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Coconut Biotechnology: Towards the Sustainability of the 'Tree of Life'

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Preface

Coconut is often referred to as the ‘tree of life’. Primarily grown on 12 million hectares across more than 90 tropical and subtropical countries, coconut is one of the world’s most highly valued palm crops. This species contributes directly to the amenity and income for 20 million smallholder farmers and their dependents, providing food, health benefits, structural products as well as aesthetic beauty to the landscape. Apart from coconut water and sugar, beneficial effects of various oil products have been increasingly acknowledged worldwide by users, becoming one of the most attractive functional foods in recent years.

The present volume has 12 chapters contributed by academics and researchers from numerous countries including Australia, France, Vietnam, Mexico, Indonesia, the Philippines, Iran, China, Britain, Sri Lanka, Canada and Papua New Guinea. The volume covers most of the recent developments in coconut biotechnology, starting from the latest methods used for the identification of genetic diversity, pests and disease-causing agents to several applications for conservation and safe movement of germplasm, clonal propagation, improving the value of food products and promoting sustainable livelihoods.

The editors of this book express their deep gratitude to all the chapter contributors for sharing their work in this volume. We are also thankful to Springer Nature for giving us a chance to compile this important book. We hope that the contents presented in this book will be useful to the readers involved in coconut research and for all those interested in this amazing plant.

St Lucia, QLD, Australia Steve Adkins

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About the Editors

Steve Adkins Professor Steve Adkins is Professor of Plant Physiology at The University of Queensland (UQ). He obtained a degree in Botany and Zoology from the University of London and a PhD in Weed Physiology from the University of Reading in England in 1981 and has served as a postdoctoral fellow at the University of Saskatchewan, Saskatoon, in Canada (1981–84) and at Murdoch University, Perth, Australia (1984–88). Professor Adkins joined UQ in 1988 and has spent the last 30 years studying various tropical and subtropical crops and pastures, their weeds and the native plant community. He has held several leadership roles at UQ since 2010, including Deputy Director and Acting Director in the UQ Centre for Plant Architectural Informatics. In these roles, he has led initiatives that have improved teaching quality and the student experience, instituted guidelines and funding schemes for supporting the career development of RHD students and ECRs, and established several new cross-cutting research networks in collaboration with key external partners. Professor Adkins has served as Treasurer and for two terms as the President of the Asian-Pacific Weed Science Society. His research focus is tropical plants, especially coconut, and conservation using ex situ seed banking and tissue culture. He has been a principle investigator and scientific advisor on more than 50 scientific projects worth more than $12 million. Professor Adkins has published more than 180 peer-reviewed papers in international journals, including *Proceedings of the National Academy of Sciences*, and supervised more than 50 higher degree research and 40 honours students to completion.

Mike Foale Mike Foale conducted 10 years of agronomic research into coconut production in the Solomon Island, commencing in 1959, as the agronomist of the Joint Coconut Research Scheme shared by Levers Plantations (Unilever) and the Solomon Island's government. The successful Maren hybrid was released in the 1970s. Mike was also a Coconut Consultant to ACIAR from 1983 until 1992, and later joined the University of Queensland as a Senior Research Fellow specialising in coconut research. His publications include The Coconut Odyssey – ACIAR 2003.

Roland Bourdeix Holding a bachelor's degree in biological sciences, Dr. Bourdeix continued his studies at the University of Paris Sud Orsay up to the master's level in the field of Genetics and Plant Breeding. He was then recruited by the French Agricultural Research Centre for International Development (CIRAD). Dr. Bourdeix was the first French student at CIRAD to conduct a doctoral dissertation (PhD) being based permanently in a southern country, Côte d'Ivoire, West Africa. Until 2000, he continued to work in this African country, in the Department of Genetics of the Coconut Research Station 'Marc Delorme' from CNRA (National Agricultural Research Centre of Côte d'Ivoire). Since the 1990s, he conducted training activities at the University of Cocody. Dr. Bourdeix also led a number of projects and expert missions in more than 30 countries in the tropics, especially on behalf of Bioversity International and the COGENT (the International Network for Coconut Genetic Resources), which brings together 41 coconut-producing countries. The themes of his research have gradually evolved from genetics to a multidisciplinary approach, integrating ethnology and multifunctional landscape management; to understand the diversity of crops, one needs to look not only for plants but also the people who cultivate them and their cultural specificities. From 2000 to 2014, Dr. Bourdeix worked on behalf the Coconut Research Programme of CIRAD and the research Unit 'Bio cultural interactions' of CEFE (Centre for Evolutionary and Functional Ecology). In 2014, he joined the Research Unit AGAP (Genetic Improvement of Mediterranean and Tropical Plants) and its Scientific Team DDSE (Dynamics of diversity, societies and environments).

Quang Nguyen Dr. Quang Nguyen is currently an academic in the School of Biotechnology, International University of Vietnam National University, Ho Chi Minh City. Dr. Nguyen has been part of international research projects regarding coconut mass propagation and improvement. He obtained a PhD from the University of Queensland in clonal propagation of elite coconut varieties. Dr. Nguyen has been fully committed to the sustainable development of the 'Tree of Life'. His research has been published in recognised plant-related research journals, including *Planta*, *Plant Physiology and Biochemistry* and others. Dr. Nguyen has delivered talks at multiple international conferences and provided technical training for needful countries over the past few years. His present endeavour is focussed on improving plant tissue culture techniques that enable large-scale and affordable production of coconut planting materials, as well as strategic conservation of elite germplasms.

