

propagation is adopted. In cardamom, seed propagation has the advantage of not spreading katte, a viral disease. The seeds are subjected to scarification with 20% nitric acid for 10 min before sowing to enhance germination. The selected seeds pass through a primary nursery for a shorter period and a fairly lengthy secondary nursery. Seedlings 12 to 18 months old are preferred for planting in the main field except in cashew and cocoa where 3–6-month-old seedlings are used.

In view of the high variability exhibited by seedling progenies, vegetative propagation is preferred for large-scale planting of plantation crops wherever clonal propagation is feasible. It has the added advantage of precocious bearing. In coffee, a single-noded green wood cutting with leaves clipped and dipped in 5000 ppm indole butyric acid (IBA) strikes roots in 3 to 4 months. In tea, single-node semihard wood cuttings with a leaf dipped in 200 ppm naphthalene acetic acid (NAA) can be rooted easily. Patch budding is a successful method of clonal propagation of rubber and cocoa whereas in cashew it is softwood grafting. In cardamom rhizomes with two or three shoots ensure early bearing.

See also: **Primary Products:** Oils. **Production Systems and Agronomy:** Oil Palm and Coconut; Rubber. **Secondary Products:** Rubber Production.

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Oil Palm and Coconut

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Introduction

Perennial crops such as oil palm (*Elaeis guineensis*) and coconut (*Cocos nucifera*) have played and will continue to play important roles in the agriculture of the humid and semihumid tropics where they are cultivated on a large scale in both plantations and smallholdings for food and nonfood industrial purposes.

The seed of the modern oil palm industry was sown during the previous century when four seedlings from West Africa, the center of origin and diversity, were planted in Bogor, Indonesia in 1848. Oil palm was initially planted as ornamental and the first commercial plantings in Southeast Asia started in 1911. The crop diversification policy in Malaysia in the late 1950s, which was later followed by Indonesia, stimulated the rapid expansion and modernization of the industry.

On the other hand, coconut is endemic to Malesia, and later spread to many coastal tropical and semitropical areas. Coconut is the "tree of life" which supplies the basic necessities of food, fuel, and shelter for rural people in many of these areas.

This article deals with the achievements and limitations of improvement and biotechnology of these two important food and industrial crops in bridging the yield gap from the wild state to the theoretical limit.

Oil Palm

Origin and Distribution

The oil palm genus *Elaeis* (Arecaceae) has two species, *E. guineensis* ($2n=32$) and *E. oleifera* ($2n=32$). The oil palm of commerce (sometimes called the African oil palm), *E. guineensis*, is indigenous to the wild and semiwild groves of tropical and subtropical West Africa distributed from Senegal south to Angola and Zaire.

There is a secondary distribution of oil palm growing in semiwild groves on the Atlantic coast of Brazil, predominantly in Bahia, but it is believed that they were brought to Brazil from Africa by slave traders in the seventeenth century.

Elaeis oleifera is native to tropical areas of Central and South America, growing wild with very little



Figure 1 Young oil palm with fruit bunches. Upper insert: Mature bunch; lower insert: cross-section of mature fruit showing separate sources of palm oil from the mesocarp and palm kernel oil from the endosperm or kernel.

large-scale planting compared to *E. guineensis*. This is partly due to the very low yield despite the high quality of the oil. However, *E. oleifera* may play a very important role in the future with respect to interspecific hybridization and biotechnology.

Biology

Oil palm is an unbranched monoecious plant, with male and female flowers in separate inflorescences (Figure 1). It grows to a height of 30–40 m and can live to more than 150 years. It is a feather palm with its stem topped by 35 to 60 pinnate fronds borne on a columnar stem. It has an adventitious root system.

Oil palms produce about two to three fronds per month. Separate male and female inflorescences are borne on the same palm in alternate cycles and oil palm is essentially a cross-pollinated (allogamous) plant. The duration of each floral cycle is dependent on both genetic and environmental factors. The flowers are bisexual in origin, but in “males,” the stigmas are suppressed while in “females,” the stamens are underdeveloped. Each male inflorescence produces a large quantity of pollen, averaging 30 g.

Each female inflorescence may have from 700 to 1500 flowers, which are receptive for 36 to 48 h after anthesis. The flowers within an inflorescence open sporadically, taking up to 4 weeks between the initial and the last flushes. Normally, most flowers are receptive (up to 82%) on the second day after anthesis, which would be the most suitable time for pollination.

