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Phosphorus Recovery from Coconut Wastewater

Harnessing Coconut's Potential:
Partnerships for a Circular Economy and Maximized Value

Isolation, Identification and Pathogenicity of Entomopathogenic Fungi
for Coconut Asiatic Palm Weevil Management in the Philippines

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Optimizing Value and Resilience in the Coconut Sector

Global demand for coconut products, ranging from food and beverages to cosmetics, bio-based materials, and even renewable energy, continues to expand, underscoring the vast opportunities within the value chain. Despite this potential, the industry faces mounting pressures. Farmers are grappling with declining yields due to pest and disease outbreaks, aging palms, and prolonged droughts, erratic rainfall, and storm events that threaten plantation stability. The sector's future thus depends on its ability to adapt, innovate, and transition into a truly sustainable and circular economy. This edition of COCOINFO directly responds to this critical need, offering a robust body of research that provides actionable, science-based insights for farmers, researchers, industry leaders, and policymakers seeking to unlock the sector's full potential.

A central focus of the publication is improving the resilience of coconut palms under environmental stress. Research on Thailand's aromatic coconut variety highlights clear strategies to mitigate climate risks, safeguarding both farmer incomes and market stability. Complementary studies emphasize water conservation and moisture retention practices, which are critical for maintaining productivity in drought-prone and rainfall-irregular regions. Soil health research further reinforces the productivity agenda. Evidence shows that organic amendments significantly improve fertility and nut yield, with the combined application of Valarchi® Coconut-Soil Fortifier and Valarchi® Coconut-Root Feeder identified as a validated, high-return intervention. These targeted solutions move the industry beyond broad best practices toward precise, farmer-ready strategies with immediate, measurable impact.

Invasive pests remain one of the greatest threats to coconut livelihoods. This publication highlights crucial progress in sustainable pest management, particularly in controlling the Asiatic Palm Weevil (APW). Through the isolation and testing of indigenous entomopathogenic fungi (EPF), researchers validated their effectiveness as biological control agents. This innovation reduces reliance on chemical pesticides, offering an environmentally sound and scalable approach to pest management. By prioritizing biosecurity through biological control, the sector strengthens both plantation health and ecological integrity.

The most transformative contributions in this publication emphasize circular economy principles, effectively turning waste streams into valuable assets. Research quantified the physical properties of copra meal, enabling improved processing, export quality, and expanded applications as animal feed. This strengthens downstream markets and stabilizes the overall value chain. Another pioneering study developed a method to extract struvite (magnesium ammonium phosphate) directly from coconut wastewater. This dual-purpose solution both treats effluent and produces a slow-release fertilizer, addressing both environmental challenges and economic opportunities.

Together, these innovations embody a powerful waste-to-wealth transformation and illustrate how the sector can integrate profitability with sustainability.

The International Coconut Community urges all stakeholders such as farmers, researchers, private industry, and policymakers to act collectively in applying these vital insights. This publication is a record of scientific achievement that is critical for the continued development of the coconut sector.

DR. JELFINA C. ALOUW
Director General
Editor-in-Chief

Isolation, Identification and Pathogenicity of Entomopathogenic Fungi for Coconut Asiatic Palm Weevil Management in the Philippines

Sabiniano Q. Lamban[1], Johana C. Orense[2], Jayson S. Dungog[1], and Liberty H. Canja[3]

The Asiatic palm weevil (APW), *Rhynchophorus ferrugineus* Oliver (Coleoptera: Curculionidae) is a hidden, lethal tissue borer of the coconut palms and 40 other crops (FAO, 2019). The early stage of attack is very difficult to detect since the larvae feed on the soft internal tissues of coconut trunk and cabbage (PCA, 1994). Under careful observation, one may be able to detect infested palms with holes in the crown or trunk or base (Figure 1), with or without oozing brown liquid and chewed up fibers.

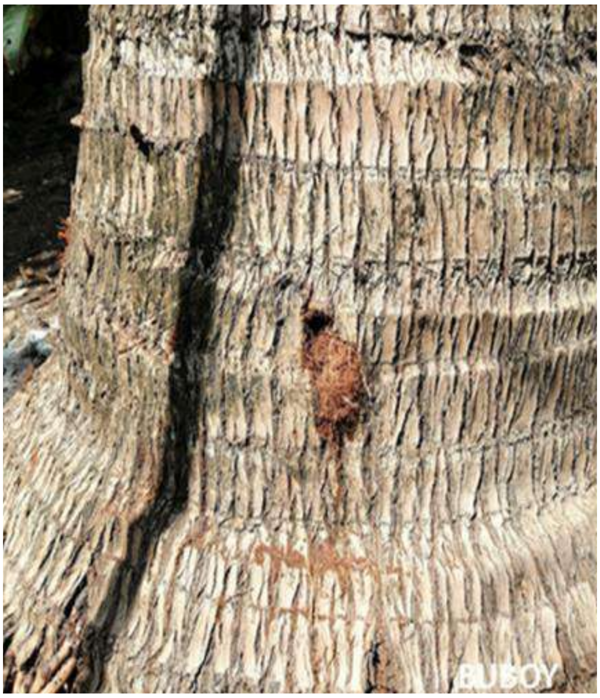

Figure 1. R. ferrugineus larval feeding hole at base of coconut trunk

At high infestation level symptoms resembling drought stress and bud rot infection, like wilting or yellowing, may be observed (Figure 2). Young palms within the age group of 2 to 15 years are more prone to attack but 3-6 year-old palms that start to develop boles are more susceptible.

Validation of APW infestation by Davao Research Center (DRC) in the provinces of Leyte, Eastern Samar, Camarines Sur, Davao del Sur, and

Figure 2. Extreme R. ferrugineus damage to palm showing wilted spear leaf

Sarangani last 2019 revealed that the percent infestation of coconut palms inspected ranged from 4%-63%.

Current recommended methods for APW management involved cutting down and burning severely infested palms, monitoring and mass trapping of adults with pheromone lures, cultural control and chemical treatments (ICPD Technoguide No.4, series of 2020). However, continous chemical application can lead to the development of pest resistance, thus creating public concerns about the adverse effect of widespread chemical use to human health and farm animals, food safety and to the environment. Consequently, other management techniques such as the use of entomopathogenic fungi (EPF) as biological control agents are explored.

EPFs are important natural control agents of insect pests. They infect their hosts through the external cuticles and are pathogenic to both soft and hard-bodied insects. Thus, EPFs have been widely studied and evaluated against many arthropods of agricultural importance. Recently, EPF's were discovered to have other ecological roles since many are known to be plant endophytes, plant diseases antagonist, rhizosphere colonizer and plant growth promoters. (Lacey et al., 2015).

There are few records on the occurrence of natural enemies of *R. ferrugineus*, which might be attributed to the cryptic habitat of the eggs, larvae and pupae which protect them from such natural enemies. Normally, the natural enemies do not play an important part in controlling of *R. ferrugineus*, though there were some attempts in using the predacious black earwig *Chelisoches morio* under laboratory and field conditions. However, these did not provide a measurable impact on the control of weevil (Sarwar, 2016).

In developed countries, there are numerous records of entomopathogenic fungi commercially produced to manage arthropod pests. In the Philippines, however, development on the use of these biorationals are still in progress, as there have been no records yet of EPFs being screened for mangement of APW.

The objective of the study is to isolate, identify and test the pathogenicity of indigenous entomopathogenic fungi (EPF) for the management of Asiatic palm weevil (APW).

MATERIALS AND METHODS

Soil sampling

Soil samples were collected from coconut fields in the Philippine provinces of Leyte, Eastern Samar, Camarines Sur, Davao del Sur, and Sarangani that were known to be infested with APW. Soils were scooped out one meter around the trunk by digging at a depth of 5-10 cm. In each sample area, soil was taken from five sample sites in a diagonal manner traversing the infested area. The samples were then combined. About 1 kg composite samples were taken from each sample area and labelled.

Isolation and culturing

Soil samples were sifted through a 1.5 cm mesh sieve. Isolation of the fungus was done using the insect bait method of Meyling (2007). In a plastic jar (11 x 14 cm) 100 g of the soil sample was placed and one (1) laboratory reared APW larva was added. There were six (6) set-ups per sample. The set-ups were incubated at 25 ± 2°C for a period of 14 days. The plastic jars were turned upside down every day. After 14 days, mycosed APW larvae were recorded and isolated (Figure 3). Entomopathogenic fungi were isolated from the sporulating cadavers by streaking spores on potato dextrose agar (PDA). Pure cultures were obtained and transferred to

Figure 3. Insect baiting for isolating EPF from the soil

PDA slants and incubated at 25-28°C for 7 days to allow sporulation. These were maintained at 8°C as mother cultures for further screening.

Identification of the entomopathogenic fungi

The morphology of EPF was studied macroscopically by observing colony features (color and texture) and observed microscopically observes under a compound microscope for the conidia, conidiophores and spores arrangement. EPF were identified with the aid of manual prepared by Humber (2012).

Growth rates were also observed as basis for identification. The growth rate of the colonies was evaluated by inoculating a 7-day old 10mm agar disc in PDA medium in Petri plates and incubated at a temperature of 25°C. The colony diameter from each fungus was measured at 6 and 12 days after incubation.

Mass production of Asiatic palm weevil

APWs were reared in the laboratory to provide clean test insects for the pathogenicity testing. The insects were grown in an alternative diet of sago (*Cycas revolute*) flour. Adults were set to mate and oviposit in groups of at least five pairs placed on the substrate and allowed to develop. Uniform sized larvae in the same instar, were used in the pathogenicity testing.

Pathogenicity test

Two-week-old culture of each fungus isolate was inoculated to as many as 10 APW larvae of the same instar using the dipping technique. Subsequently, treated APW larvae were placed in plastic containers with moist coconut cabbage which was previously washed with sterile water (Figure 4). Fresh substrate was added to the boxes every week. Mortality of the larvae was observed everyday up to the 7th day after treatment.

Figure 4. Plastic containers with moist coconut cabbages as incubation chamber of APW larvae treated with entomopathogen

Data analysis

Percentage larval mortality percentage was calculated using the formula:

$$\% \text{ Mortality} = \frac{A}{D} \times 100$$

Where: A = number of dead larva due to fungi infection
D = total number of insect being tested

The percentage mortality obtained was then corrected using Abbots's formula:

Table 1. Morphological characterization of the different isolates of entomopathogenic fungi in PDA

Isolate	Origin	Colony Color	Hyphae	Conidia	Identification
001	Malungon, Sarangani	White, Orange brown	Hyalin	Cylindris to elips, contain of single cell, no color	*Lecanicillium* sp.
002	Buenavista, Quinapondan, E. Samar	White	Hyalin	Round hyalin	*Peroconia* sp.
003	PCA-Davao Research Center, Davao del Sur	Light to dark green	Hyalin	Cylindris, hyalin	*M. anisopliae*
004	PCA-Albay Research Center, Camarines Sur	Light to dark green	Hyalin	Cylindris, hyalin	*M. anisopliae*
005	Cabacungan, Dulag, Leyte	Light to dark green	Hyalin	Cylindris, hyalin	*M. anisopliae*
006	Sta. Cruz, Jaro, Leyte	Light to dark green	Hyalin	Cylindris, hyalin	*M. anisopliae*
007	Guinapoliran, Balankayan, E. Samar	Light to dark green	Hyalin	Cylindris, hyalin	*M. anisopliae*

$$\% \text{ Mortality} = \frac{P_0 - P_c}{100 - P_c} \times 100$$

Where: P_0 = percentage of the dead test larva in the treatment
P_c = percentage of dead insects in the control

RESULTS AND DISCUSSION

Isolation and Identification of the entomopathogenic fungi

The insect baiting technique was used to selectively isolate EPF from the soil sample. Mycosis was first observed in larvae after just five (5) days of inoculation. Mycosed APW larvae were the basis for isolation and identification of the spectrum of entomopathogenic fungi indigenously present in soils.

Based on Humber's Manual (2012), the cultural physical and morphological characteristics of isolates were assessed. The geographical isolates were distinguished through their difference in color of colony and conidial structures. Seven (7) geographical isolates of EPFs were found from the provinces of Leyte, Eastern Samar, Camarines Sur, Davao del Sur, and Sarangani. Three (3) genera of fungi were initially identified from the samples: *Lecanicillium*, *Peroconia* and *Metarhizium*. Five geographical strains of *Metarhizium*, with different characteristics and colony colors were noted (Table 1). A *Lecanicillium* isolate was found in Saranggani and *Peroconia* from E. Samar Province.

Physiological characterization of entomopathogenic fungi

The observation on the colony growth rate of each of the geographical isolates was conducted 6 days and 12 days after inoculation (DAI). In general, the growth of *Lecanicillium* and *Peroconia* was faster than the *M. anisopliae* isolates (Table 2).

The three genera exhibited the following characteristics:

Lecanicillium has upright conidiophore, differentiated from the negative hypha, and a lot of branches along the bar and is needle-shaped. Some colonies are flat shaped at the base. Fungal colony diameter grew rapidly in PDA medium for 12 days (Figure 5 A1 & A2).

Table 2. Average diameter of entomopathogenic fungi colonies in PDA, 6 and 12 days after inoculation (DAI)

Isolate	Origin	Identification	Colony Diameter (mm)	
			After 5 Days	After 10 Days
001	Malungon, Sarangani	*Lecanicillium* sp.	14	100
002	Buenavista, Quinapondan, E. Samar	*Peroconia* sp.	0	100
003	PCA-Davao Research Center, Davao del Sur	*M. anisopliae*	71	100
004	PCA-Albay Research Center, Camarines Sur	*M. anisopliae*	14	100
005	Cabacungan, Dulag, Leyte	*M. anisopliae*	57	100
006	Sta. Cruz, Jaro, Leyte	*M. anisopliae*	29	100
007	Guinapoliran, Balankayan, E. Samar	*M. anisopliae*	0	*100*

Table 3. Pathogenicity of different isolates to R. ferrugineus larvae, 5 days post-inoculation (PI)

Isolate	Origin	Species	% Mortality	
			After 5 Days	After 10 Days
Control		**Distilled Water**	**0**	**0**
001	Malungon, Sarangani	*Lecanicillium* sp.	14	100
002	Buenavista, Quinapondan, E. Samar	*Peroconia* sp.	0	100
003	PCA-Davao Research Center, Davao del Sur	*M. anisopliae*	71	100
004	PCA-Albay Research Center, Camarines Sur	*M. anisopliae*	14	100
005	Cabacungan, Dulag, Leyte	*M. anisopliae*	57	100
006	Sta. Cruz, Jaro, Leyte	*M. anisopliae*	29	100
007	Guinapoliran, Balankayan, E. Samar	*M. anisopliae*	0	*100*

Peroconia has round spiny spores and hyaline hyphae. It grew rapidly in PDA medium with aerial white mycelia (Figure 5 B1 & B2).

Metarhizium has white colonies in the beginning but later changed to dark green as the colony aged (Figure 5 C1 to G1). It has insulated mycelium; upright coated branched conidiophore with varying sizes and filled with conidia, single-celled hyaline coloured conidia, and spherical-shaped cylinders (Figure 5 C2 to G2).

Screening for virulence against APW

Five isolates of *M. anisopliae*, one isolate of *Lecanicillium* and one isolate of *Peroconia* were subjected to an initial bioassay to select fungi with highest virulence against *R. ferrugineus*. After five days post-inoculation (PI), APW larvae treated with *M. anisopliae* Isolates 003 and 005 had the highest mortality rate of 71% and 57%, respectively. Low pathogenicity rate of 14% was recorded for larvae treated with *Lecanicillium* Isolate 001 and *Metarhizium* Isolate 004, while a 29% mortality rate occurred when APW larvae was treated with *Metarhizium* Isolate 006. No larval mortality was observed in the control and larvae treated with *Peroconia* and *Metarhizium* isolate 007 (Table 3). In general, the different geographical isolates exhibited different pathogenicity against *R. ferrugineus* larvae at five days PI.

At ten (10) days PI, the mortality of larvae treated with *M. anisopliae* isolates (all geographical strains) reached 100%. Mortality was not observed in the control group for the duration of the screening.

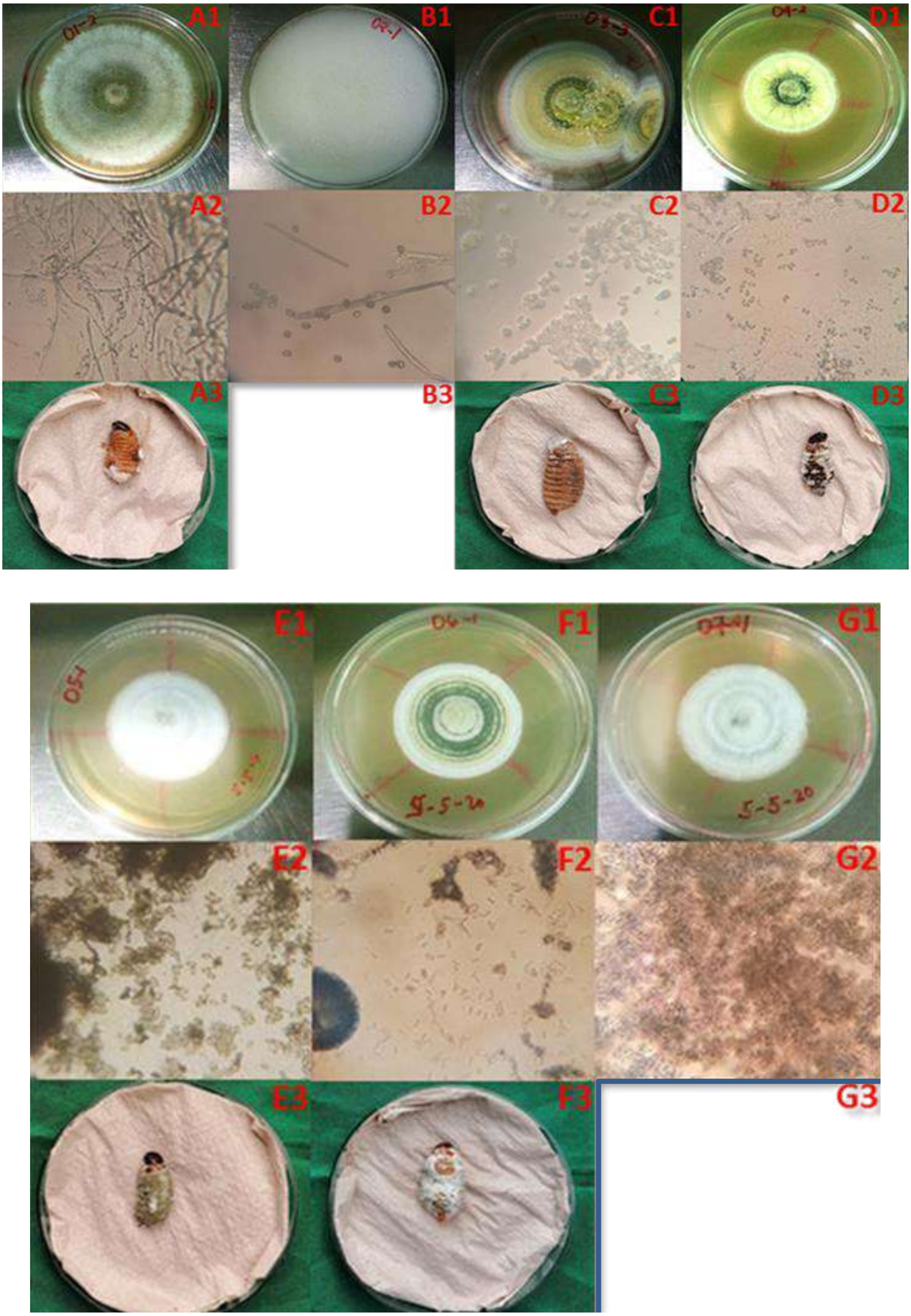

*Figure 5. The character profiles of entomo-pathogenic fungi (EPFs) and the symptoms of APW larva infected by different isolates. **A.** Lecanicillium sp. (Malungon, Sarangani); **B.** Peroconia sp Buenavista, (Quinapondan, E. Samar); **C.** Metarhizium anisopliae (Davao Research Center); **D.** Metarhizium anisopliae (Albay Research Center); **E.** Metarhizium anisopliae (Cabacungan, Dulag, Leyte; **F.** Metarhizium anisopliae (Sta. Cruz, Jaro, Leyte); **G.** Metarhizium anisopliae (Guinapoliran, Balankayan, E. Samar); **1.** colony; **2.** condial structure; **3.** symptoms of infected APW larva;*

CONCLUSIONS AND RECOMMENDATIONS

Three genera of enthomopathogenic fungi; *Lecanicillium*, *Peroconia* and *M. anisopliae* were isolated from the five (5) different Provinces surveyed. Based on laboratory bioassays, two isolates of M. anisopliae from Davao Research Center (DRC) and Cabacungan, Dulag, Leyte were found to be most virulent to APW larvae achieving 71% and 57% larval mortality within 5 days post-inoculation, respectively. The two *M. anisopliae* isolates are now considered as potential BCA's for *R. ferrugineus*.

