GROWTH AND PRODUCTION OF COCONUT

Steve Adkins and **Mike Foale**
University of Queensland, Brisbane, Australia

Hugh Harries
Coconut Time Line, Weymouth, England

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Summary

For untold millennia the coconut palm has been the basis of a critical life support system, not only for island and coastal communities in the humid tropics but also for inland areas in countries like India, the Philippines, Indonesia and Thailand. It is arguably the most used plant on earth in terms of number and utility of its products, ranging from the edible kernel and oil, delicious water, sweet sap, and countless derivatives of the fiber, foliage and trunk. The coconut was the foundation of vegetable oil production for importation by developing industrial economies from the 19th century until the mid-twentieth century when many competing crops entered the market for edible oil.

In spite of the loss of its leading role in the fat and non-mineral oil market the production of coconut has continued to expand in the traditional environment of small-holders and subsistence farmers in the tropical world. It has a unique capacity to grow in highly variable soil conditions while being limited to regions of moderate to high rainfall. The undoubted health benefits of coconut oil, which comprises as much as sixty percent of the diet of some islanders, have yet to be fully accepted by consumers and health professionals in temperate countries.

This chapter describes the botany, growing conditions and crop management of the coconut palm and comments on its uses and social benefits now and in the future.

1. Introduction

The coconut palm (*Cocos nucifera*) is a tropical tree species which once was the first major estate crop, extending over large uniform areas, but is now mainly grown and harvested by small farmers. In addition to the production of vegetable oil for industrial uses from cosmetics and explosives to bio-fuels and health and wellness products, it is also a fiber crop, a food and beverage crop, and a visual amenity palm for tourist hotels, golf courses and city parks and village gardens throughout the tropics. From its natural habitat on the shoreline of uninhabited oceanic islands to inland locations on the fringes of deserts and the foothills of mountain ranges, it can provide every necessity for survival of castaways, subsistence consumption, local markets and international trade.

The coconut has provided critical sustenance for countless tropical coast-dwellers over many millennia before becoming, during more than a century, the primary source of vegetable oil in many temperate industrial countries. The remarkable diversity of its products, derived from coconut fruit, i.e. juice, edible kernel, oil, shell, fiber and peaty cortex; plus building material from the frond and trunk; edible "heart-of-palm" from the growing point; sap (toddy) to drink and provide sugar, and fuel from the bunch stalks, all of these provide the rationale for the title “The Tree of Life” respectfully bestowed upon this palm. Industrial uses further include the separation of glycerin and fatty acids, the production of soaps, detergents and bio-diesel, and coco methyl ester (CME) for mixture with regular diesel.

The coconut was probably disseminated naturally throughout the Old World humid tropics, between coasts and islands of the Indian Ocean to those in the mid-Pacific, millions of years before human migrations. Its presence would have made possible the eventual successful settlement of sea-going colonizers on many remote, and at first sight, desolate coral atolls, principally in the Pacific region. Thriving human communities came to rely on coconut for a great deal of their sustenance, combining up to three-quarters of their dietary energy from coconut with an abundance of fish and other aquatic food. Such a simple diet astonished the early European navigators as they explored the coasts of south-east Asia, Melanesia and Polynesia, finding the people to be physically strong and healthy. These sailors avidly collected coconuts to add to their ship-board supply of food and drink.

In the mid 19th century a rapid population increase took place in Europe and North America, hand-in-hand with industrialization and the need for many new goods like candles, soap, margarine, mats and mattresses, explosives, etc. From the 1860s there was a steep decline in the supply of whale oil giving rise to a strong demand for a cheap and readily available alternative. Coconut oil, already an important domestic item in the Far East, had two other advantages in Europe and North America: it became solid below 25º C, and it resembled traditional lard, but as a vegetable oil it did not transmit animal infections. The consequent rise in the price of coconut oil resulted in a wholesale investment in plantations from the 1890s until the 1920s (Foale, 2003).

Coconut oil has for a long time been considered a valuable raw material above any other use, mainly after it was discovered that oil could be separated from copra. Coconut could then be stored and transported as copra, which is produced by drying the kernel, ideally down to 6% moisture for long storage. Laboratory analysis of moisture free copra reveals 65 to 69% oil. Afterwards, coconut oil became very popular as frying oil, shortening, and a substitute for dairy cream and butter in many recipes.

