AAR WELCOMES OUR NEW RECRUITS

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AAR NEWSLETTER

SEPTEMBER 2016

Letter from the Editor

AAR has achieved an important milestone in July this year, celebrating its 30th year of excellence in scientific innovation. Throughout the past 30 years, AAR has prided itself as one of the leading tropical plantation crop research centres in Malaysia and Indonesia, introducing many new technologies and research breakthroughs to the agricultural industry.

It is hoped that AAR will continue to flourish and achieve even greater milestones in the coming years!

With regards,
Goh Chai Yeen

Celebrating 30 Years of Excellence in Innovation

1986 - 2016

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Oil Palm 101

Everything you need to know about oil palm, exclusively written by the oil palm gurus

AAR Social News

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Check out the latest additions to the family

PRODUCTION SYSTEM AND AGRONOMY — OIL PALM

K. J .GOH, C. K. WONG, P. H. C. NG

ABSTRACT

Oil palm, *Elaeis guineensis* Jacq., thrives in the humid, tropical region where it originated as a pioneer forest species before being domesticated over 8000 years ago. In 2013/14, it was harvested from about 15.7 million hectares which constituted 5.8% of the land cultivated with oil crops but produced 29.8% of the world vegetable oils and fats. It is not only the world most productive oil crops but also has the highest dry matter production among tree crops. Its rapid growth rate, superb productivity and good returns to investment might be attributed to systematic plant breeding efforts since 1940s, science driven agro-management practices, and high demand for its versatile uses.

The synergy between the plant breeder's interest to improve the genetic yield potential of oil palm towards the maximum theoretical oil yield of 18.5 t ha^{-1} yr^{-1}, the agronomist's interest to maximize the genetic expression of oil palm in each field through site-specific inputs i.e. to attain site yield potential and the planter's ingenuity to minimize crop loss probably explain the continual good improvement in oil yields. Despite its success as an agricultural crop, oil palm development has created much controversy in relation to tropical logged-over forest conversion, biodiversity and land rights. Balancing these concurrent goals of development and conservation requires science-based information and perhaps, a paradigm shift.

Keywords:
agronomy; management; oil palm; plantation; plant breeding

Book chapter for the Encyclopedia of Applied Plant Sciences, 2nd Edition, Elsevier.

INTRODUCTION

Oil palm, *Elaeis guineensis* Jacq., is a tropical, perennial crop which is mainly cultivated for its vegetable oil, which comprises both palm oil and kernel oil. Palm oil is derived from the mesocarp whereas kernel oil from the endosperm or kernel (**Figure 1**). Both vegetable oils from oil palm are constituents of many foods, oleochemicals, medicinal and health products, household products and industrial products. About 16% of world palm oil is converted to biodiesel.

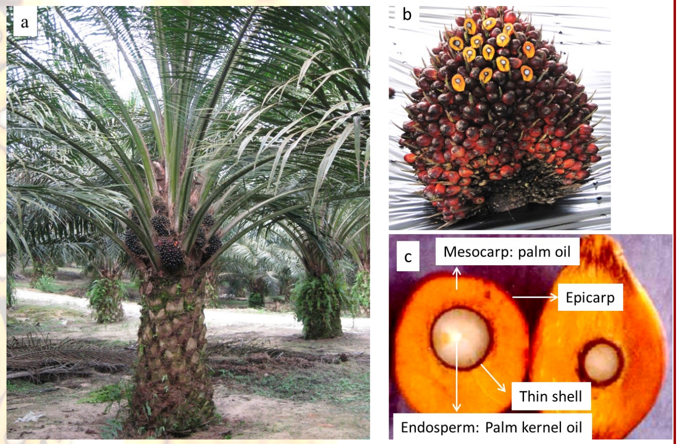

Figure 1. *Young mature oil palm with fruit bunches (a) Upper insert: mature bunch (b) lower insert: cross-section of mature fruit showing two sources of vegetable oil i.e. palm oil from mesocarp and palm kernel oil from the endosperm or kernel*

Oil palm thrives in the humid, tropics and was harvested from about 15.7 million hectares in 2013/14 (**Table 1**). However, it occupies only 5.8% of the land cultivated with oil crops but produces 29.8% of the world vegetable oils and fats. Worldwide, about 53% of the land planted with oil palm is owned by smallholders and government institutions. Nevertheless, the more productive and profitable plantations are run by large companies where the best man-

Family Day

On 14th May, The Nahara, Kalumpang, welcomed 70 people from AAR for a fun-filled family day. Various traditional family games, such as the much loved 'kutip gula-gula dalam tepung', and shirt-drenching (literally) 'sambut belon air', were held for both toddlers and adults. After the rounds of exciting games, attendants then enjoyed a free-and-easy evening by the river.

Of course, there was lots of food for the picnic too! An absolutely lovely day– check out the photos for some of the biggest smiles!

Say CHEESEEEEE!

PT AARSC

PT AARI Breaking Fast 2016

PT AARI employees were joined by their families, senior manager from Mandau, and Nilo representatives for a finger-licking break-fast on 24th June 2016 at Fave Hotel, Pekanbaru. Participants also went home with a Raya goody bag as a token of appreciation.

AARSC

SOCIAL NEWS & EVENTS

Chinese New Year 2016 Celebration

AARSC kickstarted 2016 with the Chinese New Year 2016 Celebration. On 18th February, a hundred people gathered at AAR Kota Damansara's very own cafeteria and tossed the Yee Sang, wishing for good prosperity in this new year. There was also a showcase of traditional Chinese calligraphy by the many hidden talents in AAR.

Badminton Doubles Tournament

9th April was a sweaty day for many. A badminton doubles tournament was held at Lead Sport Centre, Kota Damansara, with 18 teams from the main office and TC lab smashing away in the courts. A huge round of applause for the winners!