Julianne Biddle Dr. Julianne Biddle grew up on a cattle farm in Central Queensland, Australia, and has experience working in science, agriculture, science communication and project management. Dr. Biddle is a Doctor of Philosophy in Ecology, Evolution and Genetics from the Australian National University (ANU), Honours in Biochemistry and Molecular Biology and a Bachelor of Science in Advanced Studies, Biochemistry and Molecular Biology, Cell Biology and Biological Sciences. Dr. Biddle's most recent research at the University of Queensland has focussed on coconut biotechnology and demand-led plant breeding in Africa. Dr. Biddle is newly appointed to the role of Director Multilateral Engagement, Research Strategy, at the Australian Centre for International Agricultural Research (ACIAR) and is also the Alternate Member from Australia on the CGIAR System Council.

Chapter 1
Towards the Sustainability of the "Tree of Life": An Introduction

Uron Salum, Mike Foale, Julianne Biddle, Amirhossein Bazrafshan, and Steve Adkins

1.1 Introduction

This book on the potential role of biotechnology in preventing a disastrous decline in the production of edible products of the coconut has been produced at a critical moment to show how this decline might be arrested. This first chapter provides detailed information on the very large human population immersed in coconut production, their productivity and income, and the place of coconut in national economies and trade, serving to build the case that the coconut industry needs urgent support. The anticipated deeply negative impact on almost 100 million producers and workers in the industry adds great urgency to the task of developing the affordable means to regenerate the coconut resource and stabilize the economic and social future for all involved.

1.1.1 Background

Cocos nucifera L., the coconut, is justifiably referred to as the *tree of life*, especially in the Asian and Pacific Regions. It is a unique palm that inhabits coastal and nearby land areas across most of the tropics. Nearly all parts of the palm, from the crown to the roots, serve the human economy. Its contribution to both the food and non-food chains has a significant impact on the socio-economic welfare of large rural populations in the tropical world which depend on it. Coconut is grown in over 90 countries, but only about 50 countries

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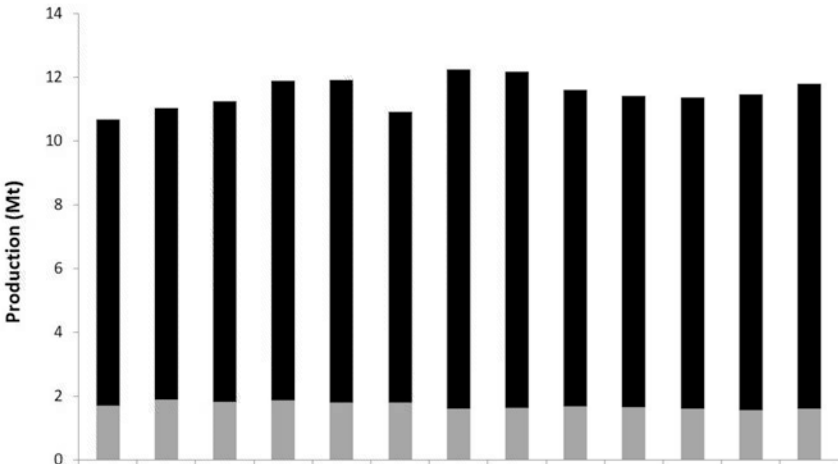
to date utilize it commercially for income generation apart from known traditional and household uses. While a significant volume is consumed domestically, the exported products and by-products reach consumers in over 110 importing countries (International Coconut Community 2019). Coconut farms are mostly village-based smallholder in nature and operation, occupying a land area measuring less than 1 ha in most instances. Country statistics indicate that over 95% of the global coconut palm population is owned by smallholder farmers (International Coconut Community 2010–2018).

1.2 Current Status of Coconut Production

The global annual coconut production in 2017 was 11.82 million t, and 2018 volumes were expected to be 12.13 million t, in copra equivalent terms. The 18 member countries of the International Coconut Community (ICC) contributed over 87% of this global production, with 10.27 million t in 2017 (International Coconut Community 2010–2018). Production has not fluctuated much in the last decade (Fig. 1.1). Besides the devastating effects of extreme climatic events, and damage by pests and diseases, the production levels shown are largely considered to be the outcome of very little or no replanting in most countries. Current records indicate an alarming increase in the proportion of senile palms, reaching between 50% and 70% in most countries.

The slight increase recorded from 2017 is attributed largely to favourable weather conditions enabling crop recovery from prior years of prolonged drought. The successful recovery effort in the Philippines after the 2013 Typhoon Haiyan devastation is notable, as production has been revitalized through the National Coconut Productivity Program (United Coconut Association of the Philippines 2019).



	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
ICC Countries	8.97	9.14	9.44	10.01	10.11	9.12	10.65	10.54	9.94	9.76	9.76	9.90	10.2
Other Countries	1.7	1.89	1.81	1.87	1.8	1.8	1.6	1.63	1.67	1.65	1.59	1.55	1.6

Fig. 1.1 The global production of coconut from 2006 to 2017 (million t in copra equivalent terms) (International Coconut Community 2010–2018)

Country statistics show that Indonesia has the largest area under coconut at 3.6 million ha, followed by the Philippines and India with 3.0 and 2.0 million ha, respectively (Table 1.1). Productivity ranking shows India highest at an average of 10,000 nuts ha^{-1} $year^{-1}$ against the rest of the Community at an average of 4500 nuts ha^{-1} $year^{-1}$.

Higher productivity in India, Malaysia, Vietnam, and Sri Lanka is a direct result of increased replanting with high-yielding varieties, better crop management practices, and adoption of viable coconut-based farming systems (Ramanandam et al. 2018). This is an indication of the scope for an increase in productivity through improvements in varietal selection, crop husbandry, and farm management.

Copra and coconut oil are the major products traded in the global market, providing an important source of vegetable oil with both edible uses and industrial applications (International Coconut Community 2019).

