21	62.73	3.36
T19	1.07	49.9	3.32
T20	1.54	53.73	3.35

Note: The sensory score column of the ranking test shows the consumer preference for the jam: the highest sensory score means the most preferred, and the higher the sensory score, the greater the preference (maximum is 6 points corresponding to 6 experimental samples).

3.3. Effect of fruit jam addition on quality of soy yogurt

To improve the sensory and nutritional quality of soy yogurt, varying amounts of fruit jam (5%, 10%, 15%, and 20%) were tested. Incorporating 15% dragon fruit jam yielded the highest sensory scores, enhancing texture, masking beany odors, and providing a balanced sweetness and tartness with a pleasant fruit aroma. The vibrant pink color from red dragon fruit further boosted visual appeal, a key factor in consumer acceptance. Lower jam levels (5% and 10%) had minimal impact, while excessive addition (20%) resulted in an overly sweet taste that overshadowed the yogurt's natural sour taste (Figure 3). Thus, a 15% addition was deemed optimal, offering a harmonious blend of flavors and aromas.

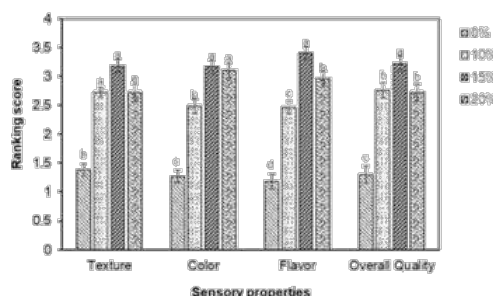


Figure 3. Sensory quality of soy yogurt supplemented with different fruit jam ratios

A comparison of the quality of soy yogurt with fruit jam and commercially available animal-based yogurt in Vietnam revealed no statistically significant difference in acidity (0.70% vs.

0.75%), indicating similar sourness and stability. However, due to the 15% fruit jam in the soy yogurt compared to 4.6% strawberry jam in the animal-based yogurt, the soy yogurt had approximately 3% higher carbohydrate content. Conversely, the animal-based yogurt had higher lipid and protein levels, attributed to the addition of milk fat, milk powder, and whey powder in its formulation. A notable advantage of the soy yogurt was its significantly higher total polyphenol content, doubling that of the animal-based yogurt. This increase is linked to the polyphenol-rich ingredients in soybeans and the dragon fruit, apple, and passion fruit used in the jam (Table 6). Adding dragon fruit jam to soy yogurt has proven to enhance its quality and health benefits, as shown in this study and supported by previous research (Givens, 2020; García-Burgos et al., 2020; Amal et al., 2016).

Table 6. Nutritional quality analysis of soy yogurt with fruit jam and animal-based yogurt

Quality attribute	Soy yogurt with jam addition	Animal-based yogurt
Protein (%)	2.69b ± 0.01	3.21a ± 0.02
Lipid (%)	1.28b ± 0.01	2.64a ± 0.11
Carbohydrate (%)	20.26a ± 0.01	17.19b ± 0.14
Acidity (%)	0.70b ± 0.01	0.75a ± 0.01
Total polyphenol content (mg/kg)	298.7a ± 8.7	147.1b ± 1.8

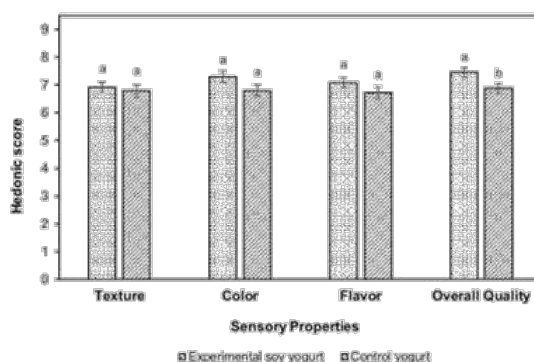


Figure 4. Sensory quality of soy yogurt with fruit jam and animal-based yogurt

Consumer acceptance of soy yogurt with fruit jam was high, with Hedonic scores ranging from 6.9 to 7.5 for texture, color, flavor, and overall quality. While sensory attributes were comparable to the animal-based yogurt (control), the overall quality was rated higher, likely due to the unique appearance and flavor of the soy yogurt with fruit jam addition, which appealed to consumers (Figure 4).

4. CONCLUSION

This study highlights the potential of dragon fruit as a versatile and sustainable ingredient for developing value-added food products, addressing postharvest challenges and enhancing the economic value of this important crop. The production of dragon fruit wine demonstrates an innovative approach to utilizing lower-grade fruits, effectively reducing postharvest losses while offering a novel product with market potential. Similarly, the fruit jam meets consumer demands for health-oriented products rich in nutrients and antioxidants, showcasing its versatility as an ingredient in various food applications. The integration of dragon fruit jam into soy yogurt further underscores the synergies between these two nutritious components, resulting in an

innovative product with enhanced sensory and nutritional qualities. This combination not only diversifies the range of plant-based and fruit-based products but also aligns with global trends toward healthier and more sustainable food options. Future research and market exploration are recommended to further optimize and scale these solutions, ensuring their broader application and long-term impact.

Acknowledgment

The authors of this article greatly appreciate the financial support of the Flemish Inter University Council (VLIR-UOS, Projects No. ZEIN2015PR413 and VN2022TEA532A103).

References

- Chien, H.-L., Huang, H.-Y., & Chou, C.-C. (2006). Transformation of isoflavone phytoestrogens during the fermentation of soymilk with lactic acid bacteria and bifidobacteria. *Food microbiology*, 23(8), 772-778.
- Gunaseena H. P. M., D. K. N. G. Pushpakumara and M. Kariyawasam (2007). Dragon fruit *Hylocereus undatus* (Haw.) Britton and Rose. Underutilized fruit trees in Sri Lanka. New Delhi, World Agroforestry Centre. pp. 110-142.
- Herbach K. M., Fl. C. Stintzing and R. Carle (2004). Thermal degradation of betacyanins in juices from purple pitaya [*Hylocereus polyrhizus* (Weber) Britton and Rose] monitored by high-performance liquid chromatography-tandem mass spectrometric analyses. *European Food Research and Technology*. 219 (4). pp. 377-385.
- King T., M. R. (2001). Practical Advanced Biology. Nelson Thornes.
- Kosseva M., V. K. Joshi and P. S. Panesar (2016). Science and technology of fruit wine production. Academic Press.
- Le Bellec F., F. Vaillant and E. Imbert (2006). Pitahaya (*Hylocereus* spp.): a new fruit crop, a market with a future. *Fruits*. 61 (4). pp. 237-250.
- Lim Y. Y. and J. Murtijaya (2007). Antioxidant properties of Phyllanthus amarus extracts as affected by different drying methods. *LWT-Food Science and Technology*. 40 (9). pp. 1664-1669.
- Nguyen Phuoc Minh (2014). Various factors influencing to red dragon fruit (*Hylocereus polyrhizus*) wine fermentation. *International Journal of Multidisciplinary Research and Development*. 1(5). pp. 94 - 98.
- Sabbe S., W. Verbeke and P. V. Damme (2009). Confirmation/disconfirmation of consumers' expectations about fresh and processed tropical fruit products. *International journal of food science and technology*. 44 (3). pp. 539-551.
- Santos, J., Pretto, J., Polon, A., Monego, M., & von Laer, A. (2014). Evaluation of mango (*Mangifera indica*) yoghurt acceptability. *Magistra*, 26(CBPFH), 239-242.
- Tabart J., C. Kevers, J. Pincemail, J. Defraigne and J. Dommès (2009). Comparative antioxidant capacities of phenolic compounds measured by various tests. *Food Chemistry*. 113(4). pp. 1226- 1233.
- TCVN 7033:2002 for carbohydrate content determination.
- TCVN 6688-1:2007 (ISO 8262-1:2005) for lipid content determination.
- TCVN 8125:2015 (ISO 20483:2013) for protein content determination.
- Weng, B. B.-C., Yuan, H.-D., Chen, L.-G., Chu, C., & Hsieh, C.-W. (2023). Soy yoghurts produced with efficient GABA (γ -aminobutyric acid)-producing *Lactiplantibacillus plantarum* ameliorate hyperglycaemia and re-establish gut microbiota in streptozotocin (STZ)-induced diabetic mice. *Food & Function*, 14(3), 1699-1709.

CURRENT POST-HARVEST QUALITY AND TECHNOLOGY PRACTICES OF THE TROPICAL FRUIT INDUSTRY IN MALAYSIA

Biai, Christopher John, Mazlan, Mohd Ali Hanafiah, Mohd Shah, Lilynorfeshah

Aras 10 & 12, Wisma Tani, No. 30, Persiaran Perdana, Presint 4, 62624, Putrajaya

MALAYSIA

christopherjb@doa.gov.my, ali.hanafiah@doa.gov.my, lilynorfeshah@doa.gov.my

This report aims to share the current post-harvest quality and technology practices of the tropical fruit industry in Malaysia. The selected tropical fruit collectors/ distributors/ exporters and their postharvest facilities for both small and large scale agro-penueurs of durians, jackfruits, mangosteens were visited and interviewed. The areas were covered as the followings: (1) packinghouse operations; (2) packing and packaging materials; (3) decay and insect control; (4) temperature and relative humidity control; and (5) storage of horticultural crops. Their current postharvest practices and facilities, challenges, and alternative solutions, were documented. Thus, the potential implementations would benefit the tropical fruit players and they could increase the profit of the tropical fruit industry in Malaysia.

Keywords: Tropical fruits Durian; postharvest handling process; technology and practice.

1. INTRODUCTION

The global demand for tropical fruit has been increasing. The research report pinpointed that the market size trend for tropical fruits will strengthen by 5.8 % of a compound annual growth rate (CAGR). It was based on the accelerated market size growth of tropical fruits between 20023 and 2024, with \$4.39 billion and \$4.64 billion, respectively. The tropical fruit market is expected to amplify to \$5.85 billion in 2023. The Asia Pacific region is emphasized as a significant player in the positive trajectory of tropical fruit market growth (The Business Research Company, 2024). Indeed, The Food and Agriculture Organization of the United Nations reported that the three top exported tropical fruits: Banana, Avocado, and durian; have been dominated by Thailand, Malaysia, and Indonesia (FAO) report (FAO, 2024b, 2024a).

China's rising demand for durian has escalated the global fruit Trade. It is projected that by 2030, there will be a 33% increase from 1.5 billion Kg in 2016 to 2.0 billion KG in 2030, based on the conservative scenario. Remarkably, 200% skyrocket from 1.5 billion Kg in 2016 to 2.0 billion KG in 2030 based on the growth scenario (Plantations International, 2018). An estimated 94% of this durian global trade comes from Thailand. Meanwhile, Malaysia and Indonesia account for about 3% (FAO, 2023). Therefore, the Durian industry has a huge opportunity to trade in domestic and international markets.

The Durian Postharvest Handling process along the fruit supply chain is crucial to ensure the quality meets consumer expectations. These transactions involve fruit collectors, distributors, and exporters and their postharvest facilities (Mohd Shah, 2009, 2016; Underhill and Kumar, 2017; FAO, 2023; Global Information, 2024). Nevertheless, extensive research on durian post-harvest technologies and practices to improve durian quality is limited. Knowledge of handling and fruit supply chain management in agronomy and post-harvest practices, pest and disease management, and local and global trades is still inadequate for durian industry players, especially for small and medium agropenueurs.

Hence, this report aims to recognize the Malaysian durian industry’s current post-harvest quality and technology practices. A SWOT analysis was used based on an interview with the selected durian collectors, distributors, exporters, and their post-harvest facilities for both small and large-scale agropenuers.

2. SCENARIO OF THE DURIAN INDUSTRY IN MALAYSIA

Durian (*Durio zibethinus* L) belongs Malvaceae family based on the latest molecular data findings. Formerly, it was reported in the Bombacaceae family (Ketsa et al., 2020; Encyclopædia Britannica, 2024). The fruit dominated approximately 48% of Malaysia’s 10 major fruit-cultivated areas, with 87,278 ha and 455,458 tonnes of production (Figure 1). Johor, Pahang, and Kelantan were the leading durian cultivated areas and production. The next main planted tropical fruit area was bananas, with 27,577 ha and 330,601 tonnes of production. Pineapple followed with 17,803ha and 537,231 tonnes of production. 43,894 tonnes of durian was mainly exported to Singapore, China, and Hong Kong, with a Self-sufficiency Ratio (SSR) of 108.9% (Department of Agriculture Malaysia, 2023a).

Durian varieties in Malaysia are registered by The Department of Agriculture Malaysia in accordance with the Seed Verification Scheme (SPBT). It is identified by uniquely the capital D and followed by the sequence number. 217 durian varieties are successfully acknowledged. Among the most sought-after durian varieties are D197 Raja Kunyit (Musang King) and D200 Ochii (Duri Hitam).

Musang King is popular due to its thick flesh, strickling yellowish colour, and a strong, sweet-bitter, sticky creamy taste. The fruit’s distinct characteristics are its light green ovate shape, the absence of thorns around the base of the peduncle and bottom (a starfish looks alike), and the visible loculicidal division of carpels. Meanwhile, Duri Hitam has an orange aril flesh and a distinguishable creamy slightly bitter yet sweet taste. It has a brownish-green husk/ peel oval, sharing with the absence of thorns around the base of the fruit (Department of Agriculture Malaysia, 2021, 2023b, 2023c, 2024d, 2024c, 2024e).

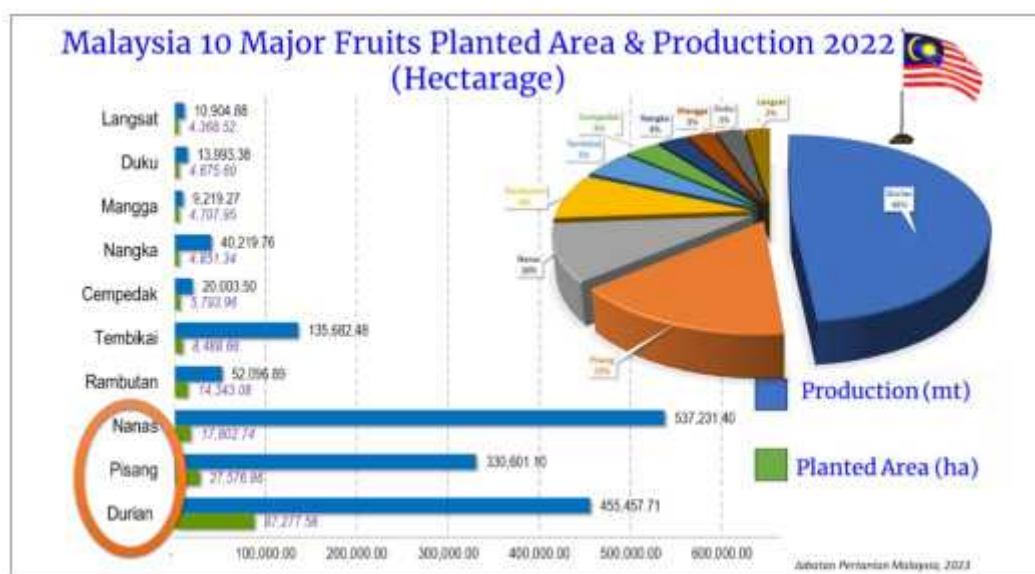


FIGURE 1: MALAYSIA 10 MAJOR FRUITS PLANTED AREA & PRODUCTION 2022 (DEPARTMENT OF AGRICULTURE MALAYSIA, 2023A)

From consumer behaviours and demand perspectives, Durian is popular among Malaysians, with a Per Capita Consumption (PCC) of approximately 12.4kg per year. In 2022, 90-95% of Malaysia’s Durian demand came from the local consumers of durian production (a total of 455,457 tonnes). However, only 5-10% of the 2022 durian production was exported (21,600 tonnes). With this strength in export volume, Malaysia has still accelerated as the second-largest global durian exporter. Malaysia exported 64% of frozen whole durian, 20% of frozen pastes, 11% of frozen pulp, and the balance of fresh fruit and pulp based on the Malaysian Phytosanitary Certification in 2022 (Plantations International, 2018; Department of Agriculture Malaysia, 2023a, 2024a). Therefore, a relationship between Malaysian consumer behaviour and the durian export volume trend could influence Malaysia’s future durian industry, economic growth, and status as a global durian exporter.

3. CURRENT POST-HARVEST TECHNOLOGIES & PRACTICES: POST-HARVEST HANDLING PROCESS OF DURIAN

Adequacy in quality control is crucial to minimizing the quality variation at each transaction along the tropical fruit supply chain and reducing postharvest losses and waste. Indeed, most tropical fruits are climacteric. Handling and Storage conditions of tropical fruits were identified as two critical points during the fruit transactions (Figure 2). The adequacy in the fruit handling focussed during harvest (picking, filling, loading & transporting), Appropriateness of managing packaging & coding, and Adequacy of the grading system. Next, the adequacy in storage conditions emphasized on Adequacy of storage conditions setting (temperature, relative humidity & controlled atmosphere) and the Adequacy of controlling/ maintaining storage conditions (Mohd Shah, 2009, 2016). Besides, literature also highlighted the importance of post harvest handling in tropical fruits and practices and the adoption of post-harvest technology at the facilities. (Champ et al., 1993; Kitinoja and Kader, 2004; Mohd Shah, 2009, 2016; Jaspreet Aulakh and Anita Regmi, 2013; Kader, 2013; Wong, Motomura and Paull, 2018; Indiarto, 2020; Small Farmers’ Agri-Business Consortium India, 2022; Kavitha and Prusty, 2024; Parmar, 2024).

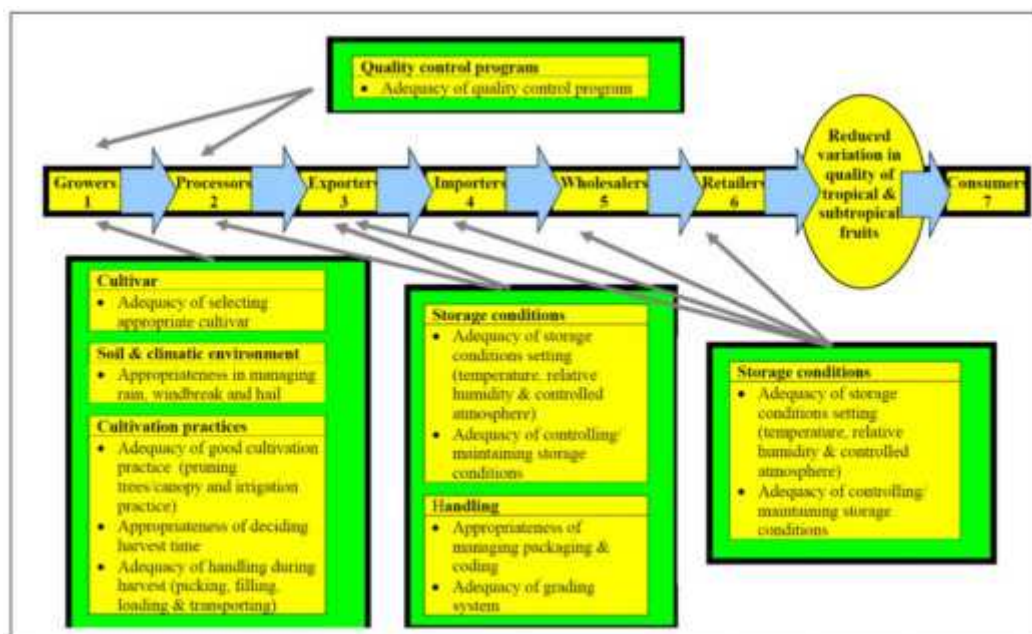


FIGURE 2: THEORETICAL FRAMEWORK OF POSSIBLE SOURCES OF VARIATION AFFECTING QUALITY ALONG THE AGRICULTURAL SUPPLY CHAIN (MOHD SHAH, 2009)

Three tropical fruit collectors/ distributors/ exporters and their postharvest facilities representative small, medium, and large-scale durian agropenuers were visited, and their plant managers, operation managers, quality, R&D managers, and some of their employees were interviewed. The observations were conducted in Bentong and Raub, Pahang in September-October 2024. The areas were covered as the followings: (1) packinghouse operations; (2) packing and packaging materials; (3) decay and insect control; (4) temperature and relative humidity control; and (5) storage of horticultural crops. Their current postharvest practices, facilities, challenges, and some way forwards were documented and evaluated by using SWOT analysis.

3.1 Postharvest Handling Process: Fresh Durian

Postharvest handling practices of fresh durian consisted of six processes (Figure 3). They were harvesting at the durian orchards, cleaning, grading, the 1st Quality Control Check before packaging, the 2nd QC check, and final packaging before distribution for local and/ or export facilities. Figure 4 outlines the procedure for exporting fresh durian to China based on the guidelines by The Department of Agriculture Malaysia (Champ et al., 1993; Kitinoja and Kader, 2004; Mohd Shah, 2009, 2016; Jaspreet Aulakh and Anita Regmi, 2013; Kader, 2013; Wong, Motomura and Paull, 2018; Indiarto, Izzati and Djali, 2020; Small Farmers’ Agri Business Consortium India, 2022; Department of Agriculture Malaysia, 2024f, 2024e, 2024a; Kavitha and Prusty, 2024; Parmar, 2024).



FIGURE 3: POSTHARVEST HANDLING PROCESS: FRESH DURIAN



FIGURE 4: PROCEDURE OF EXPORTING FRESH DURIAN TO CHINA (DEPARTMENT OF AGRICULTURE MALAYSIA, 2024F)

3.2 Postharvest Handling Process: Frozen Whole Durian

The postharvest handling process for frozen whole durian has a similar flow except for its additional liquid nitrogen fast-freeze technology and vacuum packaging steps. The frozen whole durian is composed of five focal points (Figure 3). They are cleaning, fast frozen step in a high-pressure liquid nitrogen chamber at - 80°C to -110°C for 1-hour, freezing completion, vacuum packaging, and final packaging. Figure 6 depicts the procedure of exporting frozen whole fruit durian to China based on the guidelines by The Department of Agriculture Malaysia (Safari et al., 2021; Azlin Razali et al., 2023; Department of Agriculture Malaysia, 2024f, 2024g).



FIGURE 5: POSTHARVEST HANDLING PROCESS: FROZEN WHOLE DURIAN

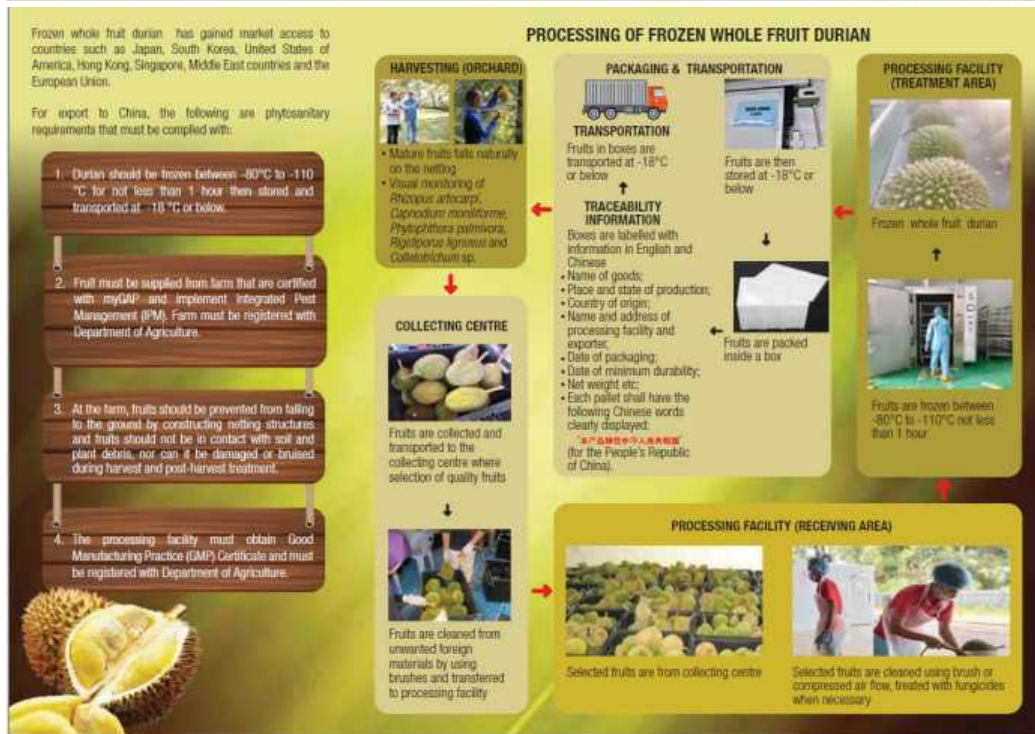


FIGURE 6: A & B - PROCEDURE OF EXPORTING FROZEN WHOLE FRUIT DURIAN TO CHINA (DEPARTMENT OF AGRICULTURE MALAYSIA, 2024G)

3.3 Postharvest Handling Process: High-Tech Durian Pulp Processing

Figure 6 represents the postharvest handling process of high-tech durian pulp. The process also follows the exported fresh durian guidelines, except some facilities use auto weighing and auto 3D pulp packaging. There are four steps: Firstly, durian pulps are weighed by using an auto-digital weighed scale conveyor machine with a designated weight calibrated before the operation, and they are transferred to the respective container. Secondly, the weighted fruit pulps in the container are inserted into the auto 3D wrapping pulp machine. Thirdly, the 3D-wrapped pulps undergo the second sealer packaging machine. Lastly, the durian pulps are ready for batch packaging.