	Men's	Women's
Champion	Soh Soo Leong (Sales) Cheng Cong Rong (Agronomy)	Afikah (TC) Rahman (TC)
1st runner-up	Roslan (Field) Zulkarnaen (EM)	Melody (PB) Nur Farina (Chem)
2nd runner-up	Selvarajah (ACC) Swaminathan (Driver)	S.Kalaivany (TC) Jessica (TC)
3rd runner-up	Mokhan (Driver) Roslin (Driver)	Siti Rohimah (Admin) Thulasi (ACC)

agement practices are science-driven, adequate infrastructure is installed to manage, harvest, process and export the produce, and basic amenities such as housing, water, electricity, schools, health and recreational facilities are provided to attract workers and their families to the plantations. Thus, countries with successful oil palm industry e.g. Indonesia, Malaysia, Thailand, Colombia and Papua New Guinea, have at least 30% of their oil palm lands developed as large-scale industrial crop and integrating it with smallholder schemes.

ORIGIN & DISTRIBUTION

The oil palm genus, Elaeis (Arecaceae), has two species, *E. guineensis* (2n = 32) and *E. oleifera* (2n = 32). The origin of the former lies in the tropical rain forest region of West Africa along the coastal belt from Liberia and down south to Angola and Zaire. The African oil palm grows in wild and semi-wild groves, and spread by people to a wider area ranging from 16° N to 15° S and eastward to Zanzibar and Madagascar. There is a secondary distribution of oil palm growing in semi-wild 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.

Table 1. *World production of vegetable oils and harvested areas of various oil crops*

Oil crop	Production (million tonnes)	% of world production	Total harvested area (million ha)	% of world harvested area
Oil palm	58.5	29.8	15.7	5.8
Soybean	43.8	22.3	114.2	42.3
Rapeseed	25.7	13.1	35.7	13.2
Sunflower	15.8	8.0	25.9	9.6
World	196.4	100	270.2	100

Source: Oil World (2014)

In Southeast Asia, oil palm was initially planted as ornamental palm and the first commercial plantings started in 1911 from the descendants of four seeds from West Africa planted in Bogor, Indonesia in 1848. The crop diversity policy in Malaysia in the late 1950s, which was later followed by Indonesia in the 1980s, spurred the expansion and modernization of the industry. The ongoing development of oil palm is further driven by the demand for biodiesel and the needs of underdeveloped nations for economic development and decent living standards by increasing the capability of poor families to buy food and basic necessities, promoting rural development by creating vibrant local markets, and providing local employment opportunities. Despite this, the crop has created much controversy in relation to tropical forest conversion, biodiversity and land rights. Balancing these concurrent goals of development and conservation requires science-based information and perhaps, a paradigm shift.

Elaeis oleifera is native to tropical areas of Central and South America, growing wild with no commercial value compared to *E. guineensis*. This is partly due to its very low yield despite the high oil quality. However, the F1 hybrid, *E. oleifera* x *E. guineensis*, is grown commercially in South America because of its tolerance to bud-rot disease and it may play a very important role in the future with respect to interspecific hybridization and biotechnology.

The wide distribution of oil palm might be attributed to its adaptability to harsh environment being a pioneer forest species in its native ecosystem in Africa. It can be found in waterlogged areas, shallow lateritic or stony soils, very sandy soils, peat, dry region with moisture stress less than 800 mm yr^{-1}, steep terrain and elevation of about 1,300 m above sea level (ASL). However, it grows best in lowland areas below 500 m in the humid tropics between 10° N and S, annual rainfall between 2000 and 2500 mm with no dry season (moisture stress less than 100 mm yr^{-1}), minimum air temperature above 20°C and maximum temperature below 35°C, effective sunshine hours exceeding 5 hr day^{-1} or 6.5 GJ m^{-2}, deep soils of 100 cm depth or more, sandy clay loam to sandy clay texture, friable and well drained, and slopes less than 4°.

BOTANY

Oil palm is a single stem, un-branched monoecious plant, with both male and female flowers in separate inflorescences borne on the same palm (**Figure 1**). 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 has 700 to over 3000 flowers, which are receptive for 36 to 72 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. Oil palm is essentially a cross pollinated palm, which is pollinated predominantly by the pollinating weevils, *Elaeis kamerunicus*. This African weevil was introduced to Malaysia in 1982 and has spread to other oil palm growing countries. The other *Elaeis* sp. and thrips are minor pollinators of oil palm.

Oil palm grows to a height of 30 to 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 produces about one to four fronds per month. Oil palm has an adventitious root system. The primary roots grow from the base of the stem and branch into secondary, tertiary and quaternary roots. The last two types of roots are non-lignified and assumed to absorb soil nutrients. Most oil palm roots are found in the top 45 cm of the soils but primary and secondary roots can descend below 2 m.

FRUITS

The fruit consists of epicarp, mesocarp, endocarp, embryo, and endosperm (**Figure 1**). The epicarp and mesocarp comprise parenchymatous cells with only mesocarp having oil droplets. The endocarp or shell consists of stone cells. The endosperm or kernel cells contain oil droplets while the aleurone grains have crystalloids.

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

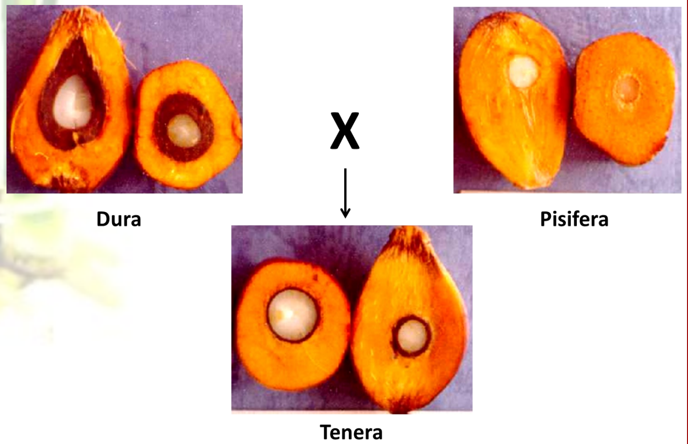

***Figure 2.** Different types of oil palm fruits: dura x pisifera = tenera as commercial DxP planting materials*

The pisifera is generally female sterile. Occasionally, there may be fertile pisiferas but the fruit set is generally low and oil to bunch ratio

disorders, pest infestations and disease infections as well as target spraying to control them.