Other edible oils, including soy, canola, cotton-seed and sunflower, and particularly palm oil, all began to compete for market share with coconut oil from the mid-20th century onwards. The ill-informed perception that coconut oil posed an unqualified risk to those vulnerable to heart disease became a mantra effectively disseminated by the marketers of the competing oils, to the detriment of the value of coconut oil. In spite of efforts to breed higher-yielding coconut hybrids the best harvest index for oil achieved in hybrids in the 1990s was 10% (Friend and Corley, 1994) compared to 18% for oil palm. The combination of lower yield potential and reduced price relative to decades earlier, meant that replanting of large aged coconut plantations collapsed. Worldwide, the existing 11 million ha of coconut palms (Table 1) are now primarily in the hands of smallholders.

In spite of the much-reduced income that coconut provides for a given level of effort it is still maintained with very low inputs, and indeed the planted area is expanding in some cases (Table 1). Sale of copra from small-holdings resumes rapidly during any upward spike in price. In the mean-time the kernel is fed to domestic animals as well as remaining a staple item in the diet. Some families, beset by poverty, continue production whatever the price.

Region	Area (Mha)	Region	Area (Mha)
Caribbean	0.15	South America	0.32
Central America	0.21	Southeast Asia	6.9

East Africa	0.49	Southern Asia	2.38
Oceania	0.49	West Africa	0.17
Total production area: 11.16 Mha			

Table 1. Area planted to coconut by region (Source: http://faostat.fao.org/).

2. Origin and Distribution

Despite the presence of botanically related genera on the plains, plateaus and highlands of continental South America, the home of the coconut is often said to be unknown. Its mode of dispersal is thought to have evolved on the coastal beaches of atolls and islands of the Indian Ocean and western Pacific. Its origin remains "A riddle wrapped in a mystery inside an enigma".

Ethnological indicators place the center of diversity for coconut in South East Asia and Melanesia. Wild coconuts were most probably present at suitable coastal locations on the fringes of the Indian Ocean when the earliest humans migrated from Africa to Asia and from Asia to Australasia, including parts of Melanesia and perhaps Micronesia, if not Polynesia. The first people would have used tender-nuts for drinking and ripe-nuts as flotation aids (Fig. 1) to reach off-shore islands, but they did not plant or cultivate coconuts because they were not farmers. That may be the reason why the first Australians were not cultivating coconuts when the Europeans arrived.

Figure 1. Floatation aid? This *niu kafa* in Samoa is similar in appearance to coconuts known in the Seychelles (person. comm. Antoine Moustache; Picture credit: Roland Bourdeix, 2010).

During the Ice Ages, between 8,000 and 14,000 years ago, an extensive land area now known as Malesia, was inundated by rising sea levels. As the shallow continental shelf between the present-day Malay Peninsula, Sumatra, Borneo and Mindanao was submerged, drinking water sources would have been contaminated and the cultivation of crops in low-lying areas forced to higher ground. Among those the coconut palm was one of the few plants that could tolerate a degree of salinity, and tender-nuts became a source of pure, sweet drinking water for the human beings in the area. Selection for increased water content, early germination and other characteristics that are now recognized as signs of domestication was consistently applied for a long time, over a large area and on each generation of coconut palms by every generation of people.

These domestic coconuts were preferred by the people who first sailed to islands in the Indian and Pacific oceans. They simply took them in their canoes for drinking or for planting with no foreknowledge that islands like Madagascar or Samoa existed or that they might find coconuts on one islandbut not (perhaps) the other. When domestic forms were taken to islands where wild coconuts were already present, intermediate forms arose through introgressive hybridization. To this day, such populations of open-pollinated coconut palms, growing in small numbers on small islands may show characteristics from either or both of the ancestral forms.

From 1499 (CE), Portuguese navigators following Vasco da Gama, and returning from the Indian Ocean, had the opportunity to introduce coconut seeds to the Cape Verde Islands off the West African coast. Just fifty years later fruit from those islands were taken to Brazil and to Puerto Rico, and later to the West African mainland and to the Atlantic coast of the Americas, from Bahamas to Brazil, and the Caribbean from Florida to Guyana. Coconuts on the Pacific coast from Mexico to Peru originated from ripe fruit carried from the Philippines as deck cargo on Spanish treasure galleon convoys in the 17-18th centuries.

The phenotypic differences between coconut populations from the Caribbean coast and the Pacific coast of Panama were recognized in Jamaica, where both types had been simultaneously introduced in 1916 after the Panama canal was opened but not until 1978 were the Polynesian names for contrasting fruit types – *niu kafa* and *niu vai* – used to characterize these as wild-type and domestic-type forms of the modern cultivated coconut.