Fruits

The fruit consists of epicarp, mesocarp, endocarp, embryo, and endosperm. The epicarp consists of a thin layer of parenchymatous cells. The mesocarp, the primary oil storage of the fruit, consists of

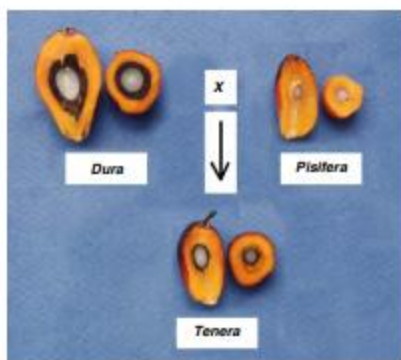


Figure 2 Different types of oil palm fruits: *dura* × *pisifera* = *tenera* as commercial D × P planting materials.

parenchymatous cells containing oil droplets. The endocarp or shell consists of stone cells. The testa cells have brown contents. The endosperm cells contain oil droplets while the aleurone grains have crystalloids. The kernel (endosperm), being the secondary oil storage of the fruit, is oval in shape and about 3 cm in length.

Fruits of *E. guineensis* are classified into three distinct forms based on shell thickness (Figure 2): (1) *dura*, homozygous dominant ($Sb^+ Sb^+$), which has a thick shell (2–8 mm); (2) *pisifera*, homozygous recessive ($Sb^- Sb^-$), which is shell-less; and (3) *tenera*, heterozygous hybrid ($Sb^+ Sb^-$) resulting from a *dura* × *pisifera* (D × P) cross, which has a thin shell (0.5–4 mm). However, there still exists, within each fruit form, considerable variation in shell thickness under apparent polygenic control.

The ratio of mesocarp to bunch of the *dura* is 25–65%, *tenera* 75–85%, and *pisifera* 95%. The *pisifera* has lower kernel content, while the *dura* and *tenera* are similar (5–10%). The *pisifera* is generally female sterile. Occasionally, there may be fertile *pisiferas* but the fruit set is generally low and oil to bunch ratio seldom exceeds that of *tenera*. Thus, *pisifera* is not exploited as planting material. It is however, used as the male parent in *dura* × *pisifera* (D × P) crosses to produce *tenera* hybrids.

Fruit color (nigrescens, virescens, and albescens) can also be used as a marker to distinguish between types of *E. guineensis* but it makes no significant contribution to oil yield.

Development of *tenera*

One of the major factors in yield improvement has come from the exploitation of genes affecting shell thickness. This discovery was the cornerstone which led to the commercial utilization of *dura* × *pisifera* (D × P) or *tenera* planting materials. There is no appreciable differences in fresh fruit bunch (FFB) yield between *tenera* and *dura* but the oil to bunch ratio (O/B) of the *tenera* (24%) is higher than that of the *dura* (18%), giving an approximately 30% higher oil yield (Table 1).

The hybrid nature of *tenera* requires the separate selection of *dura* and *pisifera* populations. Reciprocal recurrent selection and modified recurrent selection methods are usually used in improvement programs. Extensive progeny testing is essential in the selection of *pisiferas* for good general combining ability and/or specific combining ability with *duras*. The selected *pisiferas* are used as male parents to combine with selected *dura* female parents for the production of commercial quantities of D × P (*tenera*) seeds.

Breeding Populations

The primary objectives in oil palm breeding are:

- increased oil yield per hectare
- improvement of oil quality
- reduced height increment rate

Table 1 Average bunch composition (%) of oil palm *dura* and *tenera*

Components	<i>Dura</i> (sh ⁺ sh ⁻)	<i>Tenera</i> (sh ⁺ sh ⁺)
Fruit/bunch	60	60
Mesocarp/fruit	60	80
Shell/fruit	30	10
Kernel/fruit	10	10
Oil/wet mesocarp	50	50
Oil/bunch	18	24

- pest and disease tolerance
- improvement of physiological traits (bunch index, total dry matter, and bunch dry matter)
- exploitation of genotype × environment interaction.

Other traits of interest include high early yield, kernel yield, yield profile, carotene level, vitamin E content, and other minor components.

In oil palm, breeding and selection is synonymous with the developments of four Deli *dura* seedlings introduced to Bogor in 1848. Currently 90% of global D × P seed production is based on the Deli *dura* as the female parent. This is not surprising as the Deli *duras* are early bearing and superior in bunch and fruit characteristics.

It is interesting to note that, although the palms have very narrow genetic base and were initially grown as ornamentals, by chance the Deli *dura* had a valuable genotype and is still considered the best *dura* for breeding and seed production. The *pisiferas* which are used as male parents also originated from a limited number of palms from Africa.

dura and *tenera/pisifera* Breeding Populations

Modern *dura* breeding populations are almost exclusively derived from the Deli *dura* population. Some other notable *duras* are Serdang, Elmina, Gunung Melayu, Dabou, Lofindi, Dami, Coto, and NIFOR. There have been introgressions amongst these *dura* and other populations that has resulted in some overlap between different breeding programs.