Oil palm thrives in the same region as humid, tropical lowland forests where it originates. When well-managed, oil palm is one of the best crops to grow to provide food security, enhance living standards of the local people, and stimulate economic development of the nation. However, agricultural expansion and its benefits must be reconciled with land conservation of heavily logged over forests and the ecosystem goods and services from them as well as the amount of forested land needed to maintain these goods and services in each country. Better science-based information on oil palm, global carbon, biodiversity and environment over different spatio-temporal scales is required for multidisciplinary discussion and resolving this controversy and debate.

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

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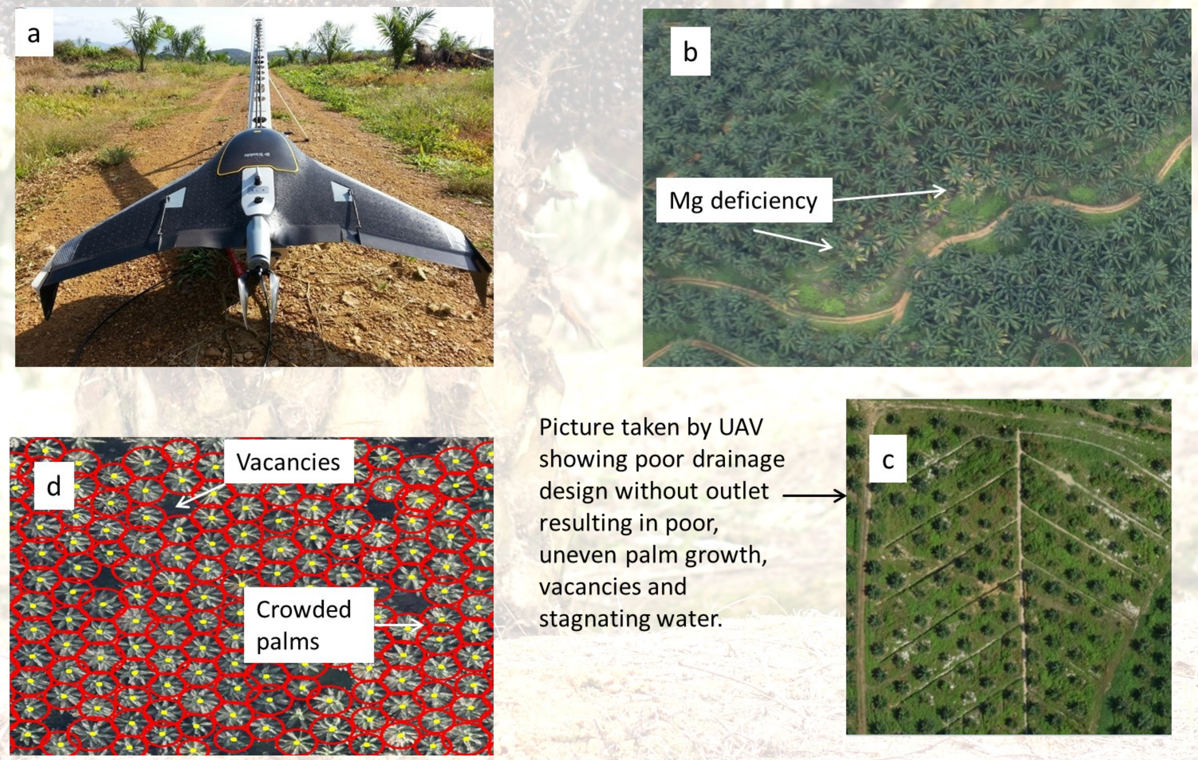


***Figure 8.** Some applications of unmanned aerial vehicle (UAV) in oil palm plantations. a) Launching UAV; b) & c) are pictures taken by UAV showing poor growth due to Mg deficiency and inadequate drainage; d) automatic counting of palms, identifying vacancies and palm sizes*

are 40 to 190 kg N ha^{-1} yr^{-1}, 15 to 70 kg P ha^{-1} yr^{-1} and 60 to 400 kg K ha^{-1} yr^{-1}.

The main competition to oil palm is noxious weeds which compete for nutrients and water as well as obstructing access to the palms particularly during the immature phase when light is abundant. Selective interventions with appropriate herbicides are implemented to maintain the desired interrow vegetation. However, the area around the palm base (palm circle) is kept clean to facilitate field operation such as collection of loose fruits during harvesting. Another source of competition is amongst the individual oil palms for light when they are planted too close. Selective thinning out of etiolated palms is then essential to address the problem.

Oil palm in Southeast Asia and Africa is relatively free of pests and diseases. The most severe pest problems are losses from mammalian pests in immature oil palm, loss of leaf area from rhinoceros beetle damage and leaf eating pests such as bagworm, nettle caterpillars and grasshoppers, casualty caused by termites in peat soil and loss of FFB from rat and squirrel damage. Vigilance, early detection and control measures such as selective application of pesticides will minimize these problems and keep the pests below their threshold levels. Other integrated pest management (IPM) techniques are also practised such as planting beneficial plants e.g. *Turnera subulata* and *Cassia cobanensis*, and establishing barn owl. There are only two major diseases infecting oil palm in Southeast Asia and Africa i.e. *Ganoderma boninense* and *Fusarium oxysporium Elaeis*, respectively. Sanitation is used to control the former disease while oil palms that are resistant to the latter are commercially available. In South America, there are more diseases e.g. bud rot and Marchitez or sudden wilt diseases, and pests e.g. spider mites (*Retracrus elaeis*), *Rhynchophorus palmarum* weevil (red ring disease) and leaf defoliators e.g. *Loxotoma elegans*.