The distribution of coconut varieties has now been investigated with DNA-based techniques, which have already supported the concept of wild-domestic-introgressed coconut types and currently identifies two major gene pools representing sources of predominantly 'wild-type' and 'domestic-type' populations from which all modern cultivars have developed (Harries, 1995; Perera *et al.*, 2009; Zizumbo *et al.*, 2005).

3. Botany

3.1. Cultivars and Classification

Vernacular names and descriptions used in 17th century publications still survive and the first systematic classifications of varieties and forms identified two groups, Tall and Dwarf, as *C. typica* and *C. nana*. Since the 1950s, coconut breeders in India and Sri Lanka recognized that each group had a small number of botanical varieties that, in turn, were subdivided into more forms on the basis of fruit size and number, geographic location or precocity and vigor, and each received a Latin tag. Today, the current names usually combine a country location with palm stature, such as Malayan Dwarf (MD) and Panama Tall (PT) or may indicate hybrid parentage, Maypan (MDxPT) or fruit color or other attribute like *spicata* inflorescnce or *makapuno* (kopyor) kernel.

The classifications agree that the tall varieties are predominantly cross-pollinated and out-breeding and the dwarf varieties highly self-pollinated and in-breeding. Self-pollination in the Dwarf results from selection under cultivation, but the Dwarf palms are easily cross-pollinated, especially when surrounded by Tall palms. The less vigorous dwarf survives because its color markers can be recognized. Whatever the origin of the dwarf form, it is clear that it was selected for its precocity, easy harvesting and attractive fruit colors. Using data from fruit component analysis (FCA) and considering the proportion of each component (husk, shell, water, kernel) rather than the absolute value, a standardized procedure, that can be carried out in the field on coconuts at a definable stage of maturity, allows breeders and conservationists collecting seed in the field to evaluate and differentiate populations.

Tissue samples collected at the same time can be subjected to a DNA profile in a laboratory, a relatively recent method applied to coconut palms to identify markers from sequencing of individual regions of the plant genome**.** Ease of DNA analysis has brought a recent boom to the application in coconut, and a micro-satellite kit for this species is available.

The research so far performed on molecular characterization of coconut diversity supports previous conclusions from FCA mentioned above, regarding the major distinctions between coconut genotypes and their geographical origin. Also, the expected implications of the degree of heterozygosity of those genotypes, from what is known about their reproductive behavior, have been reported (Zizumbo *et al*., 2005).

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Bibliography

Antonova, I. (2009). *Somatic Embryogenesis for Micro-Propagation of Coconut*. PhD Thesis, University of Queensland, Brisbane, Australia. [This PhD thesis describes a new way to undertake somatic embryogenesis of coconut].

Ashburner, G.R., Thompson, W.K. and Burch, J.M. (1993). *Effect of Alpha-Naphthalene-Acetic Acid and Sucrose Levels on the Development of Cultured Embryos of Coconut*. Plant Cell, Tissue and Organ Culture, 35: 157-163. [This popular article describes ways in which the embryo culture process of coconut is undertaken in an improved fashion].

Blake, J. (1991). *Production of Clonal Coconut Palms*. In: Silas, E.G.; Aravindakshan, M.; Jose, A.I. (eds) Coconut breeding and management. Vellanikkara: Kerala Agricultural University, pp. 167-168. [Basic document describing the way clonal propagation was undertaken in the 1980s. This was the starting approach for all new developments to this process].

Buffard-Morel, J., Verdeil, J.L. and Pannetier, C. (1992). *Somatic Embryogenesis of Coconut (Cocos nucifera L.) from Leaf Explants: Histological Study*. Canadian Journal of Botany**,** 70: 735-741. [This paper describes the possibility of undertaking somatic embryogenesis of coconut while using leaf explants as a starting material].

Foale, M. (2003). *The Coconut Odyssey - The Bounteous Possibilities of the Tree of Life*. ACIAR: Canberra. Available as a pdf file from www.aciar.gov.au/publications/MN101 [This popular account describes ways in which the full potential of coconut and its benefits may be realized for better health, food and the environment].

Foale, M.A. and Ashburner, R. (2004). *The Coconut Palm*. In: V.L. Chopra and K.V. Peter, eds.: *Handbook of Industrial Crops*, chapter 6. Indian Council for Agricultural Research, New Delhi, and Haworth Reference Press, New York. [A handy guide on the aspects of cultivation and trade, evolution and adaptation, origin and botany, cultivation and harvest, and future production and demand].

Friend, D. and Corley, R.H.V. (1994). *Measuring Coconut Palm Dry Matter Production*. Exp. Agric., 30: 223-235. [Non-destructive methods are described for estimating annual above-ground dry matter production by the coconut palm.].