Table 1.1 The production status of the International Coconut Community member countries listed alphabetically by country name

Country	Estimated households (growers)	Planted area (ha '000)	Estimate nut production ('000,000)	Nuts ha^{-1} (average)	Estimated number of palms ('000)	Estimated number of senile palms (ca. 50%)
Federated States of Micronesia	18,000	18	60	2197	2160	1,080,000
Fiji	120,000	64	159	2387	7440	3,720,000
India	12,000,000	2141	23,904	10,119	256,920	128,460,000
Indonesia	5,900,000	3610	14,356	4530	433,200	216,600,000
Jamaica	10,000	16	100	6156	1920	960,000
Kenya	90,000	177	254	1462	21,240	10,620,000
Kiribati	20,000	20	198	2730	2400	1,200,000
Malaysia	200,000	88	505	7464	10,560	5,280,000
Marshall Islands	15,000	8	38	4375	960	480,000
Papua New Guinea	300,000	221	1483	6710	26,520	13,260,000
Philippines	3,500,000	3502	13,825	4196	420,240	210,120,000
Samoa	40,000	99	267	2697	11,880	5,940,000
Solomon Islands	50,000	38	100	2631	4560	2,280,000
Sri Lanka	50,000	440	3011	6623	52,800	26,400,000
Thailand	290,000	206	686	4859	24,720	12,360,000
Tonga	25,000	31	72	2423	3720	1,860,000
Vanuatu	50,000	92	699	4512	11,040	5,520,000
Vietnam	60,000	159	1471	7834	19,080	9,540,000
Total	22,738,000	10,928	61,90	4661	1,311,360	655,680,000

A palm density of 120 ha^{-1} is used to estimate the number of palms per country (International Coconut Community 2010/18)

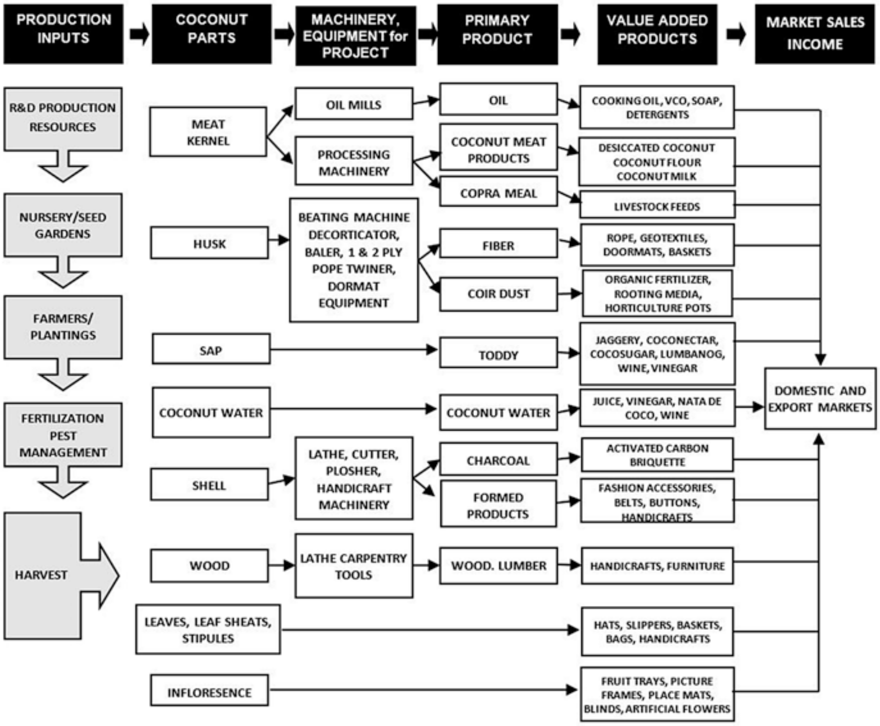


Fig. 1.2 A flow chart depicting an overview of the coconut production value chain present in most coconut-growing countries

The prices of the fresh nut and its products are largely dependent on the price of coconut oil, which is in turn affected by the price of other competing vegetable oils. Coconut is not only a source of oil but also a source of diverse food items, a beverage, a food supplement, a dairy alternative, an alternate sugar, and much more. It is the buoyant market for these diverse products that makes an ideal crop to ensure the sustainable income of farmers in this era of climate uncertainty and an increased focus on food security and poverty reduction. The range of diversified products from coconut is demonstrated in the supply value chain (Fig. 1.2).

A high volume of copra production in most countries, purchased by copra mills, is processed into crude coconut oil (CNO) and shipped to be refined, bleached, and deodorised, for distribution to consumer markets. Over 50% of CNO is utilized by the oleochemical industry to produce cleaning agents (soaps, detergents, surfactants) and more recently for the production of biofuel in some countries (International Coconut Community 2010–2018).

Statistics indicate an increasing demand for desiccated coconut (DC) and virgin coconut oil (VCO) over the last decade (Fig. 1.3). The production volume of DC, presented alongside copra and coconut oil, is an indication of the shift to higher value products that would, in the long term, reduce the production of coconut oil.

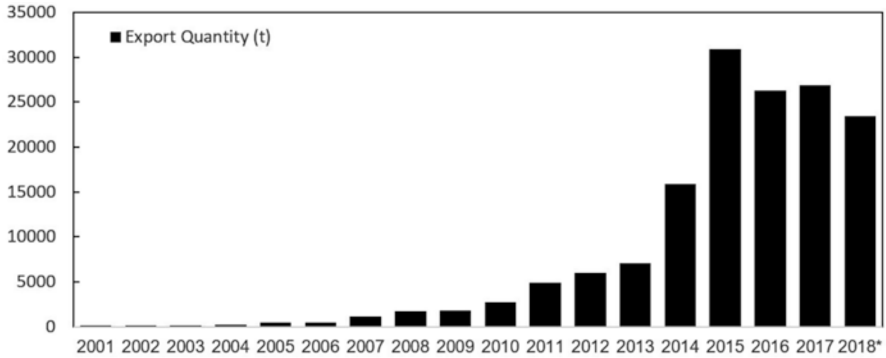


Fig. 1.3 The total Philippine export volumes of virgin coconut oil (million t) from 2001 to 2017

Income increases as producers switch to production of VCO, which has the fastest growing market among all coconut products, because of increased awareness and experience of its health benefits related to its high levels of antioxidants and medium-chain triglycerides (MCT). Such high value niche markets offer good prospects to improve the income level for the farmer. The growth in the Philippines' export of VCO has occurred in the past 15 years with an exponential growth factor of 5 between 2011 and 2015 (Fig. 1.3).