In young palms where light is not limiting, the maximum leaf area is very important for rapid growth and high early yields. First systematic pruning should commence when the lowest ripe bunches are about 60 cm above the ground. In mature palms, the average number of fronds per palm should be between 36 and 40 with no palm having less than 32 fronds, to maintain maximum leaf area for photosynthesis while ensuring ease of harvesting.

With most of the precocious palms presently planted, harvesting could commence between 24 and 26 months after planting. Good crop recovery is essential to realize the maximum returns to investment. Maintenance of harvesting rounds and efficiency of cutting bunches at the correct stage of ripeness will optimize the oil to bunch ratios. Efforts should be made to maintain 7 to 12 day rounds with 5 to 10 loose fruits per bunch before harvest, generally. Better supervision and crop recovery systems are required as the palms grow older and taller, and fresh fruit bunches become fewer and heavier. Losses and omissions of loose fruit and bunches in these areas are proportionately larger.

NEW CHALLENGES

Land cultivation is known to modify soil properties but its impact on soil biology and oil palm production is still uncertain. There is also a need to understand the interaction between soil physical, chemical and biological properties, and develop a holistic soil fertility index for oil palm.

Oil palm is now grown on diverse environments on a large scale. With the increasing lack of workers and managerial skill, there is a growing need to monitor the intricate agronomic and operational factors affecting the oil palm performances automatically and generate informed, good decisions for quick action. The use of unmanned aerial vehicle (UAV) is most applicable as illustrated by the successful identification of palms and counting their numbers in the field (**Figure 8**). Further work on UAV is on-going particularly in identifying

seldom exceeds that of tenera. However, its male inflorescence produces viable, fertile pollen and thus, used as male parent to create tenera hybrids.

Fruit color (nigrescens, virescens and albescens) can also be used to distinguish the types of *E. guineensis* but they have no difference in oil yield. Nevertheless, the ripe bunch of virescens fruit type is easier to recognize because of distinct color change from green to orange when it ripens and therefore, reduces error in the harvesting operation.

CROP IMPROVEMENT - DEVELOPMENT OF TENERA

The primary trait of interest in oil palm is oil yield, which is a product of fresh fruit bunch and oil to bunch ratio. Thus, the plant breeder ultimate aim is to raise the genetic yield potential of the current planting materials towards the potential oil yield of 18.5 t ha^{-1} yr^{-1} (**Table 2**). Apart from oil yield, other traits of interest are disease tolerance e.g. Basal Stem Rot, Fusarium Wilt and Bud Rot, oil quality e.g.

Table 2. *Yield performance of oil palm planting materials across time and spatial scales*

Planting materials/ Yield class	Year of planting/ recording	Spatial scale	Projected oil yield (tonnes ha^{-1} yr^{-1})
Maximum theoretical yield	1998	Single palm	18.5[1]
Best individual palms	2003	Single palm	14.9[2]
Wild and semiwild groves	-	-	0.2[2]
Improved natural groves	1940	-	0.8[3]
Intra population crosses	1950	-	2.5[3]
Inter population crosses	1960	-	3.3[3]
Dura 4th selection cycle	1969	-	4.5[4]
Deli Dura x CI/UA C/SP	1962	Small plot	4.9[4]
Deli Dura x Avros	1964	Small plot	7.3[4]
Deli Dura x Avros	1968	Small plot	6.9[4]
Deli Dura x Avros	1970	Small plot	7.6[4]
Deli Dura x DyAvros	1979	Small plot	8.6[4]
Deli Dura x Avros	1979	Small plot	8.9[4]
Deli Dura x Yangambi	1988	Small plot	9.5[2]
Deli Dura x Yangambi	1991	Small plot	10.8[2]
Deli Dura x Nigeria	1991	Small plot	11.5[2]
Felda materials	1990s	Family	7.4[1]
Felda materials	2000s	Family	7.9[1]
Felda materials	2010s	Family	8.1[1]
Deli Dura x DyAvros	1990s	Family	7.7[1]
Deli Dura x DyAvros x Yangambi	2000s	Family	9.3[1]
Deli Dura x Dy Avros x Yangambi/La Me'	2010s	Family	9.7[1]
Malaysia	2014	Country	4.3[5]
Indonesia	2014	Country	4.1[5]
Papua New Guinea	2014	Country	3.7[5]
Colombia	2014	Country	3.5[5]
Thailand	2014	Country	2.8[5]
Nigeria	2014	Country	2.0[5]
World	2014	World	3.7[5]

Source: [1]Goh et al. (2014); [2]Basri and Rajanaidu (2004); [3]Basiron et al. (2000); [4]Lee and Toh (1991); [5]Oil World (2014) the abundance of carotene and vitamin and the ratio of different fatty acids, and management efficiency related traits e.g. long bunch stalk, short height and non-abscission.

One of the major factors in yield improvement of oil palm leading to its utilization as a commercial oil crop is the exploitation of genes causing shell thickness. The knowledge of dura x pisifera shall yield absolute tenera oil palm that forms fertile bunches with fruits that are thin shell, leads to classical breeding approaches that segregates to dura population and pisifera population, supported by its cross-pollinated nature, in order to maximize hybrid vigour. The latter improves the palm oil yield by about 40% from the oil to bunch ratio of dura of about 23% to 33% in tenera.

Fruit type is only one of the components to oil yield that happens to be monogenic inherited. However, other components of oil yield e.g. bunch number, bunch weight, fruit-to-bunch ratio, oil-to-wet mesocarp ratio are suggested to be polygenic governed as the traits are observed being quantitative in nature. Recurrent selection, e.g. reciprocal recurrent selection and/or modified recurrent selection (**Figure 3**), is deployed in improvement programs for quantitative traits, which relies heavily on the results of progeny testing. In addition to the perennial nature of the crop, the length of one breeding cycle is compounded by the necessity to generate and evaluate the dura and pisifera populations prior to progeny testing.

