UNEDITED

PROCEEDINGS OF THE

INTERNATIONAL SEMINAR ON OIL PALM BREEDING AND SEED PRODUCTION AND FIELD VISITS

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Jointly organised by:

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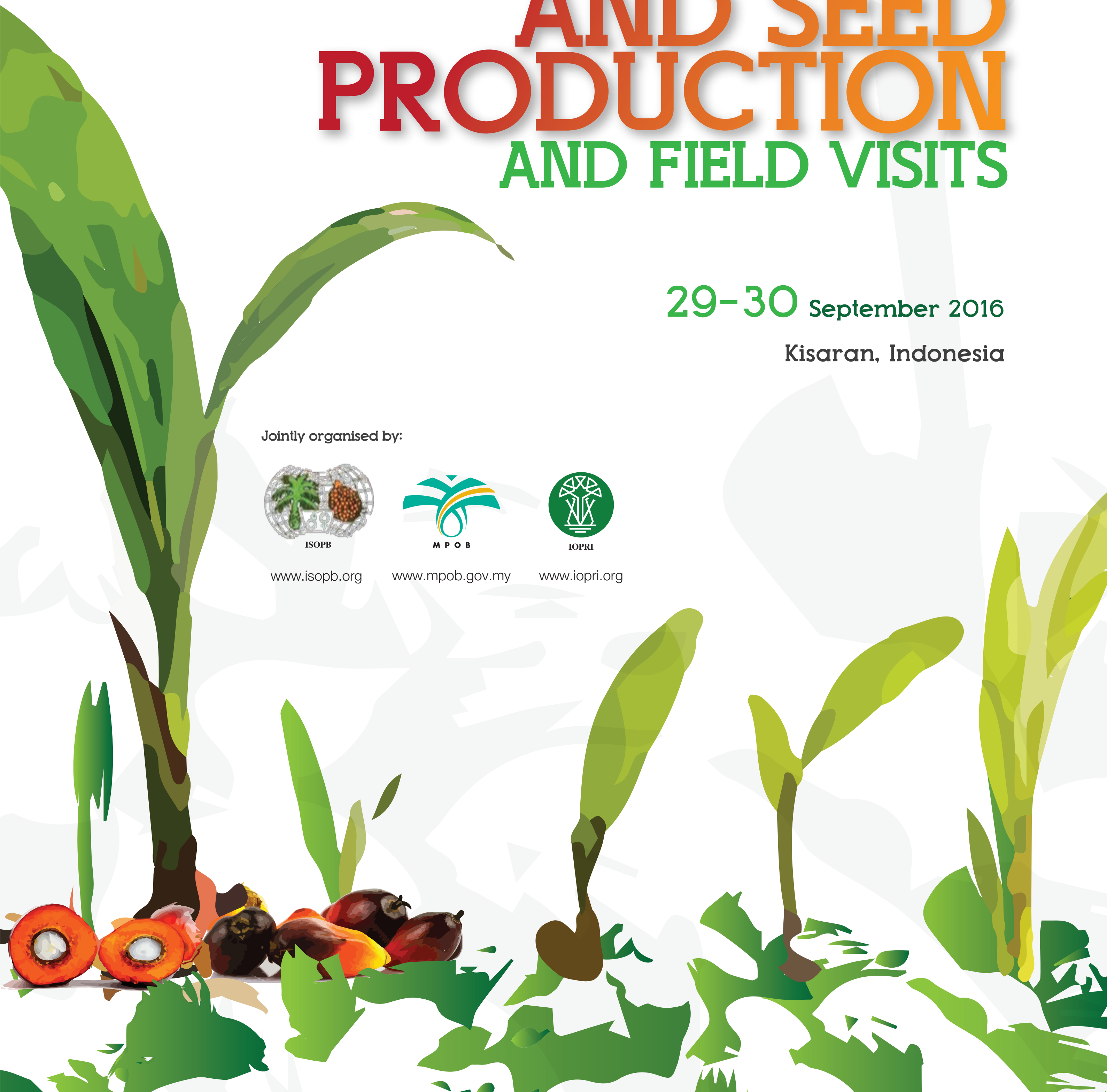

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The International Society for Oil Palm Breeders

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MPOB

Malaysian Palm Oil Board

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Indonesian Palm Oil Research Institute

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INTERNATIONAL SEMINAR ON OIL PALM BREEDING AND SEED PRODUCTION AND FIELD VISITS

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Malaysian Palm Oil Board (MPOB)

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www.mpob.gov.my

MPOB is the premier government agency entrusted to serve the country's oil palm industry. Its main role is to promote and develop national objectives, policies and priorities for the well-being of the Malaysian oil palm industry. It was established on 1 May 2000, taking over, through a merger, the functions of the Palm Oil Research Institute of Malaysia (PORIM) and the Palm Oil Registration and Licensing Authority (PORLA). Each of these respective organisations has been involved in the oil palm industry for more than 20 years and it is to render more effective services as well as to give greater national and international focus to the industry that MPOB was instituted. The organisation's activities include research, publication, development and implementation of regulations and the promotion of the palm oil industry in Malaysia. The MPOB oversees all stages of palm oil production in Malaysia, from planting to exporting to enhance the well-being of the Malaysian oil palm industry through research, development and excellent services.

The International Society for Oil Palm Breeders (ISOPB)

President: **Dr Ahmad Kushairi Din**
isopb.mpob.gov.my

The Society is known as 'Persatuan Ahli-Ahli Pembiak Baka Kelapa Sawit Antarabangsa' or 'The International Society for Oil Palm Breeders'. The general aims of the Society is to advance the knowledge of oil palm breeding through international co-operation. In order to achieve this aims, the Society has in the past and will continue to engage itself in the activities such as organising seminars and workshops both locally and internationally to facilatate the exchange and sharing of new knowledge in oil palm breeding and related aspects of oil palm cultivation. The Society also actively involved in establishment of various committees/working groups to deal with specific aspects or problems of oil palm for the purposes of exchange of views, international collaboration and dissemination of information. In addition, the Society also promotes and assists in international exchange of genetic material for breeding and selection.

Indonesian Palm Oil Research Institute (IOPRI)

Director: **Dr Hasril Hasan Siregar**
www.iopri.org

IOPRI is major oil palm research institute in Indonesia. Various technological packages have been produced by IOPRI and widely used in Indonesian oil palm industry such as superior oil palm planting materials, biological agents for pest and disease control, fertiliser formulations, integration of palm oil and cattle, and others. Additionally, IOPRI also provides laboratory analysis services (leaves, soil, water, oil and waste), technical assistance, and training. IOPRI has primary responsibility to do research and development in all aspects of oil palm and distribute the results to the oil palm industry. The scope of the research done by IOPRI includes: breeding and plant biotechnology, soil science and agronomy, plant protection, technology engineering and environmental management, yield processing and quality, and socio-techno economic.

WELCOME REMARKS by

DR AHMAD KUSHAIRI DIN

Director-General of Malaysian Palm Oil Board (MPOB)
President of the International Society for Oil Palm Breeders (ISOPB)

Y Bhg Dr Hasril Hasan Siregar
Director, Indonesian Oil Palm Research Institute (IOPRI),

Distinguished guests, speakers and participants,

Ladies and gentlemen,

Good morning. On behalf of International Society of Oil Palm Breeders (ISOPB), Indonesian Oil Palm Research Institute (IOPRI) and Malaysian Palm Oil Board (MPOB), I wish a warm welcome to members of the society, colleagues and participants to this international seminar, jointly organised by the mentioned three organisations. The theme of today's seminar is Oil Palm Breeding and Seed Production. In conjunction with the seminar, there are two field visits, namely PT Socfindo and PT ASD-Bakrie. I am sure the seminar and the field visit would be beneficial, not only to your goodself, but also to the organisation and country you are representing.

Ladies and gentlemen,

It was recalled that an event of similar nature – International Seminar on the Progress of Oil Palm Breeding and Selection, organised by ISOPB and IOPRI, was held in Medan, year 2003, which was 13 years ago. For the pass 13 years, there were many scientific breakthroughs in oil palm, typically under the discipline of molecular biology, *e.g.* the oil palm genome was sequenced and become publicly available, and the science behind of oil palm mantling was understood. These fundamental research findings are very much applicable to applied sciences like oil palm breeding. In addition, with today's technological advancement, revisiting seminar theme of such after 13 years is, hence, appropriate.

Ladies and gentlemen,

I am certain apart from the exciting content from the presentations by speakers, the scientific interactions among members and experts have always been the highlights of this seminar. The society believes that this is important in enhancing knowledge for the benefit of the oil palm industry.

Ladies and gentlemen,

I would like to thank a few groups of people: the speakers for sparing their time to share their knowledge with us, the organising committee and the secretariat from ISOPB and IOPRI, for ensuring all aspects of the seminar is in orderly manner, and most importantly, to all participants who had come near or far, making this seminar possible.

Special thanks are due to PT Socfindo and PT ASD-Bakrie for the field visits.

Thank you.

OPENING REMARKS by

DR HASRIL HASAN SIREGAR
Director of the Indonesian Oil Palm Research Institute (IOPRI)

Y Brs Dr N Rajanaidu, The Deputy President of ISOPB
Distinguished guests, speakers, participants,

Ladies and gentlemen,

Good morning,

It is a great pleasure for me on behalf of the Indonesian Oil Palm Research Institute (IOPRI) and the Organising Committee of the ISOPB to welcome the guests, speakers, and all participants of the International Society for Oil Palm Breeders (ISOPB) and Seed Production Seminar 2016 in Kisaran, North Sumatera, one of the historic places of oil palm plantation in Indonesia. I believe that The ISOPB, as an annual event since 1985, offers international cooperation between its members via transfer of advance knowledge in oil palm breeding through seminars, workshops, and field visits in countries around the globe.

The ISOPB and Seed Production Seminar 2016 will elaborate the state of the art of research and development as well as give you the opportunity to discuss about progresses reached by other experts in oil palm breeding activities as well as seed production.

Ladies and gentlemen,

Yesterday, we enjoyed field visits and had fruitful discussion during the visits in breeding trial and seed production of PT ASD-Bakrie Oil Palm Seed Indonesia and PT Socfindo. And today, we are still overwhelmed by hospitality of PT ASD-Bakrie Oil Palm Seed Indonesia by providing The Bakrie Club as the venue for today half-day seminar. Since then, I would like to take this opportunity to thank the both companies (PT ASD-Bakrie Oil Palm Seed Indonesia and PT Socfindo) for their supports and cooperation in making The ISOPB and Seed Production Seminar 2016 as a successful event.

The half-day seminar will deliberate nine papers in two sessions covering most of up to date aspects of oil palm breeding. We hope you enjoy the papers.

Ladies and gentlemen,

Finally, I would like to extend my gratitude to the delegates, chairmen, distinguished speakers, organising committees, participants, and others who have contributed in one way or another to make this seminar and yesterday field visits successful.

I wish you have a pleasant seminar.

Thank you.
Assalamualaikum wr. wb.

SESSION 1

P1

Current Status of IOPRI Oil Palm Breeding Program and Seed Production

Edy Suprianto[1]; Yurna Yenni[1]; Nanang Supena[1]; M Arif; Sujadi; Heri A Siregar; Hernawan Y Rahmadi; Sri Wening; Retno D Setiowati; Rokhanah Faizah and Abdul Razak Purba[1]

[1]Indonesian Oil Palm Research Institute, Jl. Brigjen Katamso No. 51 Medan 20158
Corresponding author's email: edygrey@gmail.com

ABSTRACT

Nowadays, oil palm area in Indonesia covers more than 11 million ha, and the Indonesian crude palm oil (CPO) production has reached 30 million tonnes. Breeding effort through the exploitation of heterosis effect from the crosses between *dura* (D) x *pisifera* (P) to produce DxP hybrid materials has undoubtedly contributed to the increasing of oil palm yield. Oil palm breeding program in Indonesian Oil Palm Research Institute (IOPRI) have been started since 1920s when the breeder in AVROS selected an elite lines SP540 T. The scheme of reciprocal recurrent selection (RRS) was applied to the base populations developed by Marihat Research Station in collaboration with IRHO - France in the beginning 1970. The first cycle of RRS produced six oil palm varieties that have been released by Ministry of Agriculture in 1985. The second cycle of RRS had been started in 1986 and had been revised in 1992. In this cycle, IOPRI tested 323 DxT crosses on 21 progeny trials that have been carried out in North Sumatera and Riau regions. The best linear unbiased prediction (BLUP) method was applied to calculate general combining ability (GCA) of the tested parents. From the second cycle of RRS, IOPRI produced five DxP hybrid varieties released in 2003, 2007, and 2010. The third cycle of RRS is a recombination of the best parents identified in second cycle, and the additional parents from Binga population. The progeny trials of the third cycle (RRS 3A) have been started in 2008, planted in North Sumatra and Kalimantan regions. Simultaneously, improvement within the groups *Dura* and *Tenera* have been undertaken. IOPRI's breeding objectives currently have not only been focused on the increasing of oil yield, but also on the development of resistance variety as well as improving oil quality. Large scale of screening to identify *Ganoderma* resistance varieties has been carrying out by involving around 350 DxP crosses. Improving oil quality has been implemented by backcross program of OG hybrids with the best parents from RRS schemes. Introduction of new oil palm genetic material from Cameroon and Angola has opened the opportunity for IOPRI to develop oil palm cultivars with novel traits. This paper will elaborate current status on oil palm breeding in IOPRI including collection of existing genetic materials, breeding objectives, breeding strategies, breeding achievement, and the use of molecular markers in oil palm breeding as well as oil palm seed production system.

Keywords: oil palm, breeding, recurrent selection.

P2

Performance of Asian Agri Group's 2nd Generation DxP Planting Materials - Moving to the Next Level of Improved DxP

Mukesh Sharma; Ang Boon Beng; Harkingto and Manjit Sidhu

Asian Agri, Jl MT Horyono No. A1, Uniplaza Building, East Tower 6th Floor, Indonesia

ABSTRACT

Asian Agri Group commenced its oil palm breeding program from a wide diversity of ABPRO germplasm from ASD de Costa Rica in 1996. The genetic background of its deli population consists of URD ex- Guthrie Chemara, KBD ex-H&C OPRS Banting, ex-Dami, PNG, ex-MARDI, ex- Socfin Johore Labis and ex-ASD de Costa Rica. The *pisifera* populations obtained were from BM 119 AVROS (ex-H&C, Banting), AVROS (Dami, PNG - DM 774, DM 735, DM 736, a composite of BM 119 introgressed with Dumpy and URT selections), Ekona Cameroon- (2/2311 T, 3/AR/7239, 14/6710 T), Ghana- ex-Calabar (32.3005 T), Nigeria ex-Calabar (32.3005 T, 1.3379T, 15.4382 T), Yangambi (YA 69 T, L 336 T), ex-Socfin Johore Labis (21061 T, 21074 T and SOC 302.91 T) as well as ex-La Me (L7T). All the parental materials were crossed and tested in large DxP trials covering 486 ha. This can be considered possibly as the largest progeny testing scheme in a single generation of breeding. Because of the extensiveness of this testing, we were able to have better precision in deciding which *dura* parents combine well with specific *pisifera* materials to produce the best *tenera* progenies. These selections form the basis of Asian Agri's 2nd generation DxP materials of which more than 600 DxP progenies have been tested with at least 5 years of yield records over a wide range of environments covering both mineral (volcanic, alluvial and inland) as well as peat (shallow and deep). From this meta-analysis as well as using GCA estimates, we identified 112 top DxP combinations arising from 12 *dura* families for GCA and 10 *dura* from separate families for SCA. Similarly, the top pisiferas were from 4 Ekona, 3 Ghana and 7 Nigerian *pisifera* families. Mean FFB yields of these DP progenies was > 33 t/ha/yr and the average OER was 33.3% implying an average CPO yield of 11.6 t/ha/yr. These parental materials are currently being propagated by selfing, sibbing and intercrosses as well as cloning, to form the next cycle of seed gardens in what will be Asian Agri's 3rd Generation of Planting Materials (GEN-3 Topaz). Concurrent with this program, we are extensively testing the elite parents in nursery inoculation trials with the expressed purpose of identifying *Ganoderma* tolerance. This will then be integrated into the conventional breeding program. As part of our on-going efforts to improve the quality of our DxP planting materials, we have raised the minimum standards and in doing so have reduced our seed production capacity from 20 million/year, down to the present 15 million saleable seeds per year.