The coconut water market has expanded rapidly, because of growing health consciousness globally. It has achieved the status of a healthy natural drink through its own merit and strong marketing. Exports from the Philippines increased from a mere 647,000 L in 2008 to 1.8 million L in 2010 and then soared up to 85 million L in 2017. The total export value of coconut water in 2017 was US$ 91.3 M. The export price of coconut water also showed an increasing trend from US$ 0.80 L^{-1} in 2008 to 1.03 L^{-1} in 2012, then reaching a plateau slightly higher at 1.07 L^{-1} in 2017. Brazil is the major exporter of coconut water in the world market, while the Philippines, Thailand, Indonesia, Sri Lanka, India, Vietnam, and Malaysia also export significant volumes (International Coconut Community 2010–2018).

The Philippines' export destinations for coconut water in 2017 included the USA (Fig. 1.4), the UK, Canada, Australia, the Netherlands, Singapore, China, Hong Kong, and the United Arab Emirates. The USA was the Philippines' biggest market, which accounted for more than 45.7 million L or 53.5% of the total exported, followed by the UK and the Netherlands which absorbed 16.8% and 5.3%, respectively, of total export volume.

Supply to the global market of coconut sap sugar is dominated by Indonesia (Fig. 1.5), Thailand, and the Philippines. There is an increasing demand for coconut sugar as an alternative sweetener, both in domestic and international markets, as it has a Glycaemic Index (GI) of less than 35, compared to pure sucrose at 100. This is beneficial for people who suffer from diabetes, indicating that there is a robust domestic and export market potential for coconut sugar. A great advantage of coconut sugar production is that it can be undertaken by village or small- to medium-scale enterprises, including cooperatives involving women. Indonesia currently has

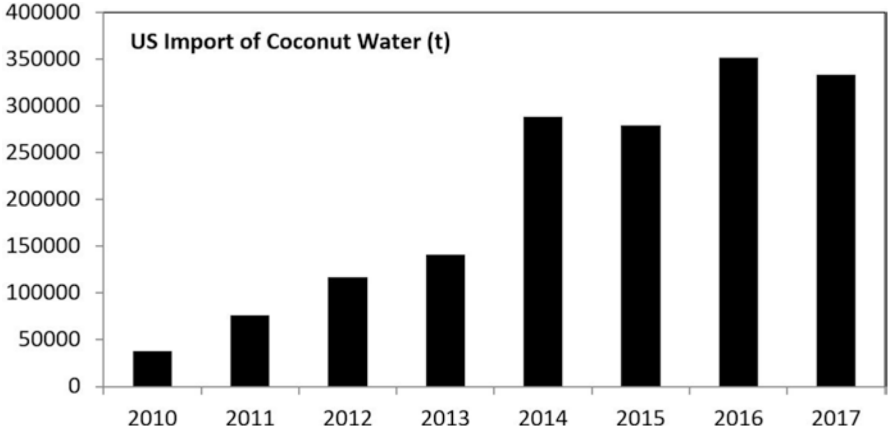


Fig. 1.4 The total volume of coconut water imported by the USA (million L) per year from 2010 to 2017 (International Coconut Community 2010–2018)

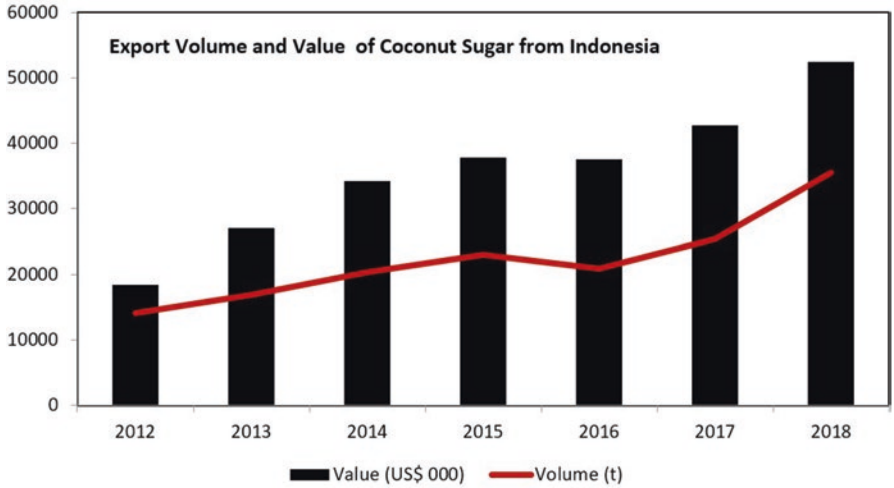


Fig. 1.5 The total export volume in t (line graph) and value in US$ (bar graph) of coconut sugar from Indonesia per year from 2012 to 2018 (International Coconut Community 2010–2018; BPS Statistics 2019)

well over 100,000 farmer households that rely on coconut sugar for their primary income (BPS Statistics 2019). Over 120,000 t of coconut sugar is produced each year with over 80% of production consumed domestically. Naturally any increase in the harvest of coconut sap for sugar further reduces the potential for nut production by the palm while tapping continues.

Competition is increasing for raw material to meet the demand for the fast-emerging, high-value products of coconut. Over 10 billion fresh mature coconuts are exported to external factories from Indonesia each year (BPS Statistics 2019).