Stringent laboratory and field screening of the isolates would have to be conducted. Moreover, the development of efficient mycoinsecticide formulation and feasible delivery systems are still to be investigated for optimum results.

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Physical Properties of Copra Meal

Jan Kathleen M. Punzalan and Kurt A. Rosentrater*

The comprehensive utilization of copra meal presents a significant opportunity for agricultural and industrial sectors, especially within regions abundant in coconut production. This research focuses on a detailed investigation into the physical properties of copra meal, aiming to establish the baseline information and fill the existing knowledge gaps to facilitate value-added applications and further commercialize usage of copra meal across various industries. The analysis showed variations in moisture content and water activity, alongside key physical attributes such as bulk and tapped density, flowability indices (Hausner ratio and Compressibility Index), thermal properties (specific heat, thermal diffusivity, conductivity, and resistivity), angle of repose, particle size, and color. Further analysis revealed the bulk density and particle size to be correlated to almost all of the other physical properties, providing insights on the essential role of these parameters on the processing and handling operations of copra meal. Connecting this baseline data about the physical characteristics of copra meal with its chemical and nutritional composition intensively studied by previous researchers, this study will help provide a more holistic understanding of copra meal's behavior during transportation, storage, and processing and unlock its full potential for future product innovations and applications.

INTRODUCTION

Copra meal is the by-product of coconut oil production resulting from the extraction of oil from the dried kernel, or copra, of the coconut. Nutritionally, copra meal consists of about 87% to 93% dry matter, with protein content ranging from 19-24% (d.b.), fat of 2-16% (d.b.) and fiber (as neutral detergent fiber) of 56-68% (d.b.) (Punzalan & Rosentrater, 2024). It has been widely used in ruminant feeding applications and various research studies in the previous years have successfully improved its feeding value for monogastric, poultry, and aquaculture applications, overcoming the limitations posed by the elevated dietary fiber content and low protein quality (Apines-Amar et al., 2015; Jaworski et al., 2014; Mukhopadhyay & Ray, 1999; Obirikorang et al., 2015;

O'Doherty & McKeon, 2000; Pham, 2017; Sundu et al., 2020). One significant advantage of copra meal is its cost-effectiveness, especially in regions where coconut production is high. In fact, the fluctuating prices of conventional feedstuffs, such as corn and soybean meal, posing a major constraint in the livestock and poultry production in the Asia and Pacific region has prompted further commercial usage of copra meal (Prayoonthien et al., 2019). Aside from its use as an alternative feed ingredient, copra meal has been explored for other value-added applications including its use as a potential prebiotic to enhance human gut health (Antia et al., 2023; Sathitkowitchai et al., 2021), substrate for bioethanol production (Saleem et al., 2016), bio-adsorbent for toxic pollutants (Reddy et al., 2024), and biothermoplastics (Ndou et al., 2013), among others.

Despite the wide range of use, nutritional and economical value, and emerging developments being pursued to enhance the potential applications of copra meal, most studies that have been done on this product have only focused on its chemical and nutritional characterization. There are still lots of gaps in looking into its physical properties which are vital in further improving its use and development. Note that the quality of biological products is intrinsically linked to their physical characteristics. For instance, previous studies have pointed out that the physical properties of feedstuffs have a direct impact on the feed intake of animals, which means that further understanding of these characteristics would be crucial in feed formulations (Apines-Amar et al., 2015; Syamsu et al., 2015). Moreover, these physical properties are essential information needed to optimize the design of appropriate handling, transportation, and storage systems (Clementson et al., 2010; Herrman & Baker, 1996). Striving into a larger scale and commercialized approach would entail a full understanding of these properties to advance and optimize its handling, processing, and storage systems. This baseline information could be essential to advance future product innovations of copra meal across various industries. Therefore, this research aimed to investigate the physical properties of copra meal including moisture content, water activity, bulk and tapped density, angle of repose, thermal properties, particle size, and color.

MATERIALS AND METHODS

Sample Preparation

Copra meal samples were obtained from various countries, which includes two unique batches from Stance Global Pty Ltd. based in Australia, fourteen different samples from copra mill facilities in the Philippines, and one sample from a local facility in India, making a total of seventeen samples. Three repeated measures were conducted for each property investigated, resulting in a total of 51 observations per property. Testing of all physical properties were done at room temperature, except for moisture content, and in a completely randomized design. Statistical analysis was then conducted via Microsoft Excel v. 2021 (Microsoft Corp., Redmond, WA) and RStudio v. 2023 (Posit Software, PBC, Boston, MA) using a Type I error rate (α) of 0.05.

Moisture Content and Water Activity

For moisture content determination, the AACC standard 44-19 air-oven method was followed using a forced-convection laboratory oven set at 135°C temperature and two hours drying time. Meanwhile, the water activity of the copra meal samples was tested using a calibrated water activity meter (AquaLab 3TE, Addium Inc, Pullman, WA).

Bulk and Tapped Density

The bulk density was measured using a standard Seedburo test weight apparatus (Seedburo Equipment Co., Chicago, Ill.) following the ASTM C29-17a procedure and the methods described in Clementson et al. (2010). Meanwhile, the tapped density was obtained based on the ASTM B527-20 and ISO 3953:2011 standard procedures for tapped density measurements. A cylindrical stainless-steel vessel of known volume was filled with copra meal and the container was mechanically tapped for one minute using a vibrating equipment. The net weight of the samples and the effective volume after mechanical tapping is used to calculate for the tapped density. The Compressibility Index (CI) and Hausner Ratio (HR) were also computed using Equations 1 and 2, respectively.

$$\text{Compressibility Index (CI)} = \frac{\rho_T - \rho_B}{\rho_T} \times 100 \quad (1)$$

$$\text{Hausner Ratio (HR)} = \frac{\rho_T}{\rho_B} \quad (2)$$

Where ρ_T is the tapped density of the sample
ρ_B is the bulk density of the sample

Particle Size

Particle size analysis adapted from ANSI/ASAE S319.4 "Method of Determining and Expressing Fineness of Feed Materials by Sieving" was done using a Ro-tap sieve shaker (RX-29, W.S Tyler, Mentor, OH) and eight stacks of ASTM E11-specified standard test sieves (Fisher Scientific Company, Pittsburgh, PA) arranged from US No. 8 (2.36 mm nominal opening size) through US No. 100 (0.150 mm nominal opening). Approximately 100g of samples was placed on the top sieve and the shaker was set for 10 minutes sieving time. No sieve agitator or flow agent was used in the analysis. After every run, the resulting mass on each sieve was weighed and the size of the particles were expressed by mass using the geometric mean diameter (dgw) and geometric standard deviation (Sgw) calculated using the formulas:

$$d_{gw} = \log^{-1}\left[\frac{\sum_{i=1}^{n}(W_i \log \bar{d}_l)}{\sum_{i=1}^{n} W_i}\right] \tag{3}$$

$$S_{gw} = \log^{-1}\left[\frac{\sum_{i=1}^{n}(W_i \log \bar{d}_l - \log d_{gw})^2}{\sum_{i=1}^{n} W_i}\right]^{\frac{1}{2}} \tag{4}$$

where d_i is the diameter of sieve openings of the i^{th} sieve

d_{i+1} is the diameter of sieve openings in next larger than i^{th} sieve

d_{gw} is the geometric mean diameter

$\bar{d}_l$ is the geometric mean diameter of particles on i^{th} sieve = $(d_i \times d_{i+1})^{1/2}$

S_{gw} is the geometric mean standard deviation

W_i is the weight fraction on the i^{th} sieve

Angle of Repose

The angle of repose is an important property in determining the flowability of materials and in the design of storage systems since it is indicative of the effective fill and overall storage capacity (Beakawi & Baghabra, 2018). For granular materials, this is usually defined as the angle measured between the steepest slope that the material makes with a horizontal plane without collapsing (Mohsenin, 1980). For this study, the angle of repose was determined by allowing the copra meal to fall freely from a topless plywood box with transparent front covering and a small opening spout at the bottom, as adapted on the methods described by Mohsenin (1980).

Thermal Properties

Thermal properties (specific heat, thermal conductivity, resistivity, and diffusivity) were determined using a thermal properties analyzer (KD2 Pro, Decagon Devices, Pullman, WA).

Color

Color is an important intrinsic characteristic in quality control and is associated with the nutritional value of agricultural products. To objectively quantify the color of the copra meal and to assess variations from one sample to another without limitations from traditional visual inspection, a CR-410 Konica Mirolta Chromameter (Konica Minolta Optics, Chiyoda, Tokyo, Japan) was used in the study. The color analysis was based on the CIELAB opposable color scale, a three-axis color system where the value of L* indicates the level of light to dark, a* scale represents the red-green axis, with negative values attributed to green and positive values representing red, and b* characterizes the blue-yellow axis, with negative values indicating blue and positive values representing yellow (Punchihewa & Arancon, 1999).

RESULTS AND DISCUSSION

The moisture content of the samples varies substantially, with values ranging from 2.56% to 12.36% dry basis. The amount of moisture present significantly impacts the physical and chemical characteristics of biological products. Several factors, such as the differences in the drying and extraction method employed during the processing of raw copra to produce coconut oil and copra meal, as well as the storage duration and conditions, can be attributed to this variability in the moisture levels of the samples obtained from different sources. In fact, the efficiency of the drying process on-farm is deemed to be the most crucial step in copra and coconut oil production ("Copra Extraction Meal," n.d.), which in turn significantly affects the properties of the by-products. The moisture content of copra meal intended for export are required to be maintained between below 10% to lessen the risks of aflatoxin contamination during prolonged storage (FDA, 1984).

Meanwhile, the water activity (aw) of the samples ranges from 0.13 to 0.64, with a mean value of 0.39. Water activity represents the amount of available

Table 1. Physical properties of copra meal

Properties	Source[2]	No. of Observations	Minimum	Maximum	Mean	S.D.
Moisture Content (MC), %db	Overall	51	2.56	12.36	6.80	2.10
	1	6	2.56	3.09	2.92	0.27
	2	42	4.17	12.36	7.35	1.69
	3	3	6.95	6.95	6.95	0.00
Water Activity (a_w)	Overall	51	0.13	0.64	0.39	0.12
	1	6	0.13	0.15	0.14	0.01
	2	42	0.32	0.64	0.43	0.08
	3	3	0.34	0.34	0.34	0.00
Bulk Density, kg/m^3	Overall	51	0.13	0.64	0.39	0.12
	1	6	0.13	0.15	0.14	0.01
	2	42	0.32	0.64	0.43	0.08
	3	3	0.34	0.34	0.34	0.00
Tapped density, kg/m^3	Overall	51	434.0	637.2	552.7	47.5
	1	6	507.3	525.3	518.1	7.1
	2	42	434.0	637.2	555.7	50.0
	3	3	572.2	583.0	579.4	6.2
Compressibility Index (CI), %	Overall	51	1.45	12.59	5.58	2.63
	1	6	7.51	12.59	9.36	1.84
	2	42	1.45	12.08	4.89	2.25
	3	3	6.51	8.34	7.66	1.01
Hausner Ratio (HR)	Overall	51	1.01	1.14	1.06	0.03
	1	6	1.08	1.14	1.10	0.02
	2	42	1.01	1.14	1.05	0.03
	3	3	1.07	1.09	1.08	0.01
Angle of Repose (AoR)	Overall	51	58.0	84.0	74.6	7.0
	1	6	77.0	81.0	79.5	1.5
	2	42	58.0	84.0	74.3	7.3
	3	3	68.0	70.0	69.0	1.0
Specific Heat (c_p), MJ/m^3-K	Overall	51	0.93	1.64	1.31	0.19
	1	6	1.33	1.53	1.41	0.07
	2	42	0.93	1.64	1.30	0.20
	3	3	1.21	1.29	1.25	0.04
Thermal Diffusivity (α), mm^2/s	Overall	51	0.09	0.11	0.09	0.01
	1	6	0.09	0.09	0.09	0.00
	2	42	0.09	0.11	0.09	0.01
	3	3	0.09	0.09	0.09	0.00
Thermal Conductivity (k), W/m-K	Overall	51	0.10	0.15	0.12	0.01
	1	6	0.11	0.13	0.12	0.01
	2	42	0.10	0.15	0.12	0.01
	3	3	0.11	0.12	0.12	0.00

Properties	Source[2]	No. of Observations	Minimum	Maximum	Mean	S.D.
Thermal Resistivity (r), m-K/W	Overall	51	6.73	10.27	8.53	0.87
	1	6	7.61	8.75	8.26	0.40
	2	42	6.73	10.27	8.56	0.94
	3	3	8.38	8.95	8.66	0.29
Color - L*	Overall	51	6.58	14.54	10.73	2.46
	1	6	7.59	8.37	7.98	0.39
	2	42	6.58	14.54	11.35	2.26
	3	3	7.38	7.79	7.60	0.21
Color - a*	Overall	51	6.58	14.54	10.73	2.46
	1	6	7.59	8.37	7.98	0.39
	2	42	6.58	14.54	11.35	2.26
	3	3	7.38	7.79	7.60	0.21
Color - b*	Overall	51	14.25	36.33	26.91	7.03
	1	6	14.25	15.00	14.59	0.33
	2	42	15.00	36.33	28.55	5.92
	3	3	28.18	28.83	28.49	0.33
Geometric Mean Diameter (d_{gw}), mm	Overall	51	0.49	0.92	0.68	0.15
	1	6	0.55	0.58	0.56	0.01
	2	42	0.49	0.92	0.70	0.16
	3	3	0.66	0.68	0.67	0.01
Geometric Std. Deviation (S_{gw}), mm	Overall	51	1.40	2.15	1.80	0.26
	1	6	1.80	1.88	1.84	0.04
	2	42	1.40	2.15	1.78	0.28
	3	3	2.03	2.08	2.05	0.03

Table 1. Physical properties of copra meal (continued)

[2] Source 1–Australia, 2–Philippines, 3–India

moisture that supports the growth of microorganisms such as bacteria, yeast, and molds. It affects the stability of the biological product during transport and storage (Chow, 1980). One important concern in the handling, distribution, and storage of copra meal is the potential risks of aflatoxin contamination, especially since it is mainly used as feed ingredient (FAO, 2001). Note that the maximum allowable aflatoxin level for export quality copra meal is 20 parts per billion (ppb) and several steps in the production of copra meal, starting from the exposure of coconut meat after splitting, during drying, and at transport and storage can be entry points for aflatoxin contamination (Chulze, 2010). This makes it particularly challenging in the handling and trade of copra meal since it is usually sourced in tropical regions with relatively high temperature and ambient humidity. To minimize risks of spoilage from bacterial and mold growth and potential aflatoxin contamination, water activity is recommended to be below 0.7 (Sundu et al., 2009).

Bulk density, a key design metric for processing, handling, and storage systems, was found to be between 415.0 to 592.8 kg/m3. This is consistent with the values obtained in previous studies which ranges from 490.0 to 560 kg/m3 (Sundu et al., 2005a, 2005b). For a given product, the bulk density can fluctuate significantly owing to the variations in the moisture level and particle size (Clementson et al., 2010). Sundu et al., (2005a) suggested that the low bulk density of copra meal significantly influences its feeding value for animal feeding applications. The study revealed that increasing the dietary bulk density of copra meal through physical alterations such as pelleting and crumbling resulted in higher weight gain when fed to broilers. Aside from its influence on the feeding value, understanding the bulk density of a feed component is also important as it affects its behavior during batching and blending processes (Clementson et al., 2010). Meanwhile, the tapped density for all samples was found to be higher than the bulk density, varying from 434.0 to

The copra meal. Photo by Kava Vinaka

637.2 kg/m3. Tapped density, also known as packed density, refers to the density achieved after applying an external force under specified conditions. This is an important parameter for bulk handling and processing of products, especially for copra meal transported as bulk cargo for export (FDA, 1984).

The angle of repose has been extensively studied to assess the flowability of granular materials, with lower values indicating better flow characteristics (Bhadra et al., 2009). For copra meal samples, the angle of repose was measured between 58° to 84°. Based on the flowability classification established by Carr (1965) and discussed in Bhadra et al. (2009), materials with a low angle of repose below 25° tend to be free-flowing, meaning they can be easily moved and handled. In contrast, granular materials with an angle of repose above 45°are considered to have poor flowability, often requiring special handling equipment to move them efficiently. The relatively high angle of repose for copra meal indicates poor flowability posing potential challenges on bulk handling and processing of materials. Among the factors affecting the angle of repose are the frictional forces and moisture content of the product (Ganesan et al., 2009). Similarly, the elevated oil content of copra meal could have contributed to its poor flowability characteristics since the free surface fat influences the flow properties in granular materials (Ganesan et al., 2008; Shah et al., 2008).

To further investigate the flow characteristics of copra meal, two parameters that are also used as a measure of flowability are calculated, namely the Hausner Ratio (HR) and Compressibility Index (CI). HR is associated with the possibility of arching or bridging of a granular material when placed in a hopper of other storage and handling equipment. Typically, values closer to 1 indicate free-flowing materials, while values greater than 1.25 suggest poor flow characteristics (Rosentrater, 2022). Meanwhile, CI is used as a gauge of particle flowability by measuring the change in volume under pressure, with lower CI values indicating better flow performance. However, HR and CI values obtained in the experiment, with an average of 1.06 and 5.58%, respectively suggest contradicting results in terms of the flowability of copra meal based on the measured AoR. The discrepancy in the flowability characteristics of materials based on these indices were also observed in previous flow studies, owing to the qualitative aspects of the measurements and the limitations of these indices to account for the cohesive properties of granular materials (Jiang & Rosentrater, 2015; Kalman, 2021; Suhag et al., 2024).

The particle size and distribution of bulk solids are both important parameters that influence the flowability and compressibility of materials (Lyu et al., 2020; Shah et al., 2008). For feed manufacturing, the particle size is also a crucial aspect as it affects nutrient digestibility and processing operations, which leads to economic implications (Asae, 2003; Goodband et al., 1995). The geometric mean diameter (dgw) and geometric standard deviation (Sgw) are used to express the particle size. The dgw represents the average size particles tend to gravitate towards in a sample, while the Sgw indicates the range of particle sizes present and the span of the distribution (Goodband et al., 1995; Rausch et al., 2005). For this study, analyses revealed that the dgw of the copra meal samples ranges from 0.49 to 0.92 mm, with a mean of 0.68 mm. Meanwhile, the Sgw of particle diameters also varies significantly between 1.40 to 2.15 mm, with a mean of 1.80 mm. The size of the particles and their distribution can differ for a specific component due to variations in raw materials and the grinding method used (Sundu et al., 2005c).