FIGURE 7: POSTHARVEST HANDLING PROCESS: HIGH TECH DURIAN PULP PROCESSING

3.4 Postharvest Handling Process: Durian Paste Processing

Durian Paste Processing comprises four transitions (Figure 8). The activities at the early stages of harvesting and cleaning at the orchard remained the same as the fresh durian handlings. Next, durian pulp (aril) and its seeds are extracted from its husk. Afterward, the pulp is removed from the seed to obtain raw durian paste. Some facilities use an auto-removal pulp machine. Subsequently, the paste undergoes a QC inspection, such as for foreign object removals. Finally, the inspected pastes are vacuum sealed and frozen for the next intended actions.

4 SWOT ANALYSIS

Figure 9 represents the finding of the current post-harvest technologies & practices to improve the durian quality by using SWOT analysis. The details are as follows:

Strengths

1. Durian has become a Diplomatic Symbol between Malaysia and other countries. For instance, durian was one of the agenda items and delicacies during official meetings with the Prime Ministers of China and Japan (The Sun, 2023; The Star, 2024). Another example is the first successful fresh durian export to China on 24 August 2024 (The Global Times, 2024). In addition, Malaysia renewed its Musang King's Intellectual Property Corporation of Malaysia

IPO from 2024 to 2034 (Asia IP, 2024).

2. The Durian Traceability system has been strengthened. The Ministry of Agriculture and Food Security Malaysia and The General Administration of Customs of the People's Republic of China (GACC) have certified:

- 48 durian facilities for frozen whole fruits, pulp and pastes, and fresh durian;
- 45 facilities for fresh durian; and
- 80 durian orchards with a Malaysia Good Agricultural Practices MyGAP certification ((Department of Agriculture Malaysia, 2024b).

Weaknesses

1. Aril Tip Burn is an internal defect found in durians. The defect is only observed after the husk is opened. It was reported due to nutrient or water supply inadequacy during the aril development period (Ketsa et al., 2020). The repeating aril tip burn experienced by durian buyers or consumers may influence their quality expectations during the next purchase. Hence, this scenario could contribute to an adverse effect on durian sellers' income and exporters (Mohd Shah and Mazlan, 2024).

2. Malaysian companies face a challenge in exporting fresh durian to China within a short logistic time frame. Fresh durians are required to reach the importing country within 48 hours. Failure to achieve this time frame would lead to deterioration in the fresh durian shelf life (Mohd Shah and Mazlan, 2024). Therefore, defective durians may deter consumers' buying preferences.

Opportunities

1. Local and global demand for durian has been remarkably accelerated. The scenario provides a golden trade opportunity for Malaysia's durian industry players (competitive business) (Rozana, 2017; Plantations International, 2018; Shamin-Shazwan et al., 2022; Department of Agriculture Malaysia, 2023a; FAO, 2023, 2024b, 2024a; Global Information, 2024; The Business Research Company, 2024).

2. The King of the Durian Kings has been recognised as the best durian champion of the year among the best Malaysian durians. The king is accoladed during The World Durian Championship (Malaysia Edition) of the Durian Festival and awards. Musang King has been awarded as the World Durian Championship in 2022, 2023 and 2024 (Channel News Asia CNA, 2022; Bangi Golf Resort, 2024).

3. The Durian Kampung Premium (DKP) competition is held yearly by the Department of Agriculture (DOA) Malaysia. This program establishes durian varieties that are cultivated using seeds. Some of the DKP nominees were Raja Benta, Mas 10, Naga Emas, and Mentega. Mentega was accoladed as the 2024 DKP champion of Lipis District, Pahang (Mohd Atar, 2024). The DKP winner and the prominent durian will be published in the DOA Plant Variety Registration list (Department of Agriculture Malaysia, 2023c). This program, together with the World Durian Championship (Malaysia Edition), could be another attraction and awareness-raising tool for the public and the Malaysia Agrotourism.

4. Consumer Behaviour, Demand, and awareness are potential areas to explore. For example, foreigners' perceptions of Malaysian durian, such as Chinese consumers' durian

taste preferences, could be organized. These activities could initiate collaborations among universities, government sectors, and durian industry players, strengthening capacity building among durian players.

Threats

1. Unpredictable Climate change trends affect the flowering and fruiting of durian trees (with such high variabilities in temperatures, rainfall periods, and weather). Durian farmers also face natural disasters, such as storms, floods, and bushfires, that could damage their durian orchards. Durian farmers have faced these dilemmas, and the climate irregularities have potentially affected fruit productibility, quality, supply and demand capacity, and farmers' income. The durian farmers' readiness to accept coping strategies and adopt the prospective technologies is still understudied and undetermined (Lilavanichakul and Pathak, 2024; Mohd Shah and Mazlan, 2024).

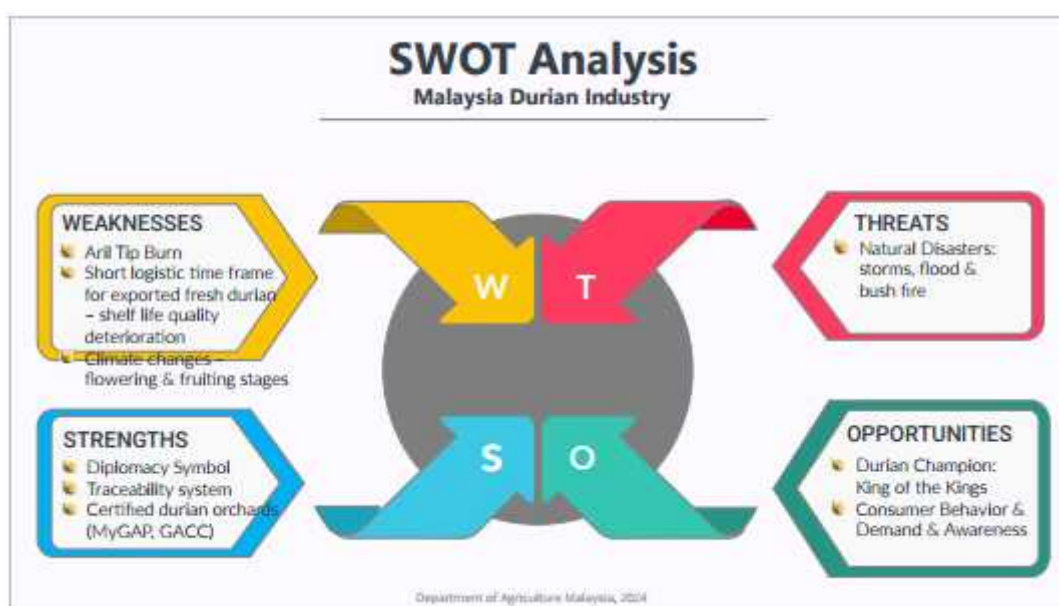


FIGURE 9: SWOT ANALYSIS - MALAYSIA DURIAN INDUSTRY

5. WAY FORWARD: POST-HARVEST TECHNOLOGIES & PRACTICES TO MINIMISE DURIAN QUALITY VARIATIONS IN MALAYSIA

The way forward of some post-harvest technologies & practices to minimise Malaysia durian quality variations could revolve around the durian's intrinsic & extrinsic quality attributes affecting consumer expectations and perceptions (Figure 10). The fruit's distinct intrinsic quality attributes are sensory properties and shelf-life. The sensory properties include appearance, texture, colour, and sound. Meanwhile, marketing is a prominent durian extrinsic quality attribute that focuses on consumer behaviour and demand (Luning and Marcelis, 2007; Mohd Shah, 2009; Pieternel A. Luning and Willem J. Marcelis, 2020).

Subsequently, there is a correlation between those sensory properties and shelf life and the suitability of adopting postharvest technology and practice in durian facilities by the durian industry players, agropenuers, or exporters. Figure 11 emphasizes the possible instrumental techniques for the quality evaluation of durian

to minimize its quality variations. Instrumental and Non-Destructive (ND) techniques use Electromagnetic, mechanical, and chemical technologies. The durian postharvest technologies and practice preferences are ND techniques. Firstly, optical, fluorescence, & Delay Light Emissions (DLE), X-ray & Gamma Nuclear, Magnetic Resonance, or Nuclear Magnetic images are possible electromagnetic technologies that can be adopted into auto-machineries. Secondly, the post-harvest instruments could use mechanical technology of ND impact or acoustic (sonic or ultrasonic vibrations). Thirdly, an electric nose is a possible ND chemical technology that can be implemented onto the machines for durian postharvest facilities (Pieternel A. Luning and Marcelis, 2009; Mohd Shah, 2016; Safari et al., 2021; Azlin Razali et al., 2023; Mohd Shah and Mazlan, 2024). The capability to adopt the right ND post-harvest technologies could minimize the quality variation in durian in Malaysia. As a result, Malaysia's durian supply and demand could be strengthened to prosper the fruit industry and facilitate economic growth.

The following section presents seven examples of the current available ND instrumental techniques implemented in fruit and vegetable or food companies that could be potentially adopted by Malaysian durian industry players (Figure 12).

5.1 Fruit Paste QC Checking

Firstly, Breeze Vers 2020.1.0. is an advanced real-time data analysis utilizing hyperspectral image data, quantitative analysis, and classification recording? This ND electromagnetic technology has been applied on a machine to detect foreign objects in food packaging (Pediktera, 2020) The instrument could be integrated with auto-robotic arms to pick up or extract the identified foreign objects, such as seeds, husks, or branch fragments, from durian pastes.

5.2 ND Internal Fruit Scanning

The second example of ND electromagnetic technology adopted in fruit post-harvest practices is the Q Eye Multisensor Quality Scanner. The Infra-Red (IR) machine auto-sorts fruits, such as apples, onions, oranges, and avocados, by scanning, grading, and classifying them on a conveyor line system. It differentiates fruits' shape, internal defects, and colour uniformity (BIOMETIC, 2019). This technology could be implemented on durians for their homogenous shape and internal quality inspections.

5.3 Auto Fruit Cleaning, Drying, Waxing, Sorting, and Grading line System

Thirdly, automatic avocado cleaning, drying, waxing, sorting, weighing, and grading instruments are incorporated into a single controlled line system. A batch of avocados undergoes a cleaning or washing compartment attached with a sequence set of brushes, water sprayers, and quick air dryers. Later, the fruits are weighted by a designed digital auto section of the line system. After sorting, the avocados are ready for packing, storage, and/or distribution. The single-controlled ND line machinery increases the efficiency of the post-harvest fruit handling, ensuring rapid fruit handling and quality uniformity (FstSort, 2019). This one-line auto system can be exerted on potential durian post-harvest transaction handling equipment.

5.4 ND Internal Fruit Defect Detector

The next fourth machine of the current available ND instrumental techniques is implemented in Harumanis (the King of Malaysian Mangoes). Several methods have been sought to maximise the quality of fresh Harumanis exported to Japan and safeguard the mangoes from

insects, diseases, and internal deficiencies. One of the mango-consistent quality challenges is Insidious Fruit Rot (IFR), an internal fruit disease that contributes to exported fruit non-conformity. Electromagnetic, mechanical, and chemical technologies have been introduced using an electronic nose (e-nose), an acoustic sensor incorporated with a Charge Coupled Device (CCD), and IR detectors. Another ND technique is a Near-Infrared (NIR) spectroscopy instrument consisting of a piezoelectric vibration sensor and electret microphone. These techniques non-destructively detect the IFR occurrence and the Brix sweetness reading in Harumanis (Musa et al., 2010; Ahmad Saad et al., 2012; Zakaria et al., 2021; Mahayadin, 2023; Salleh et al., 2023) The ND instrumental technique can be adopted in Durian post-harvest handling facilities to identify Aril Tip Burn, the internal non-comity affecting Durian quality, and consumer purchasing behaviours.

5.5 AI Fruit Sorting Technology

SpekSense, the AI fruit sorting technology from Deltron is the fifth example of the current post-harvest technologies & practices to minimize durian quality variations in Malaysia. The SpekSense implements a Short-Wave Near-Infrared (SW-NIR) approach. It can record the physicochemical properties of fruit quality such as apples, mandarin, and apricot. This AI-driven, non-destructive sorting technology offers fruit efficiency, effectiveness, and quality conformity (Deltron, 2024). The SpekSense also has the potential to be utilized in durian postharvest facilities.

5.6 Portable Non-Destructive Sweetness Detector

Portable ND Brix Meter is the sixth ND instrument example in this section. One series utilising IR spectroscopy technique is applied for melon sweetness detection. Farmers now can non-destructively access the sweetness or the ripeness of their produce straight from the orchards (Atago, 2024). Furthermore, UltraBrix is another ND method for obtaining sugar cane brix sweetness data. This ultrasonic technique's data provides the optimum harvest time and fermentation stage during winemaking. It comprises two piezoelectric transducers (signal transmitter and receiver), a pulse generator, an instrumentation amplifier with a bandpass filter, and an amplitude meter (Liu, Pu and Sun, 2017; da Costa et al., 2021). Correspondingly, another ND with fast access to grape wine fermentation stages is adopting the visible and near-infrared (VNIR) and short-wave infrared (SWIR) segments (Kalopesa et al., 2023; Feng, Ruiz Rodríguez and Palma, 2024). These instrumental techniques may be implemented to determine the durian sweetness level pre- and post-harvest transactions.

5.7 Auto Crack/Broken Egg Detector

An auto egg crack or broken and internal defect detector is the last example of current post-harvest technologies and practices to minimize durian quality variations in Malaysia. It features ND optical sensing technology, a photoelectric sensor, and an ultrasonic instrument for ensuring egg quality uniformity. The technology is intertwined with Artificial Intelligence (AI), cloud computing, and Internet of Things (IoT) applications (Kim et al., 2022; Tang, Hu and Wang, 2022; Ahmed et al., 2023; Science, 2023) In fruit postharvest facilities, this instrumental technique allows Durian to be aligned on the conveyer compartment undergoing this ND internal or cracked inspection.

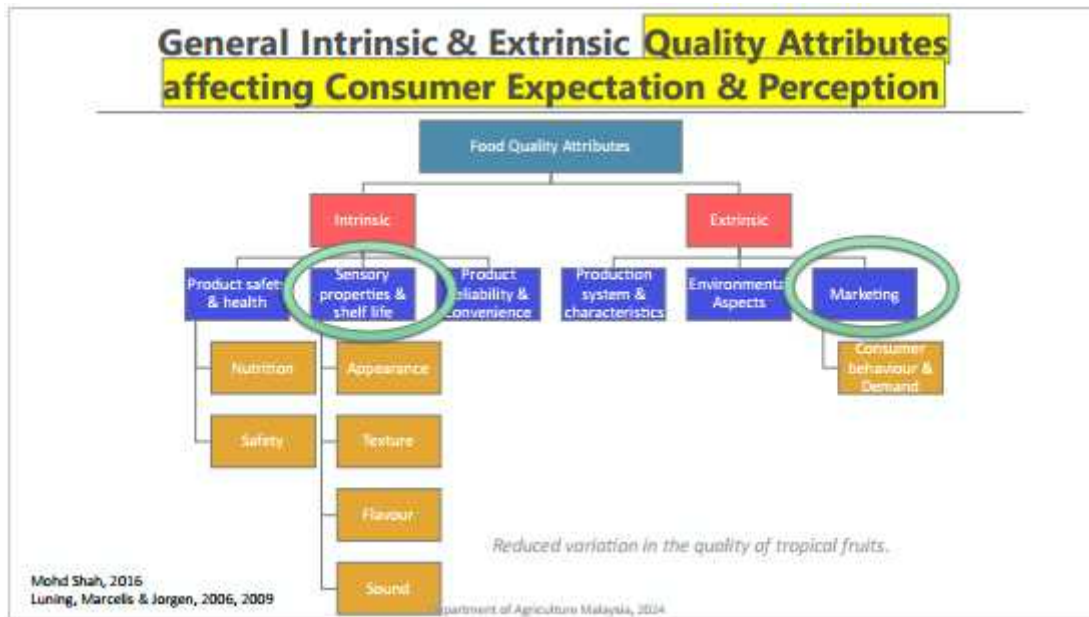


FIGURE 10: GENERAL INTRINSIC & EXTRINSIC QUALITY ATTRIBUTES AFFECTING CONSUMER EXPECTATION & PERCEPTION (MOHD SHAH, 2009; PIETERNEL A LUNING AND MARCELIS, 2009)

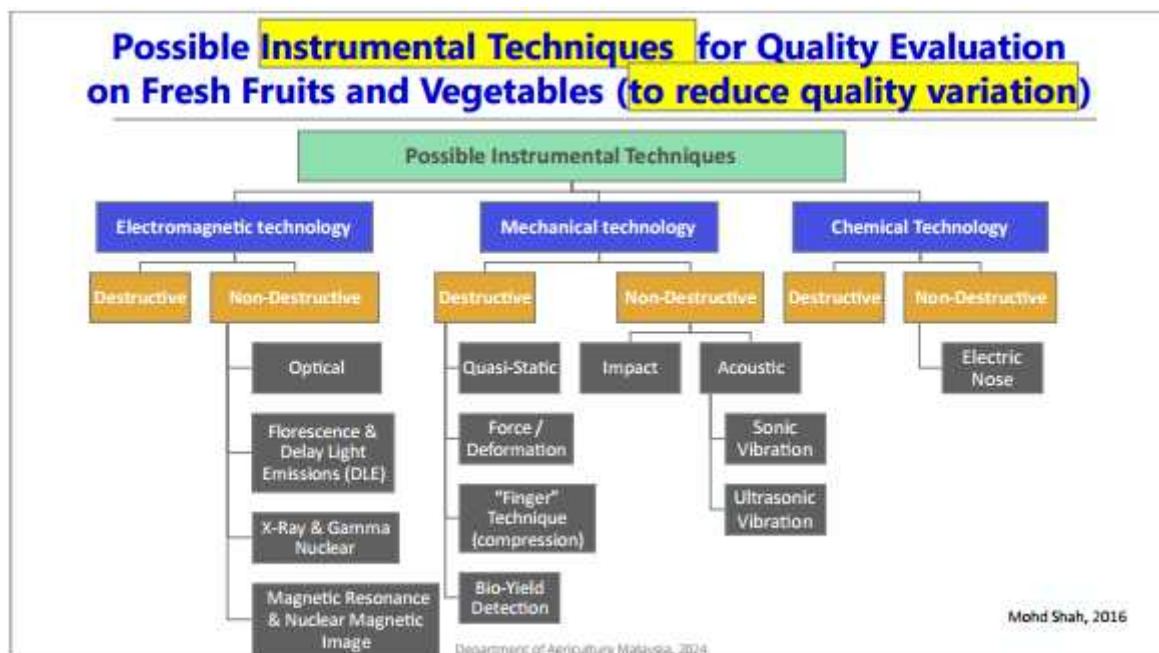


FIGURE 11: POSSIBLE INSTRUMENTAL TECHNIQUES FOR QUALITY EVALUATION ON FRESH FRUITS AND VEGETABLES (TO REDUCE QUALITY VARIATION) (MOHD SHAH, 2016)



FIGURE 12: WAY FORWARD: POTENTIAL POST-HARVEST TECHNOLOGIES & PRACTICES TO MINIMISE DURIAN QUALITY VARIATIONS IN MALAYSIA BASED ON CURRENT FOOD TECHNOLOGY (BIOMETIC, 2019; FTSORT, 2019; PEDIKTERA, 2020; YANG ET AL., 2020; ZAKARIA ET AL., 2021; MAHAYADIN, 2023; SALLEH ET AL., 2023; SCIENCE, 2023; DELTRON, 2024)

6 CONCLUSION

This paper explored the current post-harvest technologies and practices for improving the quality of tropical fruits in Malaysia, focusing on Durian. The respective data from the observations of the durian post-harvest facility visits and interviews with the designated key personnel in Bentong and Raub, Pahang, were collected and analysed using a SWOT test from September to October 2024. The durian global and local demand and supply trend was investigated at the beginning of the section. Next, the post-harvest quality elements were focused on the fruit's current post-harvest technologies and practices at the exporter facilities for fresh and frozen whole fruits, high-tech fruit pulp packaging, and paste processing.

The findings highlighted first the strengths: durian has become a global diplomatic symbol, and the fruit traceability system has been strengthened to conform to the regulations of the exporting countries. Second, the weakness is Aril Tip Burn, a durian internal defect that has been reported and is a challenge for fruit exporters. Moreover, the exporters also face difficulty ensuring the fruits reach their destination within the allowable time frame. Third, the opportunities are the massive trend in the durian global trade forecasted until 2030, and several durian varieties will be recognized and registered through The King of the Durian Kings and The Durian Kampung Premium competitions. Besides, the consumer behaviour study could be extended to enrich the durian export opportunities. Fourth, the threat is climate unpredictability affecting the durian trees' development and productivity. As a way forward, seven examples of the current available ND instrumental techniques implemented in fruit and vegetable or food companies were introduced that could be potentially adopted by Malaysian durian industry players.

ACKNOWLEDGMENTS

The study was possible with the support of The Ministry of Agriculture and Food Security Malaysia, The Department of Agriculture Malaysia, foremost to The Agriculture Director General, Dato' Nor Sam binti Alwi, and The Director of The Development and Crop Industry Division, Mr. Christopher John Biai, the respective Durian exporters in Bentong and Raub, Pahang, and the officers of The Pahang Department of Agriculture. The authors would like to thank all colleagues for grammar corrections and helpful comments on the manuscript, and Mr. Mohd Ali Hanafiah bin Mazlan for his durian expertise and networking, for his team visit together, and for providing recent material for study and photographs for artwork

REFERENCES

- Ahmad Saad, F.S. et al. (2012) 'Bio-inspired Sensor Fusion for Quality Assessment of Harumanis Mangoes', *Procedia Chemistry (Bio-Sensing Technology)*, 6, pp. 165–174. Available at: <https://doi.org/10.1016/j.proche.2012.10.143>.
- Ahmed, M.W. et al. (2023) 'Non-destructive optical sensing technologies for advancing the egg industry toward Industry 4.0: A review', *Comprehensive Reviews in Food Science and Food Safety. John Wiley and Sons Inc*, pp. 4378–4403. Available at: <https://doi.org/10.1111/1541-4337.13227>.
- Asia IP (2024) 'Malaysia extends durian IP protection for 10 more years'. Available at: <https://asiaiplaw.com/article/malaysia-extends-durian-ip-protection-for-10-more-years>.
- Atago (2024) Pocket IR Brix Meter PAL-HIKARi 30 (Melon). Available at: <https://atago.net/en/atagodirect/index.php?key=MCY49755> (Accessed: 7 December 2024).
- Azlin Razali, N. et al. (2023) 'The Standard Operating Procedure (SOP) for Exporting Frozen Whole Durian Fruit to The Republic of China', *JOURNAL OF AGRIBUSINESS MARKETING*, 11(2). Available at: <https://doi.org/10.56527/jabm.11.2.2>.
- Bangi Golf Resort (2024) 'World Durian Championship: Malaysia Edition (King of Kings)'. Available at: <https://www.facebook.com/share/1EWtYjmDj9/?mibextid=LOQJ4d> (Accessed: 3 December 2024).
- BIOMETiC (2019) Biometric Innovative Fruit Scanning. Available at: <https://www.youtube.com/watch?v=Wim0AGSUFbw> (Accessed: 4 December 2024).
- Champ, B. et al. (1993) 'Postharvest Handling of Tropical Fruits', in proceedings of an international conference held at Chiang Mai, Thailand. The Australian Centre for International Agricultural Research (ACIAR)
- Channel News Asia CNA (2022) The king of kings: Penang growers top competition with durians from 40-year-old Black Thorn tree. Available at: <https://www.channelnewsasia.com/asia/malaysia-penang-durian-black-thorn-ochee-king-sungai-baong-2810101> (Accessed: 3 December 2024).
- da Costa, M.V.A. et al. (2021) 'UltraBrix: A device for measuring the soluble solids content in sugarcane', *Sustainability (Switzerland)*, 13(3), pp. 1–19. Available at: <https://doi.org/10.3390/su13031227>.
- Deltron (2024) SpekSense: AI fruit sorting technology from Deltron. Available at: https://www.youtube.com/watch?v=H848wKb_tI (Accessed: 4 December 2024).
- Department of Agriculture Malaysia (2021) SENARAI DAFTAR VARIETI TANAMANJABATAN PERTANIAN MALAYSIA. Putrajaya, Malaysia: Department of Agriculture Malaysia. Available at: https://epengembangan.doa.gov.my/tanaman/buah-buahan/durian/#flipbook-df_12001/29/ (Accessed: 1 December 2024).
- Department of Agriculture Malaysia (2023a) Buku Statistik Tanaman (Sub-Sektor Tanaman Makanan). Putrajaya, Malaysia: Department of Agriculture Malaysia.