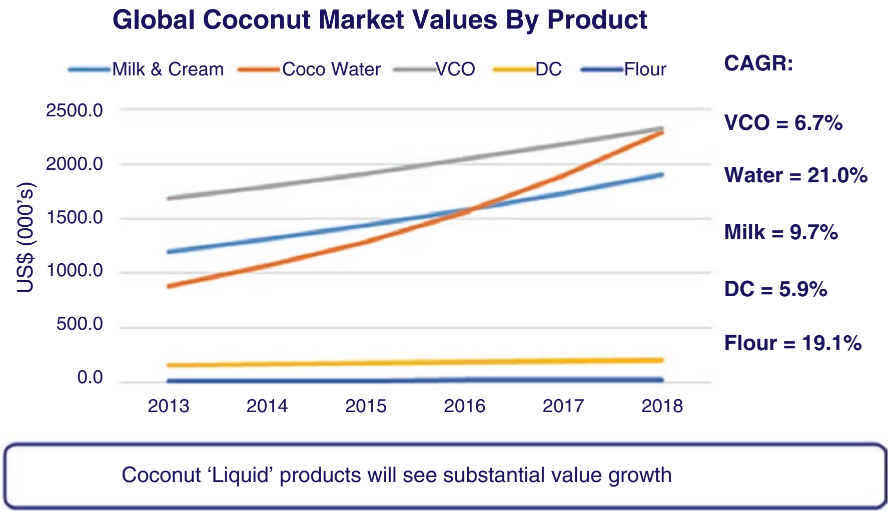


Fig. 1.6 A line graph of the total individual market values in US$ for high-value coconut products in the Philippines over time between 2013 and 2018 (Franklin Baker 2019)

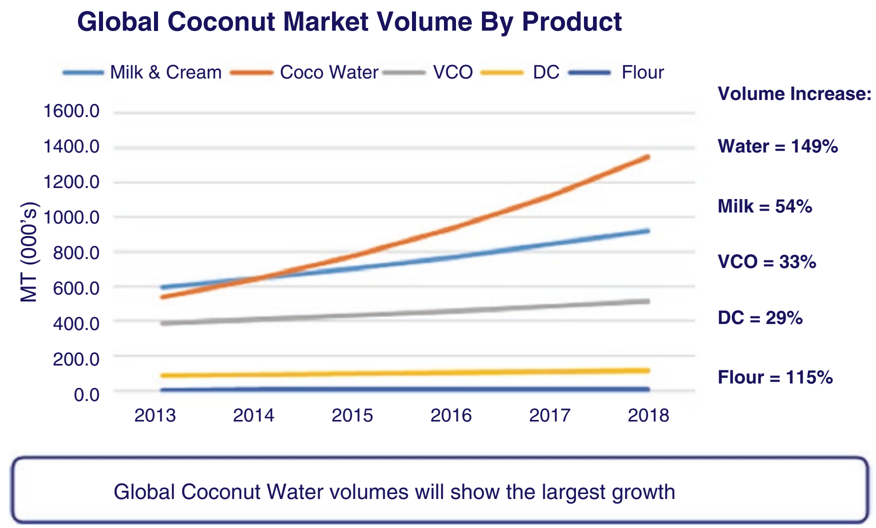


Fig. 1.7 A line graph of the total individual market volume in million t for high-value coconut products in the Philippines over time between 2013 and 2018 (Franklin Baker 2019)

This is to the detriment of local processors who, reportedly, operate at as little as 50% capacity as a result. The trend in market value in the Philippines, across a 5-year period for water, milk, VCO, DC, and flour, shows the three “liquid” products to be undergoing a substantial growth in value (Fig. 1.6) and production (Fig. 1.7) (Franklin Baker 2019).

1.3 Significance to Income and Livelihoods

Coconut is consumed as a household food in areas that produce or have access to both young and mature fresh fruit. Safe healthy water and kernel from both young and mature fruit is traditionally consumed directly as a nourishing drink and food. Milk extracted from freshly grated coconut, usually from the mature fruit, is commonly used in various forms of cooking for daily household meals. Consumption varies by country and ranges between two to four fruit per day per family. The coconut has contributed to food security, nourishment, health, and overall wellness of millions of people living in the coconut world for millennia.

It is equally important to acknowledge that an estimated 30 million rural households are fully engaged as farmers growing coconuts. An additional 60 million households would be economically dependent on coconut through gainful employment on farms (an average of two families assisting full time as farm labour to each farmer) and at processing factories and involved in marketing activities (including produce transportation) across the globe. The impact of the global market in importing countries could involve consumers numbering up to nearly 500 million households utilizing fresh coconut, coconut oil, and their by-products as food, food supplements, soap and cosmetics, and medical treatment for various physical ailments. The overall impacted population, fully engaged, involved with and active in the coconut value chain is estimated at 700 million people, and at the present rate of increase it could soon impact on the livelihood of over 1 billion of the world's population. Coconut is therefore recognized as a very important crop in the global human economy.

According to World Bank data, 12 members of the International Coconut Community are classified as low- to middle-income countries with minimum of US$ 1005 per year earnings, which is US$ 2.73 day^{-1}, while 6 are in the upper- to middle-income category (World Bank 2019). The global poverty line is defined at an income of US$ 1.90 day^{-1}, and since 2015 about 700 million of the world's population are living in extreme poverty. Many among such poor people are rural village-based farmers, including coconut farmers (Table 1.2).