Current 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. Introgressions amongst these duras and other populations

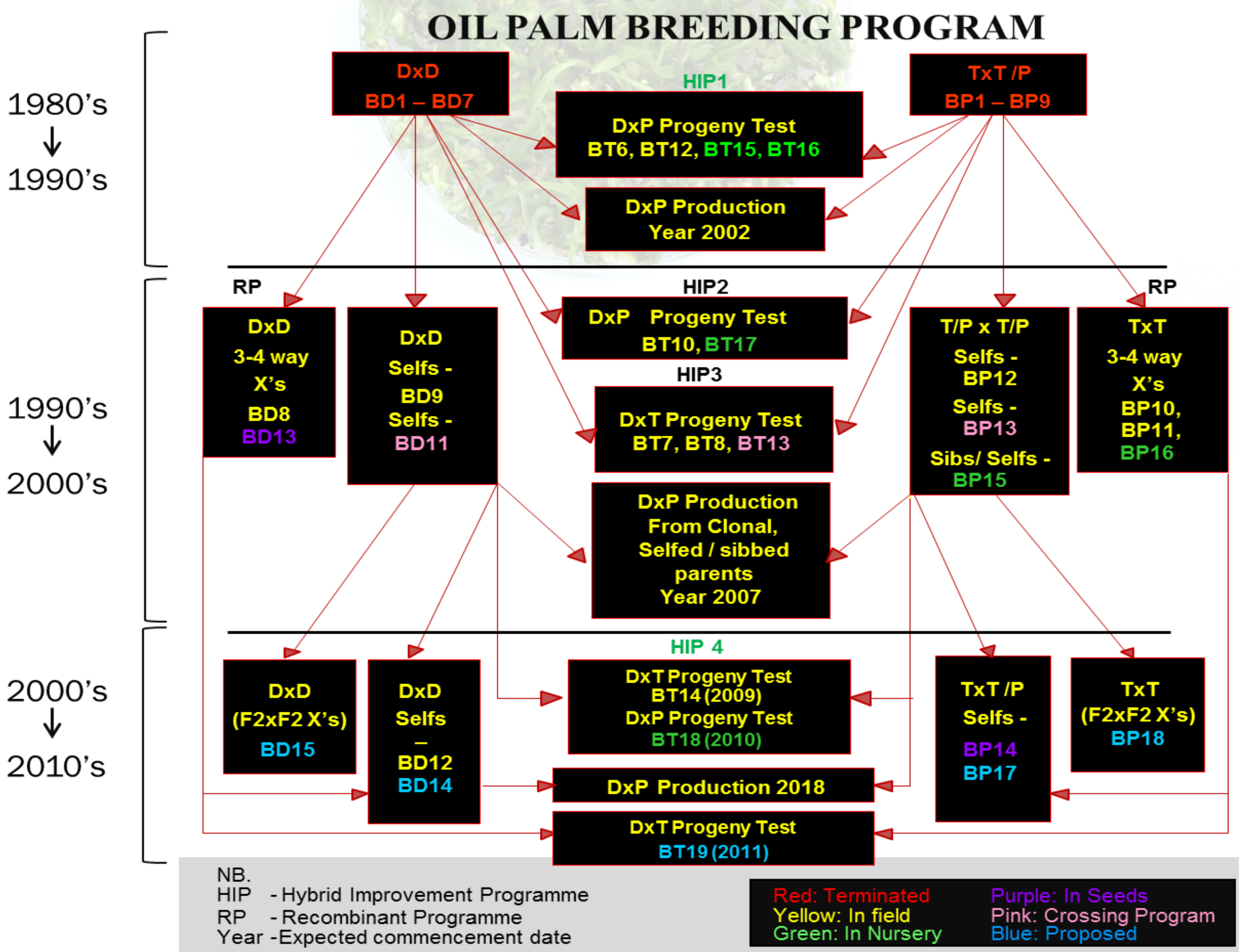


***Figure 3.** A modified recurrent selection scheme for oil palm breeding used by Advanced Agriecological research (AAR)*

required. The design of new plantings or replanting must take into consideration the need for mechanization of all field operations including harvesting and collection in future. Errors made at this stage are difficult and costly to amend. Moreover, sufficient labor for effective management of oil palm plantations is now a major constraint to achieving site yield potentials in Malaysia and the more interior areas of Indonesia.

After land clearing and field planting of oil palm, leguminous cover crops such as 4 kg *Pueraria javanica*, 4 kg *Calapognium mucunoides* and 2.0 kg *Calapogonium caeruleum* per hectare and mixed with the shade tolerant *Mucuna brateata* (136 to 148 plants per hectare) must be established quickly (**Figure 7**) to improve soil fertility and organic matter, suppress weeds, conserve soils and water, enhance soil physical property e.g. infiltration rate, reduce soil temperature and sequester C through their rapid growth (about 15 t dry matter ha^{-1} yr^{-1}). These benefits increase the site yield potential of oil palm by about 12%.

Oil palm is a relatively easy crop to manage with its relatively low density per hectare and ecological adaptability. Thus, minimal maintenance practices are implemented except to supply adequate nutrients, retain soil moisture, reduce competition and minimize pest and diseases. Since oil palm is mainly rainfed, the retention of soil moisture involves reducing soil moisture evaporation through good ground vegetation such as soft grasses and legumes, and mulching with by-products e.g. empty fruit bunches, decanter cakes and palm oil mill effluent; trap rain water in the field through broad frond stacking and conservation terraces; and increase water infiltration rate.

Most tropical soils are highly weathered and have poor soil fertility particularly in soil nutrients. Tropical soils are also very diverse with wide ranging soil properties. Thus, to sustain the oil palm growth and yield, site-specific fertilizer programs tailored to meet the palms' nutritional needs in a balanced proportion are implemented. In general, the N, P and K rates

Planting a mixture of legume species to obtain full ground cover within 6 months after planting (a). Picture taken when the oil palm was 12 months old.

Picture taken of the same field when the oil palm was 70 months old and palm canopy is fully closed (b). The shade tolerant legume, *Mucuna brateata*, still thrived in the inter-row area.