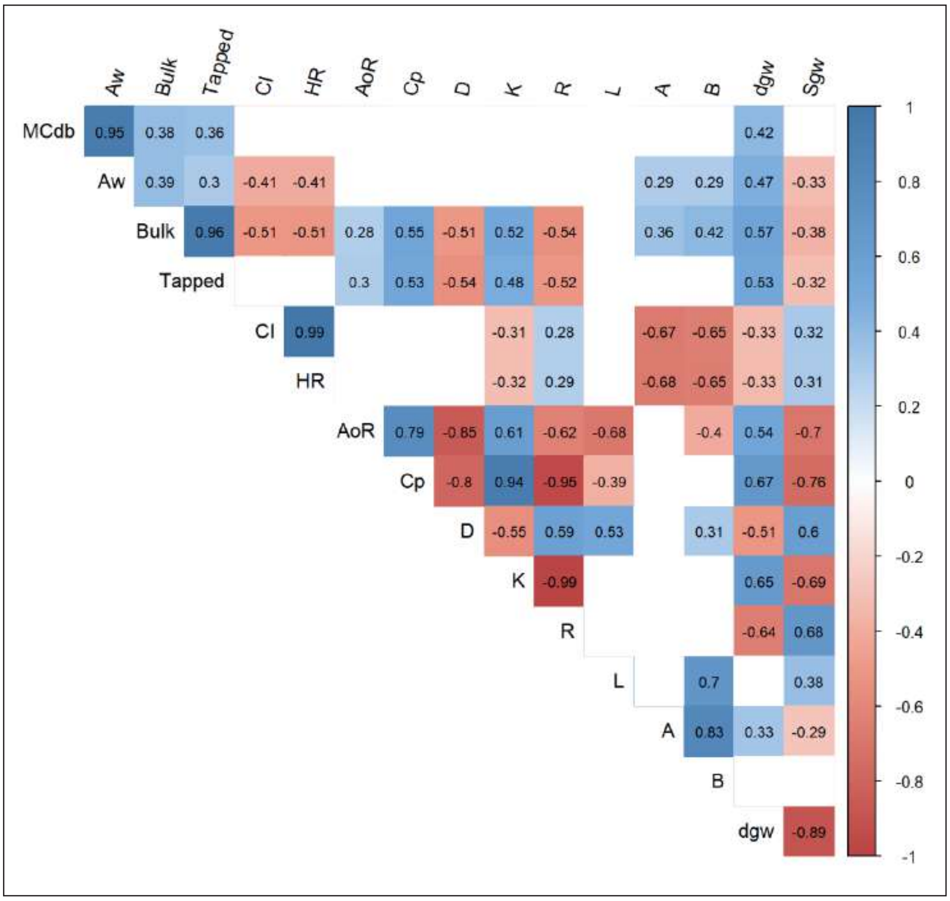

Figure 1. Correlogram of the physical of the copra meal samples

The thermal properties of biological products are another important area to look at in order to understand how the material will behave when subjected to heat over time during processing and storage. Excessive heating or insufficient cooling may result in economic and quality issues, posing the need to predict the thermal behavior of the materials during processing operations. The thermal conductivity of the samples varies from 0.10 to 0.15 W/m-K while thermal resistivity ranges from 6.73 to 10.27 m-K/W. There is not much variability in terms of the thermal diffusivity among samples, ranging from 0.09 to 0.11 mm2/s. The specific heat of copra meal ranges from 0.93 to 1.64 MJ/m3-K, which is comparable to other plant-sourced feed ingredients obtained by Jiang & Rosentrater (2015).

Overall color appearance of copra meal samples can be distinguished as brownish color, except for the lighter sample obtained from India. "L" values varied from 37.12 to 85.40, values of "a" were between 6.58 to 14.54, and "b" ranged from 14.25 to 36.33. The values for "L" are more varied than that of "a" and "b" scales and appear to be significantly higher for the samples obtained from India, hence the lighter color. Studies revealed that excessive heating of copra meal during the drying operation or oil extraction process can affect the digestibility of copra meal-based diets when used as feed ingredient (Guarte et al., 1996). This can be attributed to the destruction of viable nutrients brought about by the Maillard reaction, which in turn affects feed digestibility. Furthermore, among the main indicators used to determine the quality and grade of copra for domestic and international markets is the color of the coconut meat since this is often indicative of heat damage due to excessive heat exposure and improper drying temperatures (ICC, 2023; Ratnayake, 1999). In fact, the degradation in quality and price discount resulting from this undesirable

Table 2. Correlation coefficients (r) of the physical properties of copra meal and associated p-values (α = 0.05)[1]

	MC	**a_w**	**Bulk**	**Tapped**	**CI**	**HR**	**AoR**	**c_p**	**α**	**k**	**r**	**L**	**a**	**b**	**d_{gw}**	**S_{gw}**
MC	1.000 ---															
a_w	0.945 (0.000)	1.000 ---														
Bulk	0.385 (0.005)	0.388 (0.005)	1.000 ---													
Tapped	0.364 (0.008)	0.304 (0.030)	0.962 (0.000)	1.000 ---												
CI	-0.212 (0.135)	-0.410 (0.003)	-0.508 (0.000)	-0.254 (0.072)	1.000 ---											
HR	-0.212 (0.136)	-0.407 (0.003)	-0.514 (0.000)	-0.261 (0.064)	0.995 (0.000)	1.000 ---										
AoR	0.136 (0.342)	0.159 (0.265)	0.283 (0.044)	0.296 (0.035)	-0.051 (0.722)	-0.049 (0.731)	1.000 ---									
c_p	0.059 (0.681)	0.108 (0.450)	0.551 (0.000)	0.534 (0.000)	-0.250 (0.077)	-0.255 (0.071)	0.787 (0.000)	1.000 ---								
α	-0.072 (0.616)	-0.043 (0.766)	-0.506 (0.000)	-0.541 (0.000)	0.064 (0.656)	0.067 (0.643)	-0.852 (0.000)	-0.797 (0.000)	1.000 ---							
k	0.077 (0.592)	0.150 (0.293)	0.522 (0.000)	0.482 (0.000)	-0.311 (0.026)	-0.317 (0.023)	0.612 (0.000)	0.942 (0.000)	-0.555 (0.000)	1.000 ---						
r	-0.077 (0.593)	-0.129 (0.367)	-0.544 (0.000)	-0.517 (0.000)	0.281 (0.045)	0.289 (0.039)	-0.623 (0.000)	-0.951 (0.000)	0.593 (0.000)	-0.993 (0.000)	1.000 ---					
L	0.015 (0.917)	0.013 (0.930)	0.124 (0.385)	0.103 (0.473)	-0.147 (0.302)	-0.152 (0.287)	-0.682 (0.000)	-0.386 (0.005)	0.532 (0.000)	-0.221 (0.119)	0.237 (0.095)	1.000 ---				
a	0.101 (0.480)	0.291 (0.038)	0.359 (0.010)	0.189 (0.184)	-0.674 (0.000)	-0.676 (0.000)	-0.034 (0.811)	0.179 (0.209)	0.022 (0.880)	0.252 (0.075)	-0.219 (0.123)	0.274 (0.052)	1.000 ---			
b	0.144 (0.313)	0.294 (0.036)	0.417 (0.002)	0.267 (0.058)	-0.649 (0.000)	-0.651 (0.000)	-0.402 (0.003)	-0.053 (0.714)	0.308 (0.028)	0.100 (0.484)	-0.066 (0.643)	0.697 (0.000)	0.831 (0.000)	1.000 ---		
d_{gw}	0.416 (0.002)	0.467 (0.001)	0.569 (0.000)	0.532 (0.000)	-0.330 (0.018)	-0.331 (0.018)	0.542 (0.000)	0.672 (0.000)	-0.512 (0.000)	0.649 (0.000)	-0.642 (0.000)	-0.069 (0.630)	0.331 (0.018)	0.250 (0.077)	1.000 ---	
S_{gw}	-0.233 (0.099)	-0.329 (0.018)	-0.378 (0.006)	-0.319 (0.022)	0.315 (0.024)	0.309 (0.027)	-0.698 (0.000)	-0.757 (0.000)	0.603 (0.000)	-0.694 (0.000)	0.680 (0.000)	0.375 (0.007)	-0.289 (0.039)	-0.077 (0.592)	0.893 (0.000)	1.000 ---

[1] Values in the parentheses are the associated p-values at significance level (α = 0.05)

non-enzymatic browning process, which causes copra to turn a burnt color when exposed to high temperatures, has sparked research into drying methods and regimes to prevent this occurrence (Friendly, 2002; Sudaria, 1993). Aside from the unprocessed copra input, the extraction method for coconut oil also contributes to the variability in the sensory color of the resulting copra meal.

A Pearson correlation analysis was conducted to further investigate the interplay of the different physical and thermal properties of the copra meal samples and quantify the strength and direction of the linear relationship between two quantitative variables. A correlogram, shown in Figure 1, was also generated to visualize the results of the correlation test. In this correlogram, positive correlations are depicted in blue, while negative relationships are indicated by red. The depth of the colors corresponds to the strength of the correlation where darker shades represent stronger correlations (Abd El-Wahab et al., 2020). Of the 120 Pearson product-moment correlations, 75 are significantly different ($p < 0.05$) while the rest are not, as shown in both Table 2 and Figure 1. As indicated, nine pairs of variables had correlation coefficients (r) exceeding 0.80, with six even exceeding 0.90, indicating quite robust linear associations. As expected, water activity is positively correlated with the moisture content, as is the case for bulk and tapped density. Since both Compressibility Index (CI) and Hausner Ratio (HR) are derivative functions of these two density properties, they are found to be strongly related to each other. It is important to note how most of the properties are moderately correlated to the bulk density and particle size (and distribution) of the samples, suggesting further examination on the extent of this variation at different levels especially since these parameters are directly influenced by the processing operations employed. These two properties, used as a measure of the flowability of materials, also have significant impact on bulk handling and transport as well as downstream processing for other potential value-added use. For instance, bulk density has been pointed out to affect the feed intake of copra meal on birds attributed to the tendency of bulky feedstuffs to take up more space in the digestive system of the animals, hence the tendency to consume more water than regular feeds (Apines-Amar et al., 2015). Similarly, feed particle size and distribution impacts intake and digestibility, with recent studies proving that the inclusion of coarser feeds actually improves nutrient uptake in birds and the preference increases with the age of species (Hyline International Feed Granulometry and the Importance of Feed Particle Size in Layers, 2016). This could be a starting point since a positive relationship has also been established between bulk density and particle size in the samples tested.

CONCLUSION

The moisture content of the four batches of copra meal varies significantly from 2.56% to 12.36% dry basis, while water activity ranges from 0.13 to 0.64. The average bulk and tapped density were calculated at 522 kg/ m3 and 553 kg/ m3, respectively. Several properties affecting the flowability of granular materials were also determined, with a mean angle of repose of 74.6°, Hausner Ratio (HR) of 1.06, and Compressibility Index (CI) of 5.58. The thermal properties of copra meal were also found to be comparable to other feed ingredients such as Distiller's Dried Grains with Solubles (DDGS), with an average thermal conductivity of 0.12 W/m-K, specific heat of 1.31 MJ/m3-K, thermal diffusivity of 0.09 mm2/s, and resistivity of 8.53 m-K/W. Particle size analysis revealed a geometric mean diameter of 0.68 mm and a geometric standard deviation of 1.80 mm. Overall color appearance was distinguished as brownish, with "L" value of 53.4, "a" value of 10.7, and "b" value of 26.9 based on the CIELAB scale. The Pearson correlation analysis revealed that 75 out of the 120 product-moment correlations are significantly different at alpha value of 5%. One notable observation is that most of the other measured physical properties are found to be moderately correlated to the bulk density and particle size of the samples. Quantifying the effects and establishing the relationship of these characteristics at varying levels is an aspect that can be potentially analyzed because they play a pivotal role in the processing operations, its export and commercial use as a feed ingredient, and other potential applications in other industries. Nevertheless, the baseline data found in this study, which has not been looked into up to this date, would provide a complete understanding of the product and how it behaves during transport, storage, and downstream processing. Forward-looking, the need to connect these physical characteristics with the chemical parameters, such as the protein and oil content of copra meal samples, would give a more sufficient description of the behavior of these properties and how they influence the measured variability among samples, particularly its flowability.

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Climate Change and Its Effects on Aromatic Variety in Thailand

Anjana J. Atapattu*

The aromatic coconut industry in Thailand is currently facing unknown challenges due to the increasing effects of climate change, especially in major production regions including Ratchaburi and Samut Sakhon Provinces. A comprehensive assessment was carried out to evaluate the varied effects of climate variability on the production and quality of aromatic coconut cultivars. This assessment was conducted with the engagement of systematic field observations and in-depth consultations with researchers and technical experts. Based on the gathered information, suitable adaptation strategies were suggested to improve the resilience and sustainability of aromatic coconut cultivation. The assessment identified significant negative effects on major phenological stages, including flowering, nut setting, and overall yield performance, emphasizing the urgent need for the adoption of climate-resilient practices.

INTRODUCTION

The aromatic coconut industry has emerged as one of the most significant agricultural sectors in Thailand, placing the country as a major exporter of high-quality coconut products. However, recent changes in climatic incidences, which have caused climate change, have disrupted the prevailing production systems, requiring timely and feasible adaptation strategies. Aromatic coconut varieties are well-known for their unique flavour and have a higher market value. however, they are extremely susceptible to adverse environmental conditions. Their physiological sensitivity makes them highly vulnerable to fluctuations in temperature, precipitation, and other climatic variables.

Field investigations from major cultivation regions have shown a significant decline in both yield and fruit quality, which were strongly related to changes in climate conditions. These problems require the immediate need to identify and implement practicable solutions to ensure the sustainability and productivity of aromatic coconut cultivation.

MATERIALS AND METHODS

Field inspections were conducted in April 2025 in the Ratchaburi and Samut Sakhon Provinces, at the K-Fresh facilities and nearby plantations, which were the main study sites.

Data collection was based on three principal approaches. At the beginning, field observations were done to assess the conditions of the plantation, document the plant health indicators, and evaluate the prevailing agronomic practices. Secondly, technical consultations were carried out with semi-structured interviews with local farmers and industry experts to gather insights on production trends, past performance records, and the effectiveness of current adaptation strategies. Finally, environmental monitoring was conducted on the main environmental parameters, such as ambient temperature, relative humidity, soil moisture content, and water availability, to assess the influence of climatic conditions on coconut production.

RESULTS AND DISCUSSION

Climate Change Impacts on Aromatic Coconut Production

Environmental Stressors

A number of climate-related impacts that affect the aromatic coconut plantations were identified through comprehensive field observations. Elevated temperatures combined with reduced relative humidity were observed to have significant physiological stress on the palms. These conditions increase the vapour pressure deficit (VPD), which has a significant impact on stomatal regulation. Increased VPD also adversely affect important reproductive parameters, including pollen viability and stigma receptivity, which are both critical factors for successful fertilization and fruit set (Figure 1).

Figure 1. Stressed-coconut palms

Figure 2. Pest and disease-affected coconut palms

Water scarcity, which has a negative impact on the general health of the palm, was another major issue found across the inspected regions. Prolonged dry spells inhibit root development, limiting the ability of the palm to access essential nutrients and moisture. Furthermore, decreased soil moisture retention capacity intensified the drought stress, compounding the negative physiological effects on the plants.

The natural defence systems of aromatic coconut palms are weakened by these environmental

Figure 3. Poor nut setting in aromatic coconut inflorescence due to climate stress

Figure 4. Disturbed fruit maturation processes by climate change

stresses, making them more vulnerable to disease outbreaks and insect infestations (Sujithra et al., 2025) (Figure 2). The production of defensive chemicals can be decreased due to climate-induced physiological weakness, creating favourable conditions for pathogens and insect pests. Additionally, secondary biotic stresses can be triggered by the combined impacts of heat stress, water scarcity, and reduced plant vigour. These interactions increase the risk to plantation productivity and the long-term sustainability of the palm by increasing the effects of climate change.

Production Impacts

The effects identified across the inspected plantations were varied and significant. A noticeable reduction in flowering intensity was regularly recorded at several sites, showing the most prominent effect on reproductive processes of the palm. Poor nut setting and reduced fruit development were prevalent, resulting in smaller, low-quality coconuts that decreased the commercial value of the harvest (Figure 3).

Yield parameters also showed concerning patterns. Significant yield losses, with reduced nut size and weight, were recorded in many plantations across affected areas. Additionally, irregular kernel development indicated disruptions in the fruit maturity, potentially affecting both the quantity and quality of the final product (Figure 4).

Adaptation Strategies

Soil and Nutrient Management

Comprehensive soil and plant-based management strategies were identified as essential components for enhancing climate resilience in aromatic coconut plantations. A comprehensive soil sample analysis is recommended, emphasizing regular sampling at 0–30 cm and 30–60 cm depths to enable thorough monitoring of soil conditions. Key parameters include soil pH, electrical conductivity, and organic carbon content, which are critical indicators of soil health and fertility (Thomas & Krishnakumar, 2024).

Nutrient management strategies guarantee the supply of balanced fertilization that integrates both organic and inorganic nutrient sources to ensure optimum plant nutrition. Regular leaf nutrient analysis is recommended as a diagnostic method to monitor nutrient uptake and status, enabling timely adjustments to fertilization as a response to changing climatic conditions.

Water Management Systems

Smart water management practices are vital for mitigating the effects of reduced precipitation and increasing drought on aromatic coconut plantations (Ranasinghe et al., 2015). Implementation of drip irrigation systems can be recommended for efficient water delivery directly to the root zone, reducing losses from evaporation and runoff. This method, when combined with carefully planned irrigation schedules based on continuous soil moisture monitoring, significantly lowers the water usage while maintaining adequate moisture content in the palms.

Improved basin management methods to promote water retention around individual palms are another strategy for moisture conservation. The application of organic mulches is recommended to conserve soil moisture and to increase soil organic matter content. The optimization of irrigation scheduling based on prevailing environmental conditions and plant water requirements can be proposed to ensure the efficient use of available water resources and to support long-term sustainability.

Microclimate Enhancement

To enhance microclimatic conditions within aromatic coconut plantations, several strategies can be introduced. Mulching with organic materials such as coconut husks and coconut fronds provides good ground cover, reducing soil moisture evaporation and regulating soil temperature fluctuations (De Costa, 2020). Mulching with coir pith also improves soil moisture retention, while the addition of green biomass increases soil organic matter and promotes nutrient cycling.

Following the recommended spacing between palms is also another important factor. It is advised to keep a spacing from 7.5 to 9 meters between two palms to facilitate better air circulation and reduce competition between species for resources. Proper spatial arrangement enhances ventilation within the plantation and improves water-holding capacity of the soil by minimizing root competition (Ng et al., 2020).

Priorities for Future Research

Climate Resilience Studies

Identifying key research areas that can support long-term adaptation strategies is important to face the impacts of climate change. One priority is understanding plant physiological responses to climate stressors. Studies on stomatal responses to vapour pressure deficit (VPD) are essential for a better understanding of plant water relations under stress, to develop crops that can maintain water efficiency in increasingly unpredictable environments. Determining the temperature limits for good nut setting is another approach to forecasting how climatic variability may affect yield stability and reproductive success. Investigating how heat stress affects pollination may result in novel strategies for protecting reproductive systems under severe weather conditions, assisting in maintaining agricultural yield despite climate change.

Another important area is the genetic exploration of drought tolerance mechanisms in both existing and potential coconut varieties. Understanding the genetic basis of stress resilience is crucial for developing improved cultivars suited to changing climatic conditions. Future breeding programmes will significantly focus on selecting and enhancing traits linked to drought tolerance, ensuring that new varieties can thrive under water-limited conditions. This strategy requires a combination of conventional breeding techniques and modern biotechnological approaches, offering a balanced pathway to accelerate the development of climate-resilient coconut cultivars. The industry may make great progress towards long-term sustainability by combining these strategies.

RECOMMENDATIONS

Short-term Interventions

To reduce the short-term impacts of water stress on coconut palms, immediate action is required. The implementation of efficient irrigation systems is an important approach to address the existing water shortages. Along with this, soil moisture conservation practices, such as mulching and reduced tillage, should be practised to maximize the use of limited water resources.

Regular monitoring of plant health indicators is essential to detect stress symptoms at early stages and implement immediate measures, minimizing potential yield losses. Improving nutrient management strategies is also important, as stressed plants often have increased nutritional demands. Adjusting fertilizer applications to meet these needs can support plant recovery and resilience. Incorporating technology and best management practices to enhance water use efficiency offers additional support in water-limited environments. Moreover, creating a favourable microclimate for sensitive aromatic coconut varieties can be achieved through well-planned mulching, spacing, and environmental adjustments to create a favourable microclimate, promoting better growth conditions and plantation productivity.

Long-term Strategies

A key priority for the future of the coconut industry is the development of climate-resilient varieties through innovative breeding programmes integrating traditional and modern genetic improvement strategies. These attempts will ensure the adaptability of the crop to emerging climate challenges. Simultaneously, the implementation of early warning systems for climate-related stress events will enable more preventive and timely management responses, safeguarding yields and minimizing losses. Equally important is the adoption of resilience-enhancing, sustainable farming practices is also important to support short-term adaptation and be sustainable and productive in the long run, ensuring the coconut industry to face changing climatic conditions.