- Department of Agriculture Malaysia (2023b) Senarai Varieti Tanaman SPBT (Lampiran 6). Available at: https://www.doa.gov.my/doa/resources/perkhidmatan/skim_pensijilan/SPBT/senarai_varieti_nov2023.pdf (Accessed: 1 December 2024).
- Department of Agriculture Malaysia (2023c) Skim Pengesahan Bahan Tanaman. Available at: <https://www.doa.gov.my/index.php/pages/view/399> (Accessed: 1 December 2024).
- Department of Agriculture Malaysia (2024a) GUIDELINES - DURIAN (FRESH FRUIT) EXPORT TO CHINA: FLOW OF FRESH DURIAN PROCESSING FOR EXPORT. Available at: https://www.kpkm.gov.my/images/11-soalan-lazim/eksport_komoditi/FLOW%20OF%20FRESH%20DURIAN%20PROCESSING%20FOR%20EXPORT.pdf (Accessed: 1 December 2024).
- Department of Agriculture Malaysia (2024b) Malaysian Phytosanitary Certification System. Available at: <http://myphyto.gov.my/EV2022> (Accessed: 1 December 2024).
- FAO (2023) Durian Global Trade Overview 2023. Rome, Italy. Available at: www.fao.org/economic/est/est_commodities/tropical-fruits (Accessed: 30 November 2024).
- FAO (2024a) Major Tropical Fruits: Market Review Preliminary Results 2023. Rome, Italy. Available at: <https://www.fao.org/markets-and-trade/commodities/tropical-fruits> (Accessed: 30 November 2024).
- FAO (2024b) Minor Tropical Fruits: Global Trade Overview 2024. Rome, Italy. Available at: <https://www.fao.org/markets-and-trade/commodities/tropical-fruits> (Accessed: 30 November 2024).
- Feng, Z., Ruiz-Rodríguez, A. and Palma, M. (2024) 'Sweet Red Wine Production: Effects of Fermentation Stages and Ultrasound Technology on Wine Characteristics', *Applied Sciences (Switzerland)*, 14(19). Available at: <https://doi.org/10.3390/app14198864>.
- FstSort (2019) Auto Fruit air blower cleaning. Available at: <https://fruitprocess.com/en-us/fruit-processing-line/avocado-washing-drying-waxing-grading-line> (Accessed: 4 December 2024).
- Global Information, Inc. (GII) (2024) Fresh Durian - Market Share Analysis, Industry Trends & Statistics.
- Growth Forecasts (2024 - 2029). Kanagawa, Japan. Available at: <https://www.giiresearch.com/report/moi1439768-fresh-durian-market-share-analysis-industry-trends.html> (Accessed: 30 November 2024).
- Indiarto, R., Izzati, A.N. and Djali, M. (2020) 'Post-Harvest Handling Technologies of Tropical Fruits: A Review', *International Journal of Emerging Trends in Engineering Research*, 8(7), pp. 3951-3957. Available at: <https://doi.org/10.30534/ijeter/2020/165872020>.
- Jaspreet Aulakh and Anita Regmi (2013) 'POST-HARVEST FOOD LOSSES ESTIMATION DEVELOPMENT OF CONSISTENT METHODOLOGY', *Agricultural and Food Sciences, Environmental Science* [Preprint]. Available at: <http://faostat.fao.org/site/354/default.aspx>.
- Kader, A.A. (2013) 'Postharvest Technology of Horticultural Crops-An Overview from Farm to Fork', *J. Appl. Sci. Technol. (Special Issue, 1)*, pp. 1-8.
- Kalopesa, E. et al. (2023) 'Rapid Determination of Wine Grape Maturity Level from pH, Titratable Acidity, and Sugar Content Using Non-Destructive In Situ Infrared Spectroscopy and Multi-Head Attention Convolutional Neural Networks', *Sensors*, 23(23). Available at: <https://doi.org/10.3390/s23239536>.
- Kavitha, R. and Prusty, R. (2024) 'Processing and Value Addition to Alleviate Post Harvest Losses in Fruits Central Institute of Temperate Horticulture', in Ch., Srinivasa Rao, N.A., Vijay Avinashilingam, and B.S.
- Yashavanth (eds) *Research and Technological Advances for Resilient Agriculture*. Hyderabad, India: ICAR National Academy of Agricultural Research Management. Available at: <https://www.researchgate.net/publication/383038573>.
- Ketsa, S. et al. (2020) 'The durian: Botany, horticulture, and utilization', in Ian Warrington (ed.) *Horticultural Reviews*. John Wiley & Sons, Inc., pp. 125-211. Available at: <https://doi.org/10.1002/9781119625407.ch4>.

- Kim, J. et al. (2022) 'Non-Destructive Detection of Abnormal Chicken Eggs by Using an Optimized Spectral Analysis System', *Sensors*, 22(24). Available at: <https://doi.org/10.3390/s22249826>.
- Kitinoja, L. and Kader, A.A. (2004) *Small-Scale Postharvest Handling Practices: A Manual for Horticultural Crops* (4th Edition). Available at: <https://www.fao.org/4/ae075e/ae075e00.htm>.
- Liu, Y., Pu, H. and Sun, D.-W. (2017) 'Hyperspectral imaging technique for evaluating food quality and safety during various processes: A review of recent applications', *Trends in Food Science & Technology*, 69 (Part A). Available at: <https://doi.org/10.1016/j.tifs.2017.08.013Get>.
- Luning, P.A. and Marcelis, W.J. (2007) 'A conceptual model of food quality management functions based on a techno-managerial approach', *Trends in Food Science and Technology. Elsevier Ltd*, pp. 159–166. Available at: <https://doi.org/10.1016/j.tifs.2006.10.021>.
- Luning, Pieter A. and Marcelis, W.J. (2009) 'A food quality management research methodology integrating technological and managerial theories', *Trends in Food Science & Technology*, 20(1), pp. 35–44. Available at: <https://doi.org/10.1016/j.tifs.2008.09.013>.
- Luning, Pieter A. and Marcelis, W.J. (2009) *Food Quality Management: Technological and Managerial Principles and Practices*. The Netherlands: Wageningen Academic.
- Mahayadin, A.R. (2023) MTE 2021 Portable Non-Destructive Internal Fruit Defect Detection System (Harumanis). Available at: <https://www.youtube.com/watch?v=a8AGtM3ejtI> (Accessed: 4 December 2024).
- Mohd Atar, N. (2024) Durian mentega dinobat juara, paling umphh..., KOSMO. Available at: <https://www.kosmo.com.my/2024/08/17/durian-mentega-dinobat-juara-kalahkan-udang-bantal/> (Accessed: 23 December 2024).
- Mohd Shah, L. (2009) *SOURCES OF VARIATIONS AFFECTING QUALITY OF TROPICAL AND SUBTROPICAL FRUITS ALONG THE SUPPLY CHAIN*. Wageningen, The Netherlands.
- Mohd Shah, L. (2016) *Instrumental and Ultrasonic Techniques in Quality Evaluation of Fresh Fruit and Vegetables*. Leeds, UK. Available at: https://etheses.whiterose.ac.uk/16193/1/MOHD%20SHAH_L.B._FOOD%20SCIENCE%20%26%20NUTRITION_PhD_2016.pdf (Accessed: 1 December 2024).
- Mohd Shah, L. and Mazlan, M.A.H. (2024) The Interviews with the Durian Exporters in Bentong and Raub, Pahang on Current Post-Harvest Technologies and Practices at their Facilities.
- Musa, R. et al. (2010) 'Examining market accessibility of Malaysia's Harumanis mango in Japan: challenges and potentials', in A. Lewis (ed.) *Business Strategy Series*. Emerald Group Publishing Limited.
- Parmar, R. (2024) 'Postharvest Technology and Value Addition', in Narinder Panotra et al. (eds) *Agriculture and Horticulture in India*. 1st edn. Uttar Pradesh, India: ND GLOBAL PUBLICATIONHOUSE. Available at: <https://www.researchgate.net/publication/380426360>.
- Pediktera (2020) Breeze Release realtime. Available at: <https://www.youtube.com/watch?v=F2ywwCVrkuw> (Accessed: 4 December 2024).
- Pieter A. Luning and Willem J. Marcelis (2020) *Food quality management: Technological and managerial principles and practices*. Wageningen Academic Publishers.
- Plantations International (2018) *Durian Global Market Report*. Kuala Lumpur, Malaysia. Available at: www.PlantationsInternational.com.
- Rozana, N. (2017) Competitiveness of Malaysia's Fruits in the Global Market: Revealed Comparative Advantage Analysis, *Malaysian Journal of Mathematical Sciences*.
- Safari, S. et al. (2021) 'From farm to China: A case study of Malaysian frozen whole durian export supply chain (Dari ladang ke China: Kajian kes rantaian bekalan eksport durian sejuk beku Malaysia dan bentuk biji)', *Economic and Technology Management Review*, 16, pp. 1–20.

- Salleh, N.M. et al. (2023) 'Development of Harumanis Mango Insidious Fruit Rot (IFR) Detection by Utilising Vibration-Based Sensors and PCA with Random Forest', *Journal of Physics: Conference Series*, 2641(1). Available at: <https://doi.org/10.1088/1742-6596/2641/1/012013>.
- Science (2023) Egg Production Farm - What's Inside an Egg (Egg Factory). Available at: <https://www.youtube.com/watch?v=rsuY7tqqg1E> (Accessed: 4 December 2024).
- Shamin-Shazwan, K. et al. (2022) 'A REVIEW: POTENTIAL OF *DURIO ZIBETHINUS* L. (DURIAN) WASTE', *Science Heritage Journal*, 6(1), pp. 21–26. Available at: <https://doi.org/10.26480/gws.01.2022.21.26>.
- Small Farmers' Agri-Business Consortium India (2022) *Post-Harvest Handling Protocol for Fruits & Vegetables*. New Delhi, India.
- Tang, W., Hu, J. and Wang, Q. (2022) 'High-Throughput Online Visual Detection Method of Cracked Preserved Eggs Based on Deep Learning', *Applied Sciences (Switzerland)*, 12(3). Available at: <https://doi.org/10.3390/app12030952>.
- The Business Research Company (2024) 'Tropical Fruits Global Market Report 2024'. Available at: <https://www.thebusinessresearchcompany.com/report/tropical-fruits-global-market-report> (Accessed: 30 November 2024).
- The Global Times (2024) 'First shipment of fresh Malaysian durians arrives in China, highlighting growing China-ASEAN'.
- The Star (2024) 'Durian diplomacy: Premier Li salutes Malaysia-China's shared resilience, marks 50 years of fruitful relations.' Available at: <https://www.thestar.com.my/news/nation/2024/06/19/durian-diplomacypremier-li-salutes-malaysia-chinas-shared-resilience-marks-50-years-of-fruitful-relations> (Accessed: 2 December 2024).
- The Sun (2023) Japan's PM tries durian for the first time during his visit to Malaysia and loved it. Available at: <https://thesun.my/style-life/going-viral/japan-s-pm-tries-durian-for-the-first-time-during-his-visit-to-malaysia-and-loved-it-IC11750923> (Accessed: 2 December 2024).
- 'Tropical Fruits Global Market Report 2024' (no date).
- Underhill, S. and Kumar, S. (2017) 'Postharvest Handling of Tropical Fruits in the South Pacific', in *International Symposium on Tropical Fruits*. Nadi, Fiji.
- Wong, K., Motomura, S. and Paull, R.E. (2018) 'Postharvest Handling and Food Safety-Layers of Protection', *Food Safety and Technology [Preprint]*, (66). Available at: <https://www.fda.gov/Food/>.
- Yang, B. et al. (2020) 'Computers and Electronics in Agriculture A portable, low-cost and sensor-based detector on sweetness and firmness grades of kiwifruit', 179. Available at: <https://doi.org/10.1016/j.compag.2020.105831Get>.
- Zakaria, N.S. et al. (2021) 'Potential of Near-Infrared (NIR) spectroscopy technique for early detection of Insidious Fruit Rot (IFR) disease in Harumanis mango', in *Journal of Physics: Conference Series*. IOP Publishing Ltd. Available at: <https://doi.org/10.1088/1742-6596/2107/1/012014>.

POSTHARVEST LOSSES OF TROPICAL FRUITS IN PACIFIC ISLAND COUNTRIES

Shalendra Prasad^{1,*} and Steven J.R. Underhill²

¹Ministry of Agriculture & Waterways, Koronivia Research Station, Nausori, Fiji.

²Australian Center for Pacific Island Research, University of the Sunshine Coast, Australia.

Shalendra.prasad@govnet.gov.fj

Horticultural small-holder farmers and market vendors in tropical regions often incur high levels of postharvest loss. As domestic tropical fruit production has increased globally, so too has postharvest loss. The United Nations FAO SAVE FOOD initiative reported that fruit and vegetable loss of up to 45% of gross farm-gate production. Other authors have reported global losses of 30 to 50%, or about 1.3 billion tonnes. Postharvest loss not only equates to a loss of edible food, but an ineffectual use of critical farm inputs such as fertilizer, irrigation water, land, planting materials, energy and human labour. High postharvest loss often disincentivizes small-holder farmers from increasing production, undermining efforts to improve rural communities and build sustainable tropical fruit exports.

Postharvest horticultural value chains involve a series of critical points, including harvesting, grading, storage and transportation, each of which can adversely impact on product quality and shelf life. Tropical fruit value chains, particularly those in the Pacific region, often lack postharvest infrastructure, have limited or ineffective cool chain management, poor transport logistics, and are vulnerable to natural disasters.

Reducing tropical fruit postharvest loss, benefits farmers and vendors and contributes to food systems sustainability and regional food security. Horticultural loss can be reduced through the adoption of improved production practice including better performing cultivars, pest and disease control, increased chain coordination. This paper discusses tropical fruit postharvest loss in the Pacific, its contributors and potential pathways to reduce these losses.

LOW PROCESSING TECHNOLOGY FOR SMALL SCALE PROCESSOR FOR SUSTAINABLE TROPICAL FRUIT INDUSTRY IN INDONESIA

Setyadjit, Ellina Mansyah, Taufik Hidayat

Research Center for Agroindustry, Research Center for Horticulture

Indonesia is a large country with a population of 283,487,931 replete with a significant diversity of tropical fruits for domestic consumption and export potential. Tropical fruit supply is usually abundant during the season but very limited in the off-season, which leads to increased market prices. However, prices are much lower during October, November, and December, when many of the fruits are in season. Even under normal production conditions, about 20-30% of tropical fruit produced are considered off-grades for the fresh market, though this number has been gradually decreasing. This paper aims to look at the development of low-cost processing technology for tropical fruit in Indonesia, focussing on two important fruit types: mangoes and bananas. In the development of processing techniques, the research follows a cycle that includes laboratory scale, scaling up (using machinery), and model technology. The full cycle takes three years to complete. During model development, it is essential to involve a "champion," meaning a resolute, forerunning focal point or expert, which could be a private company, farmer group, or small processor. The champion will bring forward the technology to the commercial scale and market. For mangoes, processing technologies for mango puree and mango juice were introduced. Based on technical processes outlined in a report, the processing model was implemented by a small processor in Cirebon, West Java, in 2003. A collaborative scheme was developed to ensure the presence of a champion in its development. Additionally, technology was developed to process unmarketable mangoes to detect the presence of resorcinol, a disease-resistant compound in mangoes. The extract has potential to treat anthracnose-like diseases and is more efficient compared to benomyl. However, this extract still needs improvement in its formulation to widen its spectrum. The second commodity is bananas. Bananas can be classified into plantains (Kapas, Tanduk), cooking bananas (Kepok, Uli), and table bananas (Gross Mitchell, Cavendish, Pisang Raja). Unripe bananas contain very high starch content and low acidity, which converts to sugar during ripening. They can be processed into various products such as flour, noodles, banana crisps, banana yogurt, banana artificial rice, and more. For low-cost processing to help reduce waste and stabilize tropical fruit prices in the market, there must be high demand or highly profitable techniques. Additionally, efficient machinery is necessary to ensure production efficiency. Finally, a champion is required to bring the technology to the broader market and society.

Keywords: Indonesia, low processing technology, added value, champion

POSTHARVEST CHALLENGES OF TROPICAL FRUITS IN ARID AND SEMIARID REGIONS

Hassan M. Ali-Dinar

King Faisal University, Saudi Arabia

The environmental diversity within the eco-zones of certain arid and semiarid regions of the world, often leads to successful cultivation and production of many tropical fruit crops. Considering regions that include countries like Saudi Arabia, Sultanate of Oman, Egypt and certain parts of Sudan, key fruits such as mango thrive very well despite the limited resources, particularly water scarcity. However, many challenges and constraints encounter the production chain of these crops. Specifically, the key postharvest challenges in these regions include the extreme high temperatures, quality management of harvested fruits, transportation and handling, proper storage facilities, proper marketing channels, price volatility, and postharvest diseases. The dominant of all is the limited awareness and knowledge of fruit growers with the proper harvest and postharvest handling approaches. It is worth mentioning that these constraints often lead the fruit growers to the selection of certain varieties that have limited resilience to the harsh environmental conditions of these arid and semiarid regions.

POSTHARVEST PROCEDURE FOR MALAYSIAN DURIAN TO CHINA BY AIR SHIPMENT

Nur Azlin Razali^{1*}, Suhana Yusof¹, Siti Aisyah Abdullah¹, Wan Mohd Reza Ikwan Wan Hussin¹, Suhana Safari², Nik Rozana Nik Masdek², Nurul Khdiyah Rosly¹, Farah Aqila Hamzah¹ and Muhammad Rusydi Sarifhudin¹

¹Horticulture Research Centre, Malaysian Agricultural Research and Development Institute (MARDI), MARDI Headquarters, Persiaran MARDI-UPM, 43400 Serdang, Selangor, Malaysia.

²Socio Economic, Market Intelligence and Agribusiness Research Centre, Malaysian Agricultural Research & Development Institute (MARDI), Persiaran MARDI-UPM, 43400 Serdang, Selangor, Malaysia.

nurazlin@mardi.gov.my

Malaysia received authorization to export fresh durian to The Republic of China on June 19, 2024, necessitating a robust postharvest procedure to ensure product quality during transport. The Malaysian Agricultural Research and Development Institute (MARDI) developed a comprehensive postharvest procedure incorporating advanced packaging and pre-cooling techniques, followed by cold storage, to optimize the preservation of durians. This procedure utilizes low-density polyethylene (LDPE) packaging with a thickness of 0.04 mm to extend the fruit's storage life, and pre-cooling to mitigate the risk of quarantine pests. A simulation study was conducted to validate the efficacy of this method under controlled cold chain conditions (7-10°C). During sample preparation, the quarantine pest, *Planococcus minor* (Maskel) (Hemiptera: Pseudococcidae) were identified. Through the application of meticulous postharvest handling procedures, including airbrush cleaning and pre-cooling treatments, the pest mortality rate achieved at 100% within 12 hours. After 48 hours, the quality evaluation of the durian samples revealed no significant changes in colour, soluble solids content, or total titratable acidity compared to freshly harvested fruit, indicating that the durians remained in excellent condition. These results are pivotal for developing a standard operating procedure (SOP) for exporting fresh durian to China. The proposed handling and storage techniques ensure that Malaysian durians are safe, high-quality, and maintain their premium status throughout the export process.

Keywords: cold storage, fruit quality, pre-cooling, quarantine, simulation study

1. INTRODUCTION

The Malaysian durian industry has shown significant growth in production and export value in recent years. The self-sufficiency rate reached 103.9% in 2023, indicating that the industry is capable of meeting both domestic and export demand (Department of Statistics Malaysia, 2024). On average, a Malaysian consumes 16.6 kg of durian per year (2023), with a 39% increase in usage compared to 2022. In 2023, fruit production in Malaysia increased compared to the previous year, with durian recording the highest rise at 136.6 thousand tonnes. This increase in production is expected to enhance the supply of local durians for both domestic and export markets.

Malaysia has been exporting durians to several nations, including not only China but also Singapore, Indonesia, and Hong Kong. These four countries are prominently ranked as the leading importers of Malaysian durians (Yusof, 2020). Malaysia exported US\$36.3 million worth of frozen durians to China in 2018 (Ariffin and Tang, 2024). This rose seven-fold to US\$260 million 2023 by using cryogenic freezing technology developed by MARDI (Nur Azlin et al.,

2020b). Consequently, durian exportation to China has evolved from being a secondary income source to a pivotal profit generator. This growth in the durian industry has created fresh employment opportunities, thereby contributing to the overall economic boost of the country. In June 2024, Malaysia received the green light to export fresh durians to China, after Chinese Premier Li Qiang met Malaysian Prime Minister Anwar Ibrahim in Kuala Lumpur to commemorate 50 years of diplomatic relations. The benefits of exporting fresh durians to China are that Malaysian durian will become available directly in fresh form in Chinese market. This will introduce more varieties of Malaysian premium durian, inspire more local entrepreneurs to invest in agribusiness and encourages farmers to adopt better farming practices and improve the quality of their products.

The postharvest loss of durian is a crucial problem that needs to be solved as this commodity has high commercial value, especially the Musang King (D197) variety. The loss happens because the shelf life is very short when stored at ambient conditions without any packaging (Nur Azlin et al., 2020a). For export purposes, durian needs external protection to avoid dehiscence (splitting) of the fruit. Low-density polyethylene (LDPE) packaging can be used as it comes in many types and thicknesses. It can provide advantages if the plastic and thickness are correctly selected.

To compete effectively in the global market, it is essential to implement advanced postharvest handling and storage techniques to maintain the premium quality of Malaysian durians. Malaysian Agricultural Research and Development Institute (MARDI) had developed a combination technique of packaging and cold storage for extending shelf life of fresh durian (CRLY2022W02967) (Razali et al., 2020). This technology suitable to be adopted in supply chain management of fresh durian for export market either by air or sea shipment. Additionally, this cold treatment method has been proven to be an effective and potential postharvest phytosanitary treatment for the disinfestation of most quarantine pests, including mealybugs, for export purposes (Hofman et al., 2003). Therefore, a simulation study was conducted under controlled cold chain conditions (7-10°C) to validate the efficacy of this method.

2. MATERIALS AND METHODS

This study employed a comprehensive postharvest procedure incorporating specific LDPE packaging thickness and pre-cooling techniques at 7°C. Durian fruit involving Musang King (D197), Black Thorn (D200), and D24 variety (n=90) was arrived at the Postharvest Complex, MARDI Serdang, sorted to discard those with any obvious signs of dehiscence as well as any visual defects. The fruit were randomised into two groups of treatments: no-packaging (control) and shrink-wrapped (LDPE plastic bag, 0.04 mm), and were all precooled at 7°C. Low-density polyethylene (LDPE) packaging with a thickness of 0.04 mm was utilized to extend the fruit's storage life, vacuum-packed was acted as commercial practice while pre-cooling was applied to mitigate quarantine pest risks.

The fruit were analysed initially and after 12-, 24- and 48-hours after precooling for target pest incidence. Emphasis was placed on 7 quarantine pests listed by the Chinese side; (*Dysmicoccus neobrevipes* (Grey Pineapple Mealybug), *Planococcus minor* (Passionvine Mealybug), *Planococcus lilacinus* (Coffee Mealybug), *Icerya pulchra* (scale insect), *Mudaria luteileprosa* (Durian seed borer), *Rastrococcus iceryoides* (Mango Mealybug) and *Albonectria rigidiuscula* (Green Point Gall: Fungus).

For quality evaluation, each fruit was assessed for any red lesions, dehiscence incidence (yes or

no) and overall acceptability rating. Total titratable acidity was measured by titrating a known volume of homogenates solution with 0.1 N NaOH to an endpoint of pH 8.1 using a digital burette. Total soluble solids (TSS) were determined by a digital refractometer (ATAGO RX-5000, ATAGO, Japan). Percentage of moisture content (durian husk) was measured by weighing a sample of the durian husk before and after drying it in an oven at a set temperature, then calculating the difference in weight as the moisture content.

3. RESULTS AND DISCUSSION

A simulation study was conducted to validate the efficacy of this method under controlled cold chain conditions (7-10°C). During sample preparation, one species of quarantine pest was identified on all durian varieties (26%). The quarantine pest identified as *Planococcus minor*, which is a mealy bug insect that is indeed common in durians in Malaysia. After going through meticulous postharvest handling, including airbrush cleaning and pre-cooling, the pest mortality rate reached 100% within 12 hours at pre-cooling treatment of 7°C.

Quality evaluation conducted after 48 hours showed no significant changes in soluble solids content, total titratable acidity and percentage of moisture content between treatments. However, Musang King without packaging was reported cracked after 48hrs (n=10), due to moisture loss. No cracked Musang King durian was found in packaged fruit. These results confirm that the postharvest procedure effectively maintains fruit quality, ensuring premium condition for export. These results are pivotal for developing a standard operating procedure (SOP) for exporting fresh durian to China. The proposed handling and storage techniques ensure that Malaysian durians are safe, high-quality, and maintain their premium status throughout the export process.