P3

Oil Palm Breeding and Seed Production in PalmElit

Turnbull, N; Cazemajor, M; Guerin, C; Louise, C; Amblard, P; Cochard, B and Durand-Gasselin, T

PT Socfindo Aek Loba, Pulau Raja, Sumatera Utara-Indonesia 21273

ABSTRACT

The exponential growth of human population has led to an increase of the demand in raw products for energy and food consumption as well as an exacerbated pressure on the ecosystem. In this context, oil palm is becoming to play a key role as a foremost oil producing crop with minimal impact on its environment. Nevertheless, major work has still to be done in order to keep improving productivity, adaptability and sustainability of this crop. PalmElit, with its priceless experience and ground breaking breeding work, completely integrates itself in this approach. The current work aims at selecting the best parents for their ability to produce DxP hybrids with high fresh fruit bunch yields and oil extraction rates; low height increment and canopy growth. In parallel specific programs are carried on in order to develop planting material adapted to the different areas were grows oil palm. This goes through the creation of oil palm seed products resistant to diseases whether it is for bud rot in South America, *Fusarium* wilt in Africa and *Ganoderma* basal stem rot in Asia. Secondary traits have also been worked on such as tolerance to drought for Africa and Asia and low lipase activity after harvest especially useful for small planters. These latest improvements are based on strong collaborations with seven different partners with whom are currently followed five experimental setups in Latin America, Africa and Asia, three disease resistance screening units for *Ganoderma* basal stem rot and *Fusarium* wilt and two tissue culture laboratories. Marker assisted selection programs as well as entomology and agronomy projects are also on-going in association with Cirad, PalmElit's majority shareholder.

At its creation in 2009, PalmElit has inherited 70 years of experience in oil palm breeding and linked it to the most recent research and development in order to bring to the planters highly advanced *E. guineensis* and *E. oleifera* x *E. guineensis* hybrid planting material. Currently, for *E. guineensis* some of the most yielding commercial crosses can reach 8.5 t of CPO ha^{-1} yr^{-1} at adult age in North Sumatra with stable production at up to 20 years old. Amongst them, some commercial crosses have height increments of 45 to 50 cm yr^{-1} and canopy of less than 600 cm ray in areas with no water deficit. For OxG hybrids, production can reach 6.5 t of CPO ha^{-1} yr^{-1} with height increments of less than 25 cm yr^{-1} in areas with no water deficit. These crosses are highly resistant to Bud rot.

ABSTRACT

The latest developments of our research are made available through the seed gardens established all around the globe in collaboration with our partners.

For South America, through our joint venture with PHV-Colombia, SEPALM, and together with Murrin Ecuador PalmElit focus on producing high yielding OxG hybrids with high resistance to Bud Rot. The seed garden in Ecuador has also a second focus on producing *E. guineensis* Deli x La Mé material including partially resistant to Bud Rot varieties.

For Africa, the seed garden in Benin created together with INRAB focuses on producing Deli x La Mé *Fusarium* wilt resistant genetic material and low lipase crosses especially created to respond to the problematic of African production seasonality. The high tolerance to drought of the Deli x La Mé material makes it particularly adapted to the regional weather conditions.

For Asia, through our joint venture with UPOIC-Thailand, SIAM ELITE PALM, we focus on producing Deli x La Mé and Deli x Yangambi planting material as well as the Deli x La Mé compact developed to improve young age profitability of oil palm for small holders. The high tolerance to drought of some Deli x La Mé material makes it particularly adapted to the regional weather conditions. Together with Socfin Indonesia, we focus on producing Deli x La Mé and Deli x Yangambi planting material as well as the Deli x La Mé *Ganoderma* partially resistant developed for Asia and its aging plantations.

This exceptional setup is carefully monitored and improved to keep on bringing to the planters the most recent progress specifically aimed at their requirements.

INTRODUCTION

According to the OECD-FAO outlook, vegetable oil consumption will increase from 167 million tonnes in 2014 to 210 million tonnes by 2024 (OECD-FAO Agricultural Outlook 2015) with more than 30% coming from oil palm production. Yet, production in Malaysia and Indonesia is forecasted to stagnate in the coming years because of the negative impact of *El Niño*, the declining yields in Malaysia as well as the effect of the land use limitations endorsed by Indonesia earlier this year. This trend, coupled to the implementation of biodiesel use policies in major countries such as the US, EU and especially Indonesia will impact the overall availability of oil palm for food consumption and should pull up the price of this major commodity (Oil World Annual, 2015). On a longer term basis, the growth of the African population, which will quadruple in the coming 40 years, will stress even more the need to intensify oil palm production especially for food consumption(World Population Prospects: The 2015 Revision – United Nation publications). This short and long term need for oil palm must be rapidly answered by increasing productivity as well as increasing planted surfaces on degraded and marginal lands with more extreme growing conditions in Asia, Africa and Latin America. This implies that highly productive planting varieties adapted to these diverse growing conditions are readily available to the growers worldwide. Thanks to its extensive research and development and its unique worldwide network of partnerships, PalmElit is able to supply planters all over the globe with optimum planting solutions to overcome biotic and abiotic limitations and improve productivity.

ORIGINS OF PALMELIT

Pre-WWII Breeding

Prior to World War II, French agricultural services were in charge of the research and development in all of the French West African colonies. The first selections of oil palm were done in Côte d'Ivoire between 1920 and 1924 (Houard, 1926 and 1927) and led to the development of the La Mé breeding population of restricted origin (BPRO). In parallel, between 1925 and 1934, 1727 hectares of palms were planted in Dabou (Côte d'Ivoire) using Deli seeds coming from Mopoli estate (Brédas, 1969). A selection from this population was made and is the base of what is known today as the BPRO "Deli Dabou". At the same time as in Côte d'Ivoire, prospection work was conducted in Benin and by 1927, 38 wild tenera palms had been selected and selfs were planted in Pobè (Gascon et de Berchoux, 1964).

1942-1984, Breeding at IRHO

At the midst of World War II, the increased demand for vegetable oil led to the creation of the "Institut pour les huiles et les oléagineux" – IRHO in 1942. This institute kept on working extensively on oil palm breeding for more than 40 years until the creation of Cirad-IRHO and then Cirad in 1984. Between 1942 and 1948, the first breeding populations "La Mé" and Deli "Dabou" were specified and improved to be later used in combinations and with other various origins in the "International Experiment" (Gascon and de Berchoux, 1964; Bénard 1965). The first Deli *Dura* x African *Tenera* crosses were tested and proved to be more productive than pure crosses. The implementation of a modified reciprocal recurrent selection scheme at IRHO was decided in 1957 (Meunier & Gascon, 1972) and the 1st cycle of recurrent selection was initiated between 1959 and 1966 in La Mé (Durand-Gasselin *et al.* 1999) which enabled a first improvement of the yield of 12 to 15% (Gascon *et al.* 1988, Nouy *et al.* 1991). From the mid-70s to the end of the 80s, a first series of 2nd cycle trials was planted through a network of IRHO research centres and partnerships in Indonesia, Côte d'Ivoire, Cameroun and South America (Nouy *et al.* 1991) which gave an improvement of 15 to 18% compared to the best crosses of 1st cycle (Gascon *et al.* 1988; Nouy *et al.* 1991). At that same time, IRHO developed its first protocols for vegetative propagation (Rabéchauld et Martin, 1976) with some improvements added in the early 80s (Pannetier *et al.*, 1981). The first clones coming from fast growing callus, planted in 1976, all showed abnormal flowering and bunch failure called mantled abnormality which led to have non-producing palms. Improvements were added later on after the creation of Cirad.

In the late 50s and early 60s, *Fusarium* wilt in Africa and Bud rot complex in South America were identified as major diseases provoking serious damages to the plantations (Turner *et al.*, 1970; Renard *et al.*, 1971). For *Fusarium* wilt, some blocks in Dabou reached 40% infected palms at 8 years old (Renard *et al.* 1972). Long standing observations in the field and with contaminated young plants showed differences in susceptibility, these results were exploited to develop a young plant screening procedure in prenursery. Sources of resistance were identified in 1st cycle material and were improved during the 2nd cycle of reciprocal recurrent selection (Renard *et al.*, 1980). For the bud rot complex, although *E. guineensis* is known to be very susceptible to the disease, Renard and Quillec reported in 1984 that the interspecific hybrids *E. guineensis* x *E. oleifera* was highly resistant. Some breeding work to develop productive hybrid palms was undertaken and led to the commercialisation of the first *Tenera E. guineensis.* x *E. oleifera* seeds to be released.

1984-2009, Breeding at Cirad

By 1984, it was decided to regroup various technical institutes into the newly formed French Agricultural Research Centre for International Development (Cirad). Although the structure changed, the breeding work as well as the partnerships setup during IRHO time went on. New 2nd cycle trials were planted in Africa, Asia and South America followed by the first interconnected genetic setup planted in Indonesia between 1995 and 2000 and where 561 crosses were tested. This block was constructed so that parent palms could all be compared and no more specific crosses which led to an improvement of the oil yield of about 8%. In parallel, tissue culture procedures were improved in the late 80s and early 90s and clones were assed for their agronomic value in various trials (Cochard *et al.*, 1999; Durand-Gasselin *et al.*, 2006). At the same period were developed new methods of analysis using the latest discoveries made in molecular biology which led to the development of the first molecular tools such as ID checking, now used in routine, or QTL analysis.

After the creation of Cirad, the work started in Côte d'Ivoire on *Fusarium* wilt was continued and new varieties resistant to the disease were released to the planters. In 2004, after some years of development, a new screening unit was setup in Cameroun with Socfin group followed by a setup in Benin in 2006. Since the first tests in the 70s, over 20.000 progenies have been screened and analysed for their level of resistance leading to the selection of production of highly resistant varieties.

Similar work was undertaken in Asia at the end of the 90s, beginning 2000s with the identifications of differences in susceptibility to Basal Stem Rot caused by *Ganoderma boninense*. Using the same idea as for *Fusarium* wilt, a nursery screening unit was successfully created and routine work started in 2009 which led to the release of the new intermediate resistant variety in 2013 (Turnbull *et al.*, 2014).

On the contrary, the causal agent of Bud Rot in Latin America is still unknown therefore breeding for resistance is difficult as it relies exclusively on field trials. Commercial material planted since the 80s has been assessed and in some areas where mortality rose to 100%, some varieties showed less than 40% infected palms (Amblard *et al.*, 2009; Louise *et al.*, 2014). Selection was done within the best varieties and crosses were found with 30 to 40% of dead palms only. These results obtained in field trials are encouraging and show that breeding for resistance in *E. guineensis* is possible even if it will require a lot of time.

2009 – Onward, Breeding at PalmElit

At the beginning of the new millennium, it was decided to separate all the breeding and seed production activities from Cirad which led to the creation of PalmElit in 2009; the company ensuring the continuity of the work done during the past 50 years. At that time, a new new experimental design was being setup in Indonesia since 2005 to test new parents from 2nd cycle as well as a large amount of newly introduced material. Since then, planting of the genetic experimental design in Indonesia has finished so as the planting of the new 3rd cycle block in Nigeria and Ecuador.

In the meantime, the tissue culture process has been improved with the use of a liquid suspension step for embryogenesis giving less than 5% abnormal palms (Durand-Gasselin *et al.*, 2010). It has been used in routine in Colombia for a little while now. Since a new lab has been built by our Indonesian partner and will be used as a tool for the breeders; specific work is also conducted in France to save highly important parental palms.

In terms of breeding for disease resistance, a new *Ganoderma* basal stem rot screening unit is being setup in Cameroun and should be operational in the coming year. Special trials for resistance to the Bud rot complex have also been planted in areas with different expressions of the disease. This new step should enable to select highly productive *E. guineensis* resistance to bud rot.

From IRHO to PalmElit, the Importance of Partnerships

For about 40 years, IRHO has benefited from its network of research stations in all of its West African colonies to setup trials and genetic gardens. Still, collaborations were organised with private companies and public research institutes in Asia and South America in order to exchange material and organise joint programs. Nowadays, although IRHO's network of stations no longer exist and some partnerships have ended, PalmElit still relies on tight collaborations and 2 joint ventures all over the world to be present in all major oil palm producing regions to setup trials, laboratories and seed gardens to fulfil the need for high quality oil palm planting solutions.

BREEDING FOR OIL YIELD

One of the main objectives of oil palm breeding is to improve the oil yield. This objective is shared between all areas of cultivation and is achieved using joint setups and analyses.

Genetic Setups

Until the mid-90s, progeny tests were generally organised as individual trials each testing a specific cross previously identified as promising. These trials used a reference cross for comparison and were organised to focus mostly on the exploitation of the specific combining ability to select the best crosses for seed production. The 1st cycle genetic block planted in La Mé in the 60s and the two 2nd cycle genetic blocks planted in the 70s and 80s in La Mé and Aek Kwasan followed this methodology. It enabled to identify high performing crosses and organise a strategy adapted to each group by promoting recombination within the Deli group and selfs within the B group.

The genetic block of Aek Loba Timur planted between 1995 and 2000 in Indonesia was the first setup conceived using an incomplete factorial mating design enabling to assess and compare many parental combinations by focusing on the general combining ability to select the best parents for seed production. Although planted in one single location, the exploitation of this block was used for all areas of cultivation since the selected parental material was spread to all seed gardens. The use of incomplete factorial mating designs as well as inter-block connecting crosses and tester palms is now being applied routinely for all genetic setups such as the ones planted in Indonesia between 2005 and 2013, in Nigeria and Ecuador between 2010 and 2016 and Cameroun since 2013. These unique arrangements enable to use the results from one set of experimental designs to increase the general knowledge for all sets of experimental designs and allow benefiting from the improvements in all seed gardens by transferring selected parental material.

All trials are planted using conventional statistical designs (4 x 4 x 5, 5 x 5 x 6 lattice trials, or Complete Randomised blocks (CRD) with 6 replicates). Dedicated setups are organised separately to assess *E. guineensis* x *E. oleifera* hybrid crosses in trials planted in South America since it is specific market.

Measuring the Oil Yield

In order to improve the selection efficiency, oil yield is divided into its components. Fresh fruit bunch yield (FFB) and oil extraction rate (OER), each subdivided into a series of traits. For FFB yield, these traits are the number of bunches (BN) and the average bunch weight (ABW). For O/B, these traits are the percentage of fruit to bunch (%F/B), the percentage of mesocarp to fruit (%M/F) and the percentage of oil to mesocarp (%O/F). Oil extraction rate (O/B) is calculated with the formula %F/B x %M/F x % O/M which is then adjusted with a correcting factor of 0.855 to correspond to industrial levels (OER).

FFB yield is assessed from 3 to 10 years old on 60 to 72 palms per cross, each tree being individually harvested and yield measured (Gascon *et al.* 1988). For specific projects up to 96 palms may be assessed and evaluation may be done on a longer term. During the analysis, an average yield is calculated on two periods of time: from 3 to 5 years old for young age estimation and from 6 to 10 years old for adult age estimation.