Strong policy support mechanisms will be essential to accelerate this transition. Providing incentives for the adoption of climate-smart agriculture will increase the embrace of adaptive strategies, while subsidies, training programmes, and technical assistance will enable access to necessary technologies. Enhancing extension services ensures that farmers are educated and equipped with the latest research-based knowledge and innovations to meet future challenges effectively.

CONCLUSION

The aromatic coconut industry in Thailand is under pressure from the adverse impacts of climate change, demanding immediate adaptation and strategic adjustments. To sustain production under these changing conditions, it is essential to adopt proposed mitigation measures while investing in further research and development. Building the capacity of all stakeholders, including farmers, researchers, industry players, and policymakers, is also important. Promoting collaborative, well-coordinated efforts across these groups will ensure the long-term sustainability and resilience of aromatic coconut production in Thailand. With shared commitment and integrated action, the industry can effectively manage climate-related challenges and secure a more sustainable future.

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Phosphorus Recovery from Coconut Wastewater

R. M. R. A. Rathnayake [1], R. Chandrabose [1], P. C. Suriyaarachchige [1], and A. Karunarathne [2]

The global popularity of coconut-based products like Virgin Coconut Oil, Desiccated Coconut, and Coconut Milk has led to significant production effluent challenges. This study addresses an environmental issue associated with coconut production wastewater by developing a method to produce struvite (magnesium ammonium phosphate) from the effluent. Coconut wastewater contains essential nutrients such as magnesium, ammonium, and phosphate, which are key to struvite formation. Trials were conducted to optimize the pH level for effective struvite crystallization, revealing that a pH of 8 yielded the best results. A crystallizer was utilized to enhance the efficiency and quality of struvite crystals formed. The resultant struvite, a slow-release fertilizer, provides essential nutrients in a balanced manner, promoting healthy plant growth while reducing environmental impact. This process not only offers a solution for nutrient recovery from waste streams but also aligns with sustainable agricultural practices and circular economy principles. The study demonstrates the potential for wider implementation, contributing to sustainable agriculture and environmental conservation.

INTRODUCTION

Coconut-based products are now popular all around the world. The production of items such as Virgin Coconut Oil, Desiccated Coconut, Coconut Milk, Coconut Skimmed Milk, Spray Dried Coconut Milk Powder, Coconut Cream, and Coconut Chips occurs globally. However, any kind of production process presents numerous challenges in various areas. This conceptual development addresses a major environmental problem associated with coconut production effluent. In the last decade, treating coconut production effluent has been particularly

Table 1. Total phosphate content of coconut production wastewater tested by MicroChem laboratory service

Coconut-based product factory	pH	Oil and grease (mg/l)	TSS (mg/l)	BOD (mg/l)	Total Phosphate content as P (mg/l)	Total Nitrate as N (mg/l)
1	4.1	8.6	290	3260	56	10
2	6	28	270	2410	547	9.9

challenging. Despite advancements in wastewater treatment technology, many production plants have started applying these techniques to their wastewater. Nevertheless, the treatment of coconut waste effluent is still not perfected. Typically, coconut waste effluent contains various nutrients such as nitrogen, phosphorus, potassium, and magnesium (Kowshalya et al., 2023).

If phosphate and Nitrate is present in the wastewater and subsequently released into water bodies, it can have significant effects. Elevated levels of phosphorus can lead to eutrophication, a process that causes excessive growth of algae and other aquatic plants. This can deplete oxygen levels in the water, harming aquatic life and disrupting ecosystems. Therefore, effective treatment of coconut production effluent is crucial to prevent environmental degradation and protect water quality.

The wastewater from coconut-based production contains varying levels of P, ranging from 10 to 600 mg/l and the Nitrate level 5 to 50 mg/l Testing conducted on effluent from popular coconut production plants is summarized in Table 01. Achieving the potential reduction of phosphate and nitrate is challenging using biological treatment systems alone. Due to the difficulty of high-rate phosphorus removal in biological treatment, alternative solutions are often sought worldwide.

On the other hand, the global conversation is increasingly focused on circular economy principles and resource recovery from wastewater. Phosphate and nitrate particularly valuable resource that can be recovered from wastewater streams. Recovered phosphorus and nitrate serves as an excellent fertilizer. Phosphorus-containing fertilizers and nitrogen-containing ones are widely used in cereal farming. In regions where soil phosphate levels are low, adding fertilizer is essential to achieving and maintaining viable cereal yields. (Annis, 2019). Therefore, by focusing on the recovery of phosphorus from coconut production wastewater, not only can environmental challenges be addressed, but valuable resources can also be reclaimed, aligning with sustainable practices and the principles of the circular economy. The following concept has been developed for the recovery of phosphate from coconut wastewater.

CONCEPT

This concept focuses on the innovative use of coconut wastewater to produce struvite (magnesium ammonium phosphate), a valuable fertilizer. Coconut wastewater contains essential nutrients such as magnesium, ammonium, and phosphate, which can be harnessed to form struvite crystals.

METHOD

Coconut wastewater typically contains high levels of magnesium, derived from the coconut's natural mineral content; phosphorus, present in organic and inorganic forms; and nitrogen, mostly in the form of nitrate (NO3-), but also including ammonium (NH4+). Struvite formation requires specific conditions, including the presence of magnesium, ammonium, and phosphate ions in a suitable pH range (typically 7 to 9). According to the table 01 pH coconut wastewater pH vary 3-5. The struvite formation needed high pH around 7-9 (Stratful et al., 2001). Then the pH should adjust using chemical before use the crystallizer.

$$NH^{4+}+Mg^{2+}+PO_4^{3-}+6H2O \rightarrow NH_4MgPO_4 \cdot 6H_2O$$

The process of struvite formation in a crystallizer involves several key steps. Firstly, the pre-treatment of coconut wastewater is necessary, including filtration to remove solid particles to prevent clogging in subsequent processes. After removing the solid particles, the pH of the effluent needs to be increased to the required level. pH adjustment to 7-9 using sodium hydroxide NaOH. The treated effluent flows into a Maintaining optimal pH (7-9), temperature (20-30°C), and mixing facilitates nucleation and growth of struvite crystals. Once crystals reach the desired size, they can be separated from the liquid phase using filtration or sedimentation. The harvested struvite is then washed and dried to remove impurities.

Crystallizer

A crystallizer is a specialized piece of equipment used in processes to facilitate the formation of solid crystals from a solution. In the context of struvite formation, a crystallizer provides the optimal conditions for magnesium, ammonium, and phosphate ions in the wastewater to combine and form struvite crystals. The process begins with the introduction of the feed solution, which contains the necessary ions. The crystallizer maintains optimal conditions, such as pH, temperature, and mixing, to promote nucleation and crystal growth. As the struvite crystals grow, they eventually reach a size where they can be harvested. This typically involves separating the crystals from the liquid phase through sedimentation or filtration. Crystallizers can operate continuously, making them efficient for large-scale industrial applications. They enable the efficient recovery of valuable nutrients from wastewater, reducing environmental pollution and providing a sustainable source of raw materials for fertilizers. This makes crystallizers a crucial component in the sustainable management of wastewater and nutrient recycling.

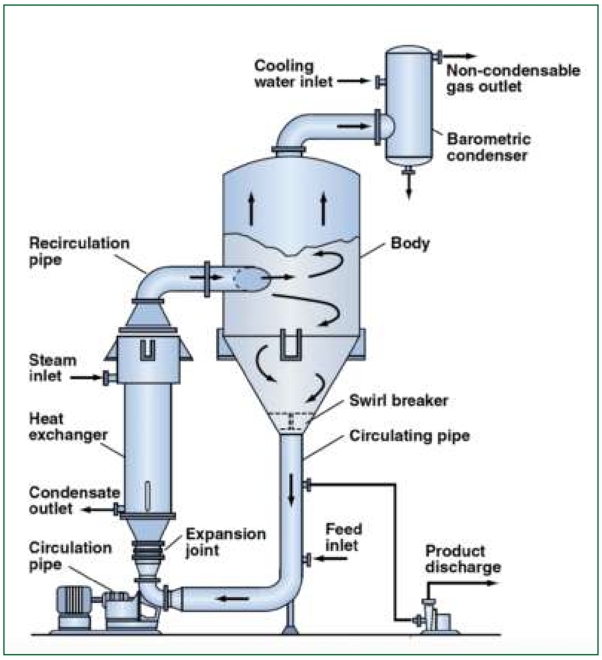

Figure 1. Process flow diagram of a crystallizer. (Source: Waterman Engineers Australia)

DISCUSSION

In the effort to develop struvite (magnesium ammonium phosphate) using coconut wastewater, a series of trials were conducted to optimize the formation conditions. Coconut wastewater, which contains essential nutrients like magnesium, ammonium, and phosphate, presents a promising source for struvite production. The initial steps involved adjusting the pH levels of the wastewater to facilitate the crystallization process.

During the trials, the pH of the coconut wastewater was incrementally increased to determine the optimal level for struvite formation. The first trial set the pH at 6, followed by subsequent trials at pH 7, pH 8, and finally pH 9. It was observed that pH 8 yielded the best results in terms of struvite crystal formation. Figure 01 illustrates the microscope image of the struvite crystals formed at pH 8, highlighting their size and structure. The crystallizer played a significant role in this process, enhancing the efficiency of struvite crystal formation by providing a controlled environment for the reaction to occur.

The role of the crystallizer cannot be overstated. It ensures that the conditions such as temperature, mixing, and pH are maintained optimally, leading to a higher yield and quality of struvite crystals. The crystallizer's ability to create a consistent and stable environment is crucial for the successful formation of struvite, as fluctuations in these conditions can significantly impact the crystallization process. The controlled environment provided by the crystallizer maximizes the contact between the nutrient ions in the coconut wastewater, promoting the efficient formation of struvite crystals.

Struvite has garnered significant attention as a potential fertilizer due to its slow-release properties and nutrient composition. Unlike conventional fertilizers that release nutrients rapidly, often leading to nutrient runoff and environmental pollution, struvite releases nutrients slowly. This slow-release characteristic ensures that plants receive a steady supply of essential nutrients over an extended period, promoting healthier and more sustained growth. Struvite contains a balanced ratio of magnesium, ammonium, and phosphate, all of which are critical for plant development (Ueno et al., 2001).

Magnesium plays a vital role in photosynthesis, as it is a central component of the chlorophyll molecule. It also helps in the activation of various enzyme systems that regulate plant growth. Ammonium provides a readily available source of nitrogen, which is essential for the synthesis of amino acids, proteins, and other vital compounds within the plant. Phosphate is crucial for energy transfer, root development, and the formation of DNA and RNA. The presence of these nutrients in struvite makes it an excellent choice for use as a fertilizer, supporting robust plant growth and development (Corre et al., 2009).

The environmental benefits of using struvite as a fertilizer are also noteworthy. By recycling nutrients from waste streams such as coconut wastewater, the process reduces the need for synthetic fertilizers, which are often produced through energy-intensive processes. This not only conserves energy but also reduces greenhouse gas emissions associated with the production of conventional fertilizers. Furthermore, the utilization of coconut wastewater, which is typically considered a waste product, adds an element of waste valorization, contributing to a more sustainable and circular economy.

CONCLUSION

In conclusion, the development of struvite from coconut wastewater represents a promising and sustainable approach to fertilizer production. The optimization of pH levels, particularly at pH 8, has been shown to significantly enhance the formation of struvite crystals. The use of a crystallizer further improves the efficiency and quality of the struvite produced. As a slow-release fertilizer, struvite provides essential nutrients in a balanced manner, promoting healthy plant growth while minimizing environmental impact. This innovative approach not only addresses the issue of nutrient recovery from waste streams but also offers a viable solution for sustainable agriculture. The positive results from the trials indicate that with further refinement and scaling, this process could be implemented more widely, contributing to a greener and more sustainable future in agriculture. (Stratful et al., 2001). Struvite formation from coconut wastewater not only provides an effective way to treat and reuse wastewater but also recovers valuable nutrients for agricultural use. By removing these nutrients from the wastewater, the process reduces eutrophication potential and improves the quality of the treated water. The recovered struvite contains essential nutrients - nitrogen, phosphorus, and magnesium - which can be used as a slow-release fertilizer, promoting sustainable agricultural practices. Additionally, struvite's slow-release properties make it an effective and environmentally friendly fertilizer, contributing to a circular economy and sustainable development goals.

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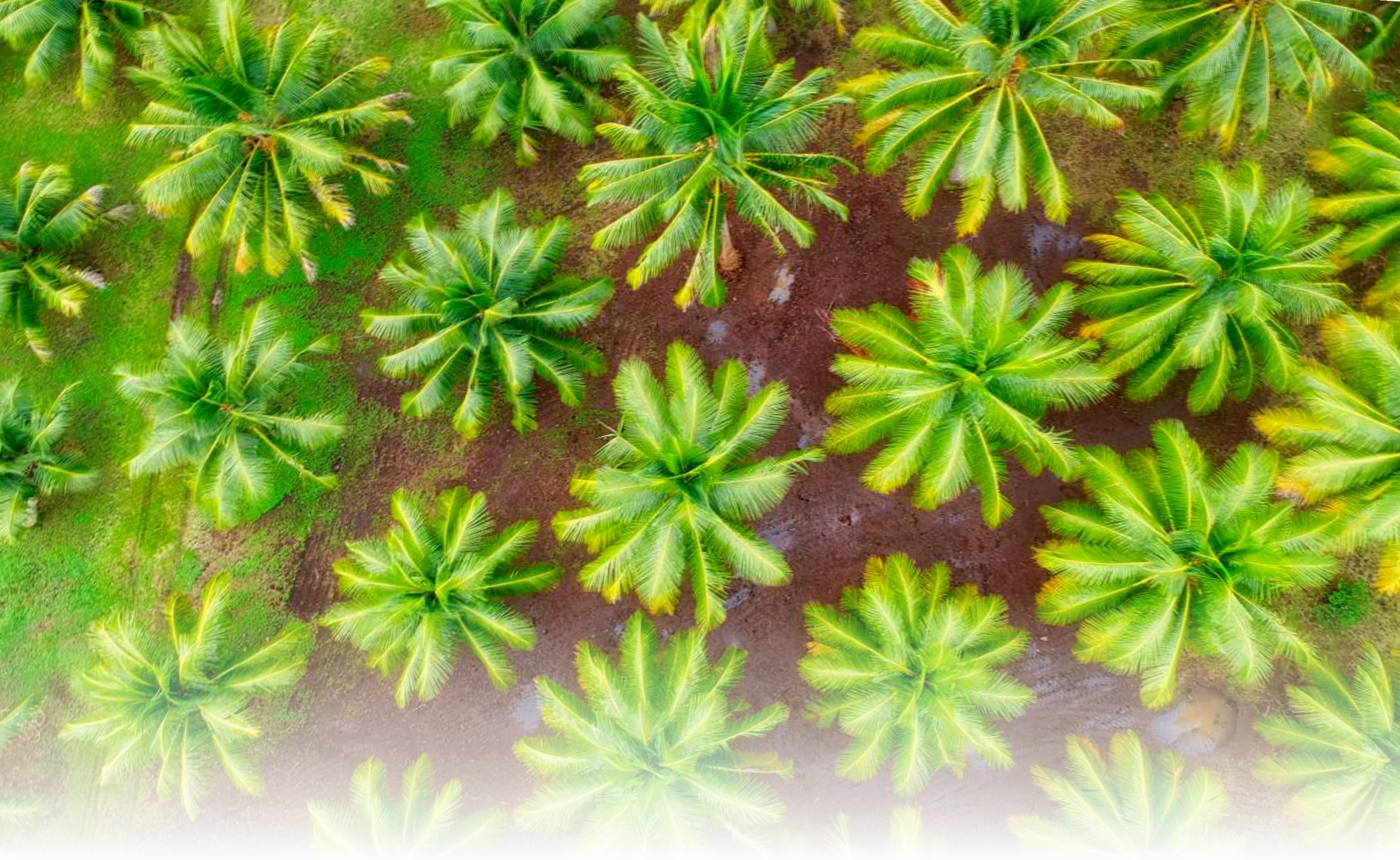

Influence of Valarchi®
An Organic Amendment on Soil and Nut Yield Improvement in Coconut

D.Sai Vaishnavi[1], R.Santhiya[1], and M. Sakthi Ishwarya[1]

The trial was conducted in a farmer holdings at Negamam village consecutively from May 2022-May 2024 to study the effect of Valarchi® Coconut - Soil fortifier and Valarchi® Coconut - Root feeder on soil quality and nut yield improvement in coconut. The trial plot soil was clay loam in texture. While initiating the trial, the soil had a pH range of 7.81 to 7.92, EC of 0.299 to 0.312 dS m-1, organic carbon 0.42 to 0.47 %, available N - 191 to 200 kg/ha, available P - 8.00 to 9.00 kg/ha, and available K - 140 to 160 kg/ha. The treatments were: T0: Control (Farmer practice), T1: Recommended Chemical fertilizers (1.3 kg urea, 2.0 kg SSP and 2.0 kg muriate of potash per palm), T2 : Valarchi® Coconut - Soil fortifier - 1 kg/palm, T3 : Valarchi® Coconut - Root feeder - 200 ml/palm, T4 : Valarchi® Coconut - Soil fortifier - 1 kg/palm and Valarchi® Coconut - Root feeder - 200 ml/palm. The palms under trial are naatu ragam. In each treatment 70 palms were tested and mean yield/palm/harvest was recorded. The soil application of Valarchi® Coconut - Soil fortifier and root feeding of Valarchi® Coconut - Root feeder resulted in significantly more number of nuts (71.2 and 73.5 nuts/palm/year) compared to other treatments during 2023 and 2024, respectively. This was followed by soil application of recommended chemical fertilizers (68.3 and 70.4 nuts/palm/year). The lowest yield was recorded in the control plot (48.0 and 48.2 nuts/palm/year, respectively).

INTRODUCTION

Coconut is a versatile tree and is the most popular crop in the world and very beneficial for health because of its high nutrient status (Baloch and Rajpar, 2014). Nutrient management in coconut is a continuous battle against soil limiting factors and

Table 1. Soil available nutrients as influenced by different treatments

Treatments	Available N (kg/ha.)		Available P (kg/ha.)		Available K (kg/ha.)	
	2022-2023	2023-2024	2022-2023	2023-2024	2022-2023	2023-2024
T0 : Control (Farmer practice)	191	193	8.00	8.12	140	136
T1 : Recommended chemical fertilizers (TNAU)	198	202	8.80	9.00	155	159
T2 : Soil application of Valarchi® Coconut - Soil fortifier	195	198	8.50	8.60	156	146
T3 : Root feeding of Valarchi® Coconut - Root feeder	192	195	8.00	8.20	144	138
T4 : Soil application of Valarchi® Coconut - Soil fortifier + Root feeding of Valarchi® Coconut - Root feeder	200	204	9.00	9.06	160	162
C.D. (P=0.05)	NS	NS	NS	NS	NS	NS

NS: Non significant

it assumes significance because coconut requires a continuous supply of nutrients throughout the year for sustained productivity (Khan, 1993).

External supply of nutrients is an essential practice in the present intensive agricultural systems. Inorganic fertilizer application is preferred by the growers for its convenient use and quick response. With the prolonged application of inorganic fertilizers, soils have lost half or more than its original levels of soil organic matter (Matson et al., 1998). Consequently, the soil microbial community which depends on Carbon for their nutrient and energy source (Fontaine et al., 2003) is adversely affected, wiping the living organisms from the productive soil ecosystem. Soil microbial processes are crucial for the plant nutrient supply, mainly through their role on soil organic matter decomposition and nutrient dynamics (Paul, 2007). Sustainable agricultural systems would ideally produce good crop yield without a cost to the environment (Tilman, 1999). Management of soil fertility through organic fertilizers is a promising practice in sustainable agricultural systems. Sustainable soil fertility management via organic agriculture system requires large quantity of organic fertilizers to supply the plant nutrient requirement. Yet the unavailability of organic fertilizers in adequate quantity to supply the entire plant nutrient requirement is a challenge. Because of this reason, Vriksha Agro sciences pvt ltd., Coimbatore recommends application of Valarchi® - an organic nutrient sources as two variants - Soil fortifier and Root feeder. Organic fertilizers such as cattle, goat and poultry manures and compost are applied to the soil for sustaining fertility through improvement in overall physical, chemical and biological properties of soil (Tennakoon et al., 1995). However, the effects of applying organic fertilizers on soil quality and yield improvement under coconut cultivation are less explored. Therefore, aim of this trial was to evaluate the effect of applying Valarchi® as soil application and root feeding on soil property improvement and yield enahancement in a common coconut growing belt of Tamilnadu (Pollachi-Negamam).