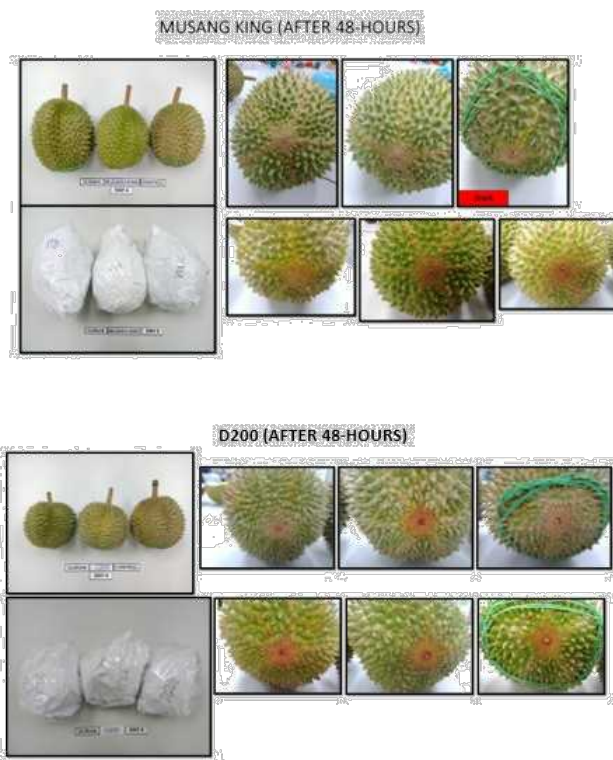




Figure 1. Overall appearance of Musang King (D197), Black Thorn (D200) and D24 durian after 48 hours pre-cooling.

Table 1. Soluble Solids Content, Total Titratable Acidity and Moisture Content of different durian variety with or without LDPE packaging and pre-cooled at 7°C.

Treatment	Soluble Solids Content (°Brix)	Total Titratable Acidity (%)	Moisture Content (%)
TRT1 : D197 durian (control)	44.20±1.12a	0.04±0.01a	56.39±2.12a
TRT2 : D197 durian (LDPE packaging)	37.20±2.78a	0.05±0.00a	55.19±1.00a
TRT 3 : D200 durian (control)	35.00±1.00a	0.03±0.01a	60.55±0.66a
TRT 4: D200 durian (LDPE packaging)	35.40±2.18a	0.06±0.01a	57.97±0.32a
TRT 5 : D24 durian (control)	35.67±1.20a	0.04±0.01a	59.50±0.65a
TRT 6 : D24 durian (LDPE packaging)	35.50±1.75a	0.07±0.01a	61.87±0.28a

4. CONCLUSION

The developed postharvest procedure effectively preserves the quality of Malaysian durians during air shipment to China, ensuring premium fruit condition. By utilizing LDPE packaging and pre-cooling techniques, the procedure mitigates quarantine pest risks while maintaining product quality. These findings support the establishment of a standard operating procedure for exporting fresh durian, contributing to the growth of Malaysia’s durian export industry.

Acknowledgement

Sincere appreciation to Malaysian Agricultural Research and Development Institute (MARDI) for supporting this research through RMK-11; P-RH405 and The Federal Agricultural Marketing Authority (FAMA).

REFERENCES

- Ariffin, A. and Tang, L. (2024). Durian farmers in Malaysia vie to offer more premium varieties to hungry Chinese consumers. Retrieved from CNA: <https://www.channelnewsasia.com/asia/malaysia-durian-farmers-china-demand-consumers-offer-premium-varieties-4651501#:~:text=Demand%20for%20the%20pungent%20delicacy,cent%20of%20its%20total%20exports>.
- Department of Statistics Malaysia. (2024). *Supply and utilization accounts selected agricultural commodities Malaysia 2019-2023*. Department of Statistics Malaysia, Putrajaya, Malaysia.
- Hofman, P.J, Stubbings, B.A., Adkins, M.F., Corcoran, R.J., White, A., Woolf, A.B. (2003). Low temperature conditioning before cold disinfestation improves 'Hass' avocado fruit quality. *Postharvest Biology and Technology*. 28 (Issue 1): 123-133.
- Nur Azlin, R., Nurul Khdiyah, R., Farah Aqila, H., Siti Aisyah, A., Wan Mohd Reza Ikwan, W.H. & Suhana, S. (2020a). Optimum Storage Temperature of Mature Drop Durian (*Durio zibethinus* CV. Musang King). *International Journal of Agriculture, Forestry and Plantation*, 10, 267-273.
- Nur Azlin, R., Siti Aisyah, A., Wan Mahfuzah, W.I & Wan Mohd Reza Ikwan, W.H. (2020b). Package technology for exporting premium whole 'musang king' durian by cryogenic freezing. *Proceeding -9th Kuala Lumpur International Agriculture, Forestry and Plantation Conference (KLIAFP9)*, 27-34.
- Razali, N.A., Zain, Z.M., Mustaffa, R., Mohamad, H., Tham, S.L., & Abdullah, S.A. (2020). Shrink-wrap packaging extend the storage life of mature-dropped durian. *International Journal of Applied Science and Engineering*, 17, 325-330.
- Yusof, A. (2020, February 07). Malaysia's Durian Industry Stung by Low Prices as Coronavirus Outbreak Affects Demand from China. Retrieved from CNA: <https://www.channelnewsasia.com/news/asia/malaysia-wuhan-coronavirus-durian-china-demand-musang-king-12404526>

QUALITY ASSESSMENT OF COMMERCIAL DRIED BANANA PRODUCTS CONSUMED IN SULTANATE OF OMAN

Iman Al Rawas¹, Mohammed Al Rizeiqi^{1,2}, Zahra Al Kharusi¹, Pankaj Pathare², Atheer Al Maqbali¹, Imran Khan¹, Mazin Al Baroumi¹

¹ College of Agricultural and Marine Sciences, Sultan Qaboos University, Oman

² Innovation and Technology Transfer Center, Sultan Qaboos University, Oman

ruzeiki@squ.edu.om

Banana fruit is regarded as a long-standing cultural history in Sultanate of Oman (simply Oman) cultivated in many of the coastal areas including Al Batinah and Dhofar governorates. It is considered one of Oman's most popular fruits due to both taste preferences within society and nutritional quality of the products. The production of bananas in Oman was estimated to be 18,432 tons in 2023. This study aims to assess the microbiological, physicochemical, and visual quality of commercial dried banana products available in the Omani market. The study has used four commercially available dried banana products purchased from the local market in Al Seeb. The study applies AOAC method for chemical analysis and ISO17025 methods for microbial enumeration. The study found that there is a significant difference in terms of total microbial counts, total fungal counts, total *Enterobacteriaceae* counts as well as physicochemical properties of the commercial dried banana products consumed in Oman using Kruskal Wallis ($p < 0.05$). Most study samples were compiled to food safety regulatory standards in Oman except for one sample that has a higher fungus count on PDA growth medium. The study is useful in assessing the safety and conformity scientific assessment of the dried banana products consumed in Oman as well as the best possible drying practices to maintain the quality attributes of the products on shelf.

Keywords: Drying, Banana, Physicochemical, Microbial, Oman

1. INTRODUCTION

Banana (*Musa* spp.) product is known as one of the most consumed fruits around the world as having a high nutritional value and good market value for consumers (FAO, 2022). The nutritional importance of bananas lies in their high amounts of carbohydrates (sugars), dietary fiber, minerals and vitamins in addition to being a suitable source of potassium and Vitamin C (Abd El-Wahhab, 2023). The presence of nutrients such as dietary fiber is an important health factor as it promotes the health of the digestive system, as well as the presence of potassium promotes cardiovascular health. Thus, the importance of the healthy product of banana goes beyond being a food source to being a therapeutic source to alleviate the severity of diseases associated with high blood pressure and also reduce the probability of some diseases such as stroke, some type of cancers and age-related diseases (Siddiq Muhammad, 2020). Together with consumer acceptance, the consumption of bananas is of paramount importance to both developed and developing countries alike. The global output of bananas and their products is approximately 135.11 million metric tons, according to FAO statistics (FAO, 2022). In Sultanate of Oman, banana cultivation occupies the second fruit cultivar after the cultivation and production of dates, especially in the southern regions of Dhofar Governorate as well as in Al Batinah Governorate in the North. Oman occupies the first place in the Gulf Cooperation Council states in terms of production of bananas which is nearly 18,400 metric tons, as stated by the Ministry of Agriculture, Fisheries Wealth and Water Resources (MoAF, 2023). Thus, the economic importance of the banana product to Oman is to enhance the terms of trade balance

associated with various banana products and the export potential for the product to other GCC countries.

Banana contains a high percentage of water (%moisture) that may reach 80%, which means that it is a fast-spoiling perishable product, both by bacteria and also by fungi (Abd El-Wahhab, 2023). Muhammed Siddiq indicated that the water content is nearly 75% and total carbohydrates was 22.84% (Siddiq Muhammad, 2020). The drying process is an important process in preserving banana products. It is widely used by different communities around the world due to the cost and efficiency of the process in preserving bananas. There are different drying processes that are used to preserve the banana product, including direct sun drying using solar radiation as well as drying using different other methods such as conventional air-drying system, vacuum drying, microwave oven drying and freeze-drying methods (Marinez S. et al., 2024). All these methods aim to reduce the amount of water present in the banana product and improve value added without significantly damaging nutrients, color and taste. This paper aims to assess the safety and the quality of dried banana products purchased in the Omani local market. The study also aims to examine the extent to which these dried banana products meet the specifications and standards associated with the dried fruits available and consumed in the Omani market.

2. METHODOLOGY

Four types of dried banana products were purchased from Oman local market in Al Seeb. These products were numbered using codes "A, B, C, D" with details of these products in terms of weight, source (country of origin) and information available on the labelling (packaging) for the later use. Three samples in triplicate of each product (N=3) were taken for the microbiology laboratory for microbial assessment as well as three other samples from each brand (or product) for Physicochemical assessment. The samples were tested for the level of fungi and yeasts using Potato Dextrose Agar medium (PDA), Total Bacterial Counts using Tryptic Soy Agar (TSA), total Coliforms using Violet Red Bile Agar (VRBA), and total *Enterobacteriaceae* count using Violet Red Bile Lactose Agar (VRBL) using spreading method. Several dilutions (10⁻¹, 10⁻², 10⁻³ and 10⁻⁴) to the sample concentration were made to facilitate the calculation of the total number of microbes present in the original sample using colony forming units per 1 gram of dried banana sample. All petri dishes were then incubated at 37°C for 1-3 days for microbial counts and 5-7 days at 25 °C for fungal counts. The lab scale colony counter was used to manually count the colony forming units from each petri dish. The second part of the analysis was to assess the physico-chemical parameters. This was used to test the triplicate samples for %moisture content using a gravimetric method in the oven at 105 °C for 24 hours (AOAC, 1990) and colorimetric method to test for color L, a, and b (Minolta, USA). All data were collected, tabulated and statistically analyzed using STATA Corp 2018 at a significant level of $p < 0.05$ (Stata Corp, 2023).

3. RESEARCH FINDINGS

The study conducted was for the assessment of the microbial and physico-chemical parameters of four different brand products (A, B, C & D) of dried bananas purchased from the Omani local market in AL Seeb (Figure.1).

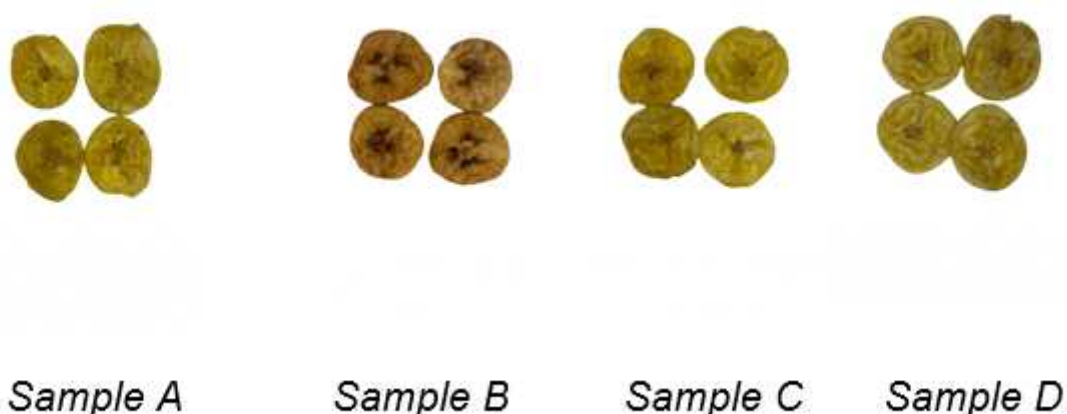


Figure.1 Study samples as coded indicating yellow color (+b) appearance for dried banana

The result in Table.1 had shown that Product Brand (A) contained the largest number of total bacterial count bacteria at the level of 2.01×10^3 cfu/gram but the cfu figure per gram of sample was still within the permissible allowable limit frameworks according to the Gulf specifications (GXG, 2010) . The results also showed that the product brand B contained the largest number of fungus at a level of 1.43×10^4 cfu/gram, which exceeded the allowable limits in the Gulf Standardization and Omani standard. Product brand (D) has the highest number of *Enterobacteriaceae* of 3.33×10^5 and zero coliform counts were detected in all the four sample products.

Table.1 Microbial Assessment (cfu) for dried banana samples

Dried Banana Products Code	Total Bacterial Count /gram of Sample	Total Fungal Count/ gram of Sample	Total Enterobacteriaceae Counts per gram of sample
Product Coded A	2.08×10^3 a	1.91×10^3 a	0 cfu/ga
Product Coded B	5.83×10^2 b	1.43×10^4 a	0 cfu/ga
Product Coded C	9.44×10^2 b	2.74×10^3 a	3.33×10^1 b
Product Coded D	1.09×10^3 a	1.02×10^4 b	3.33×10^5 c

The study has shown that all products contained moisture contents between 25%-29% which are less than 30% moisture content as shown . The dried product moisture content is essential to maintain the shelf life of the product for a longer duration. In Table.2, the results had shown that the yellow color (+b) was present in a larger amount in product D and less in product B (Table.2). The color figures represent the available polyphenols and flavonoids compounds in fruits as an indication of the health part. It depends on the drying method used, which is usually due to the thermal effect on the sugar and amino acids present in the banana product of Milliard reaction (Martins, Jongen, & van Boekel, 2000). Table 3 also shows the purity and consistency of the available color as indicated in Chroma and Hue values of the table. The hue value was significantly different in product B of the study as a less saturated yellow color compared to the other three samples.

Table.2 Color Assessment for dried banana samples used L, a & b

Samples	a+	b+	L	Chroma	Hue
Product Coded A	2.09±0.78 ^a	46.79±2.31 ^a	60.20±1.88 ^a	47.00±2.00 ^a	97.23±1.32 ^a
Product Coded B	11.05±0.75 ^b	29.07±2.31 ^b	53.23±1.48 ^b	31.33±2.08 ^b	77.00±1.00 ^b
Product Coded C	2.23±0.77 ^a	43.07±0.85 ^a	64.40±0.83 ^a	43.00±1.00 ^b	96.50±1.32 ^a
Product Coded D	1.28±0.27 ^a	61.65±2.55 ^c	61.56±1.85 ^a	47.00±3.00 ^b	98.13±0.42 ^a

All data were tested for significant difference using STATA 18 (STATA Corp, USA). The statistical analysis showed the significance difference between the four samples A, B, C from sample D as indicated in Table 1 and Table 2 using Kruskal Wallis ($p < 0.05$).

4. CONCLUSION

Banana production in Oman is classified as a second main fruit after fresh dates production. Annual production of bananas in Oman in 2022 was estimated around 18,427 MT. This study aims to assess the conformity of the available dried banana products in Oman local market based on Codex Alimentarius Commission and Gulf Standardization Organization. Four different brands of dried banana samples A, B, C & D were evaluated for microbial safety, hygienic condition as per Codex and GSO standards implemented. The study used Microbiological and physico-chemical methods as per ISO 17025 for food testing. The study found that all the study samples showed insignificant differences for conformity except for Brand D ($p < 0.05$). The study showed that all the four brands were significantly indifferent in terms of Hue values except for sample B ($p < 0.05$) indicating the least saturation of yellow color in the sample. The study suggests assessing the impact of banana drying methods on functional properties of banana including total phenolic contents and resistant starch content. The study also suggests optimizing the solar drying method for safe and palatable products to Omani consumers and trade benefits.

ACKNOWLEDGEMENT

Authors of this proceeding paper acknowledge Sultan Qaboos University (SQU) for the funded internal grant (IG/DVC/ITTC/24/01). The authors extend their appreciation to the Department of Food Science and Nutrition and Labs in charge for the support in using Food Microbiology and Food Engineering Labs.

REFERENCES

- Abd El-Wahhab, G. G., Sayed, H. A. A., Abdelhamid, M. A., Zaghlool, A., Nasr, A., Nagib, A., Bourouah, M., Abd-ElGawad, A. M., Rashad, Y. M., Hafez, M., & Taha, I. M. (2023). Effect of Pre-Treatments on the Qualities of Banana Dried by Two Different Drying Methods. *Sustainability*, 15(20), 15112. <https://doi.org/10.3390/su152015112>
- Association of Official Analytical Chemists. (1990). Official methods of analysis of the Association of Official Analytical Chemists (15th ed.). AOAC International.
- Food and Agriculture Organization. (2022). Global banana production statistics. Retrieved from <https://www.statista.com/statistics/716037/global-banana-market-volume/>

- Ministry of Agriculture, Fisheries and Water Resources. (2023). Annual report on agricultural development. Ministry of Agriculture, Fisheries and Water Resources.
- Martins, S. I. F. S., Jongen, W. M. F., & van Boekel, M. A. J. S. (2000). A review of Maillard reaction in food and implications to kinetic modelling. *Trends in Food Science & Technology*, 11(9-10), 364-373. [https://doi.org/10.1016/S0924-2244\(01\)00022-X](https://doi.org/10.1016/S0924-2244(01)00022-X)
- Martínez, S., Roman-Chipantiza, A., Boubertakh, A., & Carballo, J. (n.d.). Banana Drying: A Review on Methods and Advances. *Food Reviews International*, 40(8), 2188-2226. <https://doi.org/10.1080/87559129.2023.2262030>
- Oman leads in banana production in GCC. Oman Observer. Available at: <https://www.omanobserver.om/article/1115302/oman/oman-leads-in-banana-production-in-gcc>
- Siddiq, M.(2020). Handbook of banana production, postharvest science, processing technology, and nutrition. John Wiley & Sons, Incorporated.
- StataCorp. (2023). Stata statistical software: 18.5. StataCorp LLC.

SUCCESSFUL APPLICATION OF POSTHARVEST TECHNOLOGY FOR EXPORTING MALAYSIAN FRESH JACKFRUIT TO CHINA

Nor Hanis Aifaa Yusoff^{1*}, Joanna Cho Lee Ying¹, Siti Nurathirah Abu Hassan², Roslina Ali², Siti Nuraihan Azmi¹, Mohd Kamal Mohd Tajuddin¹, Mohammad Abhar Akmal Hamid¹ and Nur Izzati Muhsin¹

¹Horticulture Research Centre,

²Socio Economic, Market Intelligence and Agribusiness Research Centre

Malaysian Agriculture Research & Development Institute (MARDI), MARDI Headquarter, Persiaran MARDI-UPM, 43400 Serdang, Selangor

aifa@mardi.gov.my

A whole jackfruit can be stored in the 12 °C for about 2 weeks only. Fruit rot (*Botryodiplodia theobromae*) are the most prevalent diseases that contribute significantly to the post-harvest loss of jackfruit in Malaysia. The development of rots and decay after harvest is a serious problem, particularly on fruit destined for export markets that may be stored and transported over many weeks. Malaysia signed the Fresh Jackfruit Export Agreement with China on April 1, 2023, opening up a new market. Fruit coating (EONature) is proposed for use as it is one of the best techniques to prolong the shelf life of jackfruit. The shipment of fresh J33 varieties by sea from Malaysia to China has been carried out with additional fruit coating treatment in the standard operating procedures (SOP). The objective of this study is to evaluate and improve the standard operating procedures (SOP) of J33 Malaysia for the export market to China, and secondly, to evaluate the postharvest quality of jackfruit and measure the changes in temperature and relative humidity throughout the supply chain during transportation, distribution, and also during marketing in China. In this research, for the lab scale, effect of EONature surface coating on the quality and post-harvest disease control of jackfruit during storage were studied, then for technology verification, standard operating procedure (SOP) for shipping fresh jackfruit using surface coating to China were tested. The cold-chain management during sea shipment and jackfruit quality in China were monitored. This export has proven that the standard operating procedure to export fresh jackfruit to China developed by MARDI managed to maintain the quality of the J33 which is considered premium in China. The quality of the jackfruit was still preserved even after a 2-week shipment to China. This new package technology will help expand our jackfruit in China.

Keywords: Fruit rot, shelf life, export, freshness

1. INTRODUCTION

Malaysia classifies jackfruit as a high-value tropical fruit that significantly contributes to the country's economy. The rise in jackfruit production is largely driven by a substantial increase in exports. The total export volume of jackfruit grew from 3 metric tons in 2010 to 7.3 metric tons in 2021. On average, the value of Malaysia's jackfruit exports surged from US\$14.6 million in 2015 to US\$108.8 million in 2020, reflecting an impressive 644.01% increase (Tridge, 2020). Currently, Malaysia maintains a dominant presence in the traditional Singaporean market, with over 60% of its jackfruit exports directed there in 2021. The remaining exports were distributed to the Czech Republic (8%), Hong Kong (7%), the United Kingdom (5.2%), the United Arab Emirates (5%), Germany (5%), and Australia (4.5%). Aligned with Malaysia's tropical fruit export strategy, the Ministry of Agriculture and Food Security is actively promoting tropical fruits and exploring key global markets. China has been identified as a high-potential market, and based

on Malaysia's market access status for jackfruit, the country is the third, after Thailand and Vietnam, to receive approval for exporting fresh jackfruit to China.

On April 1, 2023, Malaysia signed the Protocol of Phytosanitary Requirements for the Export of Malaysian Jackfruit to China between the Ministry of Agriculture and Food Security of Malaysia and the General Administration of Customs of the People's Republic of China during the Prime Minister's official visit to Beijing, China. This protocol signifies the official approval for the export of fresh jackfruit to China. The successful entry of Malaysian jackfruit into the Chinese market is expected to enhance the country's agricultural industry, particularly in the tropical fruit sector. However, jackfruit has a short shelf life, posing a significant challenge to the Malaysian jackfruit industry due to its high susceptibility to post-harvest deterioration. Specifically, the primary concerns for J33 jackfruit during storage include rapid ripening and post-harvest diseases, particularly black rot, caused by the fungus *Lasiodiplodia theobromae*, which is characterized by swirling black mycelium. Due to its short shelf life, the export of J33 jackfruit has traditionally been restricted to countries where the distribution period does not exceed two weeks (Cho, et al., 2020). Additionally, jackfruit is a tropical fruit that is highly susceptible to chilling injuries and disease infestation when stored below its optimum temperature (12°C).

To address these challenges, MARDI has developed a technology capable of extending the shelf life of fresh jackfruit up to three weeks. This method involves applying a surface coating using EONature liquid combined with sanitation treatments. The new approach has been acknowledged in the protocol for exporting fresh jackfruit from Malaysia to China.

Since this method has yet to be validated through simulation and initial export trials, a Standard Operating Procedure (SOP) must be developed to guide exporters in ensuring the quality of fresh jackfruit is maintained throughout the supply chain. Therefore, this study aims to compare the quality of fresh jackfruit treated with coating and sanitation methods and to develop a comprehensive SOP for handling fresh jackfruit exports to China.

2. MATERIALS AND METHODS

2.1 Sample Preparation of Fresh Jackfruit

The post-harvest handling of jackfruit was conducted at a packing house in Dulai Fruits, Johor. J33 jackfruit was harvested directly from Meadow Spring Sdn Bhd's farm in Rawang, Selangor, at a maturity stage of 90–95 days after bagging, when the skin surface appeared light green or yellowish-green. The harvesting operation spanned two days to supply 300 jackfruits for a 20-foot container.

To maintain fruit quality, the jackfruits were wrapped in plastic from the farm until they arrived at the packing house. The fruits were transported using a refrigerated truck, and upon arrival, the plastic packaging was removed in a controlled environment within the packing house.

2.2 Selection and Post-Harvest Treatment

Each jackfruit underwent visual inspection to ensure it was free from diseases and insect infestations while meeting export standards. The fruit surface was cleaned using an air blow gun. The peduncle was trimmed short, and the latex-secreting area was covered with tissue to prevent latex flow.

Next, the jackfruits were soaked and washed in a cleaning tank containing 200 parts per million (ppm) of sodium dichloroisocyanurate for 1 minute. They were then immersed in an EONature coating solution until the entire surface was covered. Before packaging, the fruits were dried using an industrial fan/blower to prevent fungal growth during storage.

2.3 Jackfruit Packaging

The jackfruits were packed in double-corrugated fibreboard boxes, with the lids securely sealed using adhesive tape. The packaged jackfruits were temporarily stored in a cold room at 12°C while awaiting transportation. For shipment, the jackfruits were placed in a cold container set at 10°C for sea transport.