Composing factors of the oil extraction rate are evaluated by implementing bunch analysis at 5 and 6 years old on 40 trees per cross; for specific crosses or in parental gardens, bunch analysis maybe carried on for longer periods of time.

Breeding Value Calculation

Because of the configuration of the mating designs and the layout of the trials, data can be analysed together in order to compare all tested parental palms to one another within each group. For a parent, a breeding value is calculated for every measured trait by taking into account the performances of all crosses it is involved in as well as the mating partners it is crossed with. This method implies that all palms have been sufficiently used in the setup and the different parts are properly connected together. In case the mating designs are unbalanced, pedigree information of the assessed palms can be computed together with all phenotypic data in order to improve the power of estimation of the parent's values by taking into account any related palms tested too. This method, known as Best Linear Unbiased Prediction (BLUP) is now used in routine at PalmElit. The latest set of trials to have ended had a mean oil yield of 7.4 t/ha/yr for the 6-9 years old period with a mean GCA for oil yield of +8.3% for the 9% best group A parents and +7.8% for the 16% best group B parents (Jacquemard *et al.*, 2010). Improvements were made on the bunch production (+5.5% for group A and +4% for group B) and on oil extraction rates (+2.8 % for group A and +3.8% for group B).

ADAPTING SELECTIONS TO DIFFERENT NEEDS

In the past two decades, with the increase of oil palm cultivation, the planted areas have diversified more and more so as the different constraints linked to these areas and the demands from the planters. Since PalmElit supplies seeds worldwide, distinct breeding programs have been implemented to create planting solutions responding to these different needs and requirements.

Resistance to Diseases

Early on, the occurrence of diseases in Latin America, Africa and Asia causing quick decay of the plantations pushed the breeders to develop specific varieties of oil palm that could resist these threats. As described previously, the first category of seeds resistant to *Fusarium* wilt for Africa was developed in the 70s after extensive research and the use of an early screening method and improvements have been added ever since (Renard *et al.*, 1980). Similar work was done in Asia in the early 2000s leading to the release of the first intermediate resistant variety to *Ganoderma* basal stem rot in 2014 (Turnbull *et al.*, 2014). This resistance source is planned to be verified in Africa with African strains of *Ganoderma* spp. Extensive field trials have also been setup in Latin America since the 80s which have been used to select some *E. guineensis* parent palm with good levels of resistance to bud rot as well as interesting *E. guineensis* x *E. oleifera* hybrid palms showing high resistance and enhanced levels of oil production. All of this work was a first path to the development of specified planting material adapted to unique environments. With the multiplication of *Ganoderma* stem rot symptoms in Africa (and in Latin America to a lower extend), new programs consisting in the development of material baring double resistance have been set on tracks.

Tolerance to Drought

Over time, growers have started planting oil palm in less favourable conditions, with reduced precipitation and higher water deficits especially in Africa and some areas in Asia. Breeding for better suited oil palm in these limiting conditions became a necessity. Although no specific setup was design for that purpose, multi-location trials planted in Benin, Côte d'Ivoire and Indonesia enabled to determine that Deli x La Mé crosses, characterized by a high bunch production, had their oil yields less impacted by water deficit (Nouy *et al.*, 1999). In order to improve the selection methodology, it was decided a few years ago to set up a specific experimental design that would enable in-depth studies on drought impact amongst other purposes. Trials have been planted in Indonesia, Nigeria and Benin between 2010 and 2012 and include a broad range of crosses. Different approaches have been agreed upon to study the diversity of genetic, physiological and agronomic parameters that may be impacted by water stress. This major study should help improve the selection for drought tolerant material to be developed for Africa, India, Thailand and parts of Indonesia.

Improved Architecture

The importance of height increment in terms of impact on the duration of the plantation and the production cost is the reason why it is one of the major traits to have been taken into account in PalmElit breeding programmes for a while now (Jacquemard, 1979). Although never publicised before, it is now possible to purchase commercial hybrids with different growth rates depending on the climate and needs of the planters, the smallest hybrids have height increments of 46 to 48 cm/year with no water deficit.

More recently, the demand for more bulky palms has increased especially in Thailand and Sri Lanka, Malaysia and Indonesia to a lower extend. PalmElit was able to select for palms with a reduced canopy surface and release a new variety to be planted at 160 palms ha^{-1} improving young age profitability of the plantation. This variety was especially developed for small planters that look for quick return on investment rather than long term profit.

Decrease of Oil Acidification

Significant R&D work was undertaken a few years ago in collaboration with Cirad to study the enzymatic and genetic background of the acidification process in palm oil. The aim was to select for palms producing oil with lower acidity levels. This research project was completed in 2013 with the publication of an article in Nature (Morcillo *et al.*, 2013) and the release of the first "Low Lipase" oil palm varieties. The acidity levels of the palm oil coming from these varieties remain below the 5% threshold whether coming from bunches harvested a few days before processing or from bunches harvested overripe. This specificity greatly eases the management of the harvest and processing especially for small planters and in regions with an uneven distribution of the production along the year. It also increases the oleic fraction of the oil giving it more value which is interesting for larger plantations and refineries.

PROSPECTIVE AND NEW DEVELOPMENTS

Although some ground breaking developments have lately been achieved with the release of many brand new varieties, new projects are regularly started in house or in collaboration with Cirad and our partners. These projects aim at developing new tools for the breeders or testing new methodologies for routine use.

Tissue Culture

PalmElit has been using a new methodology where proliferation is done by mean of an embryo suspension in liquid media (Durand-Gasselin et *al.*, 2010). Although abnormalities can still be observed in the field, these represent less than 5% of the palms distributed randomly amongst the various clone. Commercial production was running for a while in Colombia for the South American market before being stopped in 2012. Since, a new laboratory has been built in Indonesia by our partner and the procedure is being implemented in routine but for a breeding and seed production purpose for the time being. The use of this tool should greatly improve the effectiveness of the breeding programs as well as increase the uniformity of the commercial seed production.

Molecular Tools

- ID checking

PalmElit currently has an extensive programme of verification of legitimacy for all the families used in seed production and breeding as well as for off type families from all the joint research programmes. For this purpose, a set of 12 microsatellites markers has been identified out of 400 markers and has been validated on a pool of 421 parent palms. Since 2005, all of the seed gardens are routinely checked and any illegitimate families are discarded.

- Linkage mapping

A first saturated genetic map was obtained in 2005 based on the control cross LM2T x DA10D which was planted in all genetic trials until early 2000. This map was made of 255 SSR markers, 688 AFLP markers and the Sh gene marker (Billotte *et al.*, 2005). These 944 markers are scattered over the 16 linkage groups and cover 1743 cM. As the experimental designs used for the evaluation of parent palms in the breeding programs do not allow for QTL detection, a specific strategy was developed based on multi-parental populations. A consensus map was built using 251 microsatellite markers, the Sh gene marker and an AFLP marker and was used on a population of 299 individuals. A set of 76 QTLs involved in 24 different phenotypic traits were thus detected (Billotte *et al.*, 2010). Since then, QTL studies have focused on the detection of traits linked to the fatty acid composition of *E. guineensis* (Montoya *et al.*, 2014) and of the interspecific back-crosses (*E. guineensis* x *E. oleifera*) x *E. guineensis* (Montoya *et al.*, 2013).

Another quantitative trait locus mapping method was recently used, which compensated for the low number of palms per progeny by using a pedigree based approach (Cochard *et al.*, 2015). It involved a two-step variance component analysis using phenotypic data from the last breeding cycle integrated to a linear mixed model with identity-by-descent (IBD) kinship matrices. Eighteen QTL regions controlling production traits were identified among a large genetically diversified sample from breeding program. This pedigree-based approach, gave similar results to the consensus linkage map developed by Billotte *et al.*, 2010 but was found to be powerful, relevant and be an economic approach to map QTLs (Cochard *et al.*, 2015. Tisné *et al.*, 2015).

- Genomic selection

A specific study was done using data from the last breeding cycle in order to develop and test a genomic model for its ability to estimate hybrid combining abilities in parental populations. The model was found to have sufficient accuracy to make a pre-selection in the group B on some yield components and resulted in an increase of more than 50% of annual genetic gain compared to traditional breeding. Genomic selection could reduce the average generation interval and increase the selection intensity, vastly speeding up the genetic progress for oil palm yield (Cros, 2014). Experimental confirmation of the simulations is on the way before adding this methodology in routine use.

Future Genetic Setups and Recombination Programs

A total of four genetic setups are currently running around the world with a monitoring done by agents based locally. Although this organisation is heavy as it represents a few thousands hectares of trials, future setups have already been planned to be planted in the coming few years to focus on the breeding for resistance to *Ganoderma* basal stem rot to develop the second generation of resistant material. Some sets of trials are also planned as part of the breeding program for resistance to bud rot whether it is in *E. guineensis* or the hybrid *E. guineensis* x *E. oleifera*.

Nowadays, more and more varieties are available to the planters that have been designed to answer one or more biotic or abiotic constraints. With the expansion of oil palm culture, the demand for even more adapted and specific material answering to two or more constraint will increase rapidly. A specific program of recombination and specification has quite recently been launched with the aim to develop very unique material adapted to local needs in Asia, Africa or Latin America. This program is primarily focusing on combining double resistances for *Fusarium* wilt and *Ganoderma* basal rot as well as combining resistance to diseases with palm bulkiness and/or low lipase activity.

CIRAD PLANTING MATERIAL

In the past years, PalmElit has developed an extensive catalogue of planting materials adapted to different areas of cultivation and constraints. These planting materials, commercialised under the brand Cirad are made available through the seed gardens established all around the globe in collaboration with our partners.

Our standard material is the Deli x La Mé, characterised by a high FFB and CPO production, higher oil content of unsaturated fats acids compared to other materials. It has also significant drought resistance characteristics and a low height increment which enables an economically profitable operation over more than 25 years. During the past decades, our breeders have improved our Deli x La Mé material, now allowing us to offer varieties with less bulky palms for high density plantation, resistances against diseases, and low lipase material. Our other performing materials are Deli x Yangambi and interspecific *E. oleifera* x *E. guineensis* hybrid.

For South America, through our joint venture with PHV-Colombia, SEPALM, and together with Murrin Ecuador; PalmElit can supply planters with material adapted to regional conditions with:

#PC$_{OxG}$ (*E. oleifera* X *E. guineensis* hybrid) highly resistant to Bud Rot (PC),

- **#PC**$_{2.0}$ / **#PC**$_{1.0}$ (*E. guineensis)* partially resistant to Bud Rot.

For Africa, the seed garden in Benin created together with INRAB focuses on producing:

- **#F**, a *Fusarium* wilt resistant material,
- **#L**, a low lipase material especially created to respond to the problematic of African production seasonality, allowing greater flexibility at the time of harvesting and milling by reducing the postharvest oil acidification process,
- **#F#L**, a *Fusarium* resistant and Low Lipase material is also available in small quantities.

For Asia, through our joint venture with UPOIC-Thailand, SIAM ELITE PALM, PalmElit has made available a series of planting material:

- **#DLM**, the classic Deli x La Mé developed using the latest improvements,
- **#DLY**, the classic Deli x Yangambi, a quick starter planting material
- **#S**, a very low height increment material,
- **#HD** (or Elite), a less bulky material developed to be planted at 160 palms/ha to improve young age profitability of oil palm for small holders
- **#G**, a *Ganoderma* intermediate resistant material

Together with Socfin Indonesia, we focus on producing the famous Deli x La Mé and Deli x Yangambi planting material as well as **#G** the Deli x La Mé *Ganoderma* partially resistant developed for Asia and its aging plantations.

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Seed Production and Oil Palm Breeding in ASD Costa Rica

Alvarado, A and Escobar, R

ASD Costa Rica (Agricultural Services & Development), PO Box 30-1000, San Jose, Costa Rica
E-mail: Sales@asd-cr.com

ABSTRACT

For almost 50 years, the ASD Costa Rica oil palm breeding program has used the genetic diversity of the two species, *E. guineensis* and *E. oleifera*, to obtain commercial varieties. Emphasis has been made on the development of varieties with reduced growth through backcrossing programs, which have helped stabilize populations with short trunks, short leaves and high oil production. This phenotype, named "compact", was bred to optimize land use, because it enables the planting of more palms per unit area and extends the lifespan of the plantations. The development of "compact" growth varieties has been the outcome of an extensive breeding effort, where palms from the *E. guineensis* gene pool with enormous yield potential were backcrossed to *E. oleifera* over four cycles, starting with a wild "OxG" hybrid palm with short trunk and leaves.

The *E. guineensis* populations involved in the backcrossing program were AVROS, La Me, Ekona and Deli, resulting in recombinants that gave origin to *dura* and t*enera*/*pisifera* "compact" populations. Using the new backcrosses to different *E. guineensis* families from the Ghana, Nigeria T/P and Deli D populations, a new set of commercial "compact" DxP varieties were released starting in 2004. An "OxG" hybrid (Amazon) bred using *pisifera*s from the "compact" origin is also being commercialized. Around 30 million seeds of "compact" varieties have been sold and now ASD is producing a new generation of advanced "compact" varieties. Thanks to the extensive work with the "compact" breeding populations, it was possible to initiate a tissue culture program using the best individuals found in each generation. By selecting the elite individuals, it would be possible to establish uniform high density clonal plantations (160 to 180 palms/ha) where some of the clones have the potential to yield up to 10-12 tons of oil per hectare.

Recently new genetic resources are under evaluation in order to increase the diversity for special traits such as higher oil yield, tolerance to diseases, slow dehiscence and high olein content. The *E. guineensis* populations used in the new recombinant varieties come from Tanzania, composite Evolution (ex. Dami composite), Ekona and Mobai (Sierra Leone).

There is no doubt that the ASD breeding program started and grew thanks to the wide genetic diversity collected all around the American oil palm belt, and also through exchange programs with research centers in Africa and Asia and the collection of wild African palms. During the last 25 years, ASD improved materials were sold to breeding programs in Thailand and Indonesia, where some groups are now producing seeds. It is therefore imperative that ASD Costa Rica continue developing advanced populations and varieties for the near future.

Keywords: ASD Costa Rica, *Elaeis guineensis*, backcrossing, oil palm seed production, oil palm breeding.

INTRODUCTION

ASD Costa Rica (Agricultural Services and Development) is a specialized company dedicated to providing oil palm planting materials. Since 1968, ASD has gathered a broad germplasm collection of both *Elaeis guineensis* and *E. oleifera* palms, which made the development of several varieties possible and ASD became a successful international oil palm seed supplier. In the period 1986-2015, more than 1.8 million hectares have been planted with ASD's varieties and clones in tropical America, Asia and Africa.

ASD developed a new generation of commercial varieties characterized by high FFB yields (30 to 35 t/ha) under good soil and climate conditions; able to be planted under deficient conditions (water stress, low temperatures, insect and disease presence); with short leaves that allow planting at higher densities (160 to 180 palms/ha) and with special traits according to market demands such as bud rot tolerance in *E. guineensis*, high unsaturated oil content (44% oleic acid) in *E. guineensis* or high kernel to bunch ratios (10 to 12%).

This document begins with a picture of past, current and future commercial seed production based on the germplasm available in ASD to show how market demand has focused on high density and special varieties. It also includes the main aspects of the development of varieties and clones for planting at high density by the ASD Costa Rica breeding program. This paper provides insight into the origin of the program and the consolidation of the genetic diversity of *E. oleifera* as well as *E. guineensis* and a summary of the selection and breeding program for *E. guineensis* populations Deli and Tanzania *dura* as well as *tenera/pisifera* Ghana and composite Evolution. The document then emphasizes the development of the ASD backcrossing program and its results in obtaining "compact" growth varieties and clones.