MATERIALS AND METHODS

The trial was conducted in a farmer holdings at Negamam village consecutively from 2022-23 to study the effect of Valarchi® Coconut - Soil fortifier and Valarchi® Coconut - Root feeder on soil quality and nut yield improvement in coconut. The trial plot soil was clay loam in texture. While initiating the trial, the soil had a pH range of 7.81 to 7.92, EC of

Table 2. Nut yield as influenced by different treatments

Treatments	Yield (nuts/palm/year)	
	May 2023	May 2024
T0 : Control (Farmer practice)	48.0	48.2
T1 : Recommended chemical fertilizers (TNAU)	68.3	70.4
T2 : Soil application of Valarchi® Coconut - Soil fortifier	56.1	60.1
T3 : Root feeding of Valarchi® Coconut - Root feeder	64.1	66.6
T4 : Soil application of Valarchi® Coconut - Soil fortifier + Root feeding of Valarchi® Coconut - Root feeder	71.2	73.5
SEd	10.16	2.11
C.D. (P=0.05)	NS	4.5

NS: Non significant

0.299 to 0.312 dS m-1, organic carbon 0.42 to 0.47 %, available N - 191 to 200 kg/ha, available P - 8.00 to 9.00 kg/ha, and available K - 140 to 160 kg/ha. The treatments were: T0: Control (Farmer practice), T1: Recommended Chemical fertilizers (1.3 kg urea, 2.0 kg SSP and 2.0 kg muriate of potash per palm), T2 : Valarchi® Coconut - Soil fortifier - 1 kg/palm, T3 : Valarchi® Coconut - Root feeder - 200 ml/palm, T4 : Valarchi® Coconut - Soil fortifier - 1 kg/palm and Valarchi® Coconut - Root feeder - 200 ml/palm. The palms under trial are naatu ragam. In each treatment 70 palms were tested and mean yield/palm/ harvest was recorded.

The Valarchi® Coconut - Soil fortifier was applied in soil as two applications viz., first application (1 kg/palm) in May – June and second application (1 kg/palm) in October – November. The input was applied in soil at 1.8 meter (or) 3-4 feet away from the base of the palm and incorporated at 10 cm depth followed by immediate irrigation. The input is an organic supplement providing macro nutrients.

Valarchi® Coconut - Root feeder was applied twice in the month of August and February. The input was diluted at 1:4 ratio with water and fed to root at 200 ml/tree. The application procedure is as follows - selection of pencil thickness feeding live root with white/light yellow/ pink colour at a distance of 2-3 feet away from base of the palm. Making a slant cut at the tip of the root and insert it into the polythene sachet containing diluted Valarchi® Coconut - Root feeder and tieing with thread. The root feeder consisted of all the essential micro nutrients including vitamins, growth regulators viz., auxin and salicylic acid.

The yield data was recorded regularly from all the palms and annual yield/palm was computed. Pre–treatment and post-treatment soil samples were collected from three palms in each treatment plot. Soil samples were drawn from the circular basin 1.0 m away form the bole, at 0-30 cm depth using spade. The soil samples were air dried in shade, ground to pass though 2 mm sieve and analyzed for available N, P and K status by adopting standard procedures (Jackson,1973).

RESULTS AND DISCUSSION

The results obtained from the present investigation as well as relevant discussion have been presented under following heads.

Soil chemical properties

The soil chemical properties under the treatment studied are presented in Table 1. The available N, P and K in the soil did not differ significantly among the treatments. The soil application of recommended dose of NPK resulted in slight increase of available N, P and K status of the soil. The soil application of Valarchi® Coconut - Soil fortifier alone or Valarchi® Coconut - Root Feeder alone showed minimal variation in the soil available nutrient status. But statiscal analysis showed that none of the treatment significantly improved the available NPK status of the soil. The highest available N, P and K status with soil application of N, P and K has been reported by may workers in different crops (Balaguravaiah et al., 2005; Tiwari et al., 2002 and Bharadwaj et al.,1994). The extraneous application of N, P and K is required besides root feeding for replenishing the depleted nutrients and also to sustain the soil health.

Nut yield

In general, over the years there was a progressive increase in the nut yield of palms (Table 2). Among the treatments, soil application of Valarchi® Coconut - Soil fortifier along with root feeding of Valarchi® Coconut - Root feeder produced significantly more number of nuts (71.2 and 73.5 nuts/palm/year) compared to other treatments during 2023 and 2024, respectively. This was followed by the soil application recommended chemical fertilizers (68.3 and 70.4 nuts/palm/year). The lowest yield was recorded in the control (48 and 48.2 nuts/palm/year, respectively). The highest nut yield recorded with the combined application of Valarchi® Coconut - Soil fortifier and Valarchi® Coconut - Root feeder has been reported to be due to the supply of the essential nutrients and growth regulators directly in to the sap of the plant system (Sharma, 2008). Further the soil application favoured the improvement in soil fertility, besides uptake of nutrients by the root system. This resulted in the increase yield of nuts.

CONCLUSION

Form the above study it can be concluded that, soil application of Valarchi® Coconut-Soil fortifier and root feeding of Valarchi® Coconut - Root feeder could be recommended for sustaining higher yield. This also helps in maintaining soil fertility in coconut gardens. Prolonged application of Valarchi® as two variants in coconut orchards will sustainably increase the nut yield apart from satisfying the nutrient requirement of coconut. This subsequently improves the soil organic matter in the soil and microbial population also builds up in the soil applied with the organic amendment - Valarchi® which need to be further studied in detail.

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Harnessing Coconut's Potential: Partnerships for a Circular Economy and Maximized Value

Shashi S. Udumann, Anjana J. Atapattu, Nuwandhya S. Dissanayaka, and Tharindu D. Nuwarapaksha

This manuscript focuses on circular economy and partnership as key drivers to address problems and create more value within the coconut value chain. It focuses on proving the concept of using circular economy principles in coconut farming and processing through waste management, generation of bioenergy from waste products, and enhanced packaging materials. The paper includes the multiple applications of coconut by-products, that are used in construction, agriculture, manufacturing of handicrafts, food products, and cosmetics, among others. nutrient cycling and agroforestry as some of the approaches of increasing productivity and at the same time practicing sustainable agriculture. The need to create partnerships along the value chain is highlighted, as well as the use of technology advancements for processing of coconut. Global market prospects for coconut-based products are discussed along with the showing better trends for future in food, cosmetics and construction sectors. The paper also discusses the barriers for circular economy models and presents policy strategies for transition to a circular economy. Advantages of implementing circular principles are highlighted in terms of environmental and social impacts such as minimization of waste and higher income for farmers. Finally, the paper discusses the possibilities of further development and enhancement of circular economy practices in coconut farming and processing.

The paper looks at ways to improve value creation and sustainability in the coconut industry, including collaborations and creative business models. It examines routes to a resilient and prosperous future through case studies and market trend analysis, emphasizing stakeholder collaboration, innovation, and sustainability as critical factors for overcoming present obstacles and establishing the sector as a leader in sustainable agricultural development for the twenty-first century.

OVERVIEW OF THE COCONUT INDUSTRY AND ITS ECONOMIC IMPORTANCE

The coconut industry which has a long history and enjoys great significance in the world is also one of the major sources of income and needful products in

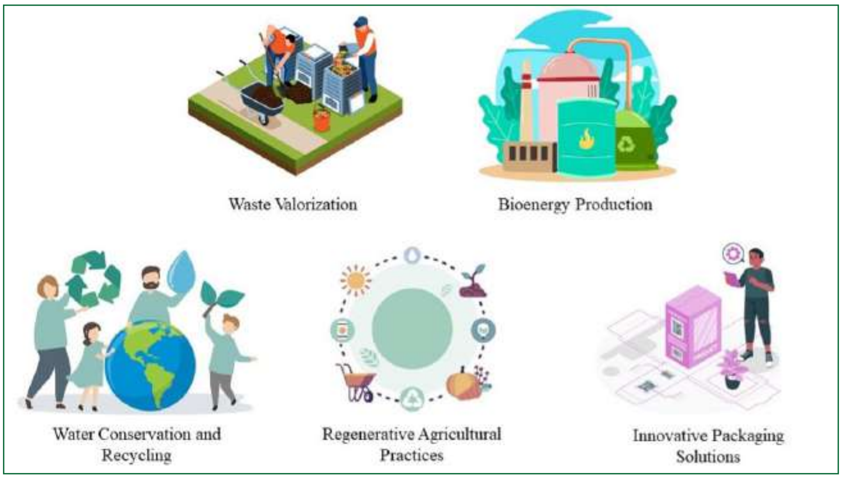

Figure 1. Circular Economy Strategies that can be applied to Coconut Production

the tropical countries (Zainol et al., 2023). With global coconut production reaching 62.5 million tons, led by Indonesia, the Philippines, and India, the industry's economic influence is considerable, with the coconut products market valued at $11.5 billion in 2021 and projected to exceed $30 billion by 2026 (Anuchi et al., 2022). The coconut product has a diverse angle spanning food products to cosmetics, pharmaceutical markets, and bio-energy markets to meet the growing demand for healthy and sustainable consumer needs (Vieira et al., 2024). However, the industry encounters several problems such as reduced productivity on aging plantations, climate change impacts, and ineffective value chains (Alouw & Wulandari, 2020; Samaraweera et al., 2024). Despite these obstacles, emerging technologies and sustainable business models present growth opportunities. The circular economy, which aims to minimize waste and enhance resource efficiency, is particularly promising for revitalizing the coconut sector (Vieira et al., 2024).

The paper looks at ways to improve value creation and sustainability in the coconut industry, including collaborations and creative business models. It examines routes to a resilient and prosperous future through case studies and market trend analysis, emphasizing stakeholder collaboration, innovation, and sustainability as critical factors for overcoming present obstacles and establishing the sector as a leader in sustainable agricultural development for the twenty-first century.

CIRCULAR ECONOMY PRINCIPLES AND THEIR APPLICATION TO COCONUT PRODUCTION

Circular Economy Principles

In order to improve sustainability in the production of coconuts, circular economy principles propose a change from the conventional "take-make-dispose" approach to a closed-loop system. The circular economy is based on three main principles (Suárez-Eiroa et al., 2019). In the first, "Designing out waste and pollution," waste is reduced by the use of recyclable or biodegradable packaging, the creation of products that utilise every part of the coconut, and the design of efficient processing facilities. The second concept, "Keeping products and materials in use," is concerned with prolonging the life of products by means of robust designs, mechanisms for reuse and refurbishing, and efficient recycling of items made from coconuts. The third, "Regenerating natural systems," seeks to improve soil health by utilizing regenerative agriculture to sequester carbon and agroforestry to restore natural ecosystems.

Application to Coconut Production

The production of coconuts can benefit from the application of circular economy ideas, which encourage sustainability and waste reduction. In order to improve resource efficiency in the coconut business, this section examines a number of measures (Figure 1), including waste valorisation, bioenergy production, water conservation, regenerative agriculture, and creative packaging ideas.

Waste Valorization
Circular economy practices in coconut production include repurposing waste materials. Coconut husks can be turned into coir fiber for use in erosion control, horticulture, and construction, such as lightweight concrete roof tiles (Darsana et al., 2016). Coconut shells can be processed into activated carbon for water treatment and air purification (Sujiono et al., 2022).

Bioenergy Production
Coconut processing waste can be utilized for bioenergy, such as biogas. There is a viability of using coconut waste for biogas production, addressing waste management while providing a renewable energy source (Atapattu et al., 2024).

Water Conservation and Recycling
Coconut processing often involves high water usage. Implementing water recycling systems can significantly reduce water consumption, which is crucial in water-stressed regions. Reusing treated wastewater helps lower operational costs and

minimize environmental impact (James & Yadav, 2021).

Regenerative Agricultural Practices
Regenerative practices in coconut farming enhance soil health, reduce synthetic input needs, and support ecosystem sustainability (Udumann et al., 2025b). These practices include using coconut husks and shells as mulch, intercropping to improve soil fertility, and composting waste to produce organic fertilizers (Dissanayaka et al., 2022; Dissanayake et al., 2023; Nuwarapaksha et al., 2022).

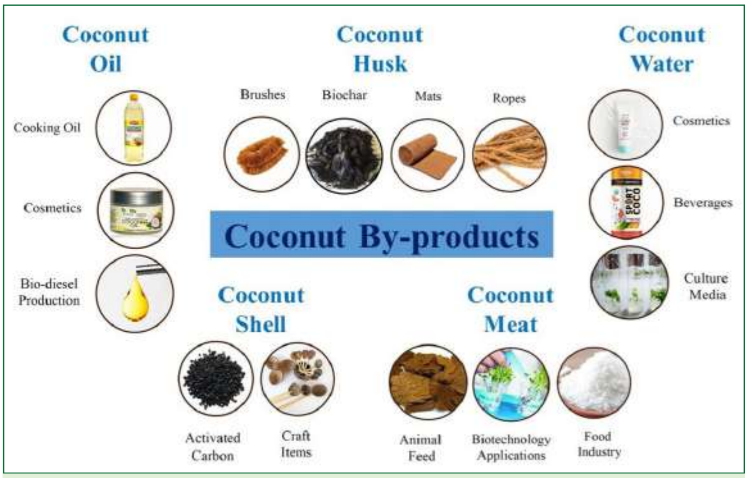

Figure 2. Coconut By-products

Innovative Packaging Solutions
The coconut industry may contribute to reduce the amount of plastic waste by using its by-products to create biodegradable packaging (Arun et al., 2022). For example, the utilization of coconut fiber can result in useful, biodegradable packaging materials that support environmental sustainability and closed loop systems.

COCONUT BY-PRODUCTS AND THEIR POTENTIAL USES

Known for its extraordinary adaptability, the coconut palm (*Cocos nucifera* L.) is sometimes referred to as the "tree of life." In order to maximize sustainability and profitability, this assessment emphasizes the value of partnerships and circular economy techniques while highlighting the many by-products from the processing of coconuts (Figure 2).

Coconut Husk (Coir)

The fibre layer that lies between a coconut shell and outer coat is called coir, or coconut husk. It is rich in cellulose, hemicellulose, and lignin, which helps to prevent rot and fungal growth (Stelte et al., 2022). Because of its ability to retain water and allow for air circulation, coir can be used in agriculture as a growing medium, an environmentally friendly soil conditioner, and a tool to reduce erosion. In addition, it is industrially produced into geotextiles, ropes, and mats for stabilizing soil, and into biochar and biogas, which are used in bioenergy solutions.

Coconut Shell

The coconut shell is used in a variety of sectors because it is long-lasting and contains less ash, mostly made up of lignin, cellulose, and hemicellulose (Singh et al., 2024). In addition to being used in mining for purifying gold, activated coconut shell is also used to purify water and air. It can also be used in gasification to produce syngas or burned for heat. Additional uses include abrasive materials in cleaning goods, filler in composites, and decorative crafts.

Coconut Water

Coconut water is a nutrient-rich beverage that has multiple uses due to its electrolytes, vitamins, and minerals content (Dissanayaka et al., 2023). It is a popular natural sports drink that may also be used as a beverage basis. It is also utilized in rehydration therapy, as a culture medium in microbiology, as a flavouring agent in culinary products, and in cosmetics for skin and hair care.

Coconut Oil

Extracted from the mature coconut kernel, coconut oil has a long shelf life and resistance to rancidity because it is heavy in saturated fats, especially medium-chain triglycerides (MCTs) (Dayrit, 2015; Hewa Pathirana et al., 2021). It is utilized as an industrial lubricant as well as in baking, cosmetics, and personal hygiene goods. Coconut oil is used in the pharmaceutical and nutraceutical industries as MCT oil, as well as a carrier oil for drugs for the creation of biodiesel.

Coconut Meat

Coconut meat, or dried copra, is rich in dietary fiber, vitamins, and minerals, and is high in saturated fats (Lesidan, 2020; Patil & Benjakul, 2018). It is processed into desiccated coconut for baking, coconut flour as a gluten-free alternative, and coconut milk and cream for cooking. It also serves as animal feed, a raw material for activated carbon, and a substrate for enzyme production. By utilizing coconut byproducts through a circular economy approach, stakeholders can maximize value while minimizing waste. This promotes sustainability, aligns with global goals, and contributes to economic growth through more sustainable production systems (Atapattu et al., 2024).

SUSTAINABLE FARMING PRACTICES AND THEIR IMPACT ON COCONUT PRODUCTION

The increasing demand for coconut products worldwide has made sustainable cultivation practices important (Figure 3). This paper, which is framed within the concepts of the circular economy to maximize value and minimize waste, examines the effects of various sustainable methods on the production of coconuts.

Nutrient Recycling

Implementing nutrient recycling practices in coconut production can significantly reduce the need for external inputs while improving soil health (Atapattu, Babalola, et al., 2025). This involves the use of coconut byproducts such as husks, shells, and leaves as organic mulch or compost (Dissanayake et al., 2023; Nuwarapaksha et al., 2023).

Integrated Pest Management (IPM)

Integrated Pest Management offers a sustainable approach to pest control in coconut farming. IPM combines biological, cultural, and chemical control methods to minimize pest damage while reducing reliance on synthetic pesticides. This approach not only improved productivity but also reduced environmental pollution and production costs, aligning with circular economy principles (Amporn Winotai, 2014).

Climate-Smart Agriculture

As climate change poses increasing challenges to coconut production, the adoption of climate-smart agricultural practices becomes essential (Dissanayaka et al., 2025). These practices aim to increase productivity while enhancing resilience to climate change and reducing greenhouse gas emissions where possible (Atapattu & Udumann, 2024).

Agroforestry Systems

Agroforestry, integrating trees with crops or livestock, has proven beneficial for coconut production, enhancing soil fertility (Dissanayaka et al., 2025), biodiversity, and providing farmers with additional income streams (Atapattu & Udumann, 2025). overall farm productivity compared to monoculture plantations, offering products like timber and fruits, thus creating a more resilient agricultural model (Dissanayaka et al., 2023; Maitra et al., 2025).

Organic Farming Practices

Organic farming, which uses natural fertilizers and biological pest control, promotes environmental and economic benefits (Atapattu et al., 2025). Research indicated higher soil organic matter and microbial activity in organic coconut plantations, leading to improved water retention and nutrient availability (Thomas et al., 2018). Additionally, organic coconuts often command premium prices, incentivizing farmers to adopt these practices.

Water Management

Efficient water management, such as drip irrigation and rainwater harvesting, enhances sustainability in coconut farming by increasing nut production while reducing water use, contributing to water conservation and energy efficiency (Thomas et al., 2018).

Sustainable farming practices in coconut production improve environmental, economic, and social outcomes. Their successful implementation often requires collaboration among farmers, researchers, industry stakeholders, and policymakers. Future research should focus on optimizing these practices for different regions and evaluating their long-term impact on ecosystems and livelihoods.

DEVELOPING PARTNERSHIPS ACROSS THE VALUE CHAIN

In the context of harnessing coconut's potential and moving towards a circular economy, developing strong partnerships across the entire value chain is crucial. This review examines the importance and impact of partnerships among key stakeholders in the

Figure 3. Sustainable Coconut Farming practices

coconut industry: farmers and cooperatives, processors and manufacturers, retailers and distributors, and research institutions and universities.

Future research should aim to quantify the long-term impacts of different partnership models and develop best practices for successful collaborations in the coconut industry. By addressing these areas, stakeholders can drive sustainable growth and innovation within the sector.

TECHNOLOGICAL INNOVATIONS IN COCONUT PROCESSING AND PRODUCT DEVELOPMENT

Technological innovations are reshaping coconut processing, enhancing value creation and supporting circular economy practices across the industry.