2.4 Export Trial Procedure via Sea Shipment

All samples were shipped from Port Klang, Malaysia, in a 20-foot refrigerated sea container. Four temperature and relative humidity (RH) loggers (HOBO CH603, Adelaide, Australia) were placed at:

1. The top middle of the container
2. The bottom middle of the container
3. The entrance middle of the container
4. The back middle of the container

The shipment took 14 days to reach Tianjin Port, China. Upon arrival, all boxes were transferred to a warehouse at Xinfadi Wholesale Market, Beijing, before retail distribution. A random selection of 30 boxes each from the coated and non-coated jackfruit batches was delivered to the Embassy of Malaysia in Beijing for post-harvest quality evaluation.

2.5 Visual Appearance, Colour Measurement, Total Soluble Solids (TSS), and Total Titratable Acidity (TTA)

On each evaluation day, the visual appearance of individual fruits was subjectively scored for disease symptoms, browning, chilling injury, and overall acceptability (Table 1). Next, the internal quality of the jackfruit was assessed. The pulp colour was measured using a colorimeter (Minolta Chroma Meter, Model CR200, Osaka, Japan), recording L (lightness), Hue, and Chroma values* from five pulp samples per replication. The Total Soluble Solids (TSS) and Total Titratable Acidity (TTA) were measured using a digital pocket Brix-Acidity Meter (ATAGO PAL-BX, Japan).

Table 1: Visual appearance of individual fruit

Disease and chilling injury on skin surface	Overall acceptability ratings
0% = No trace	5. Excellent
<25% = Slightly affected	4. Good
16-25% = Moderately affected	3. Acceptable
25-50% = Badly affected	2. Poor
>50% = Severely affected	1. Very poor

2.6 Statistical Analysis

The statistical analysis of treatment responses was performed using Analysis of Variance (ANOVA) and Least Significant Difference (LSD) test to assess whether there were significant differences ($p < 0.05$) between the different treatments and storage durations.

3. RESULTS AND DISCUSSION

3.1 Cold-Chain Monitoring During Sea Distribution

Logger data readings indicated significant temperature fluctuations during shipment. Figure 1 shows an increase in the middle-bottom and middle-back sections of the container, with temperatures rising to 13–15°C. As a result, the average container temperature during shipment was recorded at $12.01 \pm 0.88^\circ\text{C}$, compared to the pre-departure set temperature of 10°C . The findings of this study confirm that the increase in container temperature from 10°C to an average of $12.01 \pm 0.88^\circ\text{C}$ helped prevent chilling injuries in jackfruit. This temperature rise was attributed to the respiration of the 300 jackfruits inside the container during transit. Jackfruits stored at temperatures below 12°C are prone to cold injury symptoms, including softening, tissue collapse, browning, and surface pitting. Whole fresh jackfruit is more susceptible to cold injury than jackfruit pulps, which can be safely stored at $5\text{--}6^\circ\text{C}$ (Saxena, et al., 2011).

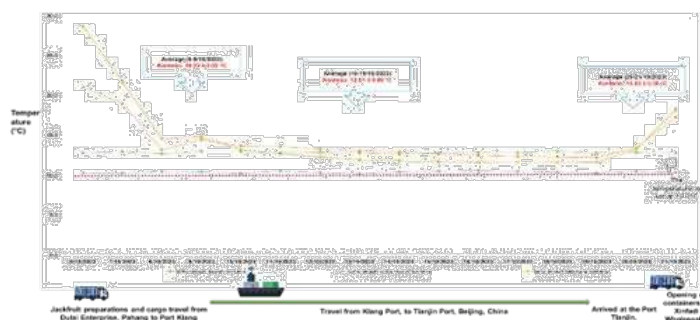


Figure 1: Comparison of temperature in sea shipment

3.2 Quality of J33 Jackfruit in Beijing, China

The physical examination of the jackfruit revealed that uncoated fruits exhibited browning on the skin surface, with some showing fungal growth symptoms (Figure 2). In contrast, jackfruit coated with EONature had a significantly better skin appearance, with minimal browning. However, most jackfruit stalks (peduncles) were found to be rotten and mouldy. This is likely due to the absorption of moisture and water during the washing process, which accelerated decay. Additionally, several opened jackfruit boxes emitted a strong aroma and were found to be fully ripe. Wholesalers preferred fruits with good surface appearance and that were not yet ripe, as these have a longer shelf life in the market. From previous research on chemical composition and flavor changes during ripening of jackfruit cultivar J33 and then observed the number of volatiles that increased during the ripening. It was also found that esters concentration was low during the first stage of maturity, after 5–6 days of ripening, jackfruit showed a significant presence of butyl acetate and 3-methylbutyl acetate, which contributed to the fruity and floral notes of the fruit (Ong, et al., 2006). These compounds play an important role in determining the effect in the overall flavour of the fruit.

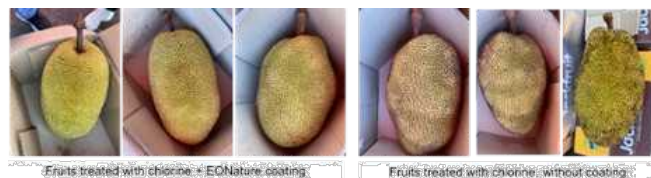


Figure 2: Comparison of the physical appearance of coated and uncoated jackfruit.

3.3 Physical Evaluation and Acceptance

Colour is a crucial parameter that influences consumer acceptance of jackfruit quality. Table 1 presents the skin colour changes observed during storage. In terms of skin colour, uncoated J33 jackfruit appeared slightly brownish-green, whereas the coated jackfruit retained its green colour. The results showed that the EONature coating had the tendency to retard skin colour changes. Colour retardation may be attributed to the gas barrier property of coatings. Coatings have been reported to extend the shelf-life of fruits and vegetables because of their reduced permeabilities to carbon dioxide, oxygen and ethylene (Arnon, et al., 2015). EONature coatings in particular reduce oxygen uptake but do not cause an equivalent increase in carbon dioxide concentration in the internal atmosphere of fruits thus preventing anaerobic fermentation. The appearance of the yellow colour in jackfruit is brought about by the degradation of chlorophyll induced by ethylene. This was further supported by pulp colour measurements, where brightness (L^*), hue (H°), and chroma (C) were monitored (Table 2), L^* value indicates the lightness or darkness of the fruit's colour. Chroma represents the colour intensity (brightness) and Hue (H°) determines the colour coordinates throughout storage. However no significant changes were found on pulp colour for coated and uncoated.

No disease symptoms were observed in coated jackfruit, unlike in uncoated samples (Table 1). Fruits treated with EONature has enhanced jackfruit quality by delaying skin browning and preventing black rot on skin surface during cold storage, followed by market conditions. Additionally, no signs of chilling injury were detected in either treatment. In terms of overall consumer acceptance, jackfruit coated with EONature was preferred due to its better visual appeal.

However, no significant differences were found between the two treatments regarding Total Soluble Solids (TSS), Total Titratable Acidity (TTA), sugar-acid ratio, and pulp colour.

Table 2: Skin colour, disease score and skin acceptability score for jackfruit coated and uncoated in China

Treatments	Skin colour	Disease score	Skin acceptability score
Uncoated (chlorine treated)	Slightly brownish green	<25%	3
Coated with EONature	Greenish yellow	0%	4

Table 2: Biochemical changes of jackfruit pulp for jackfruit coated and uncoated in China

Treatments	Lightness (L*)	Chroma (C*)	Hue (H*)	Bronzing symptoms	Aroma	Total soluble solids (% Brix)	Total titratable acidity (% citric acid)	Sugar acid ratio TSS:TTA
Uncoated (chlorine treated)	78.89a	48.74a	85.32a	No	Strong	27.6*	1.70a	16.05a
Coated with EONature	84.17a	48.31a	85.80a	No	Strong	29.1a	1.63a	17.86a
F-Test significant	ns	ns	ns			ns	ns	ns

4. CONCLUSIONS

The demand for jackfruit, particularly in the Chinese market, has increased due to positive consumer and importer acceptance. This study has demonstrated that the Standard Operating Procedure (SOP) for exporting fresh jackfruit to China, developed by MARDI, has effectively maintained the quality of J33 jackfruit as a premium product in China. The application of liquid coating treatment has successfully preserved the fruit's quality, even after an extended shipping period. This innovative packaging technology is expected to further expand the fresh jackfruit market in China.

REFERENCES

- H. Arnon, R. Granit, R. Porat and E. Poverenov. Development of polysaccharide-based edible coatings for citrus fruits: A layer-by-layer approach. *Food Chemistry* 166: 465–472. (2015)
- Cho, J, L.Y, Nur Sulastri, J. Wan Mohd, R. I (2020). Maintaining post-harvest quality of jackfruit during cold storage. *International Journal of Agriculture, Forestry and Plantation*, 10: 282-286.
- Ong, B.T, Nazimah, S.A.H, Osman, A., Quek, S.Y., Voon, Y.Y., Mat Hashim, D., Chew, P.M and Kong, Y.W (2006). Chemical and flavour changes in jackfruit (*Artocarpus heterophyllus* Lam.) cultivar J3 during ripening. *Postharvest Biology and Technology*, 40 (3): 279-286.
- Saxena A , Bawa A S and Raju P S (2011). Use of modified atmosphere packaging to extend shelf life of minimally processed jackfruit (*Artocarpus heterophyllus* L.) bulbs. *J Food Eng* 25 (4), 455 - 466

MEASURING POSTHARVEST LOSSES OF FRUITS IN MALAYSIA: INITIAL STEPS TOWARDS THE FOOD LOSS INDEX UNDER SDG 12.3.1.A

Wan Mohd Reza Ikwana Wan Hussin*, Nur Azlin Razali, Joanna Cho Lee Ying, Roslina Ali, Wan Mahfuzah Wan Ibrahim, Siti Nurathirah Abu Hassan, Nor Hanis Aifaa Yusoff, Erny Sabrina Mohd Noor and Muhammad Hakimi Harun

¹Horticulture Research Centre Malaysian Agricultural Research and Development Institute (MARDI), MARDI Headquarters Serdang 43400 Selangor Malaysia

²Socio Economic, Market Intelligence & Agribusiness Research Centre Malaysian Agricultural Research and Development Institute (MARDI), MARDI Headquarters Serdang 43400 Selangor Malaysia

³Industrial Crop Research Crop Malaysian Agricultural Research and Development Institute (MARDI), MARDI Bachok Kelantan Malaysia

wanreza@mardi.gov.my

Under SDG 12.3.1A, countries are encouraged to develop a Food Loss Index to quantify and reduce food losses across five key commodity groups. Malaysia has taken a proactive approach by collaborating with the FAO on a pilot project led by MARDI to assess fruit and vegetable losses, with a focus on pineapples and watermelons. This project aimed to generate preliminary data on postharvest losses, evaluate the effectiveness of data collection instruments and methodologies, and identify critical loss points along the supply chain. These efforts serve as an initial step toward developing a national Food Loss Index. A sample survey revealed that pineapple losses were highest on-farm, particularly at harvest (13%), primarily due to physical damage caused by sunburn, pests, and disease. In contrast, watermelons experienced greater off-farm losses, peaking at 20% upon arrival at wholesale markets, mainly due to rough handling, improper packaging, and transportation, which led to damage becoming more apparent upon arrival. Consequently, the critical loss point (CLP) for pineapples was identified at harvest, whereas for watermelons, it was at the wholesale stage. Despite limitations such as a small sample size and the lack of direct linkage between on-farm and off-farm data, this study provides valuable insights into CLPs and establishes a foundation for a more comprehensive data collection framework. Future research should involve larger, more representative sampling and enhanced enumerator training to ensure accurate loss assessments. These efforts will support the development of a national Food Loss Index and contribute to more effective postharvest loss reduction strategies.

Keywords: Pineapple, Watermelon, Harvesting, Wholesale, Supply Chain

1. INTRODUCTION

Food loss and waste present significant global challenges, impacting food security, resource sustainability, and economic development. The Food and Agriculture Organization (FAO) defines food loss as the reduction in food quantity due to inefficiencies along the supply chain, from postharvest handling to processing, excluding retail whereas food waste occurs at the retail and consumer levels, (Figure 1) (FAO 2019). Under SDG 12.3.1.A, the Food Loss Index specifically measures quantitative losses, excluding quality degradation, and includes discarded harvested produce, including imported commodities upon arrival (Bennett et al., 2022). Recognizing the urgency of addressing food losses, SDG 12.3 aims to halve global food waste at the retail and consumer levels while minimizing losses throughout production and

supply chains. To support this, nations are encouraged to develop systematic measurement frameworks across five key commodity groups: (i) cereals and pulses, (ii) fruits and vegetables, (iii) roots, tubers, and oil-bearing crops, (iv) meat and animal products, and (v) fish and fish products (FAO, 2019). To this end, Malaysia, with technical support from FAO, initiated the Pilot Data Collection and Measurement of Fruit and Vegetable Losses under SDG 12.3.1.A. Led by the Malaysian Agricultural Research and Development Institute (MARDI), this initiative focused on key perishable crops within the fruit and vegetable basket. Pineapples and watermelons, in particular, were chosen as representative fruits to assess critical loss points along the supply chain. Despite their known susceptibility to postharvest losses, systematic data collection has been inconsistent, making it difficult to accurately estimate losses by crop, region, or year. This project aimed to generate preliminary data on postharvest losses, evaluate the effectiveness of data collection instruments and methodologies, and identify critical loss points along the supply chain. These efforts serve as an initial step toward developing a national Food Loss Index.



Figure 1. Boundaries of the food supply chain in the operational definition of the GFLI (source: FAO 2019)

2. METHODOLOGY

2.1. Selection of fruits and states

This study measured postharvest losses of pineapples and watermelons in Malaysia, selected for their short storage life, high production volume, significant per capita consumption and economic importance. Pineapple is the most widely produced fruit in Malaysia, followed by durian, banana, and watermelon, with production volumes of 553,348 MT, 471,672 MT, 342,833 MT, and 139,753 MT, respectively (Department of Agriculture Malaysia, 2023). To ensure a comprehensive assessment, two key producing states were selected for each fruit based on production significance and supply chain variations. Johor and Sarawak were chosen for pineapples, while Johor and Kelantan were selected for watermelons to compare loss rates. Additionally, off-farm data were collected from Kuala Lumpur Wholesale Market and Selangor Wholesale Market, two major distribution hubs for agricultural produce in Malaysia.

2.2. Data collection instruments

The primary data collection method for this study was a sample survey. Data collection instrument was developed through a series of technical meetings with relevant stakeholders to ensure a well-structured questionnaire for both on-farm and off-farm assessments. The questionnaire consisted of three main sections: Section A (Cover), which recorded basic information such as state, district, and farm address; Section B (Farm and Respondent Information), which captured respondent details and farm operations, including total agricultural area, distinguishing between owned and rented land while excluding rented-out land; and Section C (Loss Measurement),

which focused on postharvest loss measurement based on FAO standards, considering only discarded produce. Losses were recorded at key points along the supply chain, beginning with harvest, followed by sorting, grading, and packaging on the farm, and concluding with transportation to markets, processors, or wholesalers. This section also investigated the main reasons for discarding produce to identify key loss factors. The questionnaire incorporated both single-choice and open-ended questions to ensure flexibility in responses. Additionally, the off-farm questionnaire followed a similar structure but emphasized activities beyond the farm level, including receiving, sorting, grading, repacking at wholesale markets and concluded with distribution to retail markets or other wholesale markets.

2.3. Sampling strategy

To ensure representative and reliable data collection, this study employed a stratified random sampling approach, allowing each unit in the population an equal opportunity to be selected. The sampling units were categorized into two types of agricultural holdings: household farms and non-household (commercial) farms. According to FAO (2020), household farms are operated by individual household members, while non-household farms include corporations and government institutions. In this study, household farms refer to individual farmers registered with agricultural agencies, whereas non-household farms refer to commercial farms registered with the Companies Commission of Malaysia (SSM). A three-stage sampling process was adopted:

- State Selection – Key producing states were identified for each commodity.
- District Selection – Major production districts within the selected states were chosen.
- Agricultural Holding Selection – Farms were randomly sampled from both household and commercial sectors.

For household farms, farmer lists were obtained from government agricultural agencies such as the Department of Agriculture Malaysia (DOA), Federal Agriculture Marketing Authority (FAMA), Malaysian Pineapple Board (LPNM), and Lembaga Pertubuhan Peladang (LPP). For commercial farms, data were sourced from the Department of Statistics Malaysia (DOSM) and Department of Agriculture (DOA), ensuring comprehensive coverage of all registered farms. The sample size for each crop was determined using the following formula:

$$n_h = \frac{N_h}{N} \cdot n$$

In the formula, n represents the sample size, N is the total population, and e is the margin of error. The final sample allocation was conducted proportionally across strata, ensuring an accurate representation of production patterns and postharvest handling practices based on the number of farms within each category. This systematic approach enabled the study to capture variations in postharvest losses across different farm types and geographic locations, enhancing the reliability of the findings. Within each selected district, farms were further classified into three sub-strata based on production area: Small farms (0.10 ha – 0.99 ha), Medium farms (1.00 ha – 9.99 ha), and Large farms (> 10.00 ha). This classification facilitated a structured analysis of food loss across different farm sizes. However, smallholders operating on less than 0.10 ha were excluded from the study, as their contribution to overall food loss was considered minimal and unlikely to significantly impact national-level estimates. For off-farm

sampling, the study focused on two major wholesale markets (Kuala Lumpur Wholesale Market and Selangor Wholesale Market) in the Klang Valley, a strategically located distribution hub in Peninsular Malaysia.

Table 1. Population data of Commercial Farms for pineapple and watermelon based on area of production

Commodity	Pineapple		Watermelon	
state	Johor	Sarawak	Johor	Kelantan
Small	4	2	2	0
Medium	3	0	1	0
Large	1	0	2	0
Sampling size (10%)	8	2	5	0

Table 2. Population data of registered Household Farms for pineapple and watermelon based on area of production

Commodity	Pineapple				Watermelon			
State	Johor	Sarawak			Johor		Kelantan	
Range of scale	Kluang	Pontian	Samarahan	Miri	Kota Tinggi	Mersing	Kota Bharu	Bachok
Small (0.10-0.99 ha)	12	11	2	4	0	12	6	123
Medium (1.00-9.99 ha)	16	11	12	7	1	8	0	53
Large (> 10.00 ha)	0	1	0	0	2	0	2	0
Total	28	23	14	11	3	20	8	176
Sampling size (10%)	19	15	11	9	2	16	3	62

2.4. Data entry and analysis

Upon collecting the interview data, it was entered into the CSPRO application for data processing and subsequently analyzed using SPSS Statistical Software.

3. RESULTS AND DISCUSSION

This section presents the initial findings from the pilot data collection, starting with on-farm loss measurements, followed by off-farm losses. The reference period of loss percentage is one year. It is noteworthy that, the loss percentages reported in this study reflect only quantitative losses, representing the proportion of produce discarded and ultimately sent to landfills, completely removed from the food system. Any discarded produce that is repurposed for economic use, such as processing into value-added products such as animal feed or fertilizer, is not included in these loss estimates. For simplicity, only general results will be discussed without detailed comparisons between strata

3.1 On-Farm Losses of Pineapple

Table 3. Mean losses (♯) across different on-farm operations for pineapple among respondents in Johor and Sarawak. SE represents the standard error.

State	Mean Production (MT)	Mean Losses (%)		
		Harvesting	Sorting / Grading	Transporting
Johor				
Commercial Farms	716.23	6.63%	3.71%	1.33%
SE	264.66	2.46	2.71	0.33
Household Farms	241.16	18.37%	10.18%	4.00%
SE	119.42	1.79	2.29	1.00
Sarawak				
Commercial Farms	190.40	17.5%	11.00%	0.00%
SE	67.87	2.50	9.00	n.a
Household Farms	55.49	10.04%	6.20%	7.00%
SE	14.64	2.41	3.93	3.00
Total		13%	7%	3%

Table 3 presents the mean percentage of pineapple losses at each stage of the supply chain in Johor and Sarawak. In Johor, most commercial pineapple farms cater to both export and domestic markets whereas commercial farms in Sarawak primarily supply the domestic market within the state. The highest average loss for pineapples was recorded at the harvesting stage, amounting to 13%. In this pilot study, harvest loss was measured as the percentage of fruits discarded immediately after harvest. One of the key questions in the survey assessed whether farmers had pre-orders at least 30 days before harvest, as pre-orders could help reduce oversupply and postharvest losses. Notably, 80% of respondents reported receiving pre-orders. Additionally, pineapple farmers typically apply artificial flowering hormones in staggered batches, allowing them to accurately predict the harvest date. However, significant harvest losses were still observed. This suggests that the primary cause of losses was not oversupply but rather physical damage. A major contributing factor is the high susceptibility of MD2 pineapples in Malaysia to sunburn (Figure 2) due to prolonged exposure to sunlight (Nursyuhaida et al., 2020) followed by damage due to disease, which significantly increases on-farm harvest and sorting/grading losses. Additionally, geographical and logistical factors contribute to postharvest losses. In certain areas in Sarawak, some farmers rely on small boats to transport their produce (Figure 3), and occasionally, fruits fall into the river during transit, potentially also contributing to transportation losses. However, it only involved a small subset of farmers surveyed in this study. Loss during transportation also could be associated with improper vehicle where 64% or respondent transport their produce using uncovered vehicle and 44.8% of respondents load the produce loosely and packed without any packaging inside the vehicle. This could lead to mechanical damage due to exposed to weather and also mechanical damage due to abrasion and impaction of packed consignment.



Figure 2. Physical damage due to sunburn



Figure 3. Types of vehicles used for transporting pineapples from the farm to the next point in the supply chain: (a) uncovered lorry b) small boat

3.2 Off-farm Losses of Pineapple

Table 4: Mean losses (%) across different off-farm operations for pineapples among respondents in two wholesale markets. SE represents the standard error.

Wholesale Market	Mean Quantity Received (MT)	Mean Losses (%)			
		Received/ Loaded	Sorted/ graded / repacked	Storage	Distribution
Kuala Lumpur	5.73	0.73	n.a	n.a	n.a
SE	3.34	0.49	n.a	n.a	n.a
Selangor	6.2	10.04	10	22.5	5
SE	4.45	5.73	n.a	2.5	n.a
Total		5.38	10	22.5	5

Off-farm losses were assessed upon the produce's arrival at the market. As shown in Table 4, the Kuala Lumpur Wholesale Market (KLWM) recorded lower losses compared to the Selangor Wholesale Market (SWM), likely due to differences in handling intensity. At KLWM, pineapples undergo minimal handling, as they are primarily transferred for distribution to other local markets. In contrast, wholesalers in SWM engage in multiple handling activities, including sorting, storage, and redistribution, leading to greater losses at each stage. Upon arrival at the wholesale market, pineapples transported loosely and fully stacked without packaging are placed in plastic crates for sorting, grading, storage, or distribution. Among respondents, 70% identified pest and disease infestation as the primary cause of losses upon receiving the fruits, while 30% attributed losses to physical damage. Additionally, 30% of respondents reported experiencing losses during storage and distribution, likely due to improper storage conditions, particularly unsuitable temperatures for pineapple storage. The lack of protective baskets or packaging during transportation, combined with excessive stacking during storage, further contributed to these losses (Figure 4)



Figure 4: Excessive fruit stacking during storage increases the risk of mechanical damage and disease infection

3.3. On-farm Losses of Watermelon

Table 5. Mean losses (̄) across different on-farm operations for watermelon among respondents in Johor and Kelantan. SE represents the standard error

State	Mean Production (MT)	Mean Losses (%)		
		Harvesting	Sorting / Grading	Transporting
Johor				
Commercial Farms	338.10	6.3%	0.0%	5.0%
SE	188.77	0.04	n.a.	n.a.
Household Farms	39.54	2.8%	2.8%	1.6%
SE	17.90	0.01	0.01	0.01
Kelantan				
Household Farms	38.37	1.00%	1.71%	2.00%
SE	3.52	0.00	0.01	0.02
Total		3.36%	1.5%	2.86%

Table 5 presents the mean percentage of watermelon losses at each stage of the supply chain in Johor and Kelantan. Overall, watermelon losses were relatively low compared to pineapple, with the highest losses recorded at harvest (3.36%), followed by transportation (2.86%). In Johor, commercial watermelon farms are present, whereas in Kelantan, no commercial farms were identified, meaning the data from this state reflect only smallholder agricultural holdings. Among small-scale producers, securing pre-orders from wholesalers is a common practice that helps minimize harvest losses, as most harvested fruits are already allocated for sale. However, some level of fruit discard at harvest remains unavoidable due to watermelons' susceptibility to disease. The primary reasons for fruit discard at harvest were pest and disease damage (47%) (Figure 5), followed by broken fruit (27%). A total of 80% of respondents reported conducting sorting and grading on the farm. However, postharvest losses during these processes were generally low, likely because unmarketable fruits had already been discarded at harvest. Once sorted and graded, watermelons are typically transported to wholesale or retail markets without packaging. Only 12% of respondents personally delivered their produce to the next stage of the supply chain, with most using uncovered vehicles (Figure 6); a factor likely contributing to transportation losses. During interviews, respondents were also asked about their handling of

discarded fruit. The majority reported repurposing these fruits as livestock feed, particularly for cattle. Since produce used for animal feed is reintegrated into the food system, it is not classified as postharvest loss. This practice may explain the relatively low on-farm losses observed for watermelons, despite their susceptibility to physical damage and disease.