Early research programs in Africa concentrated on breeding and improvement of *tenera* populations and the improvement of *tenera/pisifera* in Southeast Asia was largely based on the African elite *pisiferas* such as AVROS, Yangambi, La Me', and Ulu Remis.

The introgression of different breeding populations in seed production, especially in most common sources of introgressions such as Deli *dura* with Yangambi *pisifera* and others, has led to the "derived *pisifera*." The most notable derived *pisifera* are Dumpy-AVROS, URT-AVROS, and URT-Cameroon. The development of these derived *pisiferas* sometimes reflect differences in emphasis of the breeding programs. For examples, in Ulu Remis *pisifera* the emphasis is on improvements in yield, while Dumpy-AVROS *pisifera* emphasizes both yield and short palm height.

Selection of Parental Palms

Reciprocal recurrent selection or modified recurrent selection are used to maintain and select independently separate lines of *duras* and *teneras*. The

procedure is also able to avoid inbreeding effects and to allow some characteristics to be selected in *dura* and *tenera* lines to overcome problems of negatively correlated traits. For example, bunch number and average bunch weight are negatively correlated and it is not possible to maximize both in the same palm except through high selection pressure over a long period. Usually, average bunch weight, fruit to bunch, kernel to bunch, and shell to fruit are emphasized in the selection of *dura* parents, while bunch number, mean fruit weight, and mesocarp to fruit are stressed in *tenera* lines. Selection for oil is emphasized in both parental lines.

Different descendent lines of Deli *dura* have been developed through selfing and sib-mating. Some of these superior Deli *dura* lines were introgressed with other *duras*. Family selection followed by individual palm selection is commonly practiced to overcome low heritability estimates of some characters. For example, heritability of bunch yield and its components is low, while bunch quality traits such as mesocarp and oil contents of the fruits have higher estimates.

Selection of *pisifera* is indirect and troublesome compared to *dura* selection because their fruit production is so poor. The strategy is to evaluate or progeny test the *pisiferas* on the basis of actual testcrosses with selected *duras* as well as using *tenera* with *dura* crosses. Thus, the evaluation of *pisiferas* in progeny test of $D \times P$, $D \times T$, or $T \times D$ is an integral part of breeding scheme such as the reciprocal recurrent selection and modified recurrent selection. Breeding designs and specific mating systems such as North Carolina Model I, diallel or simply in biparental combinations, are used to generate these progenies. In-depth scrutiny of genetic variance components, heritability estimates, and combining abilities follow these mating designs. In the North Carolina Model I mating design, one *pisifera* is crossed with several, usually three to five *duras*, and the mean performance over all crosses is taken as a measure of the breeding value of the *pisiferas*, which allows the exploitation of general combining ability for the production of commercial seeds.

Due to the large demand for seeds coupled with long breeding cycle and other testing requirements (e.g., multilocation tests in differing areas), it is not possible to confine seed production only to those crosses between the *duras* and *pisiferas* that have undergone progeny testing. The normal procedure in commercial production is to select the *dura* and *pisifera* independently and only selected *dura* would be combined with any selected *pisifera*.

Important Traits

There are several components of oil yield but the most important are fresh fruit bunch and fruit quality characters. Fresh fruit bunch yield is highly correlated to the weight per bunch and number of bunches per palm. Bunch number and average bunch weight and fruit to bunch ratio and fruit weight have negative correlations. Positive relationships are shown between fresh fruit bunch and its components, mean fruit weight and mesocarp to fruit, bunch number, and oil yield.

Individual palms are selected from superior families on the basis of the mesocarp to fruit, shell to fruit, oil to dry mesocarp, and oil to bunch. Other characters such as fruit to bunch and kernel contents are given special attention to ensure that the traits are at reasonable levels.

Performance of Oil Palm Worldwide

Oil palm is unique in that it produces two types of oil, palm oil from the mesocarp and palm kernel oil from the endosperm (kernel). This can cause confusion as the general public thinks that these two oils are the same. The fatty acid composition of palm oil is significantly different from that of palm kernel oil and coconut oil (Table 2). Some of the similarities between palm kernel oil and coconut oil are due to their derivation from the endosperm.

The theoretical oil yield from oil palm is estimated at 18.6 tonnes ha⁻¹ year⁻¹ (Table 3), thus making it the highest oil-bearing crop of any cultivated species.

There have been tremendous improvements in oil yield and its components in the last 100 years. The average oil yield from the wild and semiwild groves is about 0.2 tonnes ha⁻¹ year⁻¹ (Table 3).