High-Pressure Processing (HPP) preserves the majority of the antioxidant activity of coconut water and nutrient content over time, while heat pasteurisation causes a noticeable decrease in these properties (Raghubeer et al., 2020). Mineral content is preserved and shelf life is increased using membrane filtration methods including ultrafiltration and nanofiltration (Junmee & Tongchitpakdee, 2015).

Supercritical fluid extraction and enzyme-assisted aqueous extraction are two techniques that have significantly increased oil output and antioxidant activity for the extraction of coconut oil while using less energy (Nik Norulaini et al., 2009). Protein-rich by-products are produced and oil production is further increased through enzyme-assisted extraction (Sorita et al., 2023). Processes like pulsed electric field (PEF) treatments and ultrasonic homogenisation have enhanced product stability and prolonged the preservation of nutrients, such vitamin C, in coconut milk and cream (Abdullah et al., 2018; Tongdonyod et al., 2023).

While plasma treatment has enhanced fibre adhesion in composite materials, coconut fibre processing has resulted in the synthesis of nanocellulose from fibres, which greatly increases the strength of bioplastics (Rajinipriya et al., 2018; Kumar et al., 2017).

Improvements in carbon adsorption and energy consumption have been made possible by developments in coconut shell processing, such as microwave-assisted activation. Hydrochar made from coconut shells has also demonstrated promise for use in energy storage applications (Foo et al., 2019; Liu et al., 2018). New items that offer sustainable substitutes for conventional plastic packaging, such as coconut protein isolates and biodegradable films, are the outcome of these advances.

MARKET OPPORTUNITIES FOR COCONUT-BASED PRODUCTS IN VARIOUS INDUSTRIES

Growing customer demand for natural and sustainable products has led to substantial growth and diversity in the coconut industry.

Products like coconut water, milk, cream, sugar, and flour are becoming more and more well-liked among consumers who are health-conscious in the food and beverage sector. Due to its low glycemic index, coconut sugar is in high demand, and virgin coconut oil is still frequently used in cooking and as a dietary supplement (Samarajeewa, 2024). Because of its moisturizing qualities, coconut oil is widely prized in cosmetics and personal care products. With the growing popularity of body washes, shampoos, and soaps made with coconut oil, the market for coconut oil in personal care products is growing. Surfactants obtained from coconuts are also being used as environmentally friendly substitutes for artificial cleansers (Ng et al., 2021).

Because of their resilience and biodegradability, coconut fibres are being utilized more and more in the textile and fabric sector. Applications for coir include agricultural products, beds, upholstery, and ropes. Moreover, activated carbon derived from coconuts is being added to textiles that absorb odours, especially sportswear (Oladele et al., 2022).

Table 1. Environmental and Social Benefits of Circular Economy in the Coconut Industry

Partnership Type	Key Insight	Benefits	Challenges	References
Farmers and Cooperatives	Farmers in networks adopt in more sustainable practices and receive yield increases	Improved productivity, sustainability, and market access	Limited resources and organizational capacity	Mwambi et al., 2020
	Cooperative members receive a more income boost and better credit access	Enhanced economic resilience		
Processors and Manufacturers	Vertical integration reduces post-harvest losses increases farmer income	Enhanced innovation and efficiency	Unequal bargaining power	Benyam et al., 2021
	Cross-industry collaborations lead to new product innovations	New market opportunities	Trust issues	
Retailers and Distributors	Direct trade partnerships increase farmer prices	Improved market acces	Power imbalances	Wijaya et al., 2018
	Sustainable sourcing reduces carbon footprint and increases sustainable farming	Better traceability and consumer satisfaction	Need for upfront investments	
Research Institutions and Universities	Collaborative research leads to new methods	Boosted innovation and practical solutions	Differing objectives and timelines between partners	Dentoni et al., 2021
	Knowledge transfer increases productivity and reduces losses due to pests	Enhanced farm productivity		

Coconut products are known for their sustainability in packaging and constructions. Coconut husk chips are utilized as a growing substrate in horticulture, while coir fibres are widely employed in erosion control and landscaping. In the construction industry, coir insulation materials and coconut fibre composites are becoming more popular. Biodegradable packaging made of coconut husks is viewed as a sustainable substitute. Activated carbon made from coconut shells is also widely used for air and water purification (Atapattu et al., 2024).

CHALLENGES IN IMPLEMENTING A CIRCULAR ECONOMY MODEL IN THE COCONUT INDUSTRY

A number of challenges stand in the way of the transition of the coconut industry to a circular economy. The main one is that smallholders dominate the fragmented structure of coconut farming, which makes it challenging to standardize procedures. This change is made more difficult by a lack of infrastructure for processing and upcycling by-products, especially in poorer nations where investors are discouraged by large initial costs. The uneven quality of products resulting from different farming and processing techniques restricts their wider use in sectors such as building and textiles, and the logistical challenges associated with gathering waste from dispersed farms impede the efficient use of resources. To sustain this strategy, customer awareness and demand for upcycled coconut products must also increase (Elfahmi et al., 2024; Melati et al., 2021; Vieira et al., 2024b).

POLICY RECOMMENDATIONS TO SUPPORT A CIRCULAR ECONOMY APPROACH IN COCONUT PRODUCTION

The adoption of a circular economy in the coconut industry necessitates broad policy backing at multiple levels. Governments should encourage investment in technologies that fully utilize coconut resources by offering tax incentives and subsidies to growers and processors that employ resource recovery and waste reduction strategies. Policies that support research and development are essential as they can enhance circular models by providing financing to institutions that specialize on creative use of coconut by-products. To get around logistical obstacles in the by-product utilization process, infrastructure development is crucial, with centralized processing facilities receiving priority. Minimum recycled content requirements for goods may stabilize the market for coconut-based products and increase consumer demand for environmentally friendly methods. Furthermore, international collaboration for information exchange and

Table 2. Future Prospects and Technological Pathways for Scaling Circular Economy in Coconut Production

Category	Key Benefits	References
Environmental Benefits	Waste reduction through full coconut utilization, reducing organic waste and methane emissions	Elfahmi et al., 2024; Vieira et al., 2024b
	Reduced deforestation by substituting coconut by-products in construction and textiles	
	Enhanced soil health and biodiversity by using coconut by-products as organic fertilizers, reducing chemical inputs	
	Water conservation by minimizing waste in coconut water processing	
Social Benefits	Increased income for farmers through value-added coconut by-products	Doe et al., 2023; Muriuki et al., 2024; Tu Nguyen et al., 2022
	Job creation in rural areas from industries based on coconut by-products	
	Improved community health through reduced pollutants and better waste management	
	Enhanced food security via improved farming productivity and sustainability	

technology transfer, as well as education initiatives to teach farmers sustainable practices and circular economy principles, are essential to advancing global progress in this field (Do et al., 2024; Elfahmi et al., 2024; Kamaruzaman et al., 2023).

ENVIRONMENTAL AND SOCIAL BENEFITS OF ADOPTING CIRCULAR ECONOMY PRINCIPLES IN THE COCONUT INDUSTRY

The adoption of circular economy principles in the coconut industry offers significant environmental and social benefits, contributing to sustainable development in coconut-producing regions. This review explores the key advantages of transitioning from a linear to a circular model in coconut production and processing.

The adoption of circular economy principles in the coconut industry offers a wide range of environmental and social benefits. These advantages underscore the importance of transitioning to a more sustainable and equitable model of coconut production and processing.

FUTURE PROSPECTS AND POTENTIAL FOR SCALING UP CIRCULAR ECONOMY PRACTICES IN COCONUT PRODUCTION

The coconut industry stands at the cusp of a significant transformation, with circular economy practices offering promising prospects for sustainable growth and innovation (Nuwarapaksha et al., 2025). This review explores the future potential and scalability of circular economy approaches in coconut production.

The future prospects for scaling up circular economy practices in coconut production are promising. With technological advancements, expanding markets, supportive policies, and collaborative ecosystems, the coconut industry is well-positioned to embrace circularity at scale, potentially revolutionizing tropical agriculture and contributing significantly to sustainable development goals.

CONCLUSION

The coconut industry stands at a pivotal juncture, poised for transformation through the adoption of circular economy principles and strategic partnerships. The enormous potential of coconut by-products—from coir to activated carbon—as well as the cutting-edge technology enabling their use, have been highlighted in this paper. When efficient processing techniques are combined with sustainable farming practices, the result is a reduction in environmental impact and an increase in output. Realising the full potential of the coconut value chain, promoting innovation, and guaranteeing a fair distribution of profits all depend on the formation of cross-sector collaborations. The advantages of circular practices for the environment and society are indisputable, despite ongoing difficulties, especially with infrastructure and standardization. Technological innovations and policy backing provide avenues to get above these obstacles. As the sector develops, it may serve as a role model for sustainable agricultural growth, greatly boosting

Table 3. Key Stakeholder Partnerships Driving the Circular Economy in the Coconut Industry

Key Area	Future Prospects & Scaling Potential	References
Technological Advancements	Biotechnology: Enzymatic processes are enabling the conversion of coconut husks into biofuels and biochemicals, creating new markets for coconut by-products.	Doe et al., 2023; Elfahmi et al., 2024; Muriuki et al., 2024; Tu Nguyen et al., 2022
	AI and IoT in Agriculture: Precision agriculture technologies improve resource use and waste management, supporting the scaling of circular practices.	
Market Expansion	Construction Industry: Coconut-based materials like coir insulation and activated carbon are expanding in green building practices.	
	Food & Beverage Industry: New market opportunities emerge with coconut protein and preservatives, promoting the use of all coconut parts.	
Policy Support & Standardization	Supportive Policies: Governments are promoting research, financial incentives, and waste reduction mandates to boost circular economy practices.	
	Standardization: International standards for coconut-based products can facilitate global trade and scaling of circular practices.	
Collaborative Ecosystems	Partnerships: Collaboration between farmers, processors, researchers, and industries is key to efficient resource use and innovation in circular practices.	
	Digital Platforms: Emerging digital tools promote resource sharing, waste exchange, and knowledge transfer, enabling small-scale farmers to participate in circular initiatives.	

rural economies and advancing global sustainability objectives. Encouraging circularity, establishing collaborations, and utilizing innovation are key to the coconut industry's future. By doing this, coconut-producing regions around the world can maximize value creation, minimize waste, and set the path for a more resilient and successful future.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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Photo from Parachute Kalpavrishka

Moisture Conservation and Water Management in Coconut Gardens

B. Hanumanthe Gowda*

Coconut is a crucial plantation crop, primarily grown in the humid tropics and tropical regions of India. Consistent nut production in coconut palms requires a year-round water supply. The coconut is grown in the coastal belt which receives substantial rainfall and it's concentrated within a few months during the monsoon season. In the coconut growing region other than the coastal belt, coconut has to be provided with supplemental irrigation. As coconut has a spreading root system without a tap root and concentrated in the top layer of soil with radius of 2 meters.

The India Meteorological Department (IMD) predicted above normal temperatures for month April to June 2025, with an anticipated increase of 6-10 days of heat wave conditions compared to normal years. Hence, there would be prolong dry spell, water scarcity and High temperatures combined with low rainfall drastically impair coconut palm health and productivity. Therefore, optimizing irrigation schedules, implementing soil moisture-conservation techniques, and adopting water-harvesting methods are critical for efficient water management and moisture conservation in coconut gardens.

MAIN OBJECTIVE OF SOIL MOISTURE CONSERVATION

Prevents Moisture Stress: Coconut palms have fibrous roots and the root zone for moisture absorption is concentrated in a circular area of 200 cm radius around the base of the coconut tree up to a depth of 100 cm. In hot, dry summers, the surface soil can lose moisture quickly. This water deficit induces stress in the palms, resulting in decreased nut yields and potential premature nut drop.

Enhanced Soil Health: Moisture conservation practices such as mulching and cover cropping improve soil structure, organic matter content, and microbial activity, creating a healthier root environment for coconut palms.

Improved nutrient uptake: Adequate soil moisture helps in effective uptake of nutrients. Without sufficient soil moisture, nutrients remain bound to soil particles and cannot be readily absorbed, even if fertilizers or manure have been applied leading to wastage and lower productivity.

Supports Nut Development: Coconut palms being perennial and produce nuts throughout the year, require a consistent supply of water throughout the year for optimal growth, flowering, and fruiting. Moisture stress, even for short periods, can negatively affect nut yield and quality.

Maintains Leaf Health: Proper watering helps keep the palm leaves green and healthy, which is essential for photosynthesis and overall plant vigor.

Improves Yield: Effective irrigation plays a key role in enhancing coconut yield, making them far more productive than coconut farms relying purely on rainfall, particularly in dry seasons

Reduces Pest Incidence: Drought-stressed palms are more vulnerable to pests like red palm weevil, rhinoceros beetle etc. Adequate irrigation keeps the Palm more resilient.

Sustainability and Cost-Effectiveness: Conserving soil moisture offers significant advantages, especially in regions with limited water resources or irrigation infrastructure. By reducing the frequency of irrigation, it directly impacts the savings in water, energy, and labor. This is crucial for sustainable agriculture, particularly in areas facing water scarcity.

Climate Change Adaptation: With changing climate patterns and increasing temperatures, moisture conservation becomes even more vital to buffer against erratic rainfall and longer dry periods.

In a nutshell, moisture stress can thus lead to:
Initially moisture stress symptoms appear in seedlings, then progress to young palms, and eventually affect mature palms, causing:

- Reduced leaf production
- Poor inflorescence development
- Immature nut fall
- Decreased nut size and copra content
- Increased susceptibility to pests and diseases
- Ultimately reduced income for the farmers,

However, these challenges can be effectively managed through proper soil moisture conservation and efficient water management.

MOISTURE CONSERVATION & WATER MANAGEMENT TECHNIQUES IN COCONUT GARDENS

Irrigation Methods

Irrigation during summer is crucial for coconut gardens because of high evaporation, increased water demand, and potential yield loss. Each palm requires 55 to 120 litres of water every day depending on the climatic conditions. Here's a focused guide on irrigation in coconut gardens during summer.

a. Drip/trickle Irrigation
The adoption of a drip irrigation system is the most efficient and ideal approach for judicious utilization of water. Drip irrigation deliver water directly to the root zone, minimizing losses and maximizing efficiency. This method is known to save approximately 30–40 per cent of water while simultaneously increasing yield by 38–40 per cent compared to basin irrigation. It also contributes to soil conservation and reduces competition from weeds for vital water and nutrients.

Figure 1. Drip/trickle irrigation

b. Sprinkler/perfo irrigation
Sprinkler/perforated pipe irrigation is less water-efficient than drip due to evaporation loss but useful for evenly distributing water in young palms, nurseries in sandy soils, and intercrops within coconut gardens. However, it's less suitable for mature palms where water conservation is key. Where uniform coverage of sprinklers uses more water than drip's direct, water-saving approach.

Figure 2. Sprinkler/perfo irrigation

c. Basin Irrigation
Basin irrigation involves creating circular basins (1.5-1.8 meters radius) around each palm and flooding them every 4-7 days, depending on the soil and there is wetting of root zones.. Irrigation channels run between two rows of palms, connecting to each basin. Using a hose pipe to fill basins directly is recommended to minimize water loss in the channels (Suited for medium scale farms)

Figure 3. Basin irrigation

d. Pitcher / pot irrigation
Pitcher/pot irrigation is a low-cost method suitable for providing slow and steady moisture to small coconut farms, particularly for young seedlings. This involves burying porous clay pots near the plants and filling them with water, which gradually seeps out to the root zone.

Rain Water harvesting

Farm Ponds
Installation of farm ponds strategically to collect surface runoff. This harvested water can then be

Figure 4. Farm ponds

stored and reused for irrigating the coconut garden, especially during dry periods.

Recharge Structures
Construct recharge pits, percolation pits, or trenches across the farm. These structures facilitate the capture and storage of rainwater, allowing it to seep into the ground and replenish the groundwater table, indirectly benefiting the coconut palms.

i. *Mulching with Coconut Husks/Leaves/Coir Pith*
Application of coconut husks with convex surface facing upwards (100 Nos.) or dried coconut leaves (15 Nos.) or coir pith up to a height of 10 cm in the basin of 1.8 m radius around the palms as mulch to reduce water loss and for soil moisture conservation during summer season. Mulching also adds organic matter to the soil and reduces the soil temperature.

ii. *Burial of Coconut Husk or Coir Pith*
Burying coconut husk or coir pith proves to be a highly effective method for conserving soil moisture. This can be achieved through two primary techniques: creating linear trenches 3 meters away from the palm trunks between rows, or by digging circular trenches at a distance of 2 meters from the trunk with dimensions of 0.5 m with & depth. In both methods, the coconut husks are arranged in layers within the trenches, ensuring the concave surface of each husk faces upwards before being covered with soil.
Coir pith @ 25 kg/palm may also be buried in circular trenches dug with 30 cm width and 60 cm depth at 1.5 – 2.0 metres radius.
Coconut husks and coir dust possess remarkable water retention capabilities, acting like natural sponges. Husks/ Dust can absorb and hold moisture approximately 6-10 times their

Figure 5. Mulching with coconut husks

weight, releasing this stored water to the coconut trees during dry spells. As these materials slowly decompose over 4-6 years (husks) and 8-10 years (coir dust), they add potash to the soil.

iii. Do not disturb soil in the coconut garden during summer months to avoid water loss.

iv. On level lands, small trenches are dug within the plantation during the rainy season to capture and retain excess rainwater for later use.

v. In sloppy areas, land may be terraced and trenches dug across. This will facilitate maximum percolation of rainwater and water storage.

vi. Cover cropping and intercropping with legumes and green Manure crops like Sunhemp, Wild sunhemp, wild indigo, glyricidia, Dhaincha, Pueraria, Mimosa, Calapagonium etc., This helps reducing soil heat and improves soil organic matter content.

vii. Application of vermi compost and organic matter (Compost /Farm Yard Manure) to improve water retention

viii. Old and senile leaves should be removed to avoid transpiration losses.

ix. Spraying of anti-transpirants like a 5% kaolin solution or whitewash on the palm trunks to reduce water loss from the tree's surface.

Soil moisture conservation and water management are critical for coconut cultivation especially in summer months. As Palms have shallow root system, moisture stress can severely impact their growth and yield. Adoption of practices such as irrigation methods like drip irrigation, rainwater harvesting through farm ponds and recharge structures, and soil moisture retention techniques such as mulching and burying coconut husk is essential. Additionally, practices like cover cropping, organic matter application, minimizing soil disturbance, and using Anti-transparent, selecting drought-tolerant varieties will further boost the resilience of coconut palms against the harsh conditions, ensuring sustained productivity.

[1] *Chief Coconut Development Officer, Coconut Development Board, Kochi-11, India*

Experts' Finding on the Health Benefits of Coconut

Dr. Fabian M. Dayrit

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Virgin coconut oil is effective in lowering C-Reactive Protein levels among suspect and probable cases of COVID-19. There were two main indicators used: recovery from COVID-19 symptoms and level of C-Reactive Protein (CRP) in the blood. These two indicators showed that VCO can be used to treat mild COVID-19 cases.

CRP is a protein that is analyzed in the blood as a quantitative measure of inflammation or infection. CRP level less than 5 mg/L indicates recovery from inflammation or infection. The recovery from COVID-19 symptoms was more rapid in the VCO group compared with the Control group: 17% in the VCO group showed improvement compared to only 4% in the Control group. Full relief from COVID-19 was attained by day 18 in the VCO group compared to day 23 in the Control group.

The level of CRP in the VCO group dropped much more rapidly and completely compared to the Control group. By day 14, the CRP level in the VCO group had fallen below the 5 mg/L, and this continued to show a decreasing trend at day 28. In comparison, the CRP level in the Control group fell slowly to 5 mg/L at day 14 and stayed at this level until day 28.

Other beneficial effects of VCO were noted from the blood assay:

- HDL-cholesterol ("good cholesterol") increased
- LDL and triglycerides remain within normal range
- Fasting blood sugar (FBS) decreased

These results show that VCO, indeed, is a healthy oil.

Source: Proceedings of the XLIX Cocotech Conference, 30 August-2 Sept 2021, Jakarta, Indonesia.