Table 1.2 New thresholds for country classification by income as of 1 July 2017 (World Bank 2017)

Threshold	Gross national income/capita (US$)	International Coconut Community country classifications
Low-income	< 1,005	Federated States of Micronesia, India, Indonesia, Kenya, Kiribati, Papua New Guinea, the Philippines, Solomon Islands, Sri Lanka, Timor Leste, Vanuatu, and Vietnam
Lower-middle-income	1,006–3,955	
Upper-middle-income	3,956–12,235	Fiji, Malaysia, Marshall Islands, Samoa, Thailand, Tonga,
High-income	> 12,235	None

The income for an Indonesian family, farming 1 ha of coconut and expecting to produce 4500 nuts ha^{-1}, would reach 3,600,000 Indonesian rupiah based on a value of 800 rupiah per nut (BPS Statistics 2019). This converts to US$ 248 $year^{-1}$ or only US$ 0.68 day^{-1}. Therefore, such a family would be already living below the global poverty line of US$ 1.90 day^{-1} potential earnings.

Despite the experience of low market prices, however, millions of families continue in coconut activities as the only source of income to enable the provision of nourishment, shelter, clothing, sanitation, basic education, and primary healthcare. These are the basic needs required to be met in achieving and maintaining an acceptable quality of life.

1.4 Critical Challenges

1.4.1 Loss of Genetic Diversity

The natural spread of the coconut throughout the islands and coastlines of the tropical world of the Indian and Pacific Oceans has, through natural selection, generated populations adapted to the biohazards presented by the local ecosystem (Harries 1978). More details are presented later, describing the tolerances often possessed by coconut populations to co-located microorganisms and insects (Chap. 2).

The objective of preserving pristine genetic diversity is becoming less achievable since the global commercialization of coconut and establishment of plantations based on seeds gathered from diverse sources. There is still a case, however, for protecting populations known to have remained free of genetic mixing while seeking to identify traits that may be unique and valuable. The method of preservation of these genotypes could reside in sustaining the isolation of the source population, while the technique of cryopreservation becomes available as a backup.

1.4.2 The Threats from Pests and Pathogens

Major pests threatening coconut palms at present are coconut rhinoceros beetle (CRB), coconut scale insect (CSI), coconut hispine beetle (CHB), black palm weevil, black-headed caterpillar, and a few others with lower incidences of damage. Among the diseases of most serious concern are the phytoplasma-related ones, such as the lethal yellowing disease (LYD), Weligama disease, Bogia coconut disease, as well as coconut bud rot. Cadang-Cadang in the Philippines appears to be confined geographically by successful quarantine regulation (Hanold and Randles 1991).

The CRB, especially the new Guam biotype, has been devastating some coconut populations in the Pacific especially in the Solomon Islands, Fiji, and Samoa, though it is present in most other countries. The CSI threatened 70% of the Philippines' coconut production at one stage until brought under control to an infestation rate of 25% of the palm population. The outbreak of CHB damage in Southeast Asia also appears to have been constrained by the introduction of a parasite.

The LYD has the potential to destroy many palms if not brought under control. It has been spreading so quickly that it has reached the Caribbean and Latin Americas, the west coast of Africa, and some Asian countries, making it a global threat to the coconut industry. When the strain of coconut bud rot in the country of destination for some germplasm has been found to differ from that of the source country, then in some cases of transferred seed, there have been serious losses (Blaha et al. 1994).

1.4.3 Senility of Existing Palms

Based on annual reports by ICC member countries, 50% of existing coconut palms have reached the senile age of 60 years and are showing a declining level of productivity to as low as 40% compared to younger palms (International Coconut Community 2010–2018). The estimated population of senile palms is over 700 million, which includes the member countries of the ICC (Table 1.1).

According to reports, all countries face the challenge presented by aging palms (International Coconut Community 2018). Without a structured effort in replanting, there will be an inevitable slump in production, especially where there has been no significant planting in the last 20–30 years. Even if serious replanting were to begin immediately, the expected slump in production could last for 10–15 years following such plantings.

1.4.4 Lack of Planting Material

Demand for planting material surpasses the potential supply of good-quality plant material if robust, locally adapted hybrids are sought. Between the existing hybrid coconut seed gardens in the Philippines, India, Indonesia, Sri Lanka, and other countries, the seednut production capacity is up to a mere 7 million seeds annually, equivalent to an annual field planting of just 34,000 ha. Farmers are presently forced to select from their own best palms to begin underplanting, i.e., a young seedling is planted between existing senile palms.

The MATAG hybrid (Malayan Yellow and Red Dwarf × Tagnanan Tall) is one of the most favoured varieties in the Philippines and Malaysia and very often desired by other countries. Regrettably MATAG is in such short supply that in Malaysia seednuts are offered at a selling price between US$ 13 and 15. The Philippine Coconut Authority seed gardens in Zamboanga, Albay, and Davao can only produce up to 1 million seednuts annually, which meets local demand to plant a mere 5,000 ha. Kenya and Malaysia recently took shipments of hybrid seednuts from Deejay Farms in India at a very high cost. Ambekele Seed Garden operated by the Coconut Research Institute in Sri Lanka delivers 500,000 seednuts a year, which is far below the needs of the country. A similar situation exists in the large growing countries of Indonesia, India, Thailand, and all Pacific countries.

For more than 20 years, Côte d'Ivoire has been mass producing two hybrids (Bourdeix et al. 2005). The improved PB121 (Malayan Yellow Dwarf × West African Tall) is one of the most productive hybrids worldwide, although they produce smaller fruits than the MATAG hybrid. The improved PB113 (Cameroon Red Dwarf × Rennell Island Tall) produces large fruits with a very thin husk. Côte d'Ivoire also has the potential to produce MATAG and other hybrids such as Sri Lanka Green Dwarf × Vanuatu Tall, tolerant to lethal yellowing disease in Ghana (Dare et al. 2010).

1.5 Role of Biotechnology Towards Sustainability of Coconut: Past and Present

Biotechnology would have a critical role to enable, scientifically, the reproduction and multiplication of the desired varieties of coconut as well as ensuring that the characteristics of early bearing, high-yield potential and disease resistance are mass produced with the objective of replenishing coconut populations. These techniques will complement the field breeding experiments that are still needed to create and select the best clones and the conventional methods of seednut production by assisted pollination used in field seed gardens (De Nucé De Lamothe and Wuidart 1992).