In properly managed growing areas, the yield is much higher, but is dependent on inputs (e.g.,

Table 2 Fatty acid composition (%) and iodine value (%) of palm oil, palm kernel oil, and coconut oil

Composition	Palm oil	Palm kernel oil	Coconut oil
C _{6:0}	—	0.3	0.5
C _{8:0}	—	4.2	8.0
C _{10:0}	—	3.7	6.4
C _{12:0}	0.2	48.7	47.3
C _{14:0}	1.1	15.6	17.6
C _{16:0}	44.0	7.5	8.4
C _{18:1}	0.1	—	—
C _{18:0}	4.5	1.8	2.8
C _{18:1}	39.2	14.8	5.8
C _{18:2}	10.1	2.6	1.8
C _{18:3}	0.4	—	—
C _{20:0}	0.4	—	—
Others	—	0.8	1.4
Iodine value	53.3	17.8	8.0

planting materials, agronomic practices) and the environment (e.g., soils, rainfall distribution). In the four largest palm oil-producing countries (Table 3), the average oil yield ranges from 3.9 to 2.1 tonnes $\text{ha}^{-1}\text{year}^{-1}$. A good commercial plantation in Malaysia is capable of producing 5.5 tonnes $\text{ha}^{-1}\text{year}^{-1}$ of oil yield. The yield is, however, dependent on the ownership of the crop which reflects the levels of inputs. Independent smallholdings produce an average oil yield of 3.3 tonnes $\text{ha}^{-1}\text{year}^{-1}$, organized smallholdings average 3.8 tonnes $\text{ha}^{-1}\text{year}^{-1}$ and private plantations yield 5.5 tonnes $\text{ha}^{-1}\text{year}^{-1}$. The average oil yields of the best plots, the best progenies, and the best individuals are 8.6, 11.5, and 14.9 tonnes $\text{ha}^{-1}\text{year}^{-1}$, respectively (Table 3) and the best individual yield is almost 80% of the theoretical yield.

Table 3 Oil yield of oil palm on the basis of total dry matter production

Yield class	Total dry matter production tonnes $\text{ha}^{-1}\text{year}^{-1}$	Oil yield tonnes $\text{ha}^{-1}\text{year}^{-1}$
Maximum theoretical yield	44	18.6
Best experimental yield:		
Best individual palms		14.9
Best selected progenies		11.5
Best plots	39	8.6
Good commercial yield (Malaysia)	32	5.5
Average national yields:		
Colombia		3.9
Malaysia	20	3.7
Indonesia	19	3.4
Nigeria	16	2.1
Wild and semiwild groves (Africa)		0.2

Table 4 Yield performance of oil palm planting materials

Materials	Year of planting	Fresh fruit bunch tonnes $\text{ha}^{-1}\text{year}^{-1}$	Oil to bunch (%)	Projected oil yield tonnes $\text{ha}^{-1}\text{year}^{-1}$
Dura				
F ₁ Bogor (unselected)	1878	16.5	17.6	2.8
Tg Morawa (unselected)	1885	16.0	17.4	2.7
Elmina (1st selection cycle)	1933	20.1	17.0	3.4
OPRS (4th selection cycle)	1969	24.8	18.3	4.5
Tenera				
DD × CI/UA/SP	1962	22.6	21.9	4.9
DD × AVROS	1964	31.0	23.5	7.3
DD × AVROS	1968	31.1	22.1	6.9
DD × AVROS	1970	31.6	24.2	7.6
DD × Dumpy-AVROS	1979	33.3	25.8	8.9
DD × Yangambi	1988	35.1	26.0	9.5
DD × Yangambi/Nigeria	1992	35.5	31.5	11.2

Improvements in Oil Yield

The performance of the unselected original progenies of the Deli *dura* was quite spectacular, with oil yield of 2.8 tonnes $\text{ha}^{-1}\text{year}^{-1}$ (Table 4). The oil yields from the unselected, first, and fourth cycle selection of Deli *dura* were 2.7, 3.4, and 4.5 tonnes $\text{ha}^{-1}\text{year}^{-1}$, an average improvement of 0.43 tonnes per selection cycle. These *duras* were used as commercial planting materials from 1910 until early 1960s.

In the early 1960s in Malaysia, *tenera* (D × P) replaced the *dura* as commercial planting material and oil yield increased to 4.9 tonnes $\text{ha}^{-1}\text{year}^{-1}$. Subsequent plantings with improved selections has resulted in further improvements of oil yield (Table 4).