Harries, H. (2009). *Learning to Live with Lethal Yellowing: Parts 1 and 2*. Coco Info International, 16 (1): 25-28 and 16 (2): 3-36. [An outbreak of lethal yellowing cannot be prevented or avoided for ever, but can be lived with if it is anticipated along the lines indicated].

Harries, H., Baudouin, L. and Cardeña, R. (2004). *Floating, Boating and Introgression: Molecular Techniques and the Ancestry of Coconut Palm Populations on Pacific Islands.* Ethnobotany Research and Applications, University of Hawai'i, Honolulu, 2: 37-53. (http:// www. ethnobotanyjournal.org/vol2/I1547-3465-02-037.pdf) [The introgression between wild types and domestic types is complicated by the subsequent movement of the introgressed germplasm following the industrialization of coconut growing for copra in the late 19th century].

Harries, H.C. (1995). *Coconut*. In: Smartt, J. and Simmonds, N.W., eds: *Evolution of Crop Plants (Second edition)*. Longman, London, pp. 389-394. [The information contained in this chapter will serve well as a source for ethnobotany as well as for researchers in fields as diverse as agriculture and archeology.].

Harries, H.C. and Paull, R.E. (2008). *Cocos nucifera Coconut*. In: Janick, J. and Paull, R.E. eds.: *The Encyclopedia of Fruit and Nuts*. Oxford University Press, USA, pp.107-118 [This major reference offers a comprehensive collection of information not only with the horticulture but also the botany of the coconut].

Howard, F. W., Giblin-Davis, R., Moore, D. and Abad, R.G. (2001). *Insects on Palms*. CABI, UK. [This book is recommended reading for tropical biologists and agriculturalists, including entomologists, horticulturists and tropical ecologists as well as palm nursery growers, managers and enthusiasts].

Karunaratne, S., Gamage, C. and Kovoor, A. (1991). *Leaf Maturity, A Critical Factor in Embryo-genesis.* Plant Physiology, 139: 27-31. [This paper describes the importance of leaf maturity in the somatic embryogenic process of coconut when using leaf explants as starting material].

Leach, B.J., Foale, M.A**.** and Ashburner, G.A. (2003) *Some characteristics of wild and managed coconut palm populations and their environment in the Cocos (Keeling) Islands, Indian Ocean.* Genetic Resources and Crop Evolution 50, 627-638. [Description of an isolated wild-type coconut population].

Meléndez-Ramírez, V., Parra-Tabla, V., Kevan, P.G., Ramírez-Morillo, I., Harries, H., Fernández-Barrera, M. and Zizumbo-Villareal, D. (2004). *Mixed Mating Strategies and Pollination by Insects and Wind in Coconut Palm* (*Cocos nucifera* L. (Arecaceae): *Importance in Production and Selection*. Agricultural and Forest Entomology, 6(2): 155-163. [Coconut palms may have evolved pollination, breeding and mating systems that ensure fruit production under a wide variety of conditions, while maximizing the probability of cross-pollination].

Ochs, R., Bonneau, X., Olivin, J., Ouvrier, M., Pomier, M., Taffin, G. de, and Zakra, N. (1991). Mineral Nutrition and Manuring with Particular Reference to the New Hybrid Varieties. In: Green, A.H., ed.: *Coconut Production. Present Status and Priorities for Research*. World Bank Technical Paper 136. [An overview of nutrient requirements of coconut].

Ohler, J.G., ed. (1999). Modern Coconut Management. Intermediate Technology Publications Ltd. and FAO, Rome, in collaboration with Leiden University, The Netherlands. [A book with four parts, covering: The Coconut Palm and its Environment; Planting material and Plantation Management; Coconut-based farming systems; and Post-harvest treatment, processing, research and development].

Perera, L, Perera, S.A.C.N., Bandaranayake, C.K. and Harries, H.C. (2009). *Coconut* In: Vollmann, J. and Rajcan, I., eds.: *Oil Crop Breeding*. Handbook of Plant Breeding Series, Springer-Verlag, Chapter 12: 369-396. [A state-of-the-art compilation and a major reference text of interest to plant breeders, agronomists, molecular biologists, physiologists, plant pathologists, food scientists and university scholars].

Rivera, R. L., Santos, G.A., Rivera, S.M., Emmanuel, E.E. and Baylon, G.B. (2008). *Development of Synthetic Variety of Coconut: PCA Syn Var 001. I. Status and Prospects*. Coconut Research and Development, 24 (1): 90-112. [Synthetic varieties are more flexible in terms of environmental adaptation due to their wider magnitude of genetic structure].