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Coconut oil rinsing reduces gingival inflammation. Oil rinsing is a type of traditional procedure that involves swishing edible oil in the mouth and then spitting it out. Virgin and regular coconut oil can be used to reduce plaque related gingivitis. However, the study shows that virgin coconut oil has better taste, odor, and texture in the mouth than regular cooking coconut oil. The advantage of coconut oil or virgin coconut oil as natural oils is that they neither cause any staining as seen in the use of mouthwashes nor there is any after taste or allergic reactions. and are readily available. Such practices cure about 30 systemic diseases and have an effect on the overall well-being of the individuals practicing it.

Source: CORD Journal, Vol. 37 2021

Experts' Finding on the Health Benefits of Coconut

DR. D. P. Athukorale

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Green Coconut has much water and is rich in proteins, minerals, vitamins, calcium, phosphores, iron, iodine, chlorine, sulphur, potassium, carbohydrates and vitamins, B1, B2, B5 and magnesium. The water also helps the hydration of the body. The green coconut has a ratio of amino acids arginine, alanine, cisteína (essential) and serina, greater than those found in cow's milk. It is perfect and natural isotonic to restitute energies in the human body.

Tender coconut water has been used in other areas of the world where intravenous solutions cannot be obtained. Japanese have used tender coconut water (T. C. W.) intravenously in Sumatra, Indonesia in World War I. Pradera et. al. have used intravenous T. C. W. for pediatric patients in Havana, Cuba without any serious reactions.

Source: Dr. D.P. Athukorale 2008. Tender Coconut Water – Its Health Benefits Cocoinfo International, 15 July: 14-16

Prof. Dr. Rabindarjeet Singh

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Coconut water (*Cocos nucifera* L.) is an ancient tropical beverage whose popularity has been increasing in recent years. This 'naturally canned' beverage is a sweet refreshing drink obtained directly from the inner part of the fruit. It is a beverage that has drawn the attention as a natural functional drink. Coconut water is sterile at source, and is very rich in potassium, and contains sodium, chloride, magnesium and carbohydrates. Therein, making it a healthier alternative to carbonated drinks including isotonic sports drinks. Apart from the lower calories due to lower sugar content, the non-carbonated coconut water is also a great source for replacing the electrolytes lost during sweating when compared to carbonated drinks. Ingestion of carbonated drinksis known to be associated with gastrointestinal discomfort in certain individuals. This "Mother Nature's" gift of coconut water, could be prized as the beverage above all other beverages for its health renewing properties.

Source: Proceedings of the XLVI Cocotech Conference 7-11 July 2014, Bandaranaike Memorial International Conference Hall Colombo, Sri Lanka.

Experts' Finding on the Health Benefits of Coconut

Dr. (Mrs.) E.R.H.S.S. Ediriweera

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- Young coconut water could be drunk to alleviate the burning sensation during micturition
- Young coconut water, breast milk, treacle of *Saccharum officinarum* (*F. Graminae*) and sugar are mixed together and given for hiccough
- Leaves of *Dregia volubilis* (*F. Asclepiadaceae*) are to be pounded and mixed with tender nut water. The juice is extracted and given in treatment of poisoning of *Nerium indicum* (*F. Apocyanaceae*)
- Water of young king coconut (before flesh is formed inside) is given for fever and it can be consumed as a diuretic in dysuria.
- A King coconut is to be opened by slicing off the top.30 gms of powdered fruits (without seeds), of *Terminalia chebula* (*F. Combretaceae*) are added to the King coconut water inside and stirred. Sliced top is then replaced (as a cover) and kept outdoors in the dew overnight. Following morning, the mixture inside is to be filtered and drunk as a purgative. This is called El Vireka by Sri Lankan traditional physicians. The number of bowel motions will increase as the person continues to drink cold water from time to time during the morning. He should not consume hot or warm food and liquids. This is good for purifying blood and cooling the body.

Dr. Bruce Fife

Certified Nutritionist and Doctor of Naturopathic Medicine, and Director, Coconut Research Center, based in USA

You cannot say LDL (low density lippoprotein) is bad and HDL (high density lippoprotein) is good. It is more complex than that. There are actually two types of LDL: one small and dense the other large and soft. The large LDL is a good cholesterol the type used to make bile, hormones, and vitamin D--it is essential to life! The small dense LDL is the type that becomes oxidized and can be harmful, as all oxidized lipids can be. Eating coconut oil (and other saturated fats) increases both HDL and the "good" LDL, thus lowering the risk of heart disease. This is one of the reasons why populations that eat a lot of coconut oil have the lowest heart disease rates in the world.

Source: Press Statement, APCC, 21 June 2017

A Bullish Coconut Oil Market in the Second Half of 2025

Alit Pirmansah[1]

The global coconut oil market in the second half of 2025 is navigating a complex landscape shaped by tightening supply, robust demand, and significant price volatility. Total production is projected to rise marginally to 3.56 million metric tons (MMT) in 2025, up from 3.50 MMT in 2024. The Philippines remains the leading producer, with its output expected to increase from 1.57 MMT in 2024 to 1.60 MMT in 2025, while other major producers like Indonesia and India are anticipated to see modest gains. Despite these increases, production will remain constrained due to adverse climatic conditions, including El Niño effects, which are limiting crop yields. These production constraints are likely to contribute to upward pressure on prices, particularly as demand continues to rise across food, cosmetic, and biofuel sectors.

Table 1. Coconut Oil Production, 2023-2025 (000MT)

Countries	2023	2024p	2025f
Philippines	1,492	1,567	1,598
Indonesia	893	831	861
India	558	503	505
Sri Lanka	43	36	39
Thailand	29	29	35
Malaysia	56	55	56
Vietnam	41	41	41
Papua New Guinea	44	40	42
Mexico	131	129	120
Others	269	268	267
World	**3,556**	**3,499**	**3,564**

Source: Oil World and ICC estimates; p: preliminary figures; f: forecasted figures

Table 3. Coconut Oil Imports, 2023-2025 (000MT)

Countries	2023	2024p	2025f
EU-27	654	634	650
USA	419	496	460
Malaysia	262	286	265
China	182	170	166
UK	20	22	20
Other countries	**650**	**631**	**644**
World	2,187	2,239	2,205

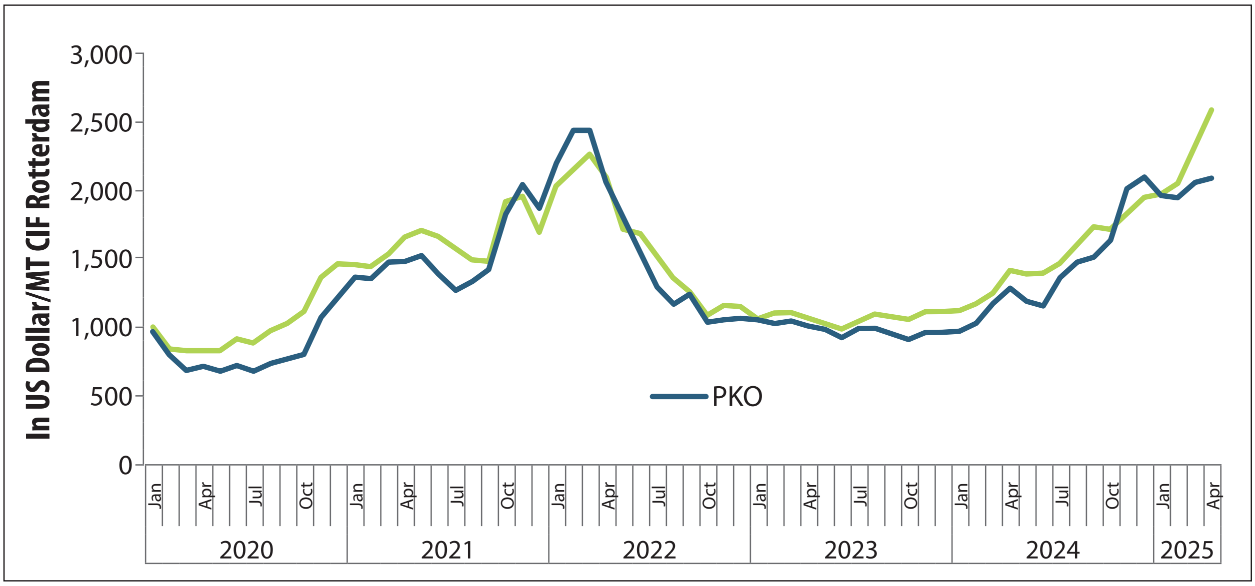
Source: Oil World and ICC estimates; p: preliminary figures; f: forecasted figures

On the import side, global demand for coconut oil is projected to stay steady, albeit with slight fluctuations. The European Union (EU-27) will continue to be the largest importer, expected to stabilize at around 650,000 metric tons, while U.S. imports will decrease slightly from 496,000 metric tons in 2024 to 460,000 metric tons in 2025. However, trade policy complexities add a layer of uncertainty. The reimposition of U.S. import tariffs—ranging from 18% to 46%—by the Trump Administration to protect domestic oilseed producers and promote U.S.-made biofuels is expected to affect key exporters like Indonesia and the Philippines. This policy, which increases costs for importers, especially food processors and biofuel blenders relying on lauric oils, has diverted some Southeast Asian coconut oil supplies toward the EU market, but not enough to fully offset the tightening global supply. These tariff-related shifts have contributed to elevated prices in both the U.S. and EU markets.

The global supply of coconut oil is expected to tighten slightly from 6.31 MMT in 2024 to 6.28 MMT in 2025. This decrease is driven by reduced imports from key markets like the U.S. and Malaysia, although growing imports from China will partially offset these declines. Exports are forecast to drop from 2.60 MMT in 2024 to 2.38 MMT in 2025 due to the tightening supply and shifts in trade dynamics. Domestic consumption is projected to rise slightly from 3.21 MMT in 2024 to 3.30 MMT in 2025, reflecting steady demand across multiple industries. However, the impact of U.S. tariffs and the strain on supply chains will likely further exacerbate price volatility in the coming years.

Price trends in early 2025 reflect the growing uncertainty in the coconut oil market, with a significant upswing observed. Coconut oil prices surged from around USD 1,976 per metric ton in January to USD 2,587 in April, a 31% increase. This sharp price recovery contrasts with the relatively subdued prices of 2023, when coconut oil ranged between USD 1,000 and USD 1,200 per metric ton. Palm kernel oil prices also rose by 6.5% over the same period, highlighting the broader market pressures on tropical oils. The recent bullish pricing is a result of supply

Figure 1. Price Trend of Lauric Oils, January 2020-April 2025 (USD/MT)



Source: ICC

Table 3. World Balance of Lauric Oils (000MT), 2024-2025

Countries	Coconut Oil		Palm Kernel Oil		Lauric Oils	
	2024p	2025f	2024p	2025f	2024p	2025f
Beginning Stocks	530	500	1,540	1,430	2,070	2,030
Production	3,499	3,564	8,366	8,438	11,648	11,711
Imports	2,285	2,214	3,316	3,345	5,648	5,608
Total Supply	**6,314**	**6,278**	**13,222**	**13,213**	**19,366**	**19,349**
Exports	2,601	2,376	3,350	3,330	5,690	5,630
Domestic Consumption	3,213	3,302	8,442	8,433	11,646	11,719
Ending Stocks	500	600	1,430	1,450	2,030	2,000
Total Distribution	**6,314**	**6,278**	**13,222**	**13,213**	**19,366**	**19,349**

Source: Oil World, USDA, and ICC estimates *p: preliminary figures; f: forecasted figures*

constraints from key producers, compounded by the effects of El Niño, coupled with rising demand from food industries, oleochemical manufacturers, and biofuel producers competing for limited tropical oil supplies. These factors suggest that the coconut oil market will continue to face significant challenges related to supply shortages, rising prices, and evolving trade policies in the near future.

The broader market context further supports growth projections. The global coconut oil market was valued at approximately USD 5.49 billion in 2025 and is expected to reach USD 7.61 billion by 2029, with a compound annual growth rate of 8.5%. This expansion is driven by increasing consumer demand for plant-based and vegan products, rising interest in natural cosmetics and personal care formulations, and the growing use of coconut oil in functional foods and beverages. Moreover, sustainability initiatives in developed markets, particularly the EU and U.S., are fuelling demand for bio-based and renewable ingredients, where lauric oils play a critical role.

Looking ahead, the coconut oil market is expected to remain volatile but fundamentally strong through the second half of 2025. Prices are projected to hold within the USD 2,500 to USD 2,700 range per metric ton for coconut oil and USD 2,000 to USD 2,150 for palm kernel oil, supported by constrained supply, firm demand, and ongoing trade frictions. However, any easing of weather disruptions or shifts in consumer preference toward less costly soft oils could moderate the current bullish outlook. Stakeholders must closely monitor climatic developments, policy changes, and evolving demand trends, especially in the biofuel and oleochemical sectors, to effectively manage risk and capitalize on emerging opportunities.

[1] *Market and Statistic Director, International Coconut Community*

Coco Events

COCO FEST 2025 DRAWS COCONUT-LOVING CROWDS IN ITS 10TH YEAR

Locals and tourists flocked to Coco Fest 2025 at Pedro St. James on Saturday as the festival of 'all things coconut' celebrated its 10th year.

Around 35 vendors set up their stalls on the grass at the historic site, selling food, drink, sweets, clothes, cosmetics and homeware to the background of live music, while children were entertained with face-painters and coconut bowling.

One of the first stalls to greet visitors to the festival belonged to Jennett Powell of Bonafide Farmer. Jennett was hard at work offering samples of her range of sauces and jams, including jerk sauce, pineapple jam and pepper jelly.

"I come here every year, it's got to be done!" said Jennett. "My products are straight from the farm and I made many of them especially for this event."

Visitors may sample handcrafted sweets including coconut pineapple pepper jelly, Bajan coconut sweetbread, and the "fan favorite" goat cheese and mango marshmallows at the Powder Monkey table, which also had other products with a coconut theme.

At a neighbouring stall, Robert Buliusz, owner of Cayman Sweet Bites, was selling coconut-flavoured treats, some of which were made especially for Coco Fest.

"It's just a hobby of mine, but it's great to be here and spread the word,' he said.

The Grand Cayman Distillery booth, which sold Barefoot Beach cocktails prepared with its toasted coconut rum, was one of the busiest. Grand Cayman Distillery CEO Moises Sevilla claimed that Coco Fest provided him with a chance to introduce the locals to his beverages.

"It's open to everyone, both tourists and locals," he said. "I love these kinds of events which have local vendors, are locally-organized and where the majority of people here are local."

Coconut rum fans

Enjoying samples of the coconut rum so much that she bought a bottle, was Daniella Man, who was visiting the festival with her son Andrew, 17.

"We came here by accident!" she said. "We're staying with friends and we wanted to go somewhere where we could see local, traditional products and maybe get a cocktail. And I love coconut rum!"

Coco Events

The Man family, who are from Transylvania, Romania, lived in Cayman for many years, and often return to the island.

"It's a place which still has community values, which is really great to see," said Daniella.

'I think Cayman would really benefit from having more events like this," said Andrew, 17, "especially events which are great for all the family."

Profits to go to charity

Any profits from the event will, like in previous years, be donated to charity, although the organizer, Cayman Islands National Attractions Authority, has yet to decide upon a charity for this year.

"We have about 35 vendors selling food products, arts and crafts, coconut oil, so many different things,' said the authority's marketing coordinator, Leanna Jarvis-Burton.

The festival was started by a health enthusiast who wanted to spread the word about the benefits of coconuts, so it started from there and has grown ever since, she said.

"It gets bigger and bigger every year and is always all about coconuts," she said. "It's for locals and tourists and we want everyone to come out and enjoy our heritage." *(Cayman Compass)*

INDONESIAN COCONUT PROCESSING INDUSTRY URGES FRUIT EXPORT RESTRICTION AMID SHORTAGE

Facing a local fruit shortage, Indonesia's coconut processing industry is urging the government to restrict shipments of the commodity abroad, including those shipped illegally.

The long dry season, caused by El Nino phenomenon, sent whole coconut production into a slump, according to Anro Simanjuntak, head of the coconut industry and various products division at the Indonesian Coconut Processing Industry Association (HIPKI).

The commodity is expected to see a 31 percent year-on-year (yoy) production decline this year. The industry is estimated to suffer a total of Rp4.3 trillion (US$266.9 million) in losses in 2024 due to the shortage.

"The domestic coconut processing industry has been short of raw materials (whole coconuts) since October 2024," Anro said as reported by Kompas.

El-Niño, which emerged from mid-2023 to the first quarter of this year, caused coconut flowers or fruit buds to fall off because they did not get enough water, he explained.

Anro went on to say that the problem was exacerbated by the increase of whole coconut exports and illegal shipments to foreign buyers, in China, Thailand, Vietnam and Malaysia. *(The Jakarta Post)*

VIETNAM'S COCONUT INDUSTRY EYES BILLION-DOLLAR MARKETS

Coconut has emerged as a key economic driver for the Mekong Delta and south-central coastal regions as it gains entry into billion-dollar markets such as the U.S. and China.

According to the Ministry of Agriculture and Rural Development, Vietnam currently boasts over 200,000 hectares of coconut cultivation. Coconut is now one of the six key crops included in the national program for industrial crop development by 2030. From generating US$180 million in export revenue in 2010, coconut exports reached $900 million in 2023, and the sector is expected to surpass the billion-dollar mark in 2024. With this trajectory, the ministry aims to enhance the scale and quality of the coconut industry for further global expansion.

On the global map of coconut production and exports, Vietnam ranks sixth among the top ten coconut-producing countries, with an annual output of nearly 2 million tons. The country's coconut quality and yield place it among the global leaders, with coconut meat making up 35% and coconut water 27%, both surpassing the global average by 5%. Dr. Tran Thi My Hanh, from the Southern Horticultural Research Institute (SOFRI), highlighted these exceptional figures.

In terms of coconut cultivation, the Mekong Delta province of Ben Tre is the largest producer, with over 80,000 hectares dedicated to the crop. Huynh Quang Duc, Deputy Director of the Ben Tre Department of Agriculture and Rural Development, noted that the province is the coconut capital of the nation, accounting for 42% of Vietnam's total coconut area. Coconut farming is a vital source of income for over 200,000 rural households in the province. In recent years, many farmers have switched from less profitable rice farming to coconut cultivation, boosting incomes and providing a sustainable livelihood. Ben Tre's coconut products are expected to generate $500 million in export revenue in 2024, contributing over 50% of the nation's total coconut export value.

The Chinese market is seen as a significant opportunity for Vietnamese coconuts. China, with its large population, has a high demand for coconut-based products, including fresh coconuts, coconut water, coconut oil, and processed coconut products. With its proximity to Vietnam, the country enjoys a competitive advantage in shipping costs compared to Southeast Asian and African competitors. Additionally, free trade agreements between ASEAN and China have facilitated easier access to this lucrative market. Vietnam's large coconut production capacity, particularly from Ben Tre and the Mekong Delta, ensures a stable supply for China.

It is estimated that China consumes around 4 billion coconuts annually, with approximately 2.6 billion being fresh. Despite the high demand, China's domestic production is insufficient, presenting an opportunity for Vietnam's coconut exports to fill this gap.

Maximizing the value of coconut

While the Vietnamese coconut sector has several advantages, experts in the coconut processing industry warn that strict management of production and exports is crucial to sustaining growth. Nguyen Phong Phu, technical director of Vina T&T Group, emphasized that the approval of Vietnam's fresh coconut exports to China has opened up significant economic opportunities. However, to maintain this success, both government authorities and producers must work together to manage production standards and combat fraudulent practices. The government must implement digital systems for managing export regions and enforce strict penalties against fraudulent activities to protect the reputation of Vietnamese coconut products.

Coconuts offer high economic value not only through the export of fresh fruits to markets like the US, Australia, and China, but also through by-products such as coir, activated carbon, and coconut-based handicrafts. Nguyen Thi Kim Thanh, chairwoman of the Vietnam Coconut Association, pointed out that of the 200,000 hectares of coconut plantations across the country, 120,000 are dedicated to the processing industry. To increase coconut value, Vietnam must invest in quality coconut varieties while also focusing on maintaining a strong processing industry.

Currently, Vietnam is emerging as a supplier of raw coconut materials to global processing markets. However, infrastructure improvements are needed in rural coconut-growing areas to reduce intermediaries and shorten the supply chain. This would allow farmers to access the market more directly, enhancing their income and creating incentives to continue growing coconuts. *(VNExpress)*

COCONUT OUTPUT LIKELY FLAT NEXT YEAR AMID AGING TREES

Philippine coconut production growth is likely to be flat next year given low yields from the country's aging trees, an industry player said.