Improvement through Agronomic Practices

The substantial increase in yield has been obtained through a combination of selective breeding and improved agronomic practices and factory efficiency. There was a gross improvement of oil yield from 1.3 tonnes $\text{ha}^{-1}\text{year}^{-1}$ in 1951 to 5.34 tonnes $\text{ha}^{-1}\text{year}^{-1}$ in 1991. Changes in fertilizer application, improved nursery practices and soil/water management, and improved factory practices have all contributed to this improvement.

The reduction in the period to first fruiting from 36 to 30 months after field planting together with other traits, such as tolerance to diseases (*Ganoderma* and *Fusarium*) and drought should help to further increase productivity.

The Role of Introduced Pollinating Insects

Prior to 1981, it was normal practice for oil palm plantations in Malaysia to conduct assisted pollination to palms up to 10 years old to improve fruit set. The results were costly and not satisfactory. The

introduction of the pollinating weevil *Elaeidobius kamerunicus* from Africa was made in 1982 with great success and the weevil has spread throughout the country and to Indonesia, the Philippines, and Thailand. Effective pollination has resulted in higher fruit set, bigger kernels, and bigger bunches, and the weevil has not had any detrimental effects on the local insects or environment. The introduction of the weevil has increased bunch weight by 28%, the flower to fruit ratio by 7%, and the kernel to fruit ratio by 17%. The oil yield increase due to pollination by the weevil amounted to 1.2%.

Development of Dwarf Palms

There is great interest in breeding dwarf palms as these are easier to harvest. Several dwarfing genotypes are available; a notable one is Dumpy E206. This has been introgressed into *pisifera* and yields are comparable to *pisifera* but with 30% shorter plants. The Malaysian Palm Oil Board germplasm collection from Africa contains other important sources of dwarf palms for breeding and there are a number of ongoing introgression programs using these materials. Early results of progeny testing showed that the height increment of the progenies averaged 45 cm year⁻¹ which is 40% less than the current commercial D × P materials.

Breeding for High Unsaturation Oil (High Iodine Value)

Palm oil has an iodine value of 53 and is semisolid at room temperature. On fractionation, it can be split into 55% liquid olein and 45% solid stearin. Olein fetches a higher market price and one objective in oil palm breeding is to further increase the proportion of olein to stearin. There are two approaches to achieve this objective: conventional breeding and biotechnology (see below). The screening of germplasm has identified plants with iodine values that exceed 60 which have been used to produce high iodine value selections for commercial planting.

The iodine value of *E. oleifera* is very high, up to 80. The interspecific hybrids between *E. oleifera* and *E. guineensis* have an iodine value of 65 but the hybrids have oil yield too low for commercial exploitation.

Breeding for High Lauric Oil

Palm kernel oil is an important source of lauric oil which is in great demand for lauric acid with the expansion of oleochemical industry worldwide. The supply of lauric oil from coconut is dwindling, partly due to its low yield and declining cultivation and palm kernel oil is one way to increase supply.

Table 5 Composition (%) of carotenoids of palm oil derived from *E. guineensis*, *E. oleifera*, and their hybrids

Type	<i>E. guineensis</i>	<i>E. oleifera</i>	<i>E. oleifera</i> × <i>E. guineensis</i> hybrid
Phytoene	1.27	1.12	1.83
cis β-carotene	0.68	0.48	0.38
Phytolfluene	0.06	Trace	Trace
β-Carotene	56.02	54.08	60.53
α-Carotene	35.06	40.38	32.78
cis α-Carotene	2.49	2.30	1.37
ζ-Carotene	0.69	0.36	1.13
γ-Carotene	0.33	0.08	0.23
δ-Carotene	0.83	0.09	0.24
Neurosporene	0.29	0.04	0.23
β-Zeacarotene	0.74	0.57	1.03
α-Zeacarotene	0.23	0.43	0.35
Lycopene	1.30	0.07	0.05
Total (mg l ⁻¹)	500–700	4300–4600	1250–1800

Screening of germplasm has revealed a considerable level of variation for kernel to bunch which could be the basis for exploitation of elite materials with high kernel content. High-yielding elite *dura* palms with high kernel to bunch contents have been introgressed to produce new planting materials with high kernel to bunch (over 10%) as compared to the current commercial planting materials with 6% kernel to bunch. Planting materials with high kernel contents will soon be released for commercial planting.

High Carotenoid and Vitamin E Content

Palm oil contains very high level of carotenes and vitamin E which are very useful for pharmaceutical and nutraceutical purposes. There is considerable variation within and between species of oil palm and their hybrids (Table 5). *E. guineensis* has a lower carotene content (500–700 mg l⁻¹) than *E. oleifera* (4300–4600 mg l⁻¹) while their hybrids are intermediate (1250–1800 mg l⁻¹) between the two parents. The vitamin E content also follows a similar pattern (Table 6).