***Figure 7.** Quick establishment of legume covers using a mixture of fast growing legumes and shade tolerant legume to protect the soils and improve soil fertility.*

point mutation causing the differences in fruit type (dura, tenera and pisifera) and fruit color (nigresens and viresens), which occurred in natural population, hence, the availability of molecular markers. The markers that segregate palms bearing different fruit types could be applied as legitimacy checks in commercial seed production and segregating breeding palms for efficient and effective field trial management.

Quantitative trait loci mapping and subsequently genomewide/genomic selection, are approaches used towards the realization of marker assisted selection for polygenic traits, which currently are still at their early stage such as proof of concept. In addition, other genomic methods are being employed in oil palm including expressed sequence tags (ESTs) from various tissues and DNA microarray for profiling gene expression and production of high-value products.

AGRO-MANAGEMENT

Oil palm growth and yield are highly responsive to the environment and management. The primary aim of best agro-management practices is to obtain the site yield potential, which is the maximum realizable yield of the planting materials at each site or field when all the agronomic and management inputs, decisions and actions are not limiting. Thus, the site-specific agronomic inputs are implemented to ameliorate the growing environment towards the ideal conditions for oil palm i.e. overcoming or alleviating any soils, water and nutritional constraints. The site yield potential of oil palm is achievable on a large scale and it varies between 30 and 43 t of fresh fruit bunches (FFB) ha^{-1} yr^{-1} in most parts of Malaysia except in marginal or degraded soils. These FFB yields were obtained under different climatic zones, planting density and palm age.

The best agro-management practices start from pre-planting where the choice of planting site and planting materials are decided.

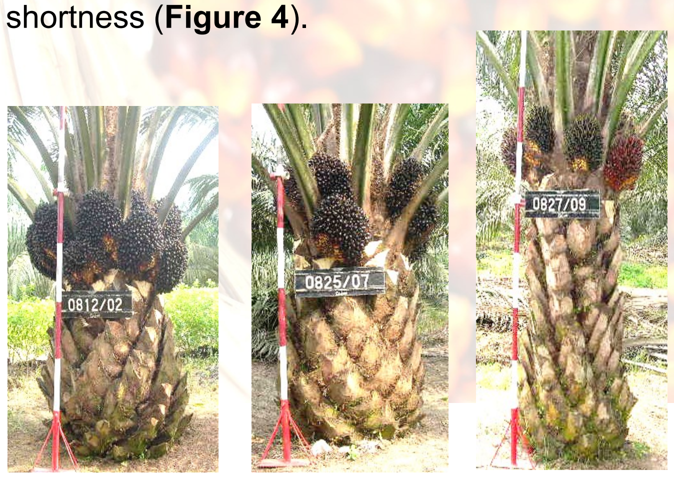
If there is a choice in planting sites, those which have high site yield potential, require less inputs and with fewer problems in crop recovery are preferred. Crop suitability surveys where the soils are checked, and input requirements and management levels assessed are highly recommended especially in new situations where experience of the crop is limited. Also, the environmental and socio-economic impacts must be assessed and the local people's opinions and consents sought prior to oil palm development.

The realities of commercial seed production are that very large numbers of parent palms are used so that high variability is inherent in the planting materials used. The exceptions are semi-clonal seeds where limited numbers of mother palm are chosen for seed production, and clones. Therefore, good nursery practices are required to produce uniform, large and well-grown seedlings at planting out. This will minimize the effects of transplanting shock and pest attacks, and achieve uniform stand of normal oil palms in the field. It is common to cull about 25% of the seedlings because of abnormal or runty forms, and most of these anomalies are disposed of at the pre-nursery stage. The seedlings are usually ready for field plantings when they are 12 to 14 months old.

Zero burn planting and replanting are now the norm in oil palm cultivation. This practice leaves behind a large quantity of biomass which decomposes naturally and sequesters C as soil organic matter in-situ. Pre-lining for an oil palm density of 136 to 148 palms ha^{-1}, except in peat soils where 160 palms ha^{-1} are usually planted, should be carried out. Terraces are constructed in hilly terrain above 10° to conserve soils and water, and provide access to the palms. In flat terrain with imperfect drainage, systematic drains are laid out to lower the water-table to about 75 cm at most times. An efficient road system for transport of FFB, mechanization and communication is absolutely necessary. In general, about 100 to 150 m of road per hectare of planted field is

have resulted in some overlap between different breeding programs. Early research programs in Africa concentrated on breeding and improvement of tenera populations while 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 prominent derived pisiferas are Dumpy-AVROS, Dumpy-AVROS-Yangambi, URT-AVROS, and URT-Cameroon (**Table 2**). The development of these derived pisiferas reflects the different emphasis in the breeding programs. For examples, in Ulu Remis pisifera the emphasis is on yield improvement, Dumpy-AVROS pisifera emphasizes both yield and short palm height while Dumpy-AVROS-Yangambi adds high bunch number and oil per bunch without compromising on yield and shortness (**Figure 4**).



Deli Dura x Dumpy-Avros-Yangambi | **Deli Dura x Dumpy-Avros** | **Deli Dura x Avros**

Figure 4. *Effect of introgressing Dumpy (dwarf) and Yangambi (high bunch number) into the Avros derived pisifera on growth and bunch characteristics of 5 years old palms. Each marking on the pole is 30 cm.*

Though oil palm has been established as a leading oil crop in the world, the lengthy breeding cycle is the key stumbling block to the production of true F1 hybrid, where every palm is genetically identical, produced from inbred lines of parents from different heterotic groups, hence homogenous but heterozygous. The commercial oil palm planting materials, however, are DxP hybrids at population level through crossing between the selfed or sib-mated duras, generated from progeny tested duras, with the progeny tested pisiferas. Mechanistically, the dura female inflorescences are isolated using bags that are densely woven with pore size smaller than a single grain of pollen. When the isolated inflorescences are receptive; the pre-harvested and processed pisifera pollen is then dusted onto the inflorescences. This is termed as controlled pollination. When the inflorescences form into a mature bunch, the bunch is further process to obtain seeds. As oil palm seeds are considered to be recalcitrant seeds, dormancy breaking by heating at 38 to 40°C for 40 to 60 days is required, before soaking the seeds to raise moisture for germination. Hence, planters commonly will either purchase pre-heated seeds or germinated seeds in order to reduce the complexity of required facilities to break dormancy.