Finally, the paper focuses and draws conclusions on the importance of developing new breeding population and varieties, especially high density ones aimed at optimizing land use and satisfying the demand for high yielding planting materials.

GENETIC DIVERSITY

Genetic diversity has been the main strength of ASD Costa Rica's oil palm breeding program. Although the first documented introduction of oil palm of known origin into the Americas goes back to 1926, and during the period 1926 to 1936 several introductions and distribution of seeds were made, the oil palm industry in this continent did not grow as much as that of Asia (Richardson 1995). Therefore, the basis of the ASD breeding program has been related to an extensive *E. oleifera* germplasm collection acquired in the 1960s and 70s in diverse regions of Honduras, Nicaragua, Costa Rica, Panama, Colombia, Surinam and Brazil, (Escobar 1981, Sterling et al 1999). Most of the *E. oleifera* collection was planted in Costa Rica but some accessions were exchanged for *E. guineensis* material from advanced generations.

The *E. guineensis* genetic materials were obtained from recognized experimental stations in Africa and Asia. They included Deli *dura*, sourced from the Chemara, Harrison & Crossfield, Banting, Socfin and Mardi (Malaysia) stations and from Dami (Papua New Guinea). Also introduced were AVROS *pisifera* palms from Harrison & Crossfield (Malaysia), Ekona from Unilever (Cameroon), Ghana and Nigeria from the Kade Station (Ghana) and the NIFOR station (Nigeria), and La Me and Yangambi from IRHO (Ivory Coast). This exchange program was strengthened with the subsequent introduction of seeds from wild palms of the Bamenda highlands (Cameroon) and Tanzania, and from several regions of Sierra Leone, Uganda, Zambia and Malawi (Alvarado *et al.* 2009). Thanks to this great genetic diversity from advanced and wild populations, ASD started breeding and seed production programs early in its existence.

The development of *E. guineensis* commercial varieties was initiated in the 1970s using Deli *dura* and AVROS *pisifera*s. The increased market demand and good performance of improved varieties accelerated the seed production program, which started in 1977. At the same time, several *E. guineensis* sources were used in "OxG" (*E. oleifera* x *E. guineensis*) trials, as well as in backcrossing programs based on a peculiar wild "OxG" hybrid. The consolidation of composite varieties is a strength in ASD program, by combining genes from various germplasm sources to assemble varieties with special characteristics, such as the "compact" varieties including Evolution Blue and the Amazon hybrid.

SEED PRODUCTION

ASD's ample genetic stock permitted the simultaneous combination of a wide range of *dura* lines, such as Deli, African (Bamenda and Tanzania) and "compact", with classical *pisifera*s AVROS, Yangambi, Ekona and La Me; recently bred Ghana, Nigeria and Evolution and "compact" pollen source populations. This allowed the release of several seed varieties with particular characteristics (Alvarado *et al.* 2009, *Table 1*).

TABLE 1. GENERAL DESCRIPTION OF THE MAIN CHARACTERISTICS OF ASD SEED VARIETIES

Origin	Density	THI	LL	t/ha	O/B	Tolerance to: (when not indicated is normal)		
						Drought	Low Temperature	Low solar radiation
Deli x AVROS *	135-143	60-65	8.0-8.5	25-30	26-28	L		L
Deli x La Me	143	50-55	7.6-8.0	25-30	<26	N/H		
Deli x Ghana	160	55-60	7.0-7.3	30-35	28-30	N/H	N/H	H
Deli x Nigeria	143	50-55	7.6-8.0	30-35	28-30			
Evolution	143	50-55	7.6-8.0	30-35	>30			
Tanzania x Ekona	143	50-55	7.6-8.0	25-30	26-28	N/H	H	
Bamenda x Ekona	143-160	45-50	7.6-8.0	22-25	26-28	N/H	H	
Deli x "Compact"	160-170	45-50	6.6-6.9	30-35	28-30			N/H
"Compact" x Ghana	170-180	45 - 50	6.6 - 6.9	30-35	28 - 30			H
"Compact" x Nigeria	160-170	45 - 50	6.6 - 6.9	30-35	28 - 30	N/H		

THI = increase in trunk height, cm/year; LL = maximum leaf length; t/ha = total fruit yield per hectare, ton; O/B = oil in the bunch, %; yield and growth data as observed at the ASD Research Station, Costa Rica, where soils and climatic conditions favor vigorous growth and limit fruit yield due to water excess; * Deli x AVROS is currently not sold by ASD but it is included to compare the performance of the other varieties, in special the "compact" varieties; L = low; N = normal; H = high.

The first variety ASD put on the market in 1986 was the classical Deli x AVROS. After 1995, demand gradually increased for other varieties, namely Deli x Ghana, Deli x Nigeria, and to a lesser extent Deli x La Me, owing to its slower growth habits and/or shorter leaves. Lately, after 2005, the "compact" varieties, suitable for high-density planting at 160-180 palms/ha, were becoming more popular *Figure 1*.

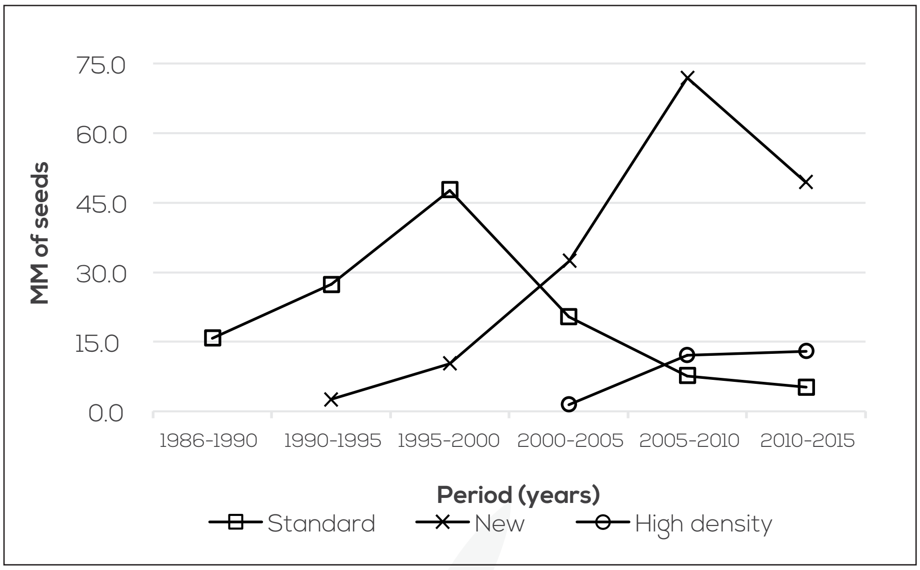

Figure 1. Variation from 1985 to 2015 in the seed demand of varieties by group.

Most of the planted area during the period 1991 to 2015 with ASD seed varieties is in America and Asia, and to a lesser extent in Africa *Table 2*.

TABLE 2. ASD SEEDS SOLD AND PLANTED AREA (HECTARES) IN THE PERIOD 1991-2015

Region	Seeds (000's)	Hectares (000's)	World (000's)	ASD share
America	148,541	874	1,235	71%
Asia	153,962	906	13,812	7%
Africa	10,162	60	1,039	6%
Total	312,665	1,840 ha	16,086 ha	11%

ASD BREEDING PROGRAM

E. guineensis

From the several *dura* (D) and *tenera/pisifera* (T/P) populations in the ASD collection, emphasis was given to the Deli *dura* population, by using the improved accessions introduced to Costa Rica. When the evaluation extended to other genetic materials, other traits were noted including the potential of the wild Tanzania origin, the good performance of the Ghana T/P families and the high oil yield potential of a modern T/P called Evolution. The following sections summarize some key aspects of these four groups.

Deli *dura*

The breeding of the Deli population in Coto, Costa Rica started in the 1970s, using advanced germplasm introduced from reputable breeding organizations in Asia. These breeding materials were grouped into five subpopulations according to the research center source: Banting, Chemara, Dami, Mardi and Socfin. Up to 2008, four selection cycles that involved pure and recombined lines were performed on the Deli population (Alvarado *et al.* 2009, *Table 3*).

TABLE 3. NUMBER OF FIELD TESTS, LINES AND DELI *DURA* PALMS EVALUATED IN COSTA RICA ALONG FOUR CYCLES OF SELECTION AND BREEDING. UPDATED FROM ALVARADO *et al.* 2009

Cycle	Period	FT	Lines	Palms	Origin (pure and inter-populations)
1	1969 - 1982	15	62	4,321	B, Che, D, Mar, Soc
2	1985 - 1992	21	100	4,827	B, Che, D, Soc, Che x B, Che x Mar, Che x D, D x Soc
3	1996 - 2003	11	235	8,917	B, Che, D, Mar, Soc, B x Che, Che x Mar, Che x D, D x Mar
4	2008 - 2016	10	91	8,232	B, Che, D, Mar, Soc, B x Che, Che x Mar, Che x D, D x Mar
Total		**57**	**488**	**26,297**	

Despite the fact that the original accessions introduced in the period 1969-1979 came from advanced populations, their FFB yields were moderate to low, the average yield during the first three years of record was 106-120 kg/palm, while oil to bunch ratios (O/B) varied from 18 to 24% *Table 4*. During the following breeding cycles, these two important traits were emphasized by crossing palms within and between populations, with the objective of increasing yields and also reducing vegetative growth and improving bunch index ratios.

TABLE 4. AVERAGE YIELD AND OIL COMPONENTS OF THE 33 DELI *DURA* GERMPLASM ACCESSIONS INTRODUCED FROM ASIAN BREEDING PROGRAMS DURING THE FIRST ASD SELECTION CYCLE (1969-1982)

Introduction	Origin	Accessions	Palms	FFB	M/F	O/M	O/B
First 1969 - 71	Socfin	3	146	106.2	62.2	43.7	19.4
	Chemara	6	354	120.4	62.9	46.8	20.4
	Banting	3	175	114.4	60.7	42.3	18.1
Second 1979	Dami	20	1621	112.2	66.3	43.7	20.6
	Mardi	1	59	114.6	67.8	48.8	23.7

FFB = fresh fruit bunch production in kg/palm/year evaluated during the first 3 years; M/F = % of mesocarp to fruit; O/M = % of oil to mesocarp; O/B = % of oil to bunch.

In the most recent cycle planted in 2008, 91 selfed lines were under evaluation representing the five original populations *Table 3*. By comparing the selected groups, the main differences were observed in FFB, while bunch traits were similar. The percentage of oil to bunch varied from 23 to 26% and it was higher than the industry standard for dura palms; so, from this group of selfings more than 1400 plants are currently being used for seed production *(see Table 5)* and some elite plants were selected for the next cycle.

A total of 32 elite Deli *dura* palms selected in the fourth cycle from the pure populations are going to be used in the next Deli *dura* breeding cycle. They were crossed within and between populations and will be planted in the field in 2018. Most of them belong to Chemara and Dami populations, based on the superior FFB and oil yield observed in Chemara and the lower vegetative growth in the Dami population *Table 5*.

TABLE 5. AVERAGE YIELD, VEGETATIVE GROWTH AND OIL CONTENT PER POPULATION OF THE 32 DELI *DURA* PALMS SELECTED IN THE FOURTH CYCLE THAT WILL PRODUCE THE NEW GENERATION OF MOTHER PALMS

Population	Palms	FFB	TH	LL	M/F	O/M	O/B
Banting	2	151.8	275	529	70.1	45.2	22.2
Chemara	14	175.6	286	509	70.1	49.6	24.6
Dami	13	154.9	231	505	68.6	45.2	20.8
Socfin	3	142.8	223	506	72.3	50.8	25.5
Average		162.6	254	508	69.7	47.6	23.0
Seed production *duras*	1450	137.0	-	-	68.7	45.7	22.1

FFB = fresh fruit bunch production in kg/palm/year yield evaluated during four years; TH = trunk height at petiole of leaf 6, in cm; LL = leaf length in cm; M/F = % of mesocarp to fruit; O/M = % of oil to mesocarp; O/B = % of oil to bunch; growth traits at 48 months of age.

Tanzania *dura*

The collection of African *dura* lines aimed to broaden the genetic basis of ASD mother palms, breeding them separately from the Deli *dura* population. Based on the rainfall and altitude of the prospecting sites, some tolerance to drought and to low temperatures was considered to be transmitted in the new varieties produced from these sources (Alvarado et al 2009, Alvarado and Peralta 2010) *Table 6*.

TABLE 6. ALTITUDE AND RAINFALL OF THE VARIOUS SITES WHERE AFRICAN *DURA* LINES WERE COLLECTED AND TOLERANCE EXPECTATIONS TO DROUGHT AND LOW TEMPERATURES (COLD)

Country and site of origin	Altitude (masl)	Rainfall (mm/year)	Expected tolerance
Cameroon, Bamenda	1600	2480	cold
Tanzania, Kigoma	880	960	cold, drought
Uganda, Entebbe	1100	1530	cold, drought
Zambia, Kawambwa	1300	1300	cold, drought
Malawi, Karonga	530	1180	drought
Ivory Coast, Kenema	60	970	drought

masl=– meters above sea level. From Alvarado and Peralta 2010.

From the African populations, the Tanzanian origin was outstanding for its good bunch characteristics (Richardson and Chavez 1986), so it has been used in seed production since 2000, mainly directed towards marginal areas. Mother palm selection was based on the F_1 population, made up of 11 lines planted in 1994, which showed high FFB (180 kg/palm, 5-year average) and O/B above 20%. Seven superior palms were selected from the F_1 generation, conserving most of the observed variability as well as high yield (187 kg/palm) and oil to bunch ratio (22%) *Table 7*.

TABLE 7. AVERAGE YIELD, VEGETATIVE GROWTH AND OIL CONTENT OF THE SEVEN *DURAS* SELECTED FROM THE TANZANIA F_1 ORIGIN PLANTED IN 1994

Line	Palm	FFB	BW	TH	LL	M/F	O/M	O/B
91C184	21	141.6	6.1	133	570	56.3	57.2	21.2
91C070	64	179.5	7.2	192	667	57.8	53.3	20.6
91C124	70	204.9	6.5	184	578	58.9	58.6	23.7
91C184	84	173.6	6.5	159	542	61.6	53.7	23.4
91C124	103	199.3	7.3	124	607	63.9	54.2	23.3
91C200	117	191.7	8.1	182	601	49.5	53.3	18.6
91C135	228	218.8	7.1	138	581	52.9	57.1	22.1
Average		187.1	7.0	159	592	57.2	55.3	21.8

FFB = fresh fruit bunch production in kg/palm/year; BW = bunch weight in kg; TH = trunk height in cm; LL = leaf length in cm; M/F = % of mesocarp to fruit; O/M = % of oil to mesocarp; O/B = % of oil to bunch; yield evaluated during 5 years, growth traits at 70 months.

The Tanzania F_2, planted from 2006 to 2010, derived from the selfings of the seven selected palms, showed low yield because of endogamy (95 kg/palm on average during the first three years of records), but good O/B percentages, in a range from 19 to 22%. Differences between families allowed a positive selection for the next F_3 cycle. Eight F_2 palms were chosen and intercrossed to produce the next generation, wherein similar or even higher oil to bunch ratios are expected in comparison with the Deli *dura* origin *Table 8*. In the Tanzania F_3, a crossing program with pollen sources also showing tolerance to drought and lower temperatures is expected to allow the development of stress-tolerant and high oil yielding varieties.