Breeding for Resistance to Pests and Diseases

The oil palm industry in Southeast Asia is relatively free of major pests and diseases. Basal stem rot caused by *Ganoderma boninense* is probably the only major disease. Only recently, a technique has been developed enabling the screening of germplasm and existing materials to select resistant palms for breeding purposes.

In Africa and some parts of Central and South America, vascular wilt caused by *Fusarium oxysporium*

is quite prevalent, causing death to both young and old palms. Tolerant genetic materials together with effective nursery screening technique for *E. oxysporium* should be able to produce planting materials resistant to this disease.

The expansion of oil palm cultivation in Central and South America has been hampered by serious diseases such as "sudden wilt" or *Marchitez*, recently identified basal stem rot and bud rot. According to one opinion, bud rot ("pudricion de cogollo" or "amarelecimento fatal") is caused by biotic factors which are yet to be identified. As a result interspecific hybrids of *E. oleifera* and *E. guineensis*, which show some form of tolerance to bud rot, have been planted in some areas in Central and South America. Although showing some form of tolerance, the interspecific hybrids are slowly being affected by bud rot. Another opinion, especially gained through experience of a similar problem in Malaysia and Indonesia, holds that bud rot is caused by abiotic factors, namely poor soil/water management, and inadequate and unbalanced major and minor nutrients.

Breeding for Physiological Traits and Environmental Adaptation

To maximize yield it is desirable to have site-specific planting materials based on the knowledge that

Table 6 Composition (%) of tocopherol and tocotrienols of palm oil derived from *E. guineensis*, *E. oleifera*, and their hybrids

Type	<i>E. guineensis</i>	<i>E. oleifera</i>	<i>E. oleifera</i> × <i>E. guineensis</i> hybrid
α-Tocopherol	21	15	19
β-Tocotrienol	23	27	28
γ-Tocotrienol	45	54	42
δ-Tocotrienol	11	4	11
Total (mg l ⁻¹)	600-1000	700-1500	600-1600

genotypes differ in their response to environmental factors such as soil, rainfall, temperature, humidity, and agronomic practices.

There is a need therefore, to breed for more efficient palms with high harvest index (HI) for site-specific environment. There is sufficient genetic variability from the available germplasm to breed for short efficient palms for increased planting density and high harvest or bunch index (BI).

Role of Germplasm

Almost 90% of the world production of oil palm seed comes from descendants of Deli *dura* which can be traced to the four Bogor palms. Realizing the importance of broadening the oil palm genetic base, many expeditions have been mounted by different groups to collect materials from the wild and semiwild groves in West Africa.

Biotechnology

Capitalizing on the palm's high productivity, the techniques of biotechnology can be employed to divert the palm's biological resources towards the production of novel, high-value products. Biotechnology is being applied to complement and enhance improvement of the palm through conventional breeding.

Genetic engineering Opportunities abound in the area of genetic engineering for oil palm by diverting the intermediates of oil synthesis to the production of industrial chemicals (bioplastics, polymers), nutraceuticals, or even pharmaceuticals. With the knowledge of the pathways involved in fatty acid biosynthesis, manipulating oil composition through genetic engineering has been an attractive goal. In oil palm, attempts are being made to produce a more liquid oil by increasing the oleic acid content (iodine value 70). The pathway that needs to be manipulated to achieve this objective is illustrated in Figure 3.

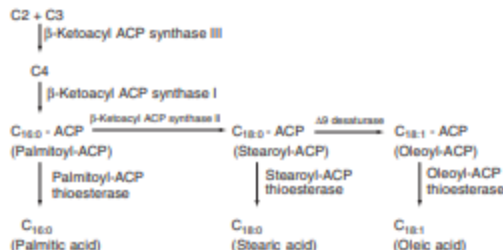


Figure 3 Pathway to achieving high oleic oil content in palm oil.

Genomics The economic value of genomic studies in a perennial crop such as oil palm lies in the ability to identify genetic markers for early selection. The use of DNA markers could greatly reduce the number of breeding cycles. Marker-assisted selection requires the availability of genetic linkage maps and genetic markers associated with the trait of interest. Genetic linkage maps for the location of genes which are potentially useful as markers in oil palm have been constructed. Quantitative trait loci (QTL) affecting carotene and oleic acid content in palm oil have been mapped. In addition, other genomic approaches are being applied to oil palm, including the generation of expressed sequence tags (ESTs) from various tissues and the use of the DNA microarray for profiling gene expression.