Riding on similar philosophy of F1 hybrid, via classical breeding approach, oil palm breeders conduct interspecific crosses on the only two oil palm species, *E. guineensis* and *E. oleifera*, that combine relatively readily, with the objective to gather useful traits from both species, e.g. high oil yield, slow vertical growth, oil with low melting point, high carotene content, high vitamin E content and disease resistance. Though the two species combine relatively easy, however, the hybrid suffers from poor pollination, hence poorer oil to bunch ratio, which subsequently affected its use as the dominant commercial planting material. Commercial OxG hybrids are mostly exclusively planted in Central and South America as the E. guineensis shows little tolerance to bud rot, which is a devastating oil palm disease in South America that kills and spreads speedily with no effective control measures.

TISSUE CULTURE

The success of oil palm tissue culture for micro-propagation reported in mid 1970s opens the avenue to fix genotypes that are superior, philosophically being the same as F1 hybrid production. The process of tissue culture is a series of culture stages with different growing media. The stages by chronological orders are: ex-plant inoculation stage, callusing stage, embryogenic callus stage, embryoid proliferation stage, shoot development stage, rooting stage and plantlet acclimatization stage (**Figure 5**). The dominant media is usually semi-solid gel culture, while in the embryogenic callus stage liquid culture might be used. The route of either entire gel culture or gel culture with liquid phase is genotype dependent.

Genetically superior individuals could be mass-selected from population with large genetic variance for micro-propagation meeting the genetic improvement desired – a short-cut approach.

Whether the genetic improvement from the tissue culture micro-propagation approach supersedes the classical breeding approach depends on the accuracy of ortet selection and the population. Breeders advocate selecting from advanced breeding populations that have high means and preferably low genetic variation, with selection emphasizing on traits with high heritability estimates, e.g. oil to bunch ratio. On average over the past two decades, tissue cultured oil palms have 18% higher oil yield ha^{-1} yr^{-1} compared with those from seeds.

However, paradigm shift in oil palm crop improvement was not observed due to the occurrence of undesirable somaclonal variants among oil palm tissue culture ramets. These variants have abnormal reproductive organ, which is known as mantle, where the vestigial androecium develop into fleshy supernumery carpels surrounding the fruit, presenting a mantle-like object (**Figure 6**). The mantle phenotype is suggested to be epigenetic in nature,