There are numerous ways in which biotechnology is currently having an impact for the industry, and its uses are expanding rapidly in laboratories around the globe. A timeline (Fig. 1.8) compares the key advances in plant biotechnology with those in coconut biotechnology and shows that coconut research has lagged behind that for other species, although developments are accelerating. This book discusses the work conducted so far, its applications, challenges, and the further work that is required to enable the wide-scale use of the different biotechnologies for industry improvement.

Chapter 3 discusses how biotechnology can be used to improve the value, processing, and utilization of coconut for food products, nutraceuticals, pharmaceuticals, fuels, and other novel materials. Chapter 4 examines how biotechnology is currently utilized for germplasm conservation both in situ and ex situ and how cryopreservation and a multifunctional approach should be applied to improve the conservation of coconut genetic resources. Germplasm collection methods, including molecular identification approaches, are considered in Chap. 5, with a focus on the conservation of pest-/disease-tolerant varieties or varieties with other elite traits. For

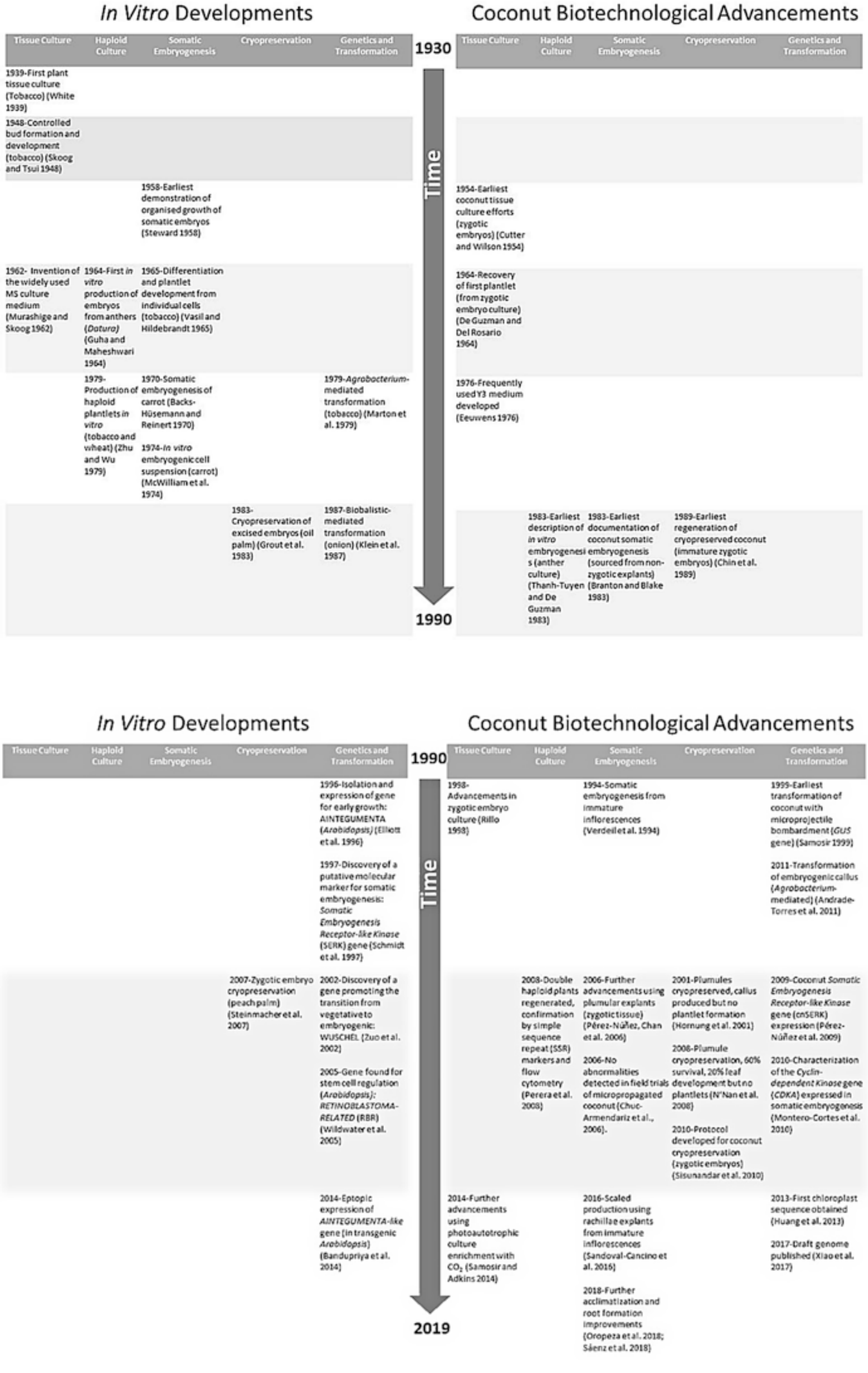


Fig. 1.8 A timeline of key plant in vitro biotechnological advances compared with important coconut biotechnological advances between 1930 and 2019

these efforts, global coordination by the International Coconut Genetic Resources Network (COGENT) is essential to reduce conservation duplication. Chapter 6 examines how since the introduction of molecular markers at the end of the twentieth century there has been a substantial advancement in plant genetics, how the development of specific molecular markers for coconut has been undertaken, and how these can be used for breeding, genetic improvement, and ultimately the conservation of coconut. Although coconut genetics has trailed other important crop species, the growing compendium of research is discussed in Chap. 7: Genome Studies for Effective Management and Utilization of Coconut Genetic Resources.