Figure 5. The main reason for high watermelon loss is decay caused by pests or disease



Figure 6. Producers use uncovered vehicles to deliver the watermelon to marketers or traders.

3.4 Off-farm Losses of Watermelon

Table 6: Mean losses (%) across different off-farm operations for watermelon among respondents in two wholesale markets. SE represents the standard error.

Wholesale Market	Mean Quantity Received (MT)	Mean Losses (%)			
		Received/ Loaded	Sorted/ graded / repacked	Storage	Distribution
Kuala Lumpur	41	20	15	4	2
SE	31	10	n.a	1	n.a
Selangor	12.86	20.6	5.57	12.8	12.5
SE	6.16	5.36	4.43	12.2	7.5
Total		20.3	10.28	8.4	7.25

Table 6 presents watermelon losses at two wholesale markets, SWM and KLWM. In both markets, approximately 20% of losses occurred at the receiving stage. 90% Respondents reported that the key contributing factors are physical damage. This could be associated with rough handling during loading and transportation, leading to bruising, cracking, or crushing, which not manifested until they reach wholesale market. This delayed appearance of damage also may explain why off-farm losses for watermelons were significantly higher than on-farm losses, Wholesalers received watermelon without packaging and will placed the fruit in plastic crated for further handling upon arrival. Watermelons are often stored at wholesale markets for extended periods before distribution. It was observed that some wholesalers store watermelons

without cleaning soil residues from their surfaces, which may contribute to storage loss due to microbial deterioration (Figure 7)

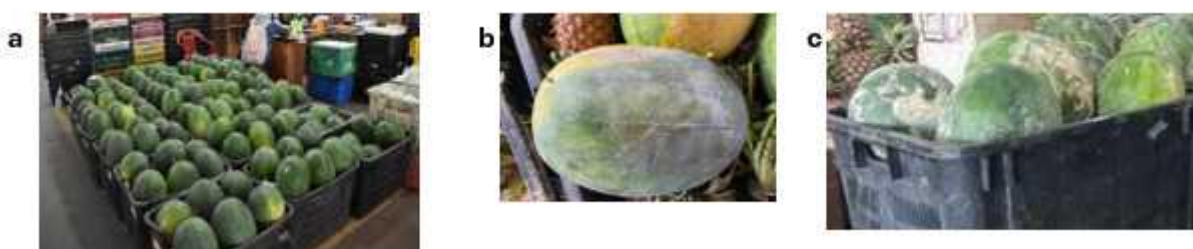


Figure 7. (a) Watermelons placed in plastic crates upon arrival at the wholesale market, (b) Bruising as a sign of physical damage, (c) Soil residue on the fruit surface.

4. CONCLUSION

This study examined postharvest losses of pineapple and watermelon along the supply chain. For pineapples, the highest losses occurred on-farm, particularly at harvest (13%), primarily due to sunburn, pests, and disease. In contrast, watermelons experienced lower on-farm losses but significantly higher off-farm losses, peaking at 20% upon arrival at wholesale markets. This indicates that the critical loss point (CLP) for pineapples is at harvest, whereas for watermelons, it is at the wholesale receiving stage. The high on-farm pineapple losses were primarily attributed to physical damage at harvest. Meanwhile high off-farm losses for watermelons are likely due to rough handling on-farm, combined with improper packaging and transportation, which led to damage becoming more apparent upon arrival and further handling at wholesale markets. These findings highlight the need for improved farmer training and research on postharvest handling practices to prevent eventual off-farm losses.

Regardless of type of crop, off-farm losses tend to be higher than on-farm losses, as farmers especially small-scale producers typically market their produce immediately after harvest, minimizing postharvest handling at the farm level. In contrast, the off-farm supply chain involves longer storage and redistribution periods, increasing the likelihood of losses. This suggests that the more handling points a product goes through, the greater the losses expected.

This study has some limitations, including a small sample size, limited representation, and the lack of direct linkage between on-farm and off-farm data, which restricted a full supply chain assessment. Despite these constraints, the findings provide valuable insights into identifying CLPs and serve as a foundation for developing a more comprehensive data collection framework. Moving forward, national-level data collection should be conducted with larger and more representative sampling. Additionally, improvements in enumerator training are necessary to minimize misinterpretation, particularly regarding the scope and definitions of harvest and postharvest losses. It is also crucial to distinguish between quantitative and qualitative losses, as the Food Loss Index under SDG 12.3.1A only accounts for quantitative losses.

Acknowledgement

We sincerely thank the Food and Agriculture Organization (FAO) for their financial and technical support in this pilot project. Special appreciation goes to Ms. Sangita Dubey, Mr. Sanghyun Jeon and Mr. Bimal K. Giri of FAORAP, along with their entire team, for their invaluable guidance

and consultation provided to the MARDI team throughout the project. Additionally, we deeply appreciate the contributions of the enumerators, project team members, and all collaborating agencies, including DOA, DOSM, FAMA, LPNM, and LPP, whose support was instrumental in the successful completion of this study.

REFERENCES

- Bennett, A, Dubey, S., Lee, W.T.K., Damen, B. and Bucatariu, C. (2022). FAO Regional Strategy on Food Loss and Waste Reduction in Asia and the Pacific. Bangkok, FAO. <https://doi.org/10.4060/cb8959en>
- Department of Agriculture Malaysia, (2023). Buku Statistik Tanaman 2023 Jabatan Pertanian Malaysia
- Fabi and English (2018). Methodological Proposal For Monitoring Sdg Target 12.3. The Global Food Loss Index Design, Data Collection Methods And Challenges. FAO
- FAO (2019). The State of Food and Agriculture 2019. Moving forward on food loss and waste reduction. Rome. Licence: CC BY-NC-SA 3.0 IGO.
- FAO (2020). World Programme for the Census of Agriculture 2020. Vol1 Programm, concepts and definitions,
- Nursyuhaida et al. (2020). Reducing Sunburn Incidence In Md2 Pineapple Using Chemical Pre-Harvest Treatment To Overcome Post-Harvest Losses In Malaysia. *International Journal of Agriculture, Forestry and Plantation*, 10 (Sept) ISSN 2462-1757

NON-DESTRUCTIVE MEASUREMENT TO PREDICT QUALITY AND THE USE OF PLASMA FINE BUBBLES FOR EXTENDING THE SHELF LIFE OF FRUITS

Y. Aris Purwanto

Center for Tropical Horticultural Studies, Department of Mechanical and Biosystem Engineering, IPB University

Postharvest handling is a critical process in fruit production, as it directly impacts produce quality, safety, shelf life, and losses. Recent advancements in Portable Near Infrared (NIR) Spectroscopy and non-thermal technology/chemical-free in postharvest processes, such as Plasma Fine Bubbles, offer innovative solutions for enhancing postharvest handling. Portable NIR spectroscopy provides a rapid, non-destructive technique for assessing fruit quality parameters such as moisture content, sugar levels, and firmness. Its portability allows for real-time monitoring during harvesting, grading, storage, and transportation, offering a more efficient way to ensure fruits meet market standards. This method provides robust and real-time quality prediction with more than 90 percent accuracy. Plasma Fine Bubbles, created by exposing water to plasma discharge, is emerging as an effective antimicrobial agent due to its rich composition of reactive oxygen and nitrogen species (RONS). The laboratory test indicated that the water exposed by plasma through the Fine Bubbles generator for 30 minutes resulted in hydroxyl radicals such as O₃, H₂O₂, H, O, etc. This technology has the potency to be applied in fruit washing to reduce microbial contamination without harmful chemicals, thereby extending shelf life and preserving fruit quality.

Keywords: plasma; fine bubble; activated water; postharvest handling; portable near-infrared spectroscopy

EFFECTS OF EPIGALLOCATECHIN-3-GALLATE (EGCG) AND CYTOKININ ON POSTHARVEST ATTRIBUTES OF LITCHI FRUIT BY MODULATING ANTIOXIDANT ACTIVITY AND CHLOROPHYLL METABOLISM AFTER HARVEST

Hua Huang*, Hailun Liu, Chao Fan, Xu Xiang

Institute of Fruit Tree Research, Guangdong Academy of Agricultural Sciences; Key Laboratory of South Subtropical Fruit Biology and Genetic Resource Utilization, Ministry of Agriculture and Rural Affairs, Guangdong Provincial Key Laboratory of Tropical and Subtropical Fruit Tree Research, Guangzhou, 510640, P. R. China

huangw0109@gmail.com

Litchi fruit pericarp is susceptible to browning after harvest. We evaluated the treatments of epigallocatechin-3-gallate (EGCG) and forchlorfenuron (CPPU) to delay the development of browning in litchi fruit stored at room temperature. The results showed that the development of pericarp browning and decrease of chlorophyll could be inhibited, and the increase of malondialdehyde (MDA) content during storage. As compared to control, the content of pericarp anthocyanins, flavonoids, and the total phenols maintained higher levels; and the decrease of antioxidant activity of 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging capacity and reducing power were slowed down in treated fruit. The enzyme activity of polyphenol oxidase (PPO), peroxidase (POD) and anthocyanase (ACN) related to oxidation of polyphenols were depressed by the combined treatments. Furthermore, the relative expression of the polyphenol oxidase and chlorophyll related genes correlation analysis revealed that the content of phenols in the pericarp negatively affected the changes in the browning index, and was positively related to the DPPH radical scavenging capacity. The combined treatments of EGCG and CPPU exhibited potential effects in delaying the pericarp browning of green mature litchi fruit by maintaining the content of polyphenols, regulating the chlorophyll catabolism after harvest.

Keywords: Litchi fruit; Pericarp browning; Epigallocatechin-3-gallate; Cytokinin; Antioxidant activity; Chlorophyll catabolism

ENZYMATIC BROWNING IN *ARTOCARPUS ODORATISSIMUS* (TERAP) AND ITS INHIBITION TREATMENTS UNDER COLD STORAGE CONDITION

Shiamala Devi Ramaiya* and Isniti Richard

Department of Crop Science, Faculty of Agricultural and Forestry Sciences, Universiti Putra Malaysia Bintulu Sarawak Campus, Nyabau Road, 97008 Bintulu, Sarawak, Malaysia

shiamala@upm.edu.my

Browning is a significant limitation in the food industry, primarily caused by enzymatic activity that escalates in response to tissue stress, negatively affecting both the cosmetic appearance of products and consumer preferences. *Artocarpus odoratissimus*, a popular indigenous fruit of Sarawak, is a climacteric fruit that remains underutilized due to its short shelf life and high perishability, which result in pronounced tissue softening and browning. Notably, there is a significant lack of research on browning mechanisms and pre-treatments to mitigate this issue, which could help extend the shelf life of *A. odoratissimus*. Therefore, this study aims to assess the extent of browning and its associated enzymatic activity in *A. odoratissimus* fruit during storage, as well as evaluate the effectiveness of various anti-browning agents in controlling enzymatic browning and preserving the phytochemical properties under cold storage at 4°C. The mature fruits were harvested and stored at ambient temperature (25°C) prior to analysis. Observations revealed that *A. odoratissimus* fruits stored at 25°C began to show surface browning by day 4, which progressed to dark browning and deterioration by day 8. The browning degree in the ripened fruits was initially 0.37 ± 0.01 , increasing slightly by day 4 (0.41 ± 0.02) and further by day 8 (0.47 ± 0.01). A strong correlation was found between the degree of browning and the activity of browning-related enzymes, specifically phenylalanine ammonia-lyase (PAL) ($R^2=0.859$) and polyphenol oxidase (PPO) ($R^2=0.858$). Treatment 3 also exhibited minimal total colour changes (ΔE) at 12.91 ± 0.79 and suppressed the activity of key enzymes involved in browning, including phenylalanine ammonia-lyase (PAL), polyphenol oxidase (PPO), and peroxidase (POD), after 4 weeks of storage. The phytochemical content, particularly ascorbic acid ($18.08 \pm 1.31 \mu\text{g g}^{-1}$) and total phenolic content (TPC) ($36.83 \pm 0.20 \mu\text{g GAE g}^{-1}$), remained higher throughout the storage period. These findings underscore the efficacy of the ascorbic acid + citric acid + calcium chloride combination as a promising preservation treatment for *A. odoratissimus* fruit, thus extending its shelf life. This research lays essential groundwork for mitigating browning in *A. odoratissimus* fruit, facilitating its commercialization as a fresh-cut product.

Keywords: anti-browning; enzymatic browning, indigenous fruit, shelf life, storage, terap

EFFECTS OF CAPROALDEHYDE TREATMENT ON SHELF LIFE, PHYSICOCHEMICAL PROPERTIES, AND ANTIOXIDANT ACTIVITY OF D24 DURIAN (*DURIO ZIBETHINUS L.*) UNDER AMBIENT TEMPERATURE STORAGE

Aidil Hakim Azhar¹, Mohd Sabri Pak Dek^{1,*}, Yaya Rukayadi¹, Nurul Syazini Ramli¹, Ahmad Haniff Jaafar¹, Ahmed Mediani², Helmi Wasoh @ Mohamad Isa³

¹Department of Food Science, Faculty of Food Science and Technology, Universiti Putra Malaysia, Serdang, Selangor, Malaysia, 43400

²Institute of Systems Biology, Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia, 43600

³Department of Bioprocess Technology, Faculty of Biotechnology and Biomolecular Sciences, Universiti Putra Malaysia, Serdang, Selangor, Malaysia, 43400

mhdsabri@upm.edu.my

Durian (*Durio zibethinus L.*) is a highly valuable edible fruit with significant economic importance for Malaysia, especially in the current context where fresh durian is being exported to other countries. However, fresh durian faces major challenges, including uncontrolled ripening processes that lead to reduced shelf life and substantial postharvest losses. Traditional postharvest techniques, such as cold storage, require significant investment, consume considerable space, and may alter the fruit's original flavor. Caproaldehyde is GRAS material that has been used in food production. Currently, there are no established postharvest techniques utilizing caproaldehyde treatment to extend the shelf life of fresh durian. The effectiveness, as well as the physicochemical and biochemical changes in caproaldehyde-treated durian remains unexplored. This study aims to evaluate the impact of caproaldehyde on the shelf life and quality attributes of D24 durian at ambient temperature. Fresh durian fruits were treated with caproaldehyde through vapor treatment for one night at ambient temperature. Sampling was conducted from day 1 to day 4, during which the opening of the husk was monitored. Key parameters assessed included total soluble solids, titratable acidity, pH, color changes, respiration rate, and weight loss. Antioxidant activity was measured using DPPH, ABTS, and FRAP assays. The results indicated that caproaldehyde treatment effectively inhibited husk opening until day 4, while the untreated group (control) exhibited husk opening by day 3. No significant changes were observed in physicochemical or antioxidant properties among all samples. However, the pH, respiration rate, and weight loss of caproaldehyde-treated durians were lower compared to the control. These findings suggest that caproaldehyde treatment can enhance the shelf life of durian by preventing husk opening. This treatment shows promise as a postharvest technique to extend the shelf life of fresh durian at ambient temperature, thereby increasing profitability in the durian market by reducing postharvest losses.

Keywords: Fresh durian, shelf life, postharvest treatment, export market, postharvest treatment

BROWNING OF JACKFRUIT (*ARTOCARPUS HETEROPHYLLUS* CV. J33) RIND DURING FRUIT DEVELOPMENT

Zhi Sin Tan¹, Phebe Ding¹, Huey Fang Teh²

¹Faculty of Agriculture, Universiti Putra Malaysia, 43400, Serdang, Selangor, Malaysia

²Sime Darby Technology Centre, Lebuhr Silikon, Universiti Putra Malaysia, 43400, Serdang, Selangor, Malaysia

phebe@upm.edu.my

Jackfruit (*Artocarpus heterophyllus*) cv. J33 is an important fruit for export. However, poor postharvest handling and prolonged transit time often results in browning of jackfruit rind, significantly diminishing its external quality. Thus, understanding the biochemical changes during fruit development is crucial, as these influence jackfruit's postharvest behaviour. Thus, this study was conducted to determine reactive oxygen species (ROS) metabolism, antioxidant systems and enzymatic browning reactions of jackfruit rind during fruit development. Fruit of 2, 4, 8 and 12 weeks after anthesis (WAA) were used in the study. Total phenolic compound (TPC), polyphenol oxidase (PPO) enzymatic activity, enzymatic and non-enzymatic antioxidant activity, ROS metabolism were assessed; individual phenolic compounds were determined by UPLC-MS/MS. Present result indicated that TPC, individual phenolic compounds, all antioxidant activities (except catalase, [CAT]) and hydrogen peroxide (H₂O₂) content in jackfruit rind were high during 2 WAA, followed by a gradual decline. Malondialdehyde (MDA) content in jackfruit rind peaked during 4 WAA but decreased in subsequent WAA. Conversely, PPO activity in jackfruit rind increased starting from 4 WAA. Initially, H₂O₂ content in jackfruit rind might have acted as signaling molecules, while during 4 WAA, the excess H₂O₂ might also have functioned as main toxic molecule to stimulate lipid peroxidation (MDA) and oxidative stress. Superoxide dismutase (SOD), CAT, ascorbate peroxidase (APX) and peroxidase (POD) were facilitated differently in jackfruit rind. During 2 WAA, APX and POD activities in jackfruit rind might have controlled the balance between ROS production and antioxidant defenses, while CAT activities have arisen as crucial enzymatic antioxidant to alleviate oxidative damage during 8 and 12 WAA. Besides, phenolic compounds in jackfruit rind, mainly played a role as an antioxidant instead of serving as substrates for oxidation reactions catalyzed by PPO enzyme.

Keywords: Jackfruit rind, fruit development, browning enzyme, phenolic compounds, antioxidants

EFFECTS OF TORCH GINGER ESSENTIAL OIL ON PATHOGENS OF DRAGON FRUIT [*HYLOCEREUS POLYRHIZUS* (WEBER) BRITTON & ROSE]

Khawarizmi bin Mohd Azizi¹, Xianzhu Deng², Xingfeng Shao^{2,*}, Phebe Ding¹

¹Faculty of Agriculture, Universiti Putra Malaysia, Malaysia, 43400 UPM, Serdang, Selangor, Malaysia

²Zhejiang Key Laboratory of Intelligent Food Logistic and Processing, Zhejiang-Malaysia Joint Research Laboratory for Agricultural Product Processing and Nutrition, College of Food Science and Engineering, Ningbo University, Ningbo 315800, China

phebe@upm.edu.my, **shaoxingfeng@nbu.edu.cn*

Dragon fruit is susceptible to postharvest diseases. This study aimed to isolate the pathogens that infect Malaysian dragon fruit during postharvest storage and evaluate the antimicrobial activity of torch ginger leaf essential oil (EO) against these pathogens. *Bipolaris cactivora* and *Fusarium incarnatum* were identified as the causal pathogens of dragon fruit during storage. In the poison agar study, 0.5% EO inhibited 60.22% of *B. cactivora* mycelial growth compared to 38.11% for *F. incarnatum*. However, conidial germination, minimum inhibitory concentration (MIC), and minimum fungicidal concentration (MFC) tests indicated that *B. cactivora* was more resistant to EO, showing higher conidial germination, MIC, and MFC values than *F. incarnatum*. Additionally, spore counts revealed that 0.5% EO completely inhibited spore production in *F. incarnatum*, while it only reduced the spore count of *B. cactivora*. Analysis of the EO showed that aldehydes and alcohols, particularly dodecanal and 1-dodecanol, were the major compounds, which are believed to be effective in controlling fungal pathogens associated with fruit rot in dragon fruit. In conclusion, torch ginger leaf EO demonstrated potential as a natural antifungal agent against both dragon fruit pathogens in vitro.

Keywords: Antifungal, composition, essential oil, *Hylocereus polyrhizus*, pathogen identification

TREE AGE AFFECTS THE VOLATILE COMPOUND PROFILE OF MUSANG KING DURIAN FRUIT

Eliwanzita Sospeter^{1,3}, Phebe Ding¹, Azizah Misran¹, Teh Huey Fang², Faridah Abas¹

¹Universiti Putra Malaysia, Malaysia, 43400 Serdang

²Sime Darby Plantation Technology Centre Sdn. Bhd. Malaysia, 43400 Serdang

³Mbeya University of Science and Technology, P.O Box 131, Mbeya, Tanzania.

ellynyeura@gmail.com, phebe@upm.edu.my, azizahm@upm.edu.my, teh.huey.fang@sdguthrie.com, faridah_abas@upm.edu.my

Musang King durian (MK) is a seasonal tropical fruit widely cultivated in Southeast Asia. It is known for its sweet, strong, and pervasive aroma. Tree age is one of the important factors affecting the eating quality parameters of durian fruits. Parameters such as volatile compounds (VOCs) play a significant role in determining the fruit's aroma and flavour. This study investigated the impact of tree age on the VOC profile of Musang King (MK) durian fruit using headspace solid-phase microextraction gas chromatography high-resolution mass spectrometry (HS-SPME-GC-orbitrap-HRMS). The analysis revealed significant variations in VOC profiles across different tree age groups. Partial least squares discriminant analysis (PLS-DA) based on variable importance in projection (VIP) have identified several key compounds with higher concentrations in fruits from young trees, including benzene, 1-ethyl-3,5-dimethyl, benzene, 1-methyl ethyl, and 1-hydroxy-2-butanone. Conversely, fruits from older trees exhibited higher concentrations of n-caproic acid vinyl ester, 4-ethyl-5-methylthiazole, propanoic acid, 3-(ethylthio)-, oxirane-methanol, propyl pyruvate, disulfide, ethyl 1-methylethyl, 1,3-oxathiolane, and propanoic acid, 2-methyl-, propyl ester, which were identified as influential marker compounds. Moreover, total sulfur compound concentration were significantly higher in fruits from middle- and old-aged trees while esters, aldehydes, and ketones were higher in fruits from younger trees. These findings suggest that tree age significantly impacts the VOC composition of MK durian and these variations can potentially respond to its aroma perception. Conclusively, VOCs can be used as a tool to differentiate and authenticate MK durian fruits from different tree ages.

Keywords: Aroma; *Durio zibethinus*; Influential markers; Musang King; Volatile compound profiling;

METABOLOMICS ANALYSIS REVEALED THE MECHANISM OF CHILLING INJURY DEVELOPMENT IN DURIAN FRUIT DURING LOW-TEMPERATURE STORAGE

Yuansuo Zhang¹, Yi Chen¹, Yingying Wei¹, Shu Jiang¹, Jianfen Ye¹, Feng Xu¹, Jiahui Chen¹, Phebe Ding², Xingfeng Shao¹

¹Zhejiang Key Laboratory of Intelligent Food Logistic and Processing, Zhejiang-Malaysia Joint Research Laboratory for Agricultural Product Processing and Nutrition, College of Food Science and Engineering, Ningbo University, Ningbo 315800, China

²Faculty of Agriculture, Universiti Putra Malaysia, Malaysia, 43400 UPM, Serdang, Selangor, Malaysia

shaoxingfeng@nbu.edu.cn

Durian (*Durio zibethinus* L.), an important tropical fruit crop in Southeast Asia, is prone to chilling injury (CI) during low temperature storage after harvest, which seriously affects its commodity quality. To investigate the mechanism of CI development in durian fruit, we carried out phenotypic analysis and physiological index determination of durian fruit stored at 5°C and 15°C, and explored the main pathways affecting the occurrence of CI in durian fruit by metabolomics. The results showed that there was obvious water core disease inside the durian stored at 5°C, and the MDA content of pulp was also evidently higher than that at 15°C. In addition, the results of metabolomics indicated that the occurrence of CI in durian fruit was accompanied by the activation of arginine and proline metabolism, linolenic acid metabolism, citric acid metabolism and other pathways, and the contents of proline, linolenic acid, arginine and isocitric acid involved in the above pathways were significantly up-regulated. The above may be the response mechanism of durian fruit to cold stress, which can provide theoretical guidance for the subsequent research on the regulation of durian CI development.

Keywords: *Durio zibethinus* L., postharvest storage, chilling injury, pulp, metabolomics

WASTE MANAGEMENT IN GREAT GIANT FOODS

Fauzan Khumaidi

PT. Great Giant Pineapple advisor for plantation and production and sustainable agrimaterial development

Fauzan.fauzan@gg-foods.com

One of Indonesia's top agricultural companies, Great Giant Foods (GGF), is dedicated to sustainability by using eco-friendly farming methods and creative waste management. With an emphasis on compost, biochar, liquid organic biofertilizers, and maggot oil as sustainable solutions for soil health, crop production, and waste reduction, this review assesses the effects of GGF's circular agriculture method. Results show that applying compost improves pH stability, decreases aluminium saturation, and increases organic matter in the soil, all of which increases soil fertility. Produced from agricultural waste, biochar reduces environmental contaminants while enhancing soil aeration, nutrient retention, and plant development. By increasing microbial diversity and nutrient availability, liquid organic biofertilizers lessen reliance on synthetic fertilizers. Furthermore, fruit coatings made from maggot oil preserve fruit quality and increase shelf life, providing a sustainable substitute for artificial waxes. By lowering dependency on fossil fuels, GGF's integrated waste-to-energy projects, such as the production of biogas from liquid waste, further promote environmental sustainability. These methods show how sustainable agriculture may increase economic viability while reducing ecological effect, and they are in line with Indonesia's regulatory framework on corporate social and environmental responsibility. The outcomes exposed in this review demonstrates how well circular agriculture works to enhance soil quality, increase crop yields, and encourage prudent resource management. The strategy used by GGF is a model for sustainable agribusiness, highlighting the significance of combining economic success with environmental management.