Tissue culture There is a need to augment the seed production in oil palm with clonal material produced via tissue culture. *In vitro* micropropagation is an attractive route to the production of oil palm planting materials. Recent field trials have indicated that increase in yield is achievable through this process. The efficiency of production through culture can be further enhanced with the use of liquid suspension cultures.

Coconut

Origin and Distribution

Coconut (*Cocos nucifera*; Arecaceae) is widely distributed in tropical regions of the world, ranging between 20° N and 20° S latitude. The fruit can float and endure long journeys in seawater. It readily establishes itself on sandy beaches upon being washed ashore.

Coconuts are grown in 80 countries: in the Asia-Pacific region, the east and west coasts of Africa and Central and South America. Coconut is the "tree of life" as it plays a vital role, in addition to giving food, drink and shelter, in the economies of many small island countries in the Caribbean, Indian, and Pacific Oceans. Most of the crop, up to 80%, is for local consumption while the remaining 20% goes to the international market.

Biology

Coconut is a perennial monocotyledon ($2n = 32$). It produces adventitious roots at the base of the stem with a prominent bole as it grows older (Figure 4). The palm has a single terminal meristem producing 30–45 fronds on the top of its stem. Generally there are three types of coconut, namely tall, dwarf, and their hybrids.



Figure 4 Young coconut palm showing high yield, precocity and early bearing.

Flowering occurs 3 to 10 years after planting. The inflorescence is a spathe and spadix type, with both male and female flowers. Coconut being allogamous with very fertile pollen, cross-pollination is very common with hybrids showing hybrid vigor.

The coconut fruit is a fibrous drupe with very thin epicarp, very thick, fibrous mesocarp surrounding a seed consisting of endocarp (shell) which has three "eyes" containing the embryo, fleshy endosperm, and water. The fruit normally matures 12 months after fertilization.

Coconut has a long life span, over 80 years, and grows to a height of 30 meters depending on the environment. In plantations, palms are usually replaced when they reach 60 years.

Uses of Coconut Palm

Coconuts have a variety of uses. The leaves provide fodder, shelter, and materials for making baskets and other traditional products. The husks are used as fuel, planting substrate, ropes, and mats. The endocarp (shell) is used as fuel and for making handicraft curios. The trunk is utilized as building

materials, shingles, flooring, furniture, curios, and fuel. Both young and mature coconuts provide a refreshing, healthy drink.

The endosperm, kernel, or meat is the main commercial commodity of the coconut industry. While in a fresh condition, the meat is processed to produce coconut skim milk and desiccated shredded coconut. After drying, the meat is called copra (5% moisture content) which upon further processing yields coconut oil and palm kernel cake. Copra, coconut oil, and palm kernel cake are traded in the international market.

Breeding and Yield Performance

Breeding objectives Copra production is dependent on the number of nuts per palm and the quality and quantity of the meat in the nut. The average oil yield of a coconut grove is about 0.5 tonnes ha⁻¹ year⁻¹, which is very low compared to palm oil and palm kernel oil. However, coconut oil has its own niche and specialty functions. In order to be competitive and sustainable, the primary objective in coconut breeding is therefore to increase yield. Other important attributes are early bearing, resistance to pests and diseases, and tolerance to abiotic stress such as drought, salinity, wind, and poor management.

Table 7 Heritability estimates of important traits in coconut

Trait	Dwarf	Tall I	Tall II	Hybrid
Number of bunches	0.08	0.65	0.11	0.13
Number of nuts per palm	0.49	0.37	0.14	0.30
Copra per nut	0.70	0.78	0.40	0.57
Copra per palm	0.09	0.17	0.35	0.27

Hybridization followed by progeny testing and selection is the most common procedure. However, the emphasis is now on hybrids of dwarf × tall and its reciprocal to exploit the advantages of dwarf coconut (precocity, dwarfness, high nut number) and that of tall coconut (high copra content). The best hybrids are further improved by reciprocal recurrent selection to exploit the traits with good combining abilities and high heritability. Copra to nut has very high heritability, while number of nuts and copra production have fairly high heritability estimates (Table 7), thus improving yield in coconut should be reasonably easy.

Germplasm Palm height and fruit color are used to classify the different types of coconut: tall and dwarf for height and red, yellow, and green for the color of the immature fruits. The varieties are named after their origin, color and/or height, such as Malayan Yellow Dwarf, Brazilian Green Dwarf, Fijian Tall, Cameroon Red Dwarf, Tall, West African Tall, Tagnanan Tall, and so on. The Coconut Genetic Resources Database contains over 1300 coconut accessions in various countries in South Asia, South-east Asia, South Pacific, and the Latin America-Caribbean region.