"We estimate coconut production to stay at the levels similar to previous years as efforts to improve productivity will take time to bear fruit," Romeo I. Chan, Axelum Resources Corp. chairman and chief executive officer, said in an e-mailed reply to questions.

Philippine coconut output has steadily decreased in recent years as most of the country's fruit-bearing trees are now too old. Coconut and its by-products remain the country's top agricultural export.

The volume of coconut production hit 14.89 million metric tons (MT) in 2023, slightly lower than 14.93 million MT a year earlier, according to data from the Philippine Statistics Authority.

"At present, the most evident challenges are the low productivity of coconut trees and inadequate infrastructure support," Mr. Chan said. "Senile trees, weather disturbances and climate change have led to declining harvest yields over the years."

Last year, President Ferdinand R. Marcos, Jr. ordered the Philippine Coconut Authority (PCA) to draft a plan to rehabilitate the coconut industry, including planting 100 million coconut trees by 2028.

Among the agency's rehabilitation plan seeks to address the advanced age of the nut-bearing trees. The agency is seeking to replant about 8.5 million coconut trees this year.

Under the Philippine Coconut Industry Development Plan 2024-2034, the replanting project is expected to increase coconut output by 4.7 billion nuts annually worth P33.1 billion by 2034.

In 2025, the PCA aims to replant 15.3 million trees, followed by 25.4 million yearly between 2026 and 2028.

Mr. Chan said the government's replanting goal could be reached if the state and private sector work together.

"In addition, the absence or lack of development in coconut regions has increasingly contributed to it being one of the most marginalized sectors, with coconut farmers considered among the poorest in the country," he added.

Mr. Chan said the struggling industry could be boosted with the appropriate use of the coco levy fund.

In 2021, Republic Act No. 11524 or the Coconut Farmers and Industry Trust Fund Act signed by then President Rodrigo R. Duterte mandated the creation of a fund that places coconut levy assets to a trust fund that will finance the rehabilitation and modernization of the industry.

"The proper utilization of the coco levy fund will be critical to help modernize the coconut industry, reinforce capabilities of smallholder farms and uplift coconut farming communities," he said.

The law also calls on the Bureau of the Treasury to transfer P10 billion to the trust fund, another P10 billion in the second year, P15 billion in the third year, another P15 billion in the fourth year and P25 billion in the fifth year.

Axelum is a Philippine Stock Exchange-listed manufacturer and exporter of coconut products. *(Business World)*

SRI LANKA COCONUT PRODUCT EXPORTERS SEEK URGENT IMPORTS TO BRIDGE CRISIS

Sri Lanka's coconut-based industries say they need imported raw material to avoid losing export markets to other countries, with a 250 million nut crop shortfall projected for the first half of 2025.

By 2023 the harvest was down to 2,950 million nuts from 3,350 million nuts. Sri Lanka Coconut Research Institute is now forecasting a 1,407 million nut harvest for the first half of 2025. In Sri Lanka around 60 percent of the harvest comes in the first half of the year.

The Ceylon Chamber of Coconut Industries say based on the first half projection Sri Lanka may see another 300 million fall in coconut harvest in 2025.

There will be at least a 200 million nut shortfall in the first four months, Jayantha Samarakoon, President of the chamber said.

Export Market Loss

"We have requested the government to grant us approval to import coconuts, dried coconut chip, or kernels for the first four months, so that industries can manage orders without cancellation," Samarakoon told reporters.

Sri Lanka has already lost the virgin coconut oil market to Vietnam and may lose the other markets also, unless imports are allowed to tide over the next few months, one exporter said.

Imports of raw material will not only help maintain export orders and prevent them from shifting to other countries, but also help moderate domestic prices, the chamber said.

Though Sri Lanka has banned imports of fresh nuts, due to fears of disease, there are well established protocols for importing coconut used in coconut producing countries including Thailand and Australia, chamber officials said.

Unlike Sri Lanka, which is wracked in import controls, Thailand is in East Asia, where export industries are based on global supply chains and free trade.

Sri Lanka exported around 782 million dollars of coconut products up to November 2024 of coir fibre pith, activated carbon, coconut milk cream, power and desiccated coconut and the full year estimate was 850 million dollars, the chamber said.

It is up from around 708 million dollars in 2023.

Fertilizer Crisis

Sri Lanka's coconut crisis is mainly the result of not fertilizing farms over the past five years, the Chamber said.

Fertilizer prices shot up over the past few year on top of import controls.

Sri Lanka's central bank went on an aggressive rate cutting (stimulus or accommodative monetary policy) drive from 2020 triggering forex shortages while the government at the time also banned chemical fertilizer to save foreign exchange.

The US Fed also printed money and triggered a commodity bubble further pushing up prices, especially up to 2022, but since it started to tighten policy, some easing of commodity prices is seen.

Before the stimulus crisis, a 50 kilo bag of coconut fertilizer cost only 1,500 rupees.

But now a 50 kilogram bag of coconut fertilizer costs 8,000 to 9,000 rupees compared to 1,500 rupees earlier.

At one time the cost of fertilizer was as much 12,000 rupees a bag, which made it too expensive for most coconut farmers, they said.

Related
Sri Lanka coconut auction postponed for second week due to lack of nuts.

Sri Lanka to grow 40,000 acres of coconut in the North.

The chamber is seeking state subsidies to give fertilizer to small farmers in particular at 4,000 rupees a bag.

Fertilizing could push yields per tree from around 56 to 86 within a year, the chamber said.

The long term solution was to expand the cultivation of coconut into new areas. *(Economy Next)*

COCONUT'S REMOVAL IN USFDA MAJOR FOOD ALLERGEN LIST TO BOOST PHILIPPINES EXPORT

The country's coconut industry got a big boost after the coconut was removed by the United States Food and Drug Administration (USFDA) from the list of major food allergens, a trade official said.

"The delisting of coconut as a major food allergen can boost demand for these products and encourage more producers and consumers to support coconut-based/containing products. This, in turn, will benefit our coconut farmers and exporters," Department of Trade and Industry (DTI) - Export Marketing Bureau Director Bianca Pearl Sykimte said in a statement.

The DTI said the delisting would waive the requirement for coconut products, particularly coconut-containing packaged foods and supplements, to secure special allergen labeling under the US Food Allergen Labeling and Consumer Protection Act of 2004 (FALCPA).

This may cover an increased demand for coconut-based products such as refined and virgin coconut oil, coconut milk, desiccated coconut, coconut water, and coconut sugar, among others, it said.

Sykimte lauded the combined and continuous efforts of the DTI and the Department of Agriculture (DA), the Philippine Coconut Authority (PCA), and the private stakeholders in addressing the industry's challenges.

"This progress underscores our commitment to support the development and growth of our coconut sector by addressing key market access and regulatory issues," she said.

Citing Mintel's global new product database from 2018 to 2023, the DTI official said over 20,000 coconut product variants are being used in the US as ingredients for food, drinks, and personal care products.

Meanwhile, coconut stakeholders welcomed the development and underscored the need for science-based information in global policymaking.

"It is a welcome development and great news for the coconut industry, not only in the Philippines but globally. The issue on food allergens has been running for decades. Finally removing coconut as a tree nut eliminates one issue against it. This is the result of a joint private-government sector effort," United Coconut Associations of the Philippines (UCAP) Executive Director Yvonne Agustin said.

Peter Paul Philippine Corporation Sales, Marketing and Export Vice President Dr. Rhoey Lee Dakis said the USFDA decision provides much-needed clarity for consumers, manufacturers, and the broader industry.

"It ensures that coconut products are no longer subject to unnecessary allergen labeling or misconceptions… We believe this progress will further strengthen the global coconut industry by removing barriers and offering consumers accurate, reliable information," Dakis said.

To date, coconut products remain the country's top export, amounting to USD524.92 million from January to October 2024, according to the Philippine Statistics Authority. *(Philippine News Agency)*

DESICCATED COCONUTS: MARKET REMAINS EXTREMELY VOLATILE

Stable exports in 2024

The experts at T.M. Duché ventured an outlook for the coconut market in 2025 at the beginning of the year. Market players at all stages of the value chain are likely to be confronted with various hurdles, including lower production volumes, a corresponding shortage of raw materials and geopolitical tensions.

Philippine desiccated coconut exports proved to be very resilient in 2024 and were 3.8% higher in the January-November period than in the same period of the previous year. Most producers were able to increase their exports, especially in the second half of the year, but then there was a big bang when a major producer in the Philippines shut down its largest production facility. It is currently uncertain whether and when this will be put back into operation in 2025.

Rains give hope

Exports of high-quality coconuts had already fallen in June, and buyers in Europe and the Middle East in particular are feeling the effects of this shortage and are desperate to find the right goods. T.M. Duché also reports that the situation in the USA is a little more relaxed and there are still some coconut stocks here, so the supply chain is much more stable. However, if the decline in exports from the Philippines continues, this could also change soon. Last year's drought significantly affected production and the quality of coconuts; however, current rainfall gives market players hope that this problem will be less pronounced in 2025.

Transportation costs could rise

According to the market experts, high competitive pressure and scarce supplies worldwide are likely to lead to unavoidable price increases, especially as demand continues to rise. Transportation costs could also rise, partly due to global economic uncertainties and partly due to the fact that detours still have to be made around the Red Sea. There are also other unpredictable factors such as inflation, longer transit times, customs changes (e.g. on the part of the USA), etc. In summary, the coconut market will continue to be extremely volatile in 2025 and it will be difficult for all market players to plan for the long term. *(Mundus Agri)*

TETRA PAK UNVEILS UHT TECHNOLOGY TO TRANSFORM COCONUT PRODUCT PROCESSING

Tetra Pak has announced the introduction of its Direct Ultra-High Temperature (UHT) technology, designed to revolutionize the processing and packaging of coconut products. This technology aims to preserve the natural flavor and nutritional value of coconut water, addressing the increasing global demand for coconut-based beverages.

In recent years, products such as fresh coconut water, coconut milk, and coconut cream have gained popularity worldwide, valued for their low cholesterol and calorie content, as well as essential nutrients. According to the Vietnam Coconut Association, eight of the top ten coconut-producing countries are in the Asia Pacific, with Vietnam ranking fourth in export value.

Processing coconuts poses challenges due to their perishable nature. Once opened, coconut water quickly loses its nutrients and flavor because of natural enzymatic activity. Rapid processing is essential to minimize food waste. Tetra Pak's UHT technology addresses these challenges by using high heat for a brief period to eliminate harmful microorganisms, followed by rapid cooling. This process can extend the shelf life of coconut products up to 12 months without requiring preservatives or refrigeration.

During the recent Coconext 2024 conference, Tetra Pak showcased its innovative solutions aimed at improving the quality and competitiveness of Vietnamese coconut products. Key benefits of Tetra Pak's Direct UHT technology include:

Customizability: The technology can adapt to various coconut products, including coconut water and coconut milk.

Nutrient Preservation: It maintains essential nutrients and natural flavors.

Enhanced Efficiency: The system reduces energy consumption and minimizes by-products.

Integrated Monitoring Systems: These provide comprehensive control over production processes.

Tetra PlantMaster and support for coconut producers

Additionally, Tetra Pak introduced the Tetra PlantMaster, an automation solution designed to optimize food production from raw material intake to final packaging. This intuitive system aims to help businesses streamline operations and reduce costs.

Ngo Thanh, Processing Director at Tetra Pak Vietnam, emphasized the company's commitment to sustainable processing solutions. Tetra Pak aims to support clients in optimizing operational costs, maintaining product quality, and ensuring traceability throughout the production process.

To further assist Vietnamese food and beverage companies, Tetra Pak invests in technologies that facilitate the development of innovative coconut-based products. The Bloom Centre in Binh Duong exemplifies this commitment by aiding companies in creating products that cater to diverse consumer needs. *(ScandAsia)*

THAI COCONUT TO INVEST P734M IN MINDANAO

Thai Coconut is set to establish its first international manufacturing plant in Mindanao with an investment of P734 million (430 million baht).

The Thai publicly listed company will build its coconut milk production facility at the Anflo Industrial Estate (AIE) in Panabo City. The 63-hectare AIE is a Philippine Economic Zone Authority (PEZA)-accredited industrial park.

The investment was formalized on February 11 at the AIE, with Thai Coconut CEO Dr. Worawat Chinpinkyo and Damosa Land Inc. president Ricardo Lagdameo leading the signing.

The facility, expected to begin operations by early next year, will boost Thai Coconut's capacity by over 60% to meet increasing demand from the US and Europe. The investment aligns with the company's board-approved strategy last January 27 to expand its coconut product line and strengthen global competitiveness.

The project will raise the company's yearly maximum production of coconut milk from 99,000 tons to 155,000 tons. The facility will first concentrate on producing canned coconut milk before branching out into other packaging types.

"Additionally, this venture presents new business opportunities by providing access to lower-cost coconut raw materials and leveraging special economic zone benefits in the Philippines. These advantages will reduce raw material costs, improve logistics efficiency, strengthen the company's supply chain, and enhance its global market competitiveness," Worawat said.

The company will establish a new Philippine subsidiary, Novococonut Inc., which has secured a 25-year land lease at AIE to construct a state-of-the-art factory for coconut milk production and export. The construction and machinery installation are expected to be completed by the first quarter of 2026.

AIE is near Davao International Container Terminal, ensuring efficient transport of raw materials and exports. The terminal offers infrastructure tailored for industrial-scale operations, including modern utilities such as electricity, water supply, wastewater treatment, and warehousing facilities.

The site is near coconut resources, leveraging the Philippines' status as one of the world's largest coconut producers. The surrounding areas of AIE are recognized for high-quality coconut cultivation, ensuring a steady and direct supply of fresh raw materials to support Thai Coconut's manufacturing and export operations.

Thai Coconut is also set to benefit from the ASEAN Free Trade Area agreements and PEZA incentives, including import tax exemptions on equipment and reduced corporate income tax rates. Additionally, the factory will export coconut water back to Thailand, further expanding its domestic and international markets.

Mindanao Development Authority chair Secretary Leo Magno, represented by Assistant Secretary Romeo Montenegro, welcomed the investment, citing its economic impact on Mindanao's coconut sector.

"This strategic investment is a major boost to Mindanao's coconut industry, adding significant value, creating local employment opportunities, and reinforcing our region's role in the global coconut supply chain," Magno said. *(PortCalls)*

Statistics

Table 1. WORLD Exports of Coconut Oil, 2019-2025 (MT)

COUNTRY	2019	2020	2021	2022	2023	2024	2025F
A. ICC Countries	**2,045,944**	**1,684,594**	**1,727,806**	**2,170,165**	**2,052,885**	**2,521,428**	**2,255,359**
Côte d'Ivoire	11,028	12,539	2,843	4,023	3,344	3,010	3,459
F. S. Micronesia	-	-	-	-	-	-	-
Fiji	2,487	2,533	1,460	1,210	1,948	1,540	1,566
India	7,828	11,096	14,445	28,320	16,201	19,118	17,958
Indonesia	610,812	577,645	611,452	685,797	722,517	656,079	654,980
Jamaica	6	9	16	29	2	2	16
Kenya	44	55	665	215	74	222	170
Kiribati	3,561	2,517	1,829	1,528	1,116	205	950
Malaysia	223,078	203,362	186,606	134,875	165,980	121,109	139,401
Marshall Islands	1,085	1,115	402	709	-	753	731
Papua New Guinea	20,975	17,732	10,099	30,184	34,637	37,450	34,090
Philippines	1,146,642	842,533	881,085	1,252,054	1,099,845	1,642,778	1,377,701
Samoa	424	8	115	100	12	76	63
Solomon Islands	4,561	5,272	5,225	4,554	5,974	4,472	4,934
Sri Lanka	4,056	5,180	3,825	4,712	5,518	6,973	6,229
Tonga	-	-	-	-	-	-	-
Thailand	1,337	1,745	1,686	740	836	677	751
Vanuatu	3,498	1,367	711	428	317	167	304
Vietnam	16,527	15,641	10,275	10,311	7,558	14,272	12,057
B. Other Countries	**306,343**	**326,671**	**343,085**	**343,737**	**407,668**	**92,099**	**120,641**
TOTAL	**2,364,387**	**2,029,045**	**2,095,166**	**2,504,621**	**2,406,930**	**2,601,002**	**2,376,000**

F: Forcasted figures; Source: ICC, ITC and Oil World

Table 2. Prices of Coconut Products and Selected Vegetable Oils, May 2024 – Apr 2025 (US$/MT)

Products	2024								2025			
	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Copra	647	632	680	780	838	859	928	1,060	1,141	1,172	1,350	1,631
Coconut Oil	1,396	1,400	1,473	1,610	1,740	1,718	1,836	1,953	1,976	2,051	2,316	2,587
Copra Meal[2]	154	135	116	94	87	135	183	230	217	183	152	157
Desiccated Coconut[2]	1,911	2,006	2,012	2,124	2,131	2,131	2,190	2,296	2,315	2,462	3,101	3,711
Mattress Fiber[1]	65	57	64	68	63	73	72	71	67	78	102	107
Shell Charcoal[3]	367	363	462	515	557	579	620	622	616	660	729	768
Palm Kernel Oil	1,196	1,156	1,365	1,480	1,515	1,636	2,015	2,099	1,962	1,947	2,064	2,090
Palm Oil	859	874	896	933	983	1,077	1,169	1,190	1,070	1,067	1,068	994
Soybean Oil	988	1,011	1,079	1,031	1,044	1,095	1,145	1,064	1,048	1,069	1,011	1,120

1: Sri Lanka (FOB); 2: Philippines (FOB); 3: Indonesia; r: revised; Source: ICC and Oil World

Table 3. World Oil Balance 2022-2024 (million tons)

Oil/Year	Oct-Sept 24/25[F]	Oct-Sept 23/24	Oct-Sept 22/23
Palm Oil			
Opening Stocks	13.50	14.91	14.65
Production	83.08	80.80	81.68
Imports	50.45	49.09	53.30
Exports	50.26	49.27	53.56
Disappear	83.70	82.04	81.16
Ending Stocks	13.06	13.50	14.91
Soybean Oil			
Opening Stocks	6.74	6.56	6.34
Production	65.99	62.90	59.43
Imports	12.73	12.01	12.00
Exports	12.66	12.19	11.97
Disappear	66.01	62.54	59.25
Ending Stocks	6.80	6.74	6.56
Groundnut Oil			
Opening Stocks	0.22	0.24	0.28
Production	4.59	4.49	4.41
Imports	0.39	0.36	0.40
Exports	0.38	0.38	0.39
Disappear	4.62	4.43	4.53
Ending Stocks	0.25	0.22	0.24
Sunflower Oil			
Opening Stocks	4.40	4.61	3.50
Production	21.20	23.58	22.07
Imports	13.81	15.83	14.19
Exports	13.68	15.99	13.92
Disappear	22.46	23.63	21.23
Ending Stocks	3.27	4.40	4.61
Rapeseed Oil			
Opening Stocks	4.23	3.89	2.92
Production	30.56	31.84	30.30
Imports	7.19	7.47	7.02
Exports	7.28	7.39	7.09
Disappear	30.88	31.58	29.27
Ending Stocks	3.82	4.23	3.89
Cotton Oil			
Opening Stocks	0.28	0.30	0.29
Production	4.59	4.49	4.41
Imports	0.12	0.11	0.12
Exports	0.13	0.11	0.12
Disappear	4.59	4.51	4.40
Ending Stocks	0.28	0.28	0.30

Oil/Year	Oct-Sept 24/25[F]	Oct-Sept 23/24	Oct-Sept 22/23
Palm Kernel Oil			
Opening Stocks	1.35	1.45	1.36
Production	8.53	8.39	8.37
Imports	3.34	3.26	3.30
Exports	3.33	3.33	3.31
Disappear	8.55	8.42	8.26
Ending Stocks	1.34	1.35	1.45
Coconut Oil			
Opening Stocks	0.63	0.50	0.46
Production	2.98	3.29	3.16
Imports	2.06	2.35	2.21
Exports	2.03	2.42	2.23
Disappear	3.14	3.09	3.09
Ending Stocks	0.50	0.63	0.50

Source: ICC and Oil World *F: forecast figures*

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