Keywords: Compost, Biochar, Compound fertilizer, Liquid Organic Biofertilizer, Maggot oil.

OHMIC HEATING-ASSISTED HYDRODISTILLATION OF ESSENTIAL OILS FROM MANDARIN CITRUS PEEL WASTE

Imro'ah Ikarini^{1,3}, Sudarminto Setyo Yuwono^{2*}, Widya Dwi Rukmi Putri², Christina Winarti³, Elok Waziroh²

¹Food Science Study Program, Faculty of Agricultural Technology, Brawijaya University, Malang 65145, Indonesia

²Department of Food Science and Biotechnology, Faculty of Agricultural Technology, Brawijaya University, Malang, 65145, Indonesia

³Research Center for Agroindustry, National Research and Innovation Agency, (BRIN), Soekarno Integrated Science Center, Bogor, 16911, Indonesia

sdmintos@ub.ac.id

The citrus beverage industry generates large quantities of citrus peels that become industrial waste. The essential oil compounds in citrus peels benefit various industries, such as pharmaceuticals, food, and cosmetics. The volatile compounds in citrus peels, including limonene, linalool, and b-pinene, have antimicrobial potential, so they can be used as food preservatives. The strong citrus aroma of citrus peels is suitable for adding to food and cosmetic products. This study aims to develop an effective and sustainable extraction technique to use citrus peel waste to produce valuable products, such as essential oils. This study compares essential oil extraction using ohmic heating and conventional distillation methods. The results showed that the ohmic heating method yielded 17.975%, and hydrodistillation conventional has 14.824% of essential oil. The results of this study are expected to contribute to reducing organic waste by utilizing citrus peel as a source of raw materials for essential oils and cellulose. Keywords: antioxidant, citrus peel, hydro distillation, ohmic heating, waste

1. INTRODUCTION

Citrus peel, a by-product of the citrus processing industry, is often considered waste, limiting its potential utilization. Citrus peel contains valuable components such as essential oils, cellulose, and pectin that can be extracted and potentially increase the added value of the waste (Tocmo et al., 2020). One of the citrus varieties that has the potential to be processed into various products is the Mandarin cv. Terigas. Essential oils extracted from citrus peel are widely used in various industries, such as food, cosmetics, and pharmaceuticals, thanks to their aromatic properties and bioactive content, including limonene, known to have antimicrobial and antioxidant activity (Imro Ikarini et al., 2024).

Various extraction methods can be used to produce essential oils, such as hydrodistillation, steam distillation, cold press, and solvent extraction. The hydrodistillation method using distilled water as a solvent on lemon peel and RGL tangerine peel produced essential oil yields of 3.615% and 3.866%, respectively. The time required for the distillation process is 2 hours, with a time to reach the boiling point of 45 minutes (Ikarini et al., 2023). The disadvantage of this method is the long distillation process time, so the energy required is high, and the yield of essential oil produced is not optimal (Tran et al., 2020). Modifying the distillation method is needed to produce high essential oil yields in a shorter time. Currently, the Ohmic Assisted Hydrodistillation (OAHD) method has emerged (Tunç & Koca, 2019). OAHD is a new distillation technology that relies on ohmic heating by passing an electric current through the material rather than conductive heat transfer. Based on research, OAHD has several advantages, including a significant reduction in extraction time and energy consumption compared to

conventional hydrodistillation methods (Mohagheghniapour et al., 2018).

OAHD has several advantages, including a significant reduction in extraction time and energy consumption compared to conventional hydrodistillation methods (Mohagheghniapour et al., 2018). Previous studies on essential oil distillation using the ohmic method, including for cumin (*Carum Carvi* L.) products based on ohmic heating, showed that the extraction time was much shorter than conventional distillation (Abdulstar et al., 2022). The OAHD method produces a higher volume of essential oil compared to conventional hydrodistillation (Hamzah et al., 2014). This study will compare the OAHD distillation process to conventional hydrodistillation from essential oils' process parameters, yield, and quality parameters, such as specific gravity and refractive index. The results of this study are expected to be applied in the industry to handle organic waste, especially citrus peels, and encourage the utilization of agricultural waste, which ultimately contributes to sustainable development goals.

2. MATERIAL AND METHODOLOGY

2.1 Material

Mandarin cv. Terigas peel waste was obtained from the production of KPRI Citrus in Batu City, East Java. Citrus peel is sorted, and the remaining pulp that is still attached to the skin is removed. Next, the orange peel is washed clean and stored in a freezer at -20 before being used in the next treatment. Chemicals, such as distilled water, and ethanol (Merck), were purchased from the Kridatama Malang store, Malang.

2.2 Ohmic Assisted Hydrodistillation (OAHD)

OAHD equipment is designed by PT. Brawijaya Smart Industri, Malang. The components consist of a 10 cm diameter chamber tube, 20 cm high, and 1 stainless electrode, a condenser. The tool is equipped with a Tasi TA612C temperature data logger and a 220 v power supply. Fresh citrus peel is blended with distilled water at a 1:2 ratio of peel to water. The sample is inserted into a distillation tube, and the voltage is set at 70 volts, distillation is carried out for 20 minutes.

2.3 Hydrodistillation

Hydrodistillation equipment includes an infrared electric stove, a 2000 ml glass tube, a ball condenser, a vacuum pump, and an essential oil container. Citrus peel is blended with aquades solvent with a ratio of orange peel: aquades 1: 2. The mixture is then put into a distillation flask, the electric stove is set at 700 watts, and distillation is carried out for 115 minutes (Imro Ikarini et al., 2023)

2.4 Extraction performance analysis

2.4.1 Yield of essential oil

The yield of essential oil is calculated by dividing the weight of essential oil (m_2) by the weight of the material (m_1), first subtracting the water content in the material. The yield is calculated based on the dry weight using the formula below:

$$Yield : \frac{m_2}{m_1} \times 100$$

2.4.2 Electrical energy consumption

Electrical energy consumption calculations are carried out using the basic electrical energy formula (Karami et al., 2022). This formula is widely used in electrical analysis and is based on the relationship between electrical power, time, and energy used. Electrical energy can be calculated by multiplying the electrical power used (P) by the duration of use (t) according to the following equation:

$$E = \frac{P}{t}$$

E is the electrical energy consumed, measured in watt-hours (Wh) or joules (J), P is the power used, expressed in watts (W), t is the duration of usage, indicated in hours (h).

2.4.3 Specific gravity and refractive index

A pycnometer was used to determine specific gravity (Lubis et al., 2022). The following are the steps: Prepare a dry, empty pycnometer and weigh it (m); fill the pycnometer with distilled water, being careful not to create air bubbles; weigh the distilled water-filled pycnometer (m1); fill the pycnometer with essential oil, being careful not to create air bubbles; and weigh the distilled oil-filled pycnometer (m2).

Measuring the refractive index of essential oils is one of the important parameters in assessing the quality, purity, and composition of essential oils. The refractive index measures how much light is bent (refracted) when passing through a liquid. The refractive index was determined using the refractometer RRC Digital Abbe Refractometer type WYA 25 at 200C (Ibrahim et al., 2021)

2.5 Statistical analysis

A completely randomized design with three replications was used to compare samples of EOs from OAHD and conventional hydrodistillation. Other data obtained were compared using a one-way analysis of variance (ANOVA) using Minitab 20 software. Duncan's post hoc test was used to compare the means.

3. RESULT AND DISCUSSION

3.1 Extraction performance of citrus essential oil

The hydrodistillation heating process involves passing hot steam through citrus peel to evaporate the contained essential oils. The material is heated indirectly through water media that is warmed by an external heat source. In OAHD, the heating process involves the direct flow of electric current through the material. The combination of material and solvent functions as an electrical conductive medium, generating internal heat through electrical resistance. Table 1 illustrates the distinction between the OAHD process and conventional hydrodistillation. Table 1 shows that the onset time of oil accumulation in OAHD is much shorter than in hydrodistillation. The statistical analysis results are significant (p <0.05). The fast rate of oil accumulation in the OAHD method can be attributed to more efficient heat transfer and faster temperature rise (Karami et al., 2022).

Table 1: Effect of extraction method on extraction performance of citrus essential oil

Extraction method	Process starting time for oil accumulation (min)	Distillation Temperature (°C)	Total Distillation Time (min)	Electrical Power (Watt)	Voltage (V)	Energy consumption (kWh/ g EO)
OAHD	9.144a±0.602	97.3	20	500	70	0.009b±0.000
Conventional Hydrodistillation	27.617b±1.263	97.6	105	700	220	0.181a±0.006

Means in columns followed by different letters indicate statistically different results ($p < 0.05$)

The rate of temperature increases in the OAHD and conventional distillation processes can be seen in Figures 1 and 2. At an extraction time of 5 minutes, OAHD has reached a temperature increase of 85°C, while in hydrodistillation, at 15 minutes, it has only reached a temperature of 60°C. In less than 10 minutes, OAHD reached a distillation point temperature of 97.3°C. The rapid temperature increase in OAHD likely accelerates oil accumulation compared to hydrodistillation. Faster oil accumulation indicates that the OAHD method is more time-efficient, potentially increasing productivity in the essential oil extraction process.

The total distillation time for the OAHD method is 20 minutes, with a power requirement of 500 watts at 70 volts. While the conventional method requires up to 115 minutes with a power of 700 watts and a voltage of 220 volts. This significant time difference shows that the OAHD method is much more efficient in reaching the boiling point and completing the entire distillation process. The use of lower electrical power by the OAHD method shows that this technology is more energy efficient. This can be seen in the energy consumption results, which show that energy consumption in OAHD is lower than that of hydrodistillation. In the study of *Achillea millefolium* L. essential oil extraction, the electrical energy consumption required was 0.39 kWh/g EO, this result was also lower compared to conventional technology in the study, which was 1.15 kWh/g EO (Karami et al., 2022). Savings in electrical energy consumption have a direct impact on saving electricity costs and can also have an impact on environmental sustainability by reducing the carbon trace of the process.

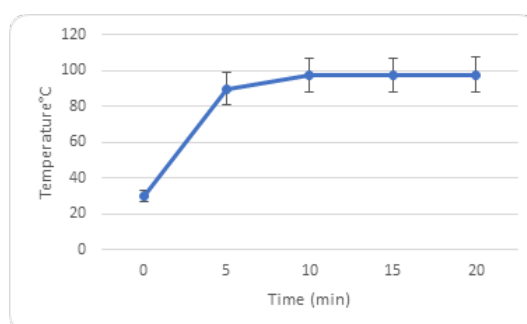


Figure 1. Graph of temperature changes during the distillation process in OAHD

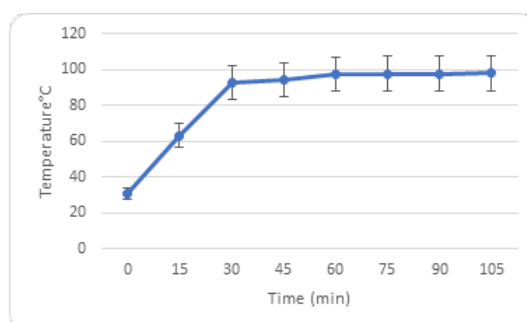


Figure 2. Graph of temperature changes during the distillation process in Hydrodistillation

3.2 Quality of citrus essential oil

The primary objective of the extraction process is to produce the best possible essential oils while accounting for energy use, time efficiency, and product quality. Selecting the appropriate distillation technique to optimize yield while preserving the quality of the essential oil produced is crucial. A high essential oil yield followed by good quality, such as specific gravity and refractive index, determines the distillation process's success. The parameters of yield, specific gravity, and refractive index of essential oil can be seen in Table 2.

Table 2: Effect of extraction method on quality of citrus essential oil

Extraction method	Yield (%)	Specific gravity (g/ml)	Refractive index
OAHD	17.975a±0.722	0.839a±0.835	1.468a±0,00
Conventional Hydrodistillation	14.824b±0.489	0.835a±0.003	1.469a±0.00

Means in columns followed by different letters indicate statistically different results ($p < 0.05$)

Table 2 shows that the OAHD yield is higher than that of hydrodistillation. The results statistically show significant differences between treatments at p-value (<0.05). OAHD produces a dry weight yield of 17.975% and hydrodistillation of 14.824%. The tangerine essential oil obtained from hydrodistillation has a yield of 3.161% (Ikarini et al., 2021).

OAHD utilizes the principle of volumetric heating, where heat is generated evenly throughout the mixture of materials and solvents. Unlike conventional hydrodistillation, which relies on conductive heat transfer from an external source, OAHD generates heat internally through electrical resistance (Tunç & Koca, 2019). This results in a more uniform and efficient heat distribution, allowing the entire mass of material to reach the optimal extraction temperature in a shorter time. This is based on the extraction time test in Table 1. The essential oils from OAHD distillation and conventional hydrodistillation have specific gravity and refractive index that are not significantly different between treatments. This shows that the quality of essential oils from the two methods has met the standards.

4. CONCLUSION

Citrus peel waste that has been discarded as waste can be processed into products with economic value, such as essential oils. The ohmic hydrodistillation process is one of the effective technological options. Ohmic hydrodistillation offers several significant advantages over conventional methods, especially regarding time and energy efficiency, product quality, and higher yield potential. While OAHD may require a higher initial investment, it offers long-term benefits in productivity and product quality

Acknowledgment

This research was supported by funding from the Professor Grant Program, Brawijaya University, under Grant No. 6583. We sincerely appreciate the university's support in enabling this study and the facilities.

REFERENCES

Abdulstar, A. R., Altemimi, A., Al-Hilphy, A. R. S., Watson, D. G., & Lakhssassi, N. (2022). Water

- distillation using an ohmic heating apparatus. *International Journal of Ambient Energy*, 43(1), 2748–2758. <https://doi.org/10.1080/01430750.2020.1773924>
- Hamzah, M. H., Che Man, H., Abidin, Z. Z., & Jamaludin, H. (2014). Comparison of citronella oil extraction methods from *Cymbopogon nardus* grass by ohmic-heated hydro-distillation, hydro-distillation, and steam distillation. *BioResources*, 9(1), 256–272. <https://doi.org/10.15376/biores.9.1.256-272>
- Ibrahim, M. K., Kadhim, S. A., & Fawaz, N. I. (2021). Refractive Index Sensor for Salty and Sugary Solution Based on Optical Fiber Technical. *Journal of Physics: Conference Series*, 1879(3). <https://doi.org/10.1088/1742-6596/1879/3/032077>
- Ikarini, Imro'ah, Harwanto, & Yunimar. (2021). Karakteristik Fisik dan Identifikasi Senyawa pada Minyak Atsiri dari Limbah Kulit Jeruk. *Agriprima : Journal of Applied Agricultural Sciences*, 5(2), 131–137. <https://doi.org/10.25047/agriprima.v5i2.436>
- Ikarini, Imro, Suwarda, R., Hani, Z., Triasih, U., & Ashari, H. (2023). Chemical Composition and Physical Characteristics of Orange Peel Essential Oil. 01004, 6–13.
- Ikarini, Imro, Yuwono, S. S., Dwi, W., & Putri, R. (2024). Mandarin citrus (*Citrus reticulata* Blanco cv . Terigas) peel essential oil as a potential nanoemulsion ingredient : Formulation , physicochemical characterization , and antibacterial activity. 02004, 1–12.
- Karami, P., Zandi, M., & Ganjloo, A. (2022). Evaluation of key parameters during ohmic-assisted hydro-distillation of essential oil from aerial part of yarrow (*Achillea millefolium* L.). *Journal of Applied Research on Medicinal and Aromatic Plants*, 31(September), 100425. <https://doi.org/10.1016/j.jarmap.2022.100425>
- Lubis, A., Mandang, T., Hermawan, W., & Sutrisno. (2022). Characterization of the Yield and Quality of Patchouli Oil Based on the Size of Chopping and Drying Type. *IOP Conference Series: Earth and Environmental Science*, 1038(1). <https://doi.org/10.1088/1755-1315/1038/1/012075>
- Mohagheghniapour, A., Saharkhiz, M. J., Golmakani, M. T., & Niakousari, M. (2018). Variations in chemical compositions of essential oil from sour orange (*Citrus aurantium* L.) blossoms by different isolation methods. *Sustainable Chemistry and Pharmacy*, 10(April), 118–124. <https://doi.org/10.1016/j.scp.2018.10.008>
- Tocmo, R., Pena-Fronteras, J., Calumba, K. F., Mendoza, M., & Johnson, J. J. (2020). Valorization of pomelo (*Citrus grandis* Osbeck) peel: A review of current utilization, phytochemistry, bioactivities, and mechanisms of action. *Comprehensive Reviews in Food Science and Food Safety*, 19(4), 1969–2012. <https://doi.org/10.1111/1541-4337.12561>
- Tran, T. H., Dao, T. P., Ngo, Q. C. T., Bach, L. G., & Huynh, X. P. (2020). Comparative evaluation of the antibacterial activities of the essential oils of *Citrus grandis* (L.) Osbeck obtained by hydrodistillation and microwave assisted extraction methods. *IOP Conference Series: Materials Science and Engineering*, 991(1). <https://doi.org/10.1088/1757-899X/991/1/012010>
- Tunç, M. T., & Koca, İ. (2019). Ohmic heating assisted hydrodistillation of clove essential oil. *Industrial Crops and Products*, 141(September). <https://doi.org/10.1016/j.indcrop.2019.111763>

PANEL DISCUSSION

Moderator: Mr. Yacob Ahmad, Advisor, International Tropical Fruits Network

Panellists:

- 1. Dr. Mohammad Sohail Mazhar, Acting Executive Director, Department of Agriculture and Fisheries, Northern Territory, Australia**
- 2. Dr. Guinevere Ortiz, Senior Scientist Postharvest-International Development, International Development Unit (IDU), The New Zealand Institute for Plant and Food Research Limited.**
- 3. Dr. Dinh Tran, Faculty of Food Science and Technology, Vietnam National University of Agriculture, Hanoi, Vietnam.**
- 4. Dr. Aris Purwanto, Faculty of Agriculture Engineering and Technology, Institute Pertanian Bogor University, Indonesia**
- 5. Dr. Shalendra Prasad, Director of Research, Department of Agriculture, Fiji**

Moderator Yacob in his introduction said that it is well known fact that postharvest losses represent a significant challenge in agricultural production including the tropical fruit sector. These losses not only affect the economic viability of our agricultural sectors but also have profound implications for food security and sustainability. At the same time there has been considerable research conducted to mitigate post harvest losses. Moderator introduced the panel, citing their expertise in the matter and proceeded with the question:

Guiding Question: How do we ensure that small farmers have access to recent technologies in postharvest management and how do we approach the different situations according to farmers' operational capacity.

a. Dr. Aris Purwanto reiterated on the lack of technology transfer between research institutions and small farmers. While there may be available postharvest technologies and equipment, they may need to be adjusted to suit the farm environment. Farmers are also sceptical of new technologies under they are already in use by other farmers or early adopters. Adoption remains limited unless proven by early adopters. This may be due to the additional cost involved in accessing the new technologies. He proposed focusing on technologies with immediate impact for farmers, such as his earlier presented plasma-activated fine bubble water and suggested that accessibility to facilities is key. As an academic, he mulled the setting up packinghouse facilities near university campuses to provide training and easier access for smallholders. Responding to the facilitator's comment, he called for greater collaboration between government and private sectors to scale these efforts.

b. Dr. Mohammad Sohail Mazhar stressed the importance of efficiency and productivity at all levels of the value chain and, that technologies introduced are consistent with on-the-ground realities. There has to be full grower involvement in defining what problems exist at the field level. Since almost 70 % work is business related, analysing issues along the value chain is imperative. Dr. Sohail also reenforced the view that stakeholders are important to resolve production issues. In capacity building, he added that handlers, processors and logistic providers be included.

c. Dr. Dinh T. Tran shared her insights from the Vietnamese perspective, where smallholders face multiple challenges especially in capacity building including insufficient training in areas including Integrated Pest Management, value chain enhancements and processing. She gave

the example of jackfruit where extension services to growers are provided by researchers and government institutions. Market-led strategies, including expanding and identifying domestic and international demand, incorporation of certification schemes such as GlobalGAP and organic certification, where pertinent, tend to boost up competitiveness. As currently practiced and slowly expanding, establishments of farmers' groups and linking with private companies is beneficial in maintaining quality, market access and minimize losses.

d. Dr. Guinevere Ortiz shared the different approaches conducted in New Zealand and the Philippines. While generally technology transfer in New Zealand is conducted by research institutions, extension services and agricultural consultants, industry bodies also fund and conduct research with research organizations and disseminate findings to stakeholders. Levies collected by horticultural boards are reinvested into innovation and technology transfer. In the Philippines, the private sector are the main players who also invest in efficient technologies and who also source their marketable supplies from smallholders according to their quality standards. The government support and extension program exists; however, private companies involvement are minimal.

e. Dr. Shalendra Prasad provided examples from Fiji, where simple, affordable technologies are more likely to be adopted. An effective extension service is imperative to ensure that technologies including hands-on demonstration plots to build farmers confidence, are beneficial and affordable. He reiterated the role of extension services and identified high input costs associated with adoption of new technologies as a major constraint.

Other comments

f. A representative from DOLE Philippines explained that many banana and pineapple growers in the country work with multinational companies and organizations to reduce losses across the supply chain. Regulatory agencies need to intensify awareness by focusing on farm-level handling and processing facility standards.

g. Dr. Setyadjit from BRIN, Indonesia commented on the processing of fruit to meet urban demand. He suggested that governments provide training support and enhancing processing initiatives for fruit vendors in the urban areas. In Indonesia, where demand for fresh and processed fruit is high, storage facilities are often inadequate. He opined the need to support sellers, improve local supply, and ensure product storage quality to meet domestic consumer expectations for value-added products. In other words, a higher demand for processed fruit, like juice will stimulate production at the farm level.

h. Dr. Hasan Dinar, from Sudan emphasized the importance of conducting supply chain studies to identify critical loss and waste points along the chain. This includes handling, processing, storage and logistic providers. He reiterated the enhancement of extension services via various media platform and use of handheld devices.

i. Dr. Mohd Akhtar from the Bangladeshi Ministry of Agriculture added that generally, postharvest management initiatives have to consider market and consumer preferences. As raised by the other members, sometimes, farmers are not accessible to best farm practices and technologies. To minimize the constraints government support to farmers' groups or cooperatives must be enhanced. On another point, he mentioned that efficient management of postharvest losses and waste can be beneficial to farmers to sustain farm operations.

Key Takeaways and Recommendations

- **Industry and Producer Led Solutions:** A bottom-up approach to define on the ground issues is imperative by engaging with the private sector, farmers and stakeholders from the start to co-design technologies based on real challenges.
- **Demonstration and Trust Building:** On-site demonstrations and success stories can catalyze technology uptake among smallholders.
- **Capacity Building Across the Value Chain:** Losses are encountered at every stage of the value chain, therefore, capacity building efforts go beyond the production phase, to processors, distributors and retailers.
- **Institutional Synergies:** Universities, government agencies, and private sector actors must collaborate to build localized infrastructure (e.g., packinghouses, processing units).
- **Market-Led Approaches:** Market research, certification, and value chain alignment have to be considered in accessing or expanding markets and at the same time, conform to quality requirements.
- **Policy and Extension Support:** Government-backed extension services, financial support mechanisms, and public-private partnerships are crucial for sustained technology dissemination.
- **Digital Platforms for Extension:** The use of digital media, especially hand-held devices to deliver extension content from pre-harvest to postharvest stages can improve reach and effectiveness.

The panel discussion highlighted that postharvest losses are not necessarily as always reported to be 30 percent across the board. Postharvest management approaches vary according to a country's agricultural development, crop type and whether production is for the domestic or export markets or both. Solutions also vary according to the degree of involvement of private businesses, smallholders, and others. Generally, for many countries, increasing smallholder access to postharvest technologies requires an integrated, participatory approach that links research, infrastructure, policy, and grassroots engagement.

CARBON AND WATER FOOTPRINT MEASUREMENT IN TROPICAL FRUIT VALUE CHAINS

María Hernández Lagana and Michael Riggs

Food and Agriculture Organization of the United Nations

Climate change poses significant challenges to the tropical fruit sector, impacting ecosystems, livelihoods, and infrastructure, particularly in developing countries where most production and export occur. The sector's vulnerability to climate variability, extreme weather events, and increased pest and disease outbreaks contributes to high rates of pre- and post-harvest losses. Additionally, growing international demand for tropical fruits has led to increased pressure on producers to adopt environmentally sustainable practices and report on their environmental and social impacts. In this context, measuring carbon and water footprints has emerged as a critical strategy for mitigating climate change and ensuring the long-term sustainability of the tropical fruit sector. Carbon footprint measurements help quantify greenhouse gas (GHG) emissions, while water footprint measurements evaluate water use and impacts. These measurements provide insights that allow stakeholders to optimize resource use, reduce costs, and comply with international standards. Moreover, they can strengthen market competitiveness and support efforts to achieve global climate and sustainability goals. To support these efforts, the Food and Agriculture Organization (FAO) has developed practical tools and methodologies, including the guide "Measuring Carbon and Water Footprints in Pineapple Value Chains", the World Banana Forum's tool to measure carbon and water footprints in banana plantations, and the Environmental eXternalities ACcounting Tool (Ex-ACT). These resources provide standardized frameworks to assess and reduce environmental impacts across tropical fruit value chains.