TABLE 8. BUNCH CHARACTERISTICS OF THE DELI AND TANZANIA PALMS SELECTED FROM THE MOST RECENT BREEDING CYCLE TO ESTABLISH A NEW MOTHER PALM GROUP IN 2018

Origin	Palms	M/F	O/M	O/B
Deli	32	69.7	47.6	23.0
Tanzania F2	8	61.4	55.2	23.8

M/F = % of mesocarp to fruit; O/M = % of oil to mesocarp; O/B = % of oil to bunch.

Ghana *tenera/pisifera*

Initially ASD used the conventional AVROS population as a pollen source, but after advancing with the phenotypic characterization of other origins, the efforts focused on higher yielding populations with slower growth. Two of these alternative pollen sources were Ghana and Evolution.

The Ghana population was introduced to Costa Rica in 1981 by Ricardo Escobar (1979, unpublished internal report) who selected a progeny derived from two outstanding teneras, 851.253T and 32.3005T, from the Dr. Wonkyi Appiah breeding program at the Kade Research Station (Ghana). Based on the good characteristics showed by the Ghana origin in Costa Rica, especially good bunch components and short leaves (Richardson and Alvarado 2003), ASD produced the F_1 (1997) and F_2 (2008) generations and started to produce commercial seeds with the Ghana parents in 2005.

The Ghana progenies show high FFB and O/B, short leaves and also tolerance to water deficit, low temperatures, crown disease and some bud rots (Alvarado et al 2009, Martinez 2012). In comparison with other pollen sources, the short leaves and low leaf area allow the production of high density varieties *Table 9* (Breure 2006, 2010).

TABLE 9. SUMMARY OF YIELD, GROWTH AND OIL CONTENT IN A PROGENY TRIAL CARRIED OUT IN INDONESIA, WHERE SEVERAL POLLEN SOURCES WERE COMPARED. FROM BREURE 2006

Origin	Lines	FFB	TH	LL	LA	O/B
AVROS	15	117	152	381	5.19	26.4
Ekona	10	121	130	382	5.05	26.1
Ghana	9	119	147	375	4.89	27.2
Nigeria	6	127	136	379	5.32	26.9
Trial average	50	120	141	377	5.04	26.6

FFB = fresh fruit bunch production in kg/palm/year; TH = trunk height in cm; LL = leaf length in cm; LA = leaf area in m^2, O/B = % of oil to bunch; yield evaluated during 4.5 years, growth traits as average of years two to seven.

The most recent Ghana population planted in Costa Rica (2008 - 2010) will be evaluated with mother palms from the Deli, Tanzania and "compact" populations in order to determine the combining abilities (GCA and SCA) aimed at selecting the best families and *pisifera* parents for the following cycles.

Evolution (composite) *tenera/pisifera*

The ASD's Evolution T/P population is composite, having been derived from outstanding palms in terms of FFB and oil yield; several details of its origin and performance look very promising and are given below (from Alvarado and Henry 2015).

Evolution originated in the Harrisons & Crossfield breeding program in Papua New Guinea, whose objective was to improve bunch index (Dumortier et al 2007). In an experiment planted in 1968, several *tenera* x *dura* progenies (trial 203) of Banting BM119 x Chemara origin were evaluated. Palm DAM736/107T was selected, characterized by its high bunch production (243 kg vs 159 in the family), reduced trunk height, high mesocarp in the fruit, and high oil in the fruit and in the bunch (32.1%) (*Table 10* , C.J. Breure, 2012, personal communication).

TABLE 10. TRAITS OF THE SUPERIOR PALM DM736/107T IN TRIAL 203 OF THE DAMI STATION, PAPUA, NEW GUINEA, PLANTED 1968. C.J. BREURE, PERSONAL COMMUNICATION, 2012

Family	FFB	TH	M/F	O/M	O/B
Trial 203	155	401	80.6	48.5	24.6
DM736	159	400	84.7	50.6	27.2
DM736/107T	243	337	88.7	53.7	32.1

FFB = fresh fruit, kg/palm/year from 4.5 to 9 years of age; TH = trunk height at 8 years of age; M/F = % of mesocarp in the fruit; O/M = % of oil in the mesocarp; O/B = % of oil in the bunch.

Palm DAM736/107T -50% AVROS Banting: 50% Deli Ulu Remis-, was combined with DAM 774/201T -50% Elmina Dumpy: 25% AVROS of unknown origin, 25% IRHO-, giving rise to a composite family that was subsequently sent to Costa Rica, where it was called DAM586. This family therefore has a pedigree consisting of 25% Elmina Dumpy, 25% Deli, 37.5 % AVROS and 12.5% IRHO. In Costa Rica the DAM586 family was superior due to the high percentage of oil in the mesocarp (53.3% vs 45.8% of the commercial control) and oil in the bunch (32.6% vs. 26.1%). Due to these characteristics it was used as a new source of pollen named Evolution. The best palm from this family, DAM586:405T, was selected because of its higher FFB (133 kg vs 94 as the average for its family) and high O/B (39.4%) *Figure 2*.

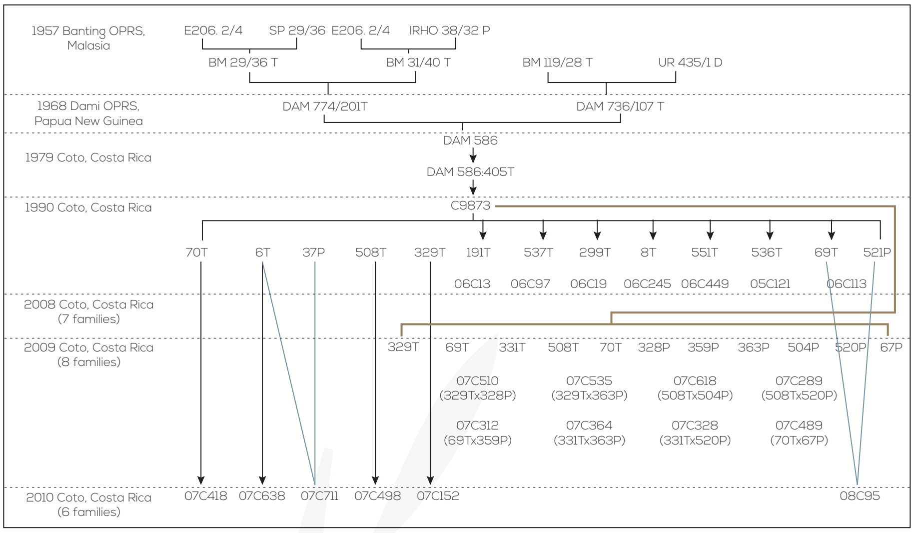

Figure 2. Genealogy of the Evolution composite planted at the ASD Experimental Station, Costa Rica.

The strengths of the Evolution origin as a pollen source were seen when comparing their performance with other *tenera* populations, established by ASD between 1979 and 2004. FFB was similar among the origins, while trunk growth rate was shortest in Evolution together with Nigeria (48 cm). However, Evolution was the best in fruit composition, since it had higher mesocarp in the fruit (89%), oil in the mesocarp (56%) and oil in the bunch (32%) *Table 11*.

TABLE 11. AVERAGE YIELD, VEGETATIVE GROWTH AND OIL CONTENT PER ORIGIN IN A SAMPLE OF PALMS FROM 11 TXP FAMILIES (POLLEN SOURCES), PLANTED FROM 1979 TO 2004, COSTA RICA

Origin	Families	Palms	FFB	THI	RL	M/F	O/M	O/B
AVROS	1	67	100.2	61	551	86.0	46.6	26.0
Ekona	2	49	105.7	53	584	88.4	53.5	30.7
Ghana	2	36	93.8	57	528	89.6	50.7	29.5
Nigeria	5	45	114.4	49	518	87.4	48.0	27.2
Evolution	1	97	97.0	48	594	89.1	55.8	32.3
Average		**294**	**102.2**	**54**	**555**	**88.1**	**50.9**	**29.1**

FFB = fresh fruit, kg/palm/year, first three years; THI = increase in trunk height, cm/year; RL = rachis length at adult age, cm; M/F = % of mesocarp in the fruit; O/M = % of oil in the mesocarp; O/B = % of oil in the bunch; growth characteristics measured in 2011.

In a progeny trial planted in 2008 in Costa Rica, some "compact" mother palms were combined with Evolution; ASD named this new variety Evolution Blue. When compared with the Deli x Nigeria control, the oil content in Evolution Blue was higher (29% vs 28%), while trunk growth was shorter (202 vs 269 cm) and leaf length smaller (514 vs 620 cm). Their short leaves will allow the establishment of Evolution Blue plantations at higher density (160 to 170 plants/ha), in comparison with standard *E. guineensis* varieties, which are usually planted at 143 plants/ha.

Backcrossing, high density populations and clones

Since the 1970s, the ASD Costa Rica oil palm breeding program has concentrated on the development of varieties with slow trunk growth and short leaves. This phenotype, named "compact", was bred to optimize land use, because it enables the planting of more palms per unit area and prolongs the lifespan of the plantation. The development of "compact" varieties has been the outcome of an extensive breeding program, where high-yielding palms from the *E. guineensis* gene pool were backcrossed to *E. oleifera* over four cycles.

The discovery of an outstanding "OxG" hybrid in 1966 with shorter leaves compared with standard "OxG" palms, and the identification of a descendant with short stem and short leaves, named original "compact" palm (OCP), led to the beginning of the backcrossing program at ASD. Given that the OCP had poor bunch quality, there was a need to introgress "compact" genes into other *E. guineensis* germplasm (Sterling et al 1987). Two different breeding strategies were adopted: successive backcrossing to E. guineensis to improve oil yield, and development of a recombinant population in each backcrossing cycle to stabilize growth traits *Table 12*. Additional details in the development of "compact" populations are given in *Table 13*.

TABLE 12. CHRONOLOGICAL EVENTS OF THE ASD BACKCROSSING PROGRAM TO DEVELOP THE "COMPACT" POPULATIONS AND THEORETICAL PROPORTION OF *E. OLEIFERA* GENES IN EACH CYCLE

Year	Cycle	Population	*E. oleifera* genes
1966	0	Hybrid OxG (wild, open pollination)	50%
1970	1	Original Compact Palm (OCP) *	25%
1978	2	First backcross (BC_1)	12.5%
1985	2.1	Sub population: BC_1F_1	12.5%
1994	2.2	Sub population: BC_1F_2	12.5%
2008	2.3	Sub population: BC_1F_3	12.5%
1986	3	Second backcross (BC_2)	6.25%
1995	3.1	Sub population: BC_2F_1	6.25%
2008	3.2	Sub population: BC_2F_2	6.25%
1995	4	Third backcross (BC_3)	3.125%
2008	4.1	Sub population: BC_3F_1	3.125%

*In fact, OCP is the first backcross but in the ASD program, since it is considered the starting point of the "compact" population, the subsequent backcrosses are named from the first in 1978; *E. oleifera* genes as expected average due to backcrossing.

TABLE 13. DETAILS RELATED TO THE CHRONOLOGICAL EVENTS OF THE ASD BACKCROSSING PROGRAM TO DEVELOP THE "COMPACT" D AND T/P LINES IN THE PERIOD 1966 TO 2008. MODIFIED FROM ESCOBAR AND ALVARADO 2003

Origin	Families	Palms	FFB	THI	RL	M/F	O/M	O/B
O x G	0	Outstanding open pollinated OxG hybrid identified						1
PCO	1	Identification of the "original compact palm" in the first OxG descendant (see note on Table 11)						1
BC_1	2	First backcross from OCP crossed to *E. guineensis* La Me, Ekona, Ulu Remis, AVROS, Yangambi and Deli *dura*; two elite T palms selected						567
BC_1F_1	2.1	Two elite T palms intercrossed and selfed; 5 D and 7 T selected in 1991						120
BC_1F_2	2.2	The elite 5 D and 7 T intercrossed; D and T selected in 2005						530
BC_1F_3	2.3	The selected D and T selfed and kept as separate D and T populations; 12 D selected in 2016						
BC_1F_4	2.4	D selected from BC1F3 are being intercrossed to stabilize the BC1						
BC_2	3	Second backcross population originated from the two BC1 selected palms crossed to *E. guineensis* Deli x AVROS, Bamenda, Ekona and AVROS; 15 D and 10 T selected						2330
BC_2F_1	3.1	The elite 15 D and 10 T intercrossed; D and T selected in 2005						2329
BC_2F_2	3.2	New population from D and T selected in BC2F1 selfed and kept apart as D and T/P groups and also cross in DxT to see GCA and SCA performance; 12 D selected in 2016						
BC_2F_3	3.3	D selected from BC_2F_2 are being intercrossed to stabilize the BC2						
BC_3	4	Third backcross population originated from the BC2 selected palms crossed to *E. guineensis* AVROS, Ekona, Nigeria, Calabar, La Me and Yangambi; 4 T selected in 2005						1088
BC_3F_1	4.1	4 T selected selfed						

D = *dura*, T = *tenera*, P = *pisifera*, cycle = selection cycle, see Table 13 for other cycle aspects; OxG = *E. oleifera* x *E. guineensis* F1 hybrid; BC = backcross; F = filial generation.

Escobar and Alvarado (2003) summarized the "compact" population performance in the period from 1978 to 1995, comparing the "compact" *tenera* palm traits with the conventional Deli x AVROS variety. It was noted that FFB and O/B increased from first to third backcrossing cycles along with the increase in trunk height as a result of the "compact" gene dilution, but the shorter leaf trait was conserved through generations. The F_1 palms derived from the second backcrossing (BC_2F_1) were the best, because they had higher O/B and lower growth when compared to the control variety. However, some families from BC_1F_2 are going to be included in the following selection cycles due to their short leaves and also to keep genetic diversity as high as possible *Table 14*.

TABLE 14. RELATIVE COMPARISON (% OF STANDARD CROSS DELI X AVROS) OF "COMPACT" *TENERA* POPULATIONS. MODIFIED FROM ESCOBAR AND ALVARADO 2003

			% of Deli x AVROS			
Origin	Palms	Cycle	FFB	TH	LL	O/B
BC_1	567	2	**77.4**	**54.4**	**87.2**	**91.7**
BC_1F_1	120	2.1	58.2	83.1	73.4	98.3
BC_1F_2	530	2.2	73.7	100.0	73.0	87.9
BC_2	2330	3	**87.3**	**67.1**	**87.2**	**102.3**
BC_2F_1	2329	3.1	84.9	59.3	76.5	108.8
BC_3	1088	4	**92.7**	**81.4**	**85.5**	**106.9**

See *Table 12* for cycle details; BC = backcross; F = filial generation; cycle = selection cycle; FFB = fresh fruit; TH = trunk height; LL = leaf length; O/B = oil in the bunch.

After 1995, efforts focused on populations derived from the first and second backcrosses. The BC_1F_3 and BC_2F_2 populations, separated into *dura*s and *tenera*s, were planted in 2008 as selfings; for this reason the FFB yield in the DxP standard cross is higher comparing to both T self groups *Table 15*.