Yield improvement There has been impressive yield improvement in coconut (Table 8). For examples, there were differences in copra yield between Malayan Yellow Dwarf and Malayan Tall of 1.16 and 1.54 tonnes ha⁻¹ year⁻¹ as "old varieties" and 2.24 and 2.30 tonnes ha⁻¹ year⁻¹ as "modern varieties" respectively (Table 8).

Table 8 Copra yield from different types of coconut

Types	Number of nuts ha ⁻¹ year ⁻¹	Copra tonnes ha ⁻¹ year ⁻¹	Oil tonnes ha ⁻¹ year ⁻¹
Old varieties planted in the 1940s and early 1950s			
Malayan Yellow Dwarf	—	1.16	0.75
Malayan Tall	—	1.54	1.00
Hybrid	—	3.28	2.13
Average high yielding varieties	—	2.25	1.46
High yielding blocks	—	2.29	1.49
Modern varieties			
Malayan Green Dwarf	—	2.24	1.45
Malayan Red Dwarf	—	2.15	1.40
Malayan Yellow Dwarf	—	2.45	1.60
Malayan Tall	8855	2.30	1.56
Hybrid			
MAWA	28819	6.06	4.09
MATAG	28945	7.24	4.78

MAWA, hybrid of Malayan Yellow Dwarf × West African Tall; MATAG, hybrid of Malayan Yellow or Red Dwarf × Tagnanan Tall from the Philippines.

Table 9 Precocity and early bearing of new coconut varieties

Years after planting	Number of nuts ha ⁻¹		
	MAWA	MATAG	Malayan Tall
3	—	900	—
4	16 200	21 292	—
5	14 900	26 293	1 150
6	20 500	27 880	3 850

However, upon crossing with elite germplasm materials, the hybrids have very high yield. The MAWA (hybrid of Malayan Yellow Dwarf × West African Tall) and MATAG (hybrid of Malayan Yellow or Red Dwarf × Tagnanan Tall from the Philippines) are yielding 6.06 and 7.24 tonnes ha⁻¹ year⁻¹ of copra or 3.94 and 4.73 tonnes ha⁻¹ year⁻¹ of coconut oil respectively (Table 8). These hybrids, especially MATAG, are also early-bearing (Table 9).

Breeding for Local Adaptation and Resistance to Pests and Diseases

In addition to low yield and high cost of production, the expansion of coconut cultivation in many countries are hampered by several pests and diseases. The lethal yellowing-like diseases (LYD) have devastated huge areas in many countries in the Latin America-Caribbean, Africa, and Pacific regions. The disease is thought to be caused by phytoplasmas and is probably the most important threat to global coconut cultivation.

Almost all of the imported germplasm and hybrids succumb to these diseases but a number of local varieties and a few imported selections show some degree of tolerance. Progenies of these types have been selected for further screening to lower disease incidence and slow rates of spread.

Other diseases include stem bleeding caused by *Ceratocystis paradoxa*, bud rot caused by *Phytophthora palmivora*, basal stem rot caused by *G. boninense* and *G. lucidum*, and red ring disease caused by the red ring nematode *Rhadinaphelenchus cocophilus*. The notable pests are black headed caterpillar (*Opisina arenosella*), red palm weevil (*Rhynchophorus ferrugineus*), rhinoceros beetle (*Oryctes rhinoceros*), termites (*Odontotermes obesus*), and whitefly (*Aleurodicus pulvinatus*).

Biotechnology

The application of biotechnology to coconut is to facilitate the breeding programs in yield improvement and crop protection, especially lethal yellowing-like diseases. Various DNA marker technologies are used for the evaluation of biodiversity in coconut germplasm, genomic analysis, mapping population, linkage

groups, and indexing of pathogens of importance to coconut. It is now possible, using molecular markers, to distinguish coconut populations from different origins. This will help in the management and utilization of germplasm. In addition the indexing of coconut pathogens by molecular markers would help to facilitate the safe movement of germplasm.

In vitro multiplication of high-yielding hybrids and individuals with desirable attributes such as resistance to lethal yellowing-like diseases and tolerance to abiotic stress is a long-term hope for the production of homogeneous planting materials. Attempts in somatic embryogenesis show that coconut is a highly recalcitrant species in *in vitro* culture.

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List of Technical Nomenclature

Latex A viscous mixture produced in the bark of some tropical trees from which rubber is derived.

See also: **Diseases:** Breeding for Disease Resistance. **Flowering and Reproduction:** Pollination. **Primary Products:** Oils. **Production Systems and Agronomy:** Plantation Crops and Plantations. **Secondary Products:** Rubber Production.

Further Reading

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