Keywords: carbon footprint, water footprint, greenhouse gas, climate change, water, sustainability, tropical fruit sector

1. INTRODUCTION

Climate change is an observed reality in the world, with countries facing widespread impacts on ecosystems, livelihoods and infrastructure. Climate variability, coupled with more frequent and intense extreme weather events, is expected to intensify and continue affecting all regions now and in the future (IPCC, 2021, 2022). Agriculture is one of the sectors hardest hit by climate change and its impacts, especially in developing countries (FAO, 2018a), making the challenge of feeding the world's growing population more difficult than ever before.

The tropical fruit sector plays a vital role in global food security, economic growth, and trade. The sector supports livelihoods, particularly in developing countries where most production and export occur, while providing nutritious foods to populations worldwide. However, the sector faces significant challenges due to its high vulnerability to climate change. The physiological and yield characteristics of tropical fruit crops are highly sensitive to variations in climate and weather, making them particularly susceptible to disruptions. Yet adapting crop plants, especially perennials, to changing conditions is a slow process that can take many years (FAO, 2024c). Moreover, the increased frequency and intensity of droughts, floods, and heatwaves,

combined with the rise in pest and disease outbreaks and growing resistance, exacerbate pre- and post-harvest losses and damage agricultural infrastructure (Bancal and Ray, 2022). These losses not only reduce the availability of food and income for producers but also contribute to food and nutrition insecurity, GHG emissions and environmental degradation, through pollution and waste of essential resources as water, soil and energy.

Stakeholders in the tropical fruit industry are also facing increasing requirements from import markets to report on the environmental and social impacts of their operations. Fast growing international demand for tropical fruits is coupled with rising concerns about natural resources management, such as water, and GHG emissions. Consumers, customers and investors are increasingly demanding products that are grown in a more environmentally sustainable way, increasing the pressure for producers and exporters to ensure the use of sustainable practices that minimize environmental footprints of their operations, and to report on their environmental performance (FAO, 2024d).

Measuring carbon and water footprints is crucial in this context. This paper explores the significance of carbon and water footprint measurement in the tropical fruit sector and presents some methodologies and tools available for assessment.

2. THE IMPORTANCE OF MEASURING CARBON AND WATER FOOTPRINTS

The agriculture sector, including tropical fruit cultivation and trade, is not only impacted by climate change; it is also a driver of it. It is estimated that agri-food systems contributed 29.7 percent of GHG emissions in 2022, mainly from farm-gate activities and pre- and post-production processes (FAO, 2024a). Emissions from the manufacturing of inputs (e.g. agrochemicals), transport, packaging and retail, and household consumption all grew by more than 80 percent from 2000 to 2022 (FAO, 2024a). A substantial amount (25–50 percent) of fruit is lost after harvest due to pathogens, poor post-harvest handling technologies, poor packaging, and inadequate infrastructure for storage, transportation, processing and recycling processes (Bancal and Ray, 2022).

Water is an irreplaceable resource essential for human life and ecosystem health. However, its availability varies widely across regions, and it is increasingly threatened by the effects of climate change. In areas where water is already scarce, shortages can have severe consequences for livelihoods, ecosystems and communities. Even in regions not facing immediate water scarcity, overexploitation and pollution from industrial and agricultural activities can degrade water quality, harming human health and biodiversity (FAO, 2024b). As climate change advances, these challenges are expected to worsen, further straining water resources and increasing the urgency for sustainable water management.

In today's world, awareness of environmental sustainability has taken a front seat in global discussions, with an increasing need to assess and mitigate the impacts of various industries, including the tropical fruit industry, on the environment.

Carbon and water footprint measurement in tropical fruit value chains can support these efforts. Carbon footprint refers to the total amount of GHG generated by human activities. In agriculture, these emissions stem from various sources, including input use for production (e.g. agrochemicals, manure), land-use change, energy consumption, transportation, and post-harvest processes. Measuring carbon footprints is essential for identifying high-emission areas in the operations and implementing strategies to mitigate the climate impact. On the

other hand, water footprint measures the potential environmental impacts related to water use, including freshwater consumption, contamination and depletion. Given the significant water needs of tropical fruit production and processing, as well as the potential for pollution of water resources, assessing the water footprint is crucial to preserving the availability and quality of water for populations and other industries (FAO, 2024b).

These assessments provide valuable insights into the environmental impact of production and trade, helping stakeholders identify ways to reduce GHG emissions and water use. Furthermore, quantifying these footprints can help producers and exporters to optimize their operations, reduce costs and comply with market regulations. Specifically, a robust calculation of carbon and water footprints offers multiple benefits to stakeholders in the tropical fruit industry, including:

- Environmental sustainability: identifying areas in operations where higher GHG emissions take place or where most water is consumed, which helps develop strategies to reduce emissions, water use and impacts on water quality.
- Regulatory compliance: supporting adherence to international standards and requirements from some certification bodies.
- Market access and competitiveness: complying with international buyers' and retailers' environmental sustainability reporting requirements, making footprint assessments and reporting a competitive advantage.
- Traceability and cost efficiency: tracing operations closely and identifying high-emission and water use areas can help optimize resource use, leading to cost savings in energy, water and inputs.
- Climate risk management: reducing emissions and managing water sustainably help build resilience against climate-related disruptions, by making resources more durable, available and of higher quality to ensure the continuity of the operations.

3. MEASURING CARBON AND WATER FOOTPRINTS IN THE TROPICAL FRUIT SECTOR

Recognizing the need for standardized footprint measurements, the Food and Agriculture Organization of the United Nations (FAO) has developed methodologies and tools to assess carbon and water footprints in the agriculture sector. These resources are designed to help stakeholders in the tropical fruit sector, as well as the broader agricultural industry, independently quantify the GHG emissions and water resource impacts resulting from their operations or projects, increase transparency and support decision-making.

3.1 Measuring carbon and water footprints in pineapple value chains

The FAO-led Responsible Fruits Project developed the guide "Measuring Carbon and Water Footprints in Pineapple Value Chains" to provide a standardized approach for assessing the environmental impacts of pineapple production, processing, packing, and transportation to the port. This methodology builds on experiences from the banana industry and offers a comprehensive, quantitative framework for evaluating GHG emissions and water resource impacts. To ensure its robustness and compatibility with global practices, the guide follows internationally recognized standards, ISO 14064 for carbon footprint measurement, and ISO 14046 for water footprint measurement. The methodology largely uses the GHG emission inventories developed by the Intergovernmental Panel on Climate Change (IPCC). The guide was tested and validated with six export-oriented pineapple-producing and packing

companies in Costa Rica, ensuring its practicality in guiding the industry's sustainability efforts (FAO, 2024b).

The footprint measurement process for the pineapple sector covers key stages of the value chain, namely, a) land preparation and planting, which includes an assessment of emissions from soil management, fertilizer use, and water consumption; b) crop management to account for inputs such as agrochemicals, irrigation, and energy use; c) post-harvest processing, to assesses water use in washing, cooling, and packing, as well as energy consumption in refrigeration and transportation; and, d) logistics and trade, which evaluates emissions from transport to the export point and storage infrastructure.

The guide also offers a list of strategies to reducing GHG emissions and water impacts associated with water scarcity, human toxicity, ecotoxicity and eutrophication in the pineapple sector. Some of these include, improving energy efficiency by adopting renewable energy sources and maximizing equipment use; fuel and logistics optimization, by making transport routes more efficient, using low-emission vehicles and alternative fuels; adopting sustainable farming practices; improving agrochemical management; and enhancing waste management. The project also developed a complementary set of learning materials about measuring carbon and water footprints to help stakeholders in the pineapple value chain make their operations more resilient and sustainable. These materials offer a comprehensive set of resources, including a training guide, three slide decks (an introductory deck providing an overview of the tools and two specific decks on carbon and water footprint methodologies), and two videos – one each on carbon and water measurement. These materials are valuable for trainers and businesses in the pineapple industry as they work to reduce their environmental impact in terms of GHG emissions, water use and water quality. Additionally, they support industry efforts to meet international market demands for sustainability and transparency.

The guide and the learning materials are available on the project website: <https://www.fao.org/markets-and-trade/responsible-fruits/climate-action/en>

3.2 Measuring carbon and water footprints in banana value chains

In 2017, the World Banana Forum (WBF) – hosted by FAO – developed a methodological guide to reduce water and carbon footprints in banana plantations worldwide. The topic was prioritized by different stakeholders in the banana industry, acknowledging the contribution of banana production and trade operations in total global GHG emissions and consumption of freshwater, as well as the high mitigation potential that the sector holds. To meet this goal of mitigation, the WBF developed a practical methodology to strengthen the efforts of the global banana industry to reduce its carbon and water footprint. The guidance document helps banana producers and businesses to assesses the GHG emissions and impacts on water resources, and mainstreams the adoption of climate-smart practices and efficient water management to enhance the environmental strategy of organizations (FAO, 2018). The methodology is available at <https://openknowledge.fao.org/handle/20.500.14283/i8333en>.

To make the methodology more accessible and user-friendly, the WBF developed the online Carbon and Water Footprint Tool (CWF 2.0). This automated tool helps banana producers and companies calculate and report the carbon and water footprints of their operations. CWF 2.0 builds on the previously developed printed methodology, offering a more interactive and efficient approach. It enables users to calculate carbon dioxide (CO₂) equivalent emissions (or removals) by categorizing them into various emission sources, such as electricity, stationary and

equipment combustion, mobile combustion, maintenance products, refrigeration, fertilizers and inputs, waste, animal traction, land use changes, and soil carbon stocks. In addition to carbon footprint measurement, the tool also quantifies the water footprint of operations, considering water consumption and impacts related to water scarcity and quality. By integrating both carbon and water assessments, the CWF 2.0 tool provides a comprehensive understanding of the environmental impacts associated with banana production, making it a valuable resource for stakeholders seeking to implement more sustainable practices. The tool enables banana industry actors to measure and track environmental impacts, identify low-carbon and efficient water management strategies, contribute to climate change mitigation and adaptation efforts, and ensure compliance with sustainability certifications for market entry.

3.3 Quantifying GHG emissions in the entire agriculture sector

The Environmental eXternalities ACcounting Tool (Ex-ACT, formerly EX-Ante Carbon balance Tool) was developed by FAO to provide a consistent way for users to estimate and track the outcomes of agricultural interventions on GHG emissions. EX-ACT is not specific to a commodity. Rather, it is the only GHG accounting tool to cover the entire agricultural sector including agriculture, forestry and other land use (AFOLU) inland and in coastal wetlands, fisheries and aquaculture, agricultural inputs and infrastructure (FAO, 2022).

The tool quantifies GHG emissions and sequestration across agricultural projects following the IPCC methodology for GHG emissions inventories, helping policymakers and project managers to evaluate the carbon impact of interventions, assess biodiversity implications, and optimize land-use planning. The Ex-ACT tool works on Excel and online, and can be accessed at: <https://exact.apps.fao.org/auth/login>

The primary aim of Ex-ACT is to help decision-makers in the public and private sectors identify the climate mitigation outcomes of agricultural interventions, including projects, policies and investments, at any stage of implementation. The tool can be applied at various scales, from local to regional and national levels, providing flexibility to meet diverse needs, including accessing funding from international financial institutions. Additionally, it helps strengthen the capacity of stakeholders to estimate, monitor and evaluate progress toward emissions reduction goals. At the policy level, Ex-ACT can support policy makers in integrating climate change mitigation objectives into national strategies and international commitments, such as Nationally Determined Contributions or National Adaptation Plans (FAO, 2022).

FAO developed an e-learning course to guide users in the understanding of the tool and its use: <https://elearning.fao.org/course/view.php?id=950>

4. CONCLUSION

Measuring carbon and water footprints in the tropical fruit sector is crucial for promoting environmental sustainability and mitigating climate change. These efforts enable producers to adopt more sustainable practices, ensuring the long-term viability of their operations while contributing to global efforts in climate change mitigation and resource conservation. By quantifying emissions, assessing water impacts, and implementing corrective measures, producers, businesses and organizations can also comply with regulations and optimize their operations, reduce costs and strengthen their competitiveness in the market. Ultimately, by taking these measures, the tropical fruit industry can achieve economic growth while safeguarding the planet for future generations.

FAO has developed several practical tools and methodologies to support these efforts, including the “Measuring Carbon and Water Footprints in Pineapple Value Chains” guide by the Responsible Fruits Project, the World Banana Forum’s automated tool for the banana industry, and the Ex-ACT tool. These resources provide robust frameworks for assessing and reducing the environmental impacts of the agricultural sector, with a specific focus on tropical fruit production.

Adopting footprint measurement strategies can help the tropical fruit industry enhance resource efficiency, meet regulatory requirements, and contribute to global climate goals. As the sector moves forward, the widespread adoption of these methodologies will be essential for building more resilient and sustainable tropical fruit value chains.

REFERENCES

- Bancal, V. & Ray, R. 2022. Overview of Food Loss and Waste in Fruits and Vegetables. Fruits and vegetable wastes. https://doi.org/10.1007/978-981-16-9527-8_1
- FAO. 2024a. Greenhouse gas emissions from agrifood systems - Global, regional and country trends, 2000–2022. FAOSTAT Analytical Brief 94. Rome.
- FAO. 2024b. Measuring carbon and water footprints in pineapple value chains. Rome. <https://doi.org/10.4060/cd1688en>
- FAO. 2024c. Adapting to climate change in the tropical fruit industry: a technical guide for avocado producers and exporters. Rome. <https://doi.org/10.4060/cc9309en>
- FAO. 2024d. Responsible business conduct in the avocado industry: a guide for producers and exporters. Rome. <https://doi.org/10.4060/cd0963en>
- FAO. 2022. Ex-Ante Carbon-balance Tool | EX-ACT – Guidelines. Second edition – Tool version 9. Rome. <https://doi.org/10.4060/cc0142en>
- FAO. 2018a. Addressing sustainable crop production priorities in National Adaptation Plans. Rome. www.fao.org/3/CA2930EN/ca2930en.pdf
- FAO. 2018b. Methodological guide to reduce carbon and water footprints in banana plantations. Rome. <https://openknowledge.fao.org/handle/20.500.14283/i8333en>
- IPCC (Intergovernmental Panel on Climate Change). 2021. Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, United States of America. <https://doi.org/10.1017/9781009157896>
- IPCC. 2022. Climate change 2022. Impacts, adaptation and vulnerability. In: IPCC. www.ipcc.ch/report/ar6/wg2

LIST OF PARTICIPANTS

NO.	NAME	DESIGNATION	ORGANIZATION
1	Mr. Abdul Azizul Rahim Badarussham	Agriculture Officer	Department of Agriculture Malaysia
2	Mr. Abdul Rashid Bin Bahri	Director General	Federal Agricultural Marketing Authority, Malaysia
3	Ms. Ainul Maria Abu Bakar	Principal Assistant Secretary	International Division Ministry of Agriculture and Food Security, Malaysia
4	Dr. Aris Yohanes Purwanto	Professor	IPB University, Bogor, Indonesia
5	Datuk Azah Hanim Ahmad	Deputy Secretary General (Policy)	Ministry of Agriculture and Food Security, Malaysia
6	Mr.Christian Anthony Tolentino Cangao	Information Officer	TFNet
7	Mr. Christopher John Biai	Director, BPIT	Department of Agriculture Malaysia
8	Ms. Dayang Nur Fashareena Datu Md. Noor	Senior Research Officer	Department of Agriculture Sabah, Malaysia
9	Ms. Deng Xianzue	PhD Scholar	Ningbo Uni China / Fac of Agri UPM, Malaysia
10	Dr. Ellina Mansyah	Senior Researcher	National Research and Innovation Agency (BRIN), Indonesia
11	Ms. Eliwanzita Sospeter	PhD Scholar	Mbeya University of Science and Technologya / Fac of Agri UPM, Malaysia
12	Ms. Farhana Hafizah Hamdan Mustafa	Pegawai Pertanian Kuasausaha BPIT Johor	Department of Agriculture Malaysia
13	Mr. Fauzan Khumeidi	Plantation Advisor / Head of R&D	Great Giant Pineapple Indonesia
14	Mr. Floro 'Roy' Ortiz	Director, Technical Services & Quality Assurance	Dole Asia Company, Ltd., Philippines
15	Mdm GDSN Chandrasena	Additional Secretary (Agri.Development)	Ministry of Agriculture and Plantation Industries, Sri Lanka
16	Dr. Guinevere (Gwen) I. Ortiz	Senior Scientist Postharvest Int. Development Unit (IDU)	The New Zealand Inst for Plant and Food Research Limited, New Zealand
17	Ms. Hariyatul Asni Abdul Rani	Admin. Officer	TFNet
18	Dr. Hassan Ali M. Dinar	Professor of Hort Science	King Faisal University, Saudi Arabia
19	Dr. He Weidi	Researcher	Institute of Fruit Tree Research, GDAAS, China
20	Ms. Huang Jiayue	Master Student	Ningbo University / Fac Agriculture UPM, Malaysia
21	Dr. Hua Huang	Researcher	Institute of Fruit Tree Research, GDAAS, China

22	Ms. Imro'ah Ikarini	Scientific Researcher Value-Added Agroindustry Product Enhancement Research Group	Research Center for Agroindustry National Research and Innovation Agency (BRIN), Indonesia
23	Ms. Jamilah Nayan	Agriculture Officer	Department of Agriculture Malaysia
24	Ms. Joanna Cho Li Ying	Senior Researcher - Biological Sciences - Physiology	Horticulture Research Centre, MARDI Headquarters, Malaysia
25	Dr. Joel L. Adorada	Senior Agriculturist	Los Baños National Crop Research, Development, and Production Support Services Bureau of Plant Industry, Philippines
26	Mr. Khairil Helmi Khalid	Operation Asst.	Department of Agriculture Malaysia
27	Mr. Kelvin Kalianon	Agriculture Officer	Department of Agriculture Sabah, Malaysia
28	Dr. Lilynorfeshah Mohd. Shah	Pegawai Pertanian Kuasausaha Negeri Pahang	Bahagian Pembangunan Industri Tanaman Seksyen Unit Pembangunan Industri Tanaman Negeri, Jabatan Pertanian Negeri Pahang, Malaysia
29	Mr. Lim Hse Khai	Director	Agro BS Sdn. Bhd., Malaysia
30	Mr. Mansalajah Musa	Senior Research Associate	Institute For Development Studies (Sabah), Malaysia
31	Ms. Maria Lagana Hernandez	Economist, Int. Investment and T.Fruits Trade and Market Division	Food of Agriculture Organization (FAO), Italy
32	"Mr. Mat lesak Ngathinee (Representative to the DG of DoA)"	Director - Pesticide and Fertilizer Control Division	Department of Agriculture (DoA) Malaysia
33	Mr. Melvin Meana	Quality Assurance and Food Safety Manager	Dole Asia Company, Ltd., Philippines
34	Dr. Mohammad Roff Mohd. Noor	Expert Member	Malaysia
35	Dr. Mohammed H. Al-Rizeiqi	Deputy Director and Associate Researcher	Sultan Qaboos University, Oman
36	Dr. Mohd. Akhtar Hossain Khan	Chief Seed Technologies	Seed Wing, Department of Agriculture, Bangladesh
37	Mr. Mohd. Ali Hanafiah Mazlan	Agriculture Officer	Department of Agriculture Malaysia
38	Mr. Mohd. Fadzlee Borhan	Operation Asst.	Department of Agriculture Malaysia
39	Mr. Mohd Khairuzamri Bin M Salleh	Director General	Malaysian Pineapple Industry Board (MPIB), Malaysia
40	Mr. Mohd. Nazrie Kamaludin	Assistant Director	International Division Ministry of Agriculture and Food Security, Malaysia

41	Dr. Mohd. Sabri Pak Dek	Senior Lecturer,	Department of Food Science, Faculty of Food Science & Technology, UPM Serdang Selangor, Malaysia
42	Mr. Muhammad Irwan Repin	Analyst	Agro Bank , Malaysia
43	Dr. Muhammad Sohail Mazhar	Senior Director Plant Industries - Agriculture Branch	Department of Industry, Tourism and Trade Northern Territory Government of Australia
44	Mr. Nadzmi Nawawi	Special Officer to the DG of FAMA	Federal Agricultural Marketing Authority, Malaysia
45	Dr. Nguyen Quoc Hung	Director General	Fruits and Vegetables Research Institute (FAVRI), Vietnam
46	Dr. Nik Rozana Nik Mohd. Masdek	Senior Reseacher - Business Management	Socio Economic, Market Intelligence and Agribusiness Research Centre, MARDI Headquarters, Malaysia
47	Ms. Noremiliawati Abdullah	Pegawai Pertanian Kuasausaha BPIT N.9	Department of Agriculture Malaysia
48	Ms. Noor Ba'ah Abdol Said	Executive Assistant	TFNet
49	Ms. Noor Zaini Ahmad	Senior Principal Asst. Director	International Division Ministry of Agriculture and Food Security, Malaysia
50	Ms. Nor Hanis Aifaa Binti Yusoff	Senior Research Officer Horticulture Research Centre	MARDI, Malaysia
51	Ms. Nur Azlin Razali	Senior Research Officer	Horticulture Research Centre, Malaysian Agricultural Research and Development Institute (MARDI), Malaysia
52	Ms. Nur Syafini Ghazali	Research Officer	MARDI, Malaysia
53	Dr. Phebe Ding	Senior Lecturer	Faculty of Agriculture, UPM , Malaysia
54	Mr. Pranab Kumar Ghosh	First Secretary (Commercial)	Bangladesh High Commission
55	Dr. Rosalizan binti Md Saleh	Director of Industrial Plant Research Center / Senior Principal Research Officer	Industrial Plant Research Center, MARDI, Malaysia
56	Dr. Roslina Ali	Principal Research Officer - Economy, Applied Economy	Socio Economic, Market Intelligence and Agribusiness Research Centre, MARDI Headquarters, Malaysia
57	Prof. Dr. Rosnah Shamsuddin	Senior Lecturer,	Department of Process and Food Engineering, Faculty Engineering, Universiti Putra Malaysia, Malaysia
58	Ms. Rovica Anak Radin	Agriculture Officer	Department of Agriculture Malaysia
59	Ms. Saifful Rizal Ibrahim	Agriculture Officer	Department of Agriculture Malaysia

60	Dr. Samsiah binti Jusoh	Deputy Director of Postharvest Management Program / Senior Research Officer	Horticulture Research Center MARDI, Malaysia
61	Dr. Setyadjit	Associate Researcher Agroindustry Production Systems and Management Research Group	"Research Center for Agroindustry National Research and Innovation Agency (BRIN), Indonesia"
62	Dr. Shalendra Prasad	Director	Research & Agriculture Scientific Services Division Ministry of Agriculture & Waterways Fiji
63	Ts. Dr. Shiamala Devi Ramaiya	Senior lecturer	UPM Campus Bintulu Sarawak, Malaysia
64	Ms. Siti Aisyah Abdullah	Research Officer	MARDI, Malaysia
65	Hon. Air Chief Marshal Sumangala Dias	High Commissioner	Sri Lanka High Commission
66	Ms. Tan Zhi Shin	PhD Scholar	Faculty of Agriculture UPM, Malaysia
67	Dr. Tran Thi Dinh	Head of Department of Food Processing Technology	Faculty of Food Science and Technology Vietnam National University of Agriculture. Vietnam
68	Ms. Wan Mahfuzah Wan Ibrahim	Research Officer - Biological Sciences Physiology	Horticulture Research Center Sintok MARDI, Malaysia
69	Mr. Wan Mohd. Reza Ikwan Bin Wan Hussin	Deputy Director Postharvest Handling Program, Horticulture Research Centre	MARDI, Malaysia
70	Mr. Yacob Ahmad	Advisor	TFNet
71	Dr. Yi Ganjun	Vice President	Guangdong Academy of Agricultural Sciences, China
72	Mr. Yuanshuo Zhang	PhD Scholar	Ningbo Uni China / Fac of Agri UPM, Malaysia
73	Ms. Zhang Yuanyuan	Master Student	Ningbo University / Fac Agriculture UPM, Malaysia
74	Dr. Zulhazmi Sayuti	Director - Horticulture Research Center	Malaysian Agricultural and Research Development Institute (MARDI), Malaysia
75	Ms. Zulina Wook	Analyst	Agro Bank, Malaysia



INTERNATIONAL TROPICAL FRUITS NETWORK

P.O. Box 334, UPM Post Office
(Block C8, MARDI Headquarters)
43400 Serdang, Selangor
Malaysia

Tel. No.: +6017 234 1270

Email: info@itfnet.org

Website: www.itfnet.org