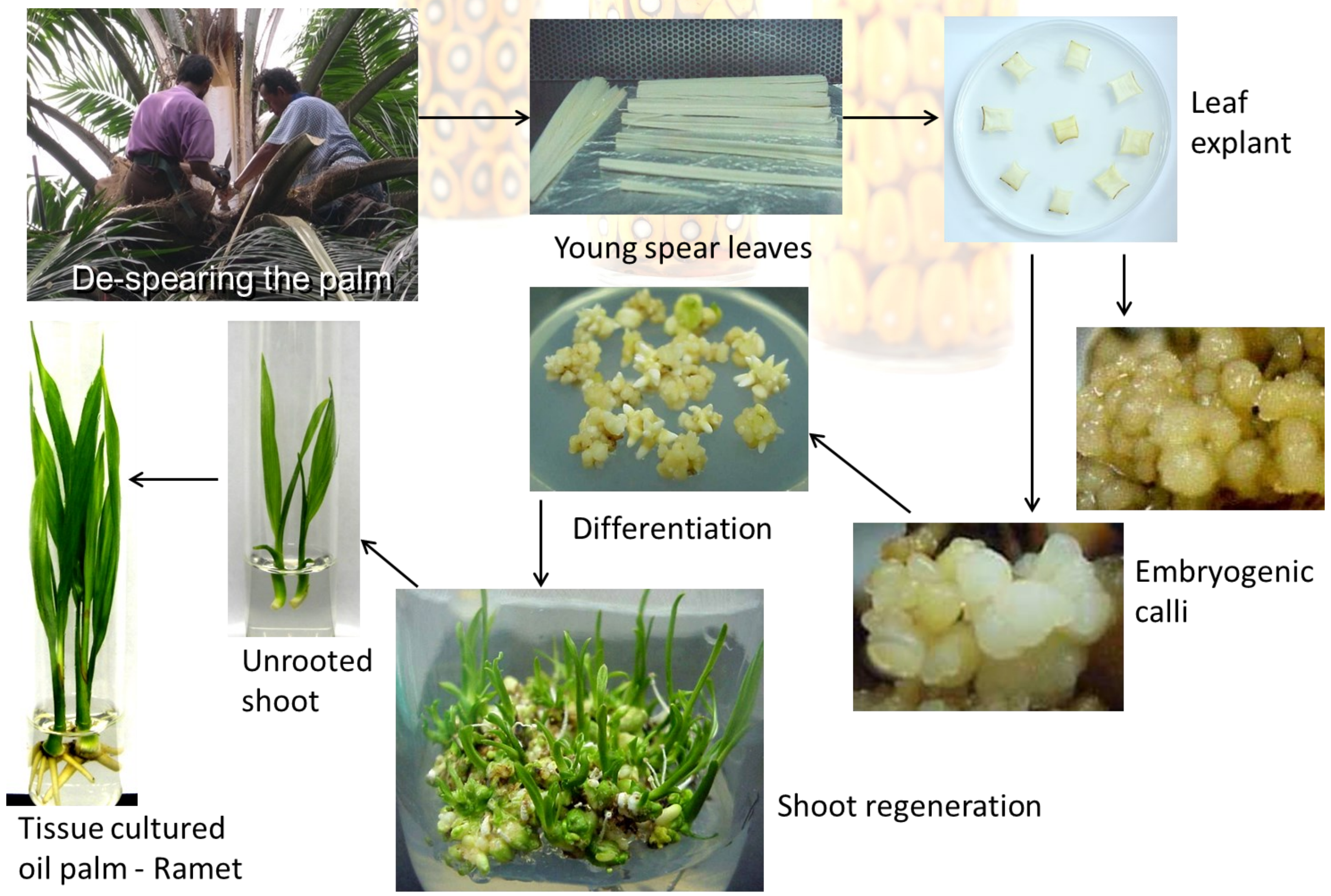


***Figure 5.** The process of tissue culturing of oil palm and its different growth stages*

where a range of mantle severity is observed with some affected ramets being revertible to the common solitary fruit structure, typically on the less severely affected ones. Severely affected ramets are commonly infertile where bunches abort before ripening. With good house-keeping, efficient laboratory management and stringent quality controls, oil palm tissue culturists could keep the average somaclonal variation to less than 5%.

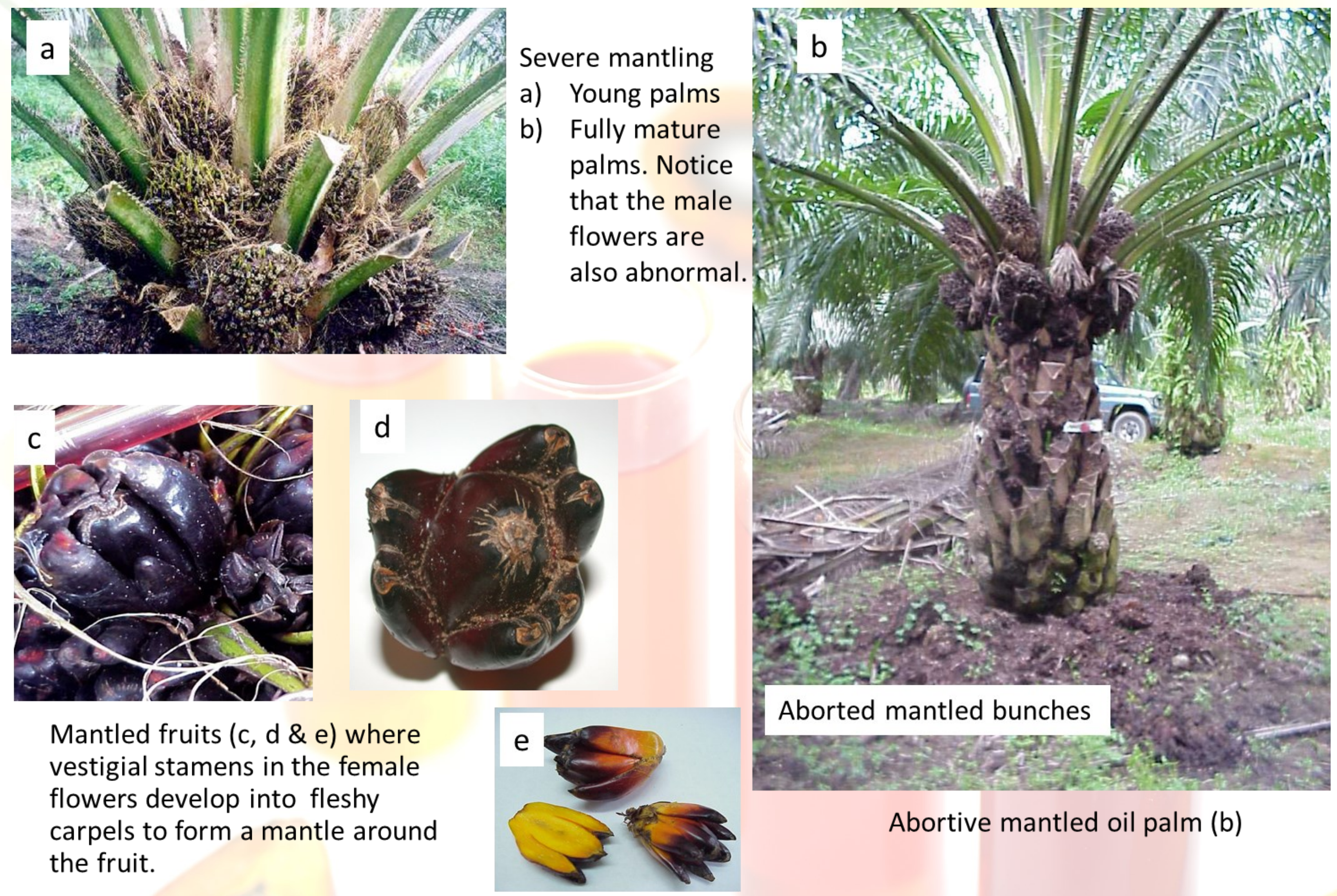


***Figure 6.** Mantled palms and fruits of tissue culture oil palms. Severe mantling will cause the bunch to abort*

In view of mantling, clonal seeds strategy was carried out as an intermediate step between the classical breeding strategy and the tissue culture strategy. Superior parents are cloned to sexually propagate superior family which is commonly bottlenecked by the rare superior maternal parents and the limited inflorescences that each can produce annually. In 2000s, commercial semi-clonal seeds were available to the planters.

MOLECULAR BREEDING

As the science of molecular genetics advances and the promises from transgenic effort in other crop become evident, similar attempts are being made in oil palm but with very limited progress. Apart from the challenges related to being a tree crop e.g. large planting area, the long breeding cycle (as multiple testing cycles are required for transgenic crop) and etc., the strong resistance by consumers on transgenic crop in general, and the consumers' misperception of palm oil as a low grade edible food, are also limiting factors.

Nevertheless, with the public availability of oil palm genome sequence in 2013, further efforts to find molecular markers for selection before flowering are made in many crop improvement programs to shorten breeding cycles speedily. In the same year, molecular biologist had successfully elucidated the single