Samosir, Y. and Adkins, S. (2003). *Coconut Embryo Culture: CO2-enrichment and Root Aeration for Improved Seedling Establishment.* In: Peiris, T.S.G. and Ranasinghe, C.S., eds.: Proceedings II, International Conference of t Coconut Research Institute of Sri Lanka, Lunuwila, pp. 77-91. [This conference paper describes a new way to establish coconut seedlings after embryo culture, improving the rate of success by a factor five].

Sisunandar, S., Y., Rival, A. and Adkins, S.W. (2010). *Cryopreservation of Coconut (Cocos nucifera L.) Zygotic Embryos does not Induce Morphological, Cytological of Molecular Changes in Recovered Seedlings*. Planta, 232: 435-447. [This popular paper describes a new way to undertake cryopreservation of coconut and the lack of any morphological/cytological/DNA changes during this process].

Turner N., Hariharan K., TidAng K., Frangioudakis G., Beale S.M., Wright, L.E., Zeng, X.Y., Leslie, S.J., Li, J-Y., Kraegen, E.W., Cooney, G.J. and Ye, J-M. (2009). *Enhancement of Muscle Mitochondrial Oxidative Capacity and Alterations in Insulin Action Are Lipid Species Dependent: Potent Tissue-Specific Effects of Medium-Chain Fatty Acids*. Diabetes, November 2009, 58: 2547-2554. [Medium-chain fatty acids (MCFA) reduce adiposity and preserve insulin action in muscle and adipose, despite inducing steratosis and insulin resistance in the liver. Dietary supplementation with MCFA may therefore be beneficial for preventing obesity and peripheral insulin resistance].

Zizumbo-Villarreal, D., Ruiz-Rodriguez, M., Harries, H. and Colunga-GarcíaMarín, P. (2005). *Population Genetics, Lethal Yellowing Disease, and Relationships among Mexican and Imported Coconut Ecotypes*. Crop Sci, 46: 2509-2516. [Lethal Yellowing (LY) is one the main diseases affecting coconut worldwide and this study suggests that genetic distance may be useful for the estimation of the potential LY mortality in regions as yet unaffected and identification of potential parents for LY resistance breeding].

Biographical Sketches

Steve Adkins is a professor at the University of Queensland (UQ) in Brisbane, Australia. He obtained his PhD in weed physiology from the University of Reading (UK, 1981) and has served as a postdoctoral fellow at the University of Saskatchewan, Canada (1981-84) and at Murdoch University, Perth, Australia (1984-88). He is now based at UQ and has spent the last 20 years studying various tropical and subtropical crops and pastures, their weeds and the native plant community. His research focus is on weed and seed biology, and conservation using *ex situ* seed banking and tissue culture. He has been a principle investigator and scientific adviser on more than 50 scientific projects in more than 15 worth more than $10 million. He has published more than 100 peer reviewed papers in international journals as well as many conference papers and book chapters. He is currently the President of the Asian-Pacific Weed Science Society.

Mike Foale studied at the universities of Adelaide (MAgSci), Cambridge (DipAgSci) and Trinidad (DTA). As a coconut agronomist in British Solomon Islands (1960-1969), he did research on: nutrition, nursery management - introducing poly bags, assembly of diverse germplasm, pollen exchange for hybrids testing; replanting strategies etc. He completed a post-graduate study on the effect of genotype and nut size on the growth rate of coconut seedlings. Moving to CSIRO in Australia in 1969 researched the physiology of water deficit in various crops. He was seconded part-time from 1984 to 1994 to the

Australian Center for International Research (ACIAR) supporting its projects on coconut genetic resources and was a member of the founding group of COGENT. Since 2008 he is an Honorary Research Consultant, University of Queensland. His particular interest is snack food from coconut kernel while also supporting a push to gain "native" status for the coconut in tropical northern Australia

Hugh Harries graduated in 1962 (B.Sc Horticulture) at London University and worked successively as UK Agricultural Research Council plant breeder (5 years); botanist/plant breeder at the Coconut Industry Board, Jamaica (10½ years); technical cooperation officer, UK Overseas Development Administration (ODA) in Thailand (5 years); chief agronomist, at the New Britain Palm Oil Development, Papua New Guinea (5 years); plant breeder, German Agency for Technical Cooperation (GTZ) and ODA coconut and cashew projects, Tanzania, (6 years); investigator at Centro de Investigación Cientifica, Yucatan, Mexico (4 years). In addition he made short-term consultancies. For the last decade he has organized web sites and email groups on coconut-related subjects and he moderates Coconut Knowledge Network & Time Line since his retirement in 2005.