In many countries, one of the greatest challenges faced by the industry is coconut pests and/or diseases. Chapter 8 considers how current technologies are being utilized for the prevention, diagnosis, control, and treatment of these biotic factors and how future biotechnology research could be applied to improve outcomes for the industry. Chapter 9 further elaborates on this by covering LYD and LY-type diseases. These diseases have had devastating impacts in numerous locations including countries in Africa, Latin America, and the Caribbean. As there is an urgent need to control these diseases, this chapter expands on the successful use of molecular detection techniques for disease diagnosis and molecular markers that are providing promising results for identifying resistant germplasm.

Tissue culture has many applications in coconut, including conservation (germplasm movement, storage, and regeneration), propagation of elite varieties such as Makapuno and Kopyor types with an endosperm that prevents conventional seedling growth (embryo rescue/embryo culture), and cloning for the mass production of plants with desired traits (micropropagation). Chapter 10 covers the foundation coconut tissue culture method: embryo culture including coconut embryo morphology and physiology, culture types, conditions, and applications. Building on this, Chap. 11 reports on coconut micropropagation for worldwide replanting needs. This method holds much hope for the coconut industry as it has the potential to provide true-to-type clones of desired germplasm. Based on the present state of availability and a lack of planting material in most countries, biotechnology applications are needed to enable coconut micropropagation through proven tissue culture techniques. Thousands of containers of tiny plantlets can be transported in a cost-effective manner to planting locations where they undergo acclimatization and transfer into well-managed nurseries. Selected genotypes with desired traits such as high productivity, disease/pest resistance, or resilience to climatic conditions can be propagated on mass to provide valuable planting material for the renewal of coconut plantations.

Finally, Chap. 12 considers using coconut biotechnology for innovative coconut breeding programs. Present strategies (conventional breeding) are contrasted with biotechnological tools which have the potential to overcome biological constraints and poor returns on investment. The chapter discusses how molecular marker technology has been applied to characterize coconut genetic diversity and for marker-assisted selection and the recent sequencing of the coconut genome.

Recent advances in coconut biotechnology can now have a critical role in enabling the multiplication of desired varieties that possess ideal characteristics (early bearing, high-yield potential and disease resistance) with the objective of replenishing large coconut populations. An obvious challenge for the application of biotechnology faced by the industry is a lack of infrastructure in many coconut-growing regions. Due to the nature of the palm, it is often grown in regions where the main barrier is geography. Geography can pose challenges for transport and infrastructure, for example, countries in the Pacific Region where coconut is produced on hundreds of islands. The consensus from most of the chapter authors is that international research collaboration is essential to gain outcomes in coconut biotechnology, to overcome limitations and avoid duplication.

1.6 The Future: How Biotechnology Might Aid the Sustainability of the "Tree of Life"

Whereas the major proportion of coconut production shifted from large-scale plantations to smallholder farmers during the twentieth century, a sustained level of global production is shown by the data presented here in this chapter. Although there has been limited replanting until now, it is the remarkable longevity of the coconut which, despite yield decline, has continued to be productive. However, serious yield decline is now anticipated. The smallholder farmer continues to cling to the almost senile resource due in part to uncertainty about the likely resistance of the next generation of palms to possible threats. The farmer also has a wish that it might achieve greater yield.

Biotechnology, as presented in this volume, is on the verge of being able to alleviate many of the farmers' concerns by offering critical control over the genetic suitability of that new generation. The combination of clonal propagation and the identification of critical genetic markers for resistance to threats specific to a region will enable "prescription" plants to be supplied.

An important question will be the affordability of the plantlets obtained by cloning. Presently the international cost of seednuts from the Brazilian Green Dwarf variety, for instance, is about US$ 1.0 plus transportation. Clones remain more expensive to produce and are expected to be sold between US$ 3.0 and 7.0 per plantlet. Hybrid seednuts are generally sold at international level between US$ 4.0 and 12.0 per nut (J.L. Konan, personal communication).

The ICC will assume a major role in persuading governments to support coconut industry authorities locally to enable this anticipated major renewal of national coconut industries. Besides the anticipated need for a subsidy to assist the farmer meet the cost of the superior plantlets, generated by significant investment locally in the biotechnology capability to produce them, attention will also be needed to support the nutritional and other management needs of the new plantations, enabling their potential high yield to be achieved.

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Chapter 2
Biology, Ecology, and Evolution of Coconut

Mike Foale, Julianne Biddle, Amirhossein Bazrafshan, and Steve Adkins

2.1 Botanical Description

Coconut (*Cocos nucifera* L.) is the sole member of the *Cocos* genus within the family Palmae (Child 1964; Nayar 2016). It conforms to the common palm anatomy of a single non-branching stem (trunk) supporting a loose hemispherical crown of fronds, the bases of which form a very compact array at their points of attachment to the trunk. Both male and female flowers are borne in the same inflorescence that arises in the axil of each frond, there being many male flowers on the distil half of the many rachillae and a relatively small number of female flowers located near the inflorescence base.

Fronds emerge at regular intervals throughout the year in an environment where there is no seasonal variation in mean temperature but more slowly during any cooler season or during a marked dry period. The number of fronds, and therefore the number of fruit bunches, varies from around 12, where there are some climatic constraints, to 17 in a particularly favourable environment with a mean monthly temperature of 28 °C and the absence of any significant soil water deficit. The position of each frond is located at 140 degrees, on a horizontal circular plane, from the fronds immediately above and below it, resulting in the fifth frond above or below a reference frond being displaced by just 20 degrees either to the right or to the left of the circle (Foale 2003). The angular sequence of frond location around the trunk in any palm population is divided into half being clockwise and half anticlockwise.

There are two distinct palm types with respect to the timing of the activity of the male and female flowers, general robustness and height. In the case of the most widespread type of palm, known as the Tall, the male flowers open and shed pollen well before the female flowers are receptive to pollen, so that cross-pollination is normal, rendering the palm genetically heterozygous (De Taffin 1998). In rare

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