TABLE 15. FFB, OIL YIELD AND GROWTH CHARACTERISTICS OF *DURA* AND *TENERA* "COMPACT" POPULATIONS COMPARED TO DELI *DURA* AND ONE *E. GUINEENSIS* DXP VARIETY, PLANTED IN 2008

Origin	FFB	THI	LL	M/F	O/M	O/B
Compact BC_1F_3, D self						
Average (21 families, 1589 palms)	120.3	48	411	60.5	42.1	17.4
Standard deviation	18.9	5	59	2.4	2.4	1.3
Compact BC_2F_2, D self						
Average (34 families, 2632 palms)	98.1	53	512	62.2	49.3	20.6
Standard deviation	19.6	7	30	3.1	3.5	3.0
Deli dura self						
Average (87 families, 6536 palms)	110.2	63	617	67.4	44.1	20.6
Standard deviation	22.3	8	47	2.7	2.8	2.1
Compact BC_1F_3, T self						
Average (9 families, 603 palms)	77.7	44	436	81.5	47.2	24.6
Standard deviation	28.3	10	42	1.4	4.0	3.8
Compact BC_2F_2, T self						
Average (11 families, 532 palms)	94.6	62	536	88.1	49.0	25.1
Standard deviation	13.0	10	52	3.1	3.2	1.9
Deli x Nigeria, DxP						
Average (12 families, 488 palms)	194.7	70	673	85.8	49.5	26.9
Standard deviation	23.6	5	23	2.3	1.1	1.7

BC_1F_3 = third filial generation from first backcross; BC2F2 second filial generation from second backcross; the number of families refers to different lines and/or the same line planted in different experiments; FFB = fresh fruit bunches, kg/palm/year (4 years of evaluation); THI = trunk height increment estimated at 90 months old, cm; LL = leaf length, 90 months old, cm; M/F = % of mesocarp in the fruit; O/M = % of oil in the mesocarp; O/B = % of oil in the bunch; bunch analysis data for *dura* palms in D selfed families and for *tenera* palms in T self and DxP.

The weaknesses of BC_1F_3 were its lower percentages of oil in the mesocarp and in the bunch, which were overcome in the BC_2F_2 population. However, the BC_1F_3 *dura* population is superior in fresh fruit yield, and both BC_1F_3 *dura* and *tenera* have shorter leaf length when compared with the next generation, BC_2F_2 *Table 15*.

Based on the performance of the two maternal populations, it was thought that the development of the new varieties for high planting density should be based mainly on the descendants of the first backcrossing cycle, BC_1, while the highest oil yields will come from the BC_2 derived population. A new selection program of *dura* palms has started within these two populations in order to create the following more productive and uniform generation. Additionally, it is possible to select outstanding *tenera* palms from the different compact populations as ortets for commercial production of high-density clones.

Since the 1980s, ASD has developed a reliable and unique protocol for cloning palms by using explants from inflorescence tissue, with almost no significant abnormalities in the field. An advantage of the backcross method and the mentioned protocol is to concentrate the "compact" genes by selecting high yielding ortets for cloning (Guzmán 1999, Alvarado *et al.* 2006).

Field results for the clones are promising. In a semi-commercial plot in Costa Rica (35 hectares), planted in 2004 on highly fertile alluvial soils, one "compact" clone (Tornado) achieved total oil yield (on an oil extraction rate basis) of 10 to 12 tons/hectare after the fifth year of harvest, planted at 190 palms/ha (it has 25% shorter leaves so it performs well at that density in a high solar radiation area). The *E. guineensis* standard variety (Deli x Nigeria) yielded less than 10 tons/hectare during the same period, planted at 143 plants/hectare, and it showed strong variation between years. Another "compact" clone (Sabre, 170 plants/hectare) showed intermediate performance *Figure 3*.

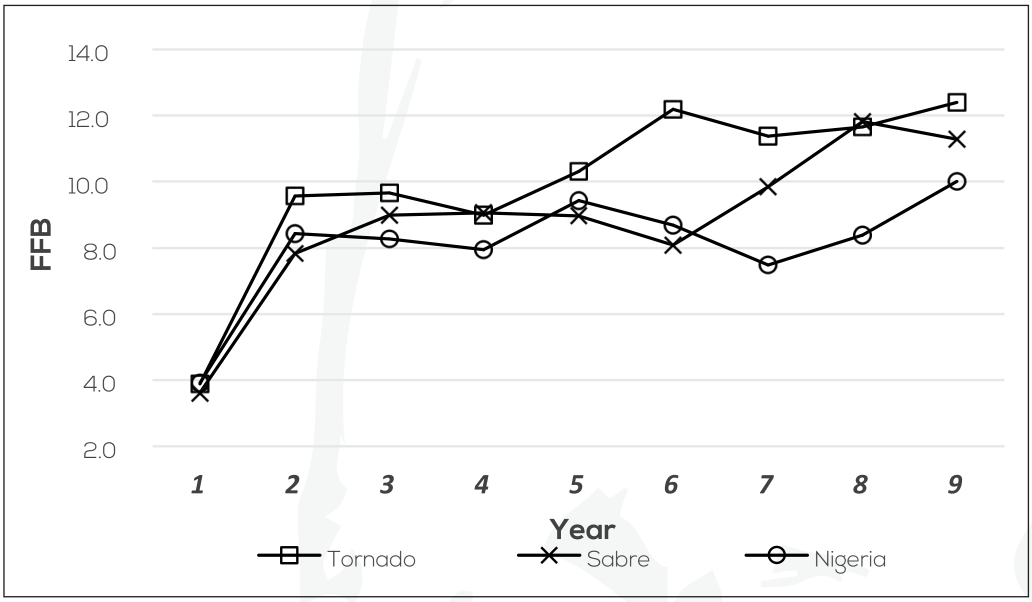

Figure 3. Oil yield in two compact clones planted in 2004, compared with the E. guineensis DxP variety Deli x Nigeria, Costa Rica.

Until recently, the ASD Tissue Culture program has cloned "compact" palms from the BC_2 TxT population planted in 1986 and some of their "reclones" from 2005. Now, an improved group of elite palms coming from the 2008 DxP compact progenies and derived from BC_1F_2 and BC_2F_1 is being introduced to the lab. The next selection cycle of high density ortets should produce clones with a good combination of total oil yield and short leaves; some of them could be planted at densities of 160 to 180 palms/ha under most planting conditions and performance on average superior to that of the Tornado reference clone is expected *Table 16*.

TABLE 16. FFB, GROWTH AND OIL YIELD IN A SAMPLE OF NEW "COMPACT" *TENERA* ORTETS FOR TISSUE CULTURE, PLANTED IN 2008 AND SELECTED IN 2016

Origin	Dens	n	FFB	THI	LL	O/B	Oil
"Compact" BC_1F3 x Ekona	143	3	204	32	653	25.9	6.6
"Compact" BC1F3 x Evolution	160	3	198	28	515	33.8	9.3
"Compact" BC1F3 x Nigeria	180	4	176	32	484	26.5	7.3
Deli x "Compact" BC2F2	160	6	212	39	544	30.0	8.8
"Compact" BC2F2	160	5	212	58	547	32.0	9.4
"Compact" BC2F1 x Ghana	170	5	180	42	570	32.6	8.7
"Compact" BC2F1 x Nigeria	143	5	244	36	693	34.1	10.3
"Compact" BC2F1 x Nigeria	160	24	236	41	629	32.7	10.7
"Compact" BC2F1 x Nigeria	170	5	244	46	543	35.3	12.8
E. guineensis Deli x Nigeria	143		195	70	673	26.9	6.5
Tornado (reference)	**180**		**174**	**43**	**557**	**31.6**	**8.6**

Dens = estimated optimum density based on leaf length and light penetration; n = number of ortets; FFB = fresh fruit bunches, kg/palm/year, 4 years of records; THI = increase in trunk height, cm/year; LL = leaf length, measured at 84 months old, cm; O/B = % of oil in the bunch; Oil = estimated total oil yield on industry basis.

Secondary traits

ASD genetic diversity has been only partially used to develop planting materials; emphasis has been put on populations with 30 or more years of selection and breeding in pursuit of high yielding and uniform varieties, while some origins showing interesting secondary traits have not been the priority in the past 20 years. For this reason, new selection programs have recently started focusing on characteristics such as *virescens* fruit color, now found in homozygous condition in some T/P Nigerian families from ASD; tolerance to bud rot, high oleic acid and low dehiscence of fruits as well as low FFA content. The last three of these have been found in particular in the "compact" families.

In general, *E. guineensis* varieties have iodine values (IV) in the range of 53-55 and they come from *dura* lines whose IV is around 51. In comparison, some "compact" dura families show IV as high as 66, suggesting that it is possible to produce commercial varieties with high unsaturation (IV = 63) and potentially greater olein yield *Figure 4*.

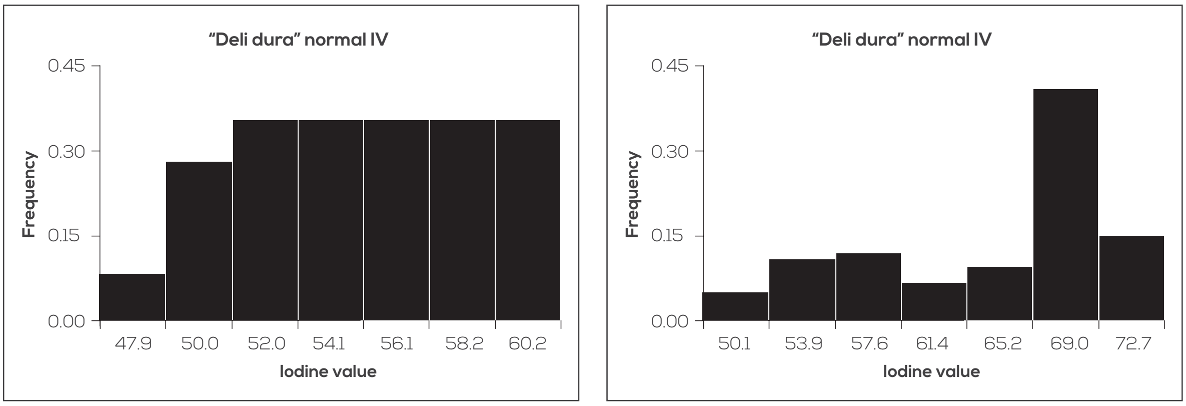

Figure 4. Iodine value in Deli dura (n = 96, IV = 51.0 ± 0.24) and "high unsaturared compact" dura (n = 395, IV = 62.8 ± 0.35) populations.

The low dehiscence condition, another interesting secondary trait, has been found in some DxP families traced back to the "compact" *dura* population. The Evolution Blue variety is outstanding in this respect; it shows a small fraction of loose fruit percentage 15 days after the first detached fruit, in comparison with a normal detachment variety like *E. guineensis* Deli x Nigeria (2.6 vs 11% of loose fruits). Additionally, some specific combinations in the "Compact" x Nigeria variety also look promising, with around half the fruit detachment of the normal varieties (5.8 vs 11% of loose fruits) *Figure 5*.

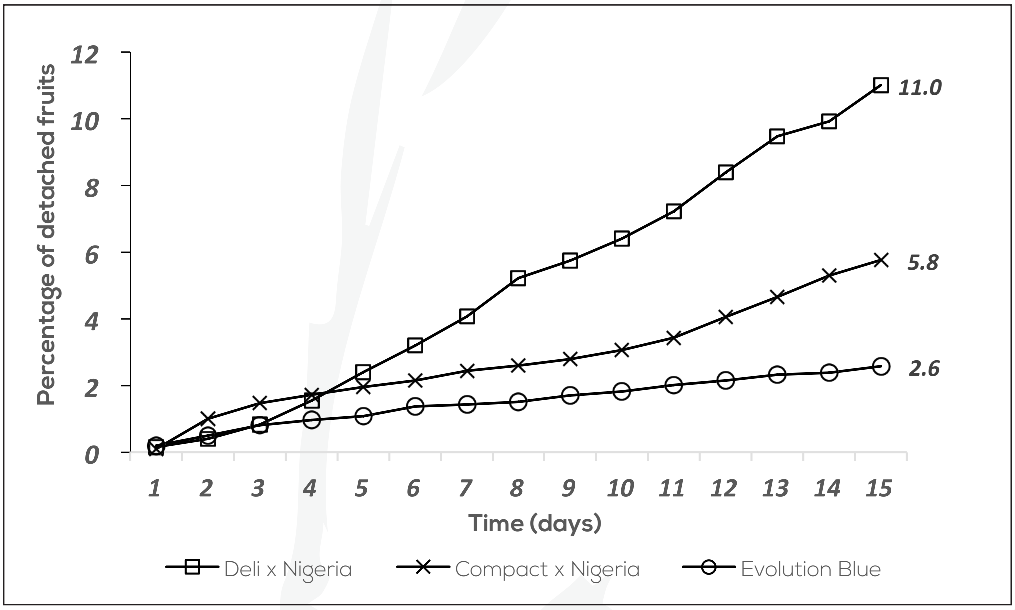

Figure 5. Percentage of detached fruits (before and after harvest, average of 10 bunches) for a 15 days period, after the first detached fruit was observed in E. guineensis Deli x Nigeria, "Compact" x Nigeria and Evolution Blue varieties. Data were taken during the rainy season of 2015.

CONCLUDING REMARKS

In order to develop the best planting materials in the medium and long term, the main strength in any breeding program is to have the greatest genetic diversity possible. This is especially important in a long cycle crop like oil palm, because a lot of time is spent in evaluating the populations to make the initial selection and to combine them for a variety release. During the process, many important genes are lost and some important primary or secondary traits may not be considered.

ASD has worked for around 50 years to consolidate the *E. guineensis* populations and varieties and at the same time define the best strategy for its "compact" backcrossing program. Along with this process, it has also consolidated the seed production business through a consistent and continuous research program and the strengths of its planting materials. Change in market demand for varieties over time has favored those with high productivity and certain special traits. ASD seed production for the upcoming years will continue to be directed towards the development of high density varieties with the highest yield potential and with some special secondary traits such as the virescens fruit color, high unsaturation, slow dehiscence and disease tolerance.

There is no doubt that the ASD breeding program started and grew thanks to the wide genetic diversity collected all around the American oil palm belt and also through exchange programs with research centers in Africa and Asia and the collection of wild African palms. During the last 25 years, ASD improved materials were sold to breeding programs in Thailand and Indonesia, where some groups are now producing seeds. It is therefore imperative that ASD Costa Rica continue developing advanced populations and varieties for the near future.

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Oil Palm Breeding and Seed Production in Africa

Bakoumé, C[1]; Ngando Ebongué, G[1]; Ajambang, W[1]; C D Ataga C D[2]; Okoye, M N[2]; Enaberue, L O[2]; Konan, J N[3]; Allou, D[3]; Diabate, S[3]; Konan, E[3] and Etta, C E[4]

[1]Institute of Agricultural Research for Development (IRAD), Centre for Oil Palm Research of La Dibamba, P.O. Box 243 Douala, Cameroon
[2]Plant Breeding Division, Nigerian Institute for Oil Palm Research (NIFOR), P.M.B 1030 300001, Benin City, Edo State, Nigeria
[3]National Agricultural Research Center (CNRA) – Oil palm program – La Mé Research Station - 13 BP 989 ABIDJAN13 (Côte d'Ivoire)
[4]Pamol Plantations Plc, P.O.Box. 5483, Akwa-Douala, Cameroon
*Corresponding author: Claude Bakoumé Tel: +237-679326613 / +60-173741884
E-mail: claude.bakoume@simedarby.com

The growth in the population of Africa has led to high demand for vegetable oils, including palm oil, for both the food and non-food uses. The continuing availability of land for cultivation will not remain indefinitely a non-limiting factor in the expansion of oil palm in the Continent. The availability of genetically high-yielding planting materials for expansion and/or replanting programmes in conjunction with the use of best agricultural practices are key factors boosting Africa's palm oil production. Given that breeding is able to manage genetic variability in the development of superior varieties, it is an ideal means for producing high-performing oil palms. In the past as oil palm became domesticated, African and European colonizers and partners sought to increase the production of oil, kernels and palm wine by increasing the number of palms or by increasing the yielding capacity of the individual palm or both. Sound results from early breeding or breeding-oriented work, to name a few, include (i) the discovery of single gene inheritance of the shell character, (ii) the development of a protocol for measurement of bunch and fruit components, (iii) the superiority of inter-origin progenies to the intra-origin ones in terms of fresh fruit bunch production due to heterosis, (iv) the almost total control of *Fusarium* wilt, and (v) the selection of "Djongo" or "the best" and LM2T, two oil palms representing the main provenances of pollens used in the production of commercial seeds for development of oil palm plantations. African oil palm research centres in countries such as Benin, Cameron, Côte d'Ivoire, Ghana, and Nigeria continue the search for new and higher performing genotypes for increased oil palm yields and productivity with special interests in (i) high fresh fruit bunch yield, (ii) fruit composition for improved oil yields, (iii) slow height growth for prolonged economic life of oil palm plantations, and (iv) tolerance to diseases and water stress. Given the relatively narrow genetic base of breeding stocks, each country has widened its oil palm germplasm through exchanges of breeding materials with research partners or through prospecting for a country's natural oil palm groves. Two cycles of selection have been completed in the continent and progenies from the third selection cycle are field planted and even undergoing assessment in some of the above countries. Superior varieties developed by second cycle of breeding programmes are quantitatively reproduced by the seed production units of the respective countries, ensuring a continent potential of about 45 million seeds from the second cycle of selection to be supplied yearly to oil palm growers. Country's annual potential varies from 4 million (estimated) in Ghana to 15 million in Nigeria.

Keywords: oil palm, high yield, slow vertical growth, germplasm, seed production potential.

INTRODUCTION

According to Zeven (1967), the oil palm has grown in Africa from very early time and there was evidence of palm oil being used 3000 years BC. The plant is of great importance to many countries in Africa. It is a considerable source of edible vegetable oils and fats and of income as well. Palm oil is the most valuable natural oil in the diet of sub-Saharan African people both as crude red palm oil and, recently, as refined oil (olein). It is also a source of industrial fats. In Nigeria, it plays a major role in the socio-economic and political life of the people. In Cameroon, it contributes to the household's stability because it is believed that providing palm oil to a wife is almost equivalent to buying her a gold-made jewelry. Hence, palm oil is also called red gold. In Côte-d'Ivoire, palm oil from Man, a mountainous region of the west of the country is highly regarded as exceptional given its fluidity and sensory qualities (Ricardo 2013). The Man's oil usually extracted traditionally is also subject of a highly developed local trade. Africans and their European colonisers understood the need of augmenting palm oil production in relation with its diverse uses which led to high demands for the commodity. Locals in the African oil palm belt have initiated mass selection for desired traits including palm oil yield. Germans did the same in 1912 in Cameroon. Unfortunately, the yield increment from mass selection was very low. Adaptation of selection scheme applied different plant species to oil palm by British and French groups led to considerable yield improvements *i.e.* from 0.2 t/ha of palm oil natural groves to about 7.5 t/ha for the best progenies. Exchanges of oil palm germplasm materials and collection of genetic resources from natural oil palm groves were anticipated solutions to the narrowing of the genetic base of breeding stocks as well as to oil palm growers and palm oil consumers' dynamic demands for new oil palm architecture and new palm oil profiles, respectively. Whatever the value added from a new product of breeding may be, the product must be propagated for supply to growers. Bakoumé (2013) noticed that one of the most important challenges facing oil palm development in Africa in the availability of planting materials. The current paper aims at (i) presenting the results from early oil palm selection works conducted in Africa, (ii) indicating priorities of current breeding programmes, and (iii) giving a global picture of oil palm seed production in Africa and in few countries.

Some sound results of early oil palm breeding in Africa

The improvement of oil palm (*Elaeis guineensis* Jacq.) by selection and breeding that started in the Democratic Republic of Congo (DRC) in the 1920s led to the selection of the famous Djongo (meaning 'the best'), one parent of SP540 whose spectacular performance recorded from Deli *dura* x SP540 made it the main pollen donor in seed production in Southeast Asia. Later, in the same country, the work of Beirnaert and Vanderweyen (1941) established the single gene inheritance of the shell character dispelling the theory, then current in French West Africa, that the tenera was a 'degenerating form of the oil palm'. Since 1960, all commercial oil palm planting materials have been *tenera* (also known as DxP).

In Nigeria, concerted efforts towards the genetic improvement of the plant and of management practices started with the establishment of the Nigerian Institute for Oil Palm Research (NIFOR) in 1939 known as Oil Palm Research Station (OPRS). Later, Blaak *et al.* (1963) developed methods of bunch and fruit analysis for good assessment of palm oil production, the raison-d'être of oil palm cultivation, of progenies planted in the field trials.

In Côte-d'Ivoire, 19 oil palms chosen from a survey made in Bingerville Botanic Gardens and also in the wild palm grove at La Mé, after breeding, led to the selection of what is today known as La Mé material of high bunch number and poor bunch characteristics. In 1946, the Institut de Recherche pour les Huiles et Oléagineux (IRHO) organised the "Expérience Internationale" consisting of an exchange of their best materials between 5 stations including La Mé (Côte-d'Ivoire), Pobé (Benin), Sibiti (Congo), Yangambi (DRC) and SOCFIN (Malaysia) (Gascon & de Berchoux 1964). Each centre did inter- and intra-origin crosses. The field progeny testing showed large variability in crosses between palms from different origins for vegetative and yield characteristics. The superiority of inter-origin progenies over the intra-origin ones resulting from heterosis in the former progenies was observed. Also, Deli x Africa progenies performed well compared to Deli x Deli and Africa x Africa progenies with high heritability for bunch number, percentage mesocarp to fruit, fruit weight and kernel weight.

A series of tests of tolerance to *Fusarium* wilt carried out at Dabou (Côte-d'Ivoire), Pobé (Benin) and Cameroon have shown that tolerance to the disease is horizontal. *Dura*, *tenera* and *pisifera* parents which possess the genes of tolerance to *Fusarium* are well known. *Fusarium* wilt is now considered to be totally under control in Africa. The control measure is preventive whereby planting material whose tolerance has been established is advised for planting in *Fusarium* wilt-affected areas. As of today all *pisifera* used in the production of *Fusarium* wilt-tolerant seeds are descendants of the original parent LM2T from Bingerville Botanic Gardens.

Current oil palm breeding works

The aims of oil palm breeding in Africa are to maximise palm oil (and kernel) yield, to reduce vertical growth to extend the plant economic life, to select for tolerance to drought to enable expansion of the planting area, to explore new sources of tolerance to *Fusarium* wilt, and most recently to improve palm oil quality (high iodine value, low free fatty acids content). The major breeding schemes are, to name a few, the reciprocal recurrent selection at La Dibamba (Cameroon), La Mé (Côte-d'Ivoire), Pobé (Benin), and NIFOR (Nigeria), followed by the modified recurrent selection at Pamol (Cameroon).

Breeding work in Côte-d'Ivoire

Two projects are shared by La Mé (Côte-d'Ivoire) with participants of ISOPB 2016 seminar *i.e.* one on the characterization of natural oil palm collections from Man in the western part of Côte-d'Ivoire and the other one on the introgression of the slow-growing nature of Akpadanou population (Benin origin) in the breeding materials of La Mé (Côte-d'Ivoire) origin.

Traditional palm oil from Man, a mountain area, is very value for its fluidity and its organoleptic qualities. The project aims at preserving oil palm genetic resources from Man and developing planting materials with high fluidity. In fact, Man's natural oil palm grove is endangered because of the development of modern agriculture using different species or improved *tenera*. A survey was conducted in eight villages within a radius of 54 km along the main roads leaving Man city (*Figure 1*). Investigations in the eight villages have permitted the referencing of 57 sub-spontaneous oil palm trees including 55 *dura* and 2 *tenera* used for traditional oil production. Bunches harvested from these trees were used for varietal determination, analysis of oil fluidity and evaluation of oil to bunch ratio. One or two fruits were cross sectioned per bunch for varietal determination. Oil fluidity was measured by determining iodine index and oil palm to bunch was determined from physic and chemical parameters using the formula:

$$O/B = F/B \times M/F \times O/M$$

where

O/B = oil to bunch ratio
F/B = fruit to bunch ratio
M/F = mesocarp to fruit ratio
O/M = oil to mesocarp ratio

The O/B was 15.74%, with values ranging from 10.38% to 27.36%. The iodine index values (I), which express oil fluidity, ranged from 54.66 to 59.77 (mean = 57.31). These values are relatively high compared to those of the planting materials (I = 50-52) currently supplied to oil palm growers. These results confirm the very good oil fluidity of Man's traditional palm trees and which combined with height variability promises real possibilities for the improvement of palm oil fluidity and economic life of oil palm in Côte-d'Ivoire.

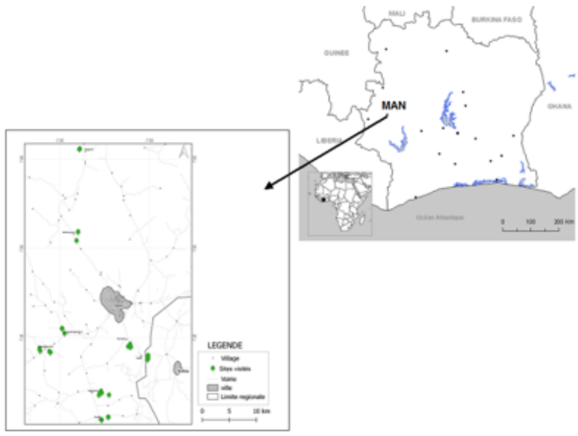


Figure 1. Locality of prospection sites.

For the introgression of the slow-growing nature of Akpadanou population (Benin origin) in the breeding materials of La Mé (Côte-d'Ivoire) origin, 11 progenies from (Apkadanou x La Mé) x La Mé and (Apkadanou x La Mé) x (La Mé x La Mé) crosses with reference to a control (DA10D x LM2T) were studied. In an experimental trial beginning in 2002 these progenies were planted to a density of 143 trees per hectare according to an in-line device. Each progeny comprises 26 trees. Oil palm height was measured at the axil of leaf 33 as described by Jacqmard (1980) using the formula

$$VC = H / (N-3.75)$$

where H = stem height, N = age of the oil palm, 3.75 = age of the fictitious off the floor of the sheet 33, from which growth rate is constant

Statistical analyses of data showed that all of the progenies tested grew slower than the control material *Table 1*, only from 19.86 to 35.89 cm per year against 45.25 cm per year for the control material. That is more than 20% reduction in vertical growth was observed in these progenies (*Figure 2)*. These results raise the prospect of selection of plant material with reduced height growth together with good fresh fruit and palm oil yield.

TABLE 1. MEAN VERTICAL GROWTH PER YEAR OF PROGENIES TESTED AND HEIGHT REDUCTION RATES WITH REFERENCE TO THE CONTROL CROSS

Croisses	Number of progenies	Mean of vertical growth (cm/yr)	Height reduction over the control (%)
DA10D x LM2T*	1	45.25	-
(AKN3 x LM10T AF) x LM2T AF	3	29.79	34
(AKN3 x LM2T AF) x LM2T AF	2	33.01	27
LM10 T AF x (AKN3 x LM2 TAF)	2	24.84	45
(AKN3 x LM10 T AF) x LM10 T AF	2	23.55	48
(AKN3 x LM2T AF) x (LM5T x LM10 T)	2	27.42	39

* Control cross

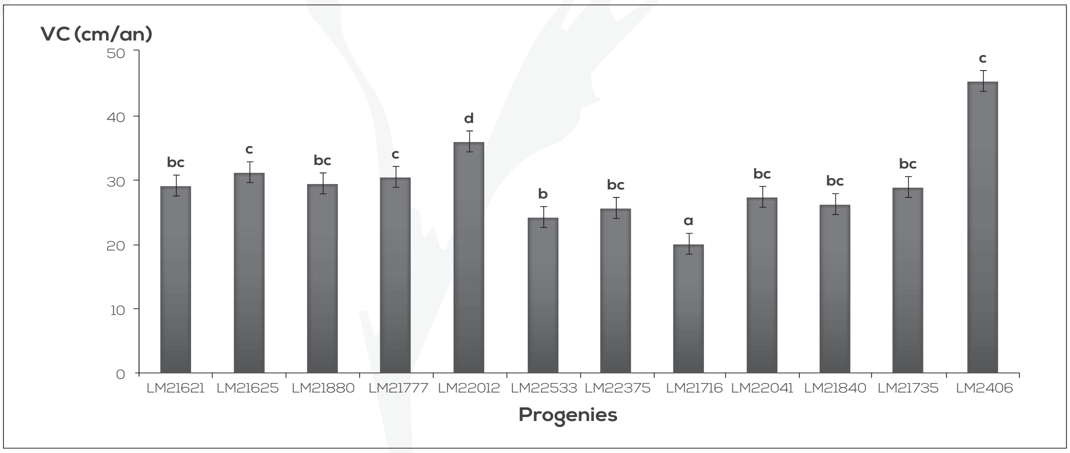


Figure 2. Average growth rates of progenies tested.

Breeding work in Nigeria

The NIFOR oil palm genetic improvement programme is aimed at exploiting both the general and specific combining abilities (additive and non-additive genetic variances) that control fresh fruit bunch (FFB) yield. The first selection cycle started in 1962. It was concluded by the United Kingdom Technical Assistance Team (UKTAT) between 1973 and 1976 (West 1976). Five (5) Deli *dura*, 9 African *dura*, and 13 *tenera* parents were selected forming the breeding stock of the second selection cycle. Introductions of some new materials were done in the combinations for the second selection cycle.

The objectives in the second cycle were to develop improved oil palm *tenera* hybrid planting materials producing yearly 20-25 metric tonnes FFB/ha, that are precocious *i.e.* starting bearing fruit bunches 2-3 years after field planting, slow growing, and tolerant to vascular wilt disease (Okwuagwu *et al.* 1986). Between 1987 and 2000, 15 field trials were planted in 80.60 hectares to test 205 progenies including 45 *dura x dura* (D x D) progenies, 16 (*tenera x tenra* (T x T) progenies, and 144 *dura x* *tenera* (D x T) test-cross progenies. Results from only three (3) of the D x T test-cross progenies trials covering 22.80 ha will be presented here. The experimental design was a RCBD with 3 or 6 replicates and 16 oil palms per elementary plot. The control was a *dura x pisifera* (DxP) progeny from the first selection cycle. Genetic progress has been made on the average bunch weight (14.46 kg vs. 10.88-11.55 kg for the control *(Tables 2, 3)*. Total bunch weight has also increased representing 106-129% of that of the control. Slow-growing progenies were 18 % shorter than the control. Genetic progress has also been made in early bearing. In fact, some progenies were as precocious as the control *(Table 4)*.

Intensive selection of desired natural oil palms by the locals has resulted in the fixation of genes controlling traits of interest for them such as (i) high sap (palm wine) yield, (ii) high bunch number of moderate weight, and (iii) dwarfism or very short internodes.

TABLE 2. PERFORMANCE AT MATURITY OF 14 SECOND SELECTION CYCLE TEST-CROSS PROGENIES FROM TRIAL 1 PLANTED IN 1987

Parameters	Trial mean		3 best progenies		Control
	D	T	D	T	
BN	3.6		3.2		3.9
ABW (kg)	13.29		14.46		10.88
FFB (kg/palm/yr)	46.27		43.75		41.10
F/B	64.9	60.0	67.1	60.3	59.4
M/F	54.9	78.2	57.2	82.3	79.2
S/F	36.0	13.9	35.8	11.3	14.7
K/F	26.3	6.7	7.0	6.3	7.4
M/B	35.7	48.9	38.2	49.5	46.4
Height (cm)	220		231		223
Crown (cm)	263		274		266

BN = bunch number, ABW = average bunch weight, M/B = mesocarp to bunch ratio.

TABLE 3. PERFORMANCE AT MATURITY OF 16 SECOND SELECTION CYCLE TEST-CROSS PROGENIES FROM TRIAL 2 PLANTED IN 1987

Parameters	Trial mean		3 best progenies		Control
	D	T	D	T	
BN	3.6		4.0		3.4
ABW (kg)	12.04		12.37		11.55
FFB (kg/palm/yr)	40.68		48.76		37.72
F/B	63.5	58.6	63.3	54.7	61.2
M/F	53.8	76.9	53.4	79.4	81.8
S/F	35.7	13.8	35.5	12.1	10.5
K/F	11.8	8.0	10.5	8.1	7.7
M/B	34.2	44.7	33.9	43.7	50.0
Height (cm)	163		164		201
Crown (cm)	267		264		274

BN = bunch number, ABW = average bunch weight, M/B = mesocarp to bunch ratio.

TABLE 4. EARLY BEARING PERFORMANCE (PRECOCITY) OF 21 SECOND SELECTION CYCLE TEST-CROSS PROGENIES FROM TRIAL 3 PLANTED IN 1993

Parameters	Trial mean		3 best progenies		Control
	D	T	D	T	
BN	4.6		-		4.8
ABW (kg)	4.36		-		4.82
FFB (kg/palm/yr)	21.73		-		21.53
F/B	-	-	-	-	-
M/F	-	-	-	-	-
S/F	-	-	-	-	-
K/F	-	-	-	-	-
M/B	-	-	-	-	-
Height (cm)	199		-		183
Crown (cm)	273		-		280

- not yet available

Deli *dura* originating from Serdang Avenue and Deli *dura* obtained from Ecuador showed good general combining ability (GCA) in crosses with two Aba/Calabar *tenera*. The Deli *dura* and Aba/Calabar *tenera* possessed different but complementary characters for FFB and, unusually, high bunch number for Deli *dura* parents and high bunch weight for Aba/Calabar *tenera* parents (*Table 5*.)

TABLE 5. GENERAL COMBINING ABILITY (GCA) RATINGS FOR BUNCH YIELD COMPONENTS OF PARENTS OF THE HIGHEST AND LOWEST YIELDING PROGENIES FROM TRIALS 2 AND 3

Parents	GCA rating		Ranking of progeny performance		
	BN	ABW	BN	ABW	FFB
Serdang Avenue Deli	High	Average			
x	x Low	x	5/15	2/15	1/15
Aba/Calabar *Tenera*		High			(129% of trial mean)
Ecuador Deli	High	Average			
x	x	x	5/17	3/17	1/17
Aba/Calabar *Tenera*	Low	High			(136% of trial mean)
IRHO Pobe Deli	Low	High			
x	x	x	11/15	11/15	15/15
Calabar *tenera*	Low	Low			(69% of trial mean)
Ufuma *dura*	Low	Average			
x	x	x	17/17	4/17	17/17
Ogba ex Calabar *tenera*	Low	High			(81% of trial mean)

Oil palm germplasm collections maintained by NIFOR

Establishment of NIFOR oil palm germplasm started in 1912 with the exploitation of the Calabar, Aba, Nkwele and, later, Ufuma natural groves of South Eastern Nigeria, which resulted in the selection of *dura* and *tenera* parent palms for breeding purposes. In addition, a very liberal exchange policy enabled the introduction of oil palm materials from various African, Southeast Asian, and Latin American origins currently exploited for breeding and selection (Okwuagwu 1986). Details of the NIFOR oil palm breeding stocks are presented in (*Table 6)*.

TABLE 6. BASE POPULATIONS OF THE NIFOR BREEDING PROGRAMME

Origin	Country	Organization	Type of materials	Year of Introduction
Calabar	Nigeria	NIFOR	12 *dura* and *tenera* with high bunch number and high bunch weight	1912-1916
Aba	Nigeria	NIFOR	5 *dura* and 6 *tenera*	1939-1941
Ufuma	Nigeria	NIFOR	166 palms from high density area in Ufuma characterized by unusually high percentage of *tenera* palms. *Tenera* selections with excellent fruit composition and high bunch number	1939
Angola	Angola	Agric. Station Njala, Sierra Leone	4 crosses and selfings from 6 original palms introduced from Angola to Sierra Leone	1960s
Yangambi	Zaire	INEAC	Seed and pollen from some of the *tenera* parent palms from INEAC breeding programme	1960s
Binga	Congo	Research Department, Binga	Pollen and crosses of 4 *tenera* palm selected for high bunch yield and good fruit composition	1960s
Lobe	Cameroon	Research Department	3 packets of seeds and pollen from 4 crosses of selected palms	1960s
La Mé	Ivory Coast	IRHO	Pollen from selected *tenera* palms with excellent fruit composition, large fruits and compact progenies	1960s
Sabah Deli	Malaysia	Department of Agriculture Malaysia	Pollen and crosses from 16 Delis in their breeding programme	1960s
Serdang Avenue Deli	Malaysia	Department of Agriculture	Crosses between 3 palms with high bunch number	1948
Ulu Remis Deli	Malaysia	Camera Programme	Palms selected for good fruit composition and high bunch yield	1960s
Dabou Deli	Ivory Coast	IRHO	Pollen from *dura* selected for high bunch yield	1950s
Pobe Deli	Ivory Coast	IRHO	Pollen from crosses within and between high bunch number and average bunch weight *dura* palms	1950s

TABLE 6. BASE POPULATIONS OF THE NIFOR BREEDING PROGRAMME (CONTINUED)

Origin	Country	Organization	Type of materials	Year of Introduction
Ecuador Deli	Ecuador	INIAP	10 crosses between *dura* palms selected for high average bunch weight and high sex ratio	1960s
Jamaica	Jamaica		Dura related to 39.419, similar in fruit composition to the Deli *dura* materials	1950s

In addition, NIFOR maintains 150 hectares of natural oil palm collections from the various parts of the country (Omoti 2003) *(Table 7)*.

TABLE 7. NIGERIAN NATURAL OIL PALM COLLECTIONS IN NIFOR GERMPLASM

Year of collection	Locality collected	Number of accessions		Total number of accessions	Year planted	Area planted (ha)
		Dura	*Tenera*			
	Aba	42	3	45		
1954	Ufuma	19	25	44	1956	40
1960s	Coastal, inland and marginal areas of Nigeria	-	-	72	1964	8
1973	45 locations within the oil palm belt of Nigeria	595	324	919	1975	40
1991	Marginal zone of Old Nsukka Province	58	23	81	1993	17

The continuous evaluation, exploitation, and conservation of the genetic diversity of oil palm groves have remained a major thrust of the Institute. Major efforts in the 1990s were directed to the Nsukka groves in the Northern fringe of the main oil palm belt, a dry area (Okwuagwu *et al.* 1993).

Six palms from the Nsukka grove including 2 *tenera* and 4 *dura* were selected and exploited *in-situ*. The bunch yield profile of these selected grove palms is presented in (*Table 8)*.

TABLE 8. BUNCH PRODUCTION AND BUNCH CHARACTERISTICS OF 6 OIL PALMS MAINTAINED *IN-SITU* IN NSUKKA NATURAL OIL PALM GROVE

Palm grove	Fruit form	Bunch number	FFB Yield (kg)	Average bunch weight (kg)	Expected FFB yield MT/ha.	Fruit number /bunch	Single fruit weight (g)	% F/B
OPI 083	*Tenera*	6	240.0	40.0	35.5	1,475	19	71
AGUIBEJE 084	*Tenera*	10	245.0	24.5	36.3	2,583	6	63
OPI 043	*Dura*	19	415.0	21.8	61.4	3,470	5	73
AGUIBEJE 001	*Dura*	11	489.5	44.5	72.4	4,050	8	76
UMUAGAMA 022	*Dura*	6	312.0	52.0	46.2	5,250	6	63
UMUAGAMA 082	*Dura*	14	322.0	23.0	47.7	1,980	8	70
Mean		11	337.3	34.3	49.9	3,134.7	8.7	69.3

Oil palm selected from Nsukka are expected (i) to contribute to the development of planting materials for dry areas, (ii) to be introgressed into the main breeding program, and (iii) to generate open pollinated progenies for new selection, and a data bank for the region (*Table 9*). Open pollinated progenies have shown a high variability for FFB and a marked slow height increment.

TABLE 9. ANNUAL MEAN YIELD AND VEGETATIVE CHARACTERISTICS OF THE 81 OPEN POLLINATED PROGENIES OF THE NSUKKA GROVE ASSESSED IN THE NIFOR MAIN STATION

Trial	Number of accessions	Fruit form	FFB (kg/palm /yr)	ABW (kg/palm /yr)	BN	Stem height (cm)	Stem girth (m)	Crown diameter (m)
56-1	49	D	32.8 (14.5-70.8)	32.8 (3.0-6.4)	7.4 (3.7-11.7)	65.2 (35.3-107.4)	2.21 (1.63-2.77)	8.34 (6.71-12.30)
56-3	22	T	19.4 (10.5-42.5)	5.0 (3.9-8.5)	3.9 (1.8-5.9)	79.4 (49.0-108.1)	2.18 (1.88-2.60)	7.87 (6.43-8.86)
56-4	9	D	16.3 (11.4-20.5)	3.57 (2.0-5.3)	4.6 (3.3-10.3)	73.6 (68.1-91.4)	2.02 (1.50-2.35)	7.71 (5.73-8.75)
NIFOR EWS 1st cycle hybrids		T	17.5 (11.0-21.79)	4.09 (3.8-4.7)	4.1 (2.9-5.2)	80.1 (75.3-87.4)	2.25 (1.94-2.43)	8.13 (7.87-8.37)

Breeding work in Cameroon

Breeding at La Dibamba

Growth and yield parameters of two progeny trials LD GP28 (28th progeny trial planted at La Dibamba) and LD GP29 are underway. Palms were planted in 2004 and 2006, respectively. The study of LD GP28 is aimed at assessing the performance of Widikum (WI) *dura* parents with reference to classical Dabou *dura*. WI is derived from La Mé (LM) *tenera* x Widikum *tenera* crosses realised at La Mé (Côte-d'Ivoire) Oil Palm Research Station including LM2T x WI15T, LM5T x WI1T, LM5T x WI10T, and LM2T x WI10T. The trial contained 25 progenies including two control progenies one from each of the (LM 2 T x DA 10 D) and (LM 2 T x DA 115 D) crosses. The experimental design was a 5 x 5 lattice with 6 replicates. On the other hand, LD GP29 trial is aimed at the introgression slow-growing material from the Pobé (Benin) origin (PO3497, PO3550) into La Mé breeding progenies (LM495, LM3131). LD GP29 consists of three progenies derived from crosses between African Group B populations of palms with a large number of small bunches.

Analyses of fresh fruit bunch production and its components as well as those of bunch and fruit characteristics are ongoing.

Oil palm germplasm collections maintained by La Dibamba

In May 2008, the Indonesian Palm Oil Board (IPOB) and the Cameroon Institute of Agricultural Research for Development (IRAD) collected 103 natural oil palm accessions were collected from all over Cameroon's oil palm belt containing 89 *dura* and 14 *tenera*. Different types by fruit colour were obtained: 96 *nigrescens*, 5 *virescens*, 1 *albescen*s, and 1 intermediate between *nigrescens* and *albescens*. Accessions were planted in trials LDGP 30 and LDGP 31 in 2011 using a RCBD with 3 and 2 replicates, respectively.

The objective of the collection was to broaden and enrich the genetic base of current breeding materials with new traits such as, to name a few, slow growth, small canopy, long peduncle, and tolerance to drought. Molecular analysis of a sample of the IRAD-IPOB natural oil palm collections has indicated a high percentage of polymorphic loci (96.43%), an abundance of neutral alleles (2.30 ± 0.90) and a very high genetic diversity (I = 0.29) (Ajambang *et al.* 2012).

From a previous collection jointly carried out in Cameroon natural oil palm groves in 2007 by IRAD and CENIPALMA, the Colombian Oil Palm Research Institute, 24 accessions (6 *tenera* and 18 *dura*) considered as complementary to the IRAD-IPOB collection were planted using RCBD design with 3 replicates in 2011. Recording of growth and fresh fruit bunch yield and its components is currently being carried out.

Breeding in Pamol Lobe

Selection started in Pamol in the 1930s among materials sourced from the nearby German Ikassa Oil Palm Estate, the Calabar Oil Palm plots established in about 1912, controlled pollination of selected palms in Ndian, a Pamol estate, and Cowan (Nigeria), with some introductions from DRC (former Zaire). Materials of Deli origin were imported from Malaysia in 1932/33.

A more scientific and comprehensive (first generation) oil palm breeding programme was initiated as far back as 1948 for yield improvement along with tests for resistance to *Fusaruim* wilt. Yields from a total of 35,000 palms were recorded, from which 362 were selected for further evaluation including 209 sourced from Cowan and 153 from Ndian and Ekona. Further selection had by 1951 reduced these numbers to 18 *dura* and 24 *tenera* mainly of Ekona and Cowan origins (*Figure 3)* which formed the bases or foundation stocks of the current breeding programme *(Tables 10, 11)*. Then, 35 first generation progenies were produced from various selfings and crossings, including 18 *dura x tenera* (D x T) crosses and four *tenera* selfings field planted at Lobe Estate in 1954 and 1955. Data of bunch production and bunch analyses led to selfing of 17 interesting *tenera*. Progenies obtained were planted in 1967 and have provided pisifera for seed production.

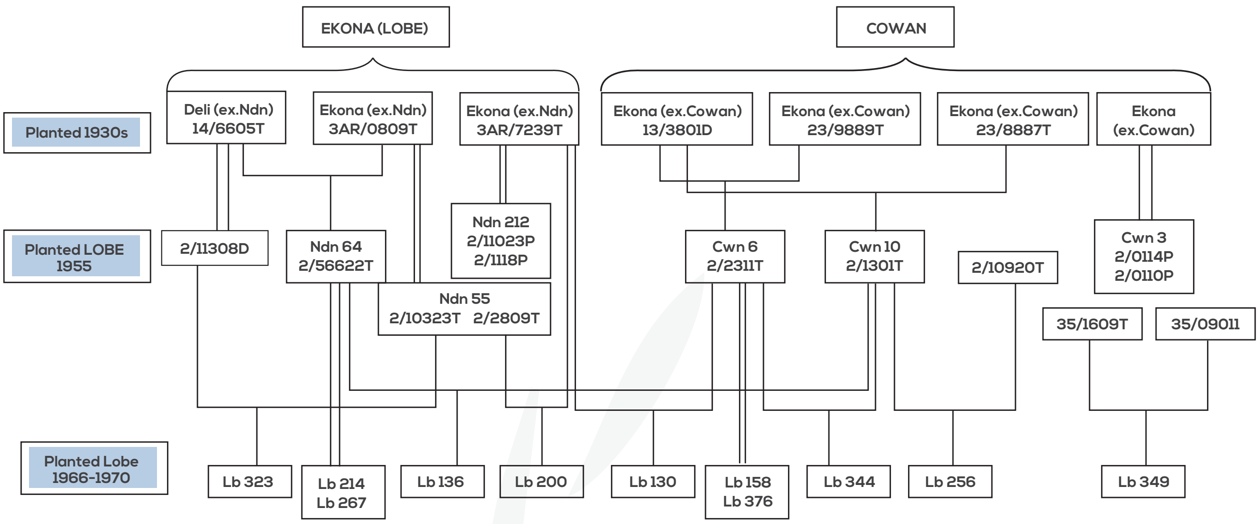


Figure 3. Ekona and Cowan ancestry of Pamol breeding programme.

TABLE 10. FIRST GENERATION *DURA* PARENTS SELECTED AT COWAN AND NDIAN ESTATES

	Mean annual yield of FFB (kg/palm)	Oil/bunch (%)	Oil/ fruit (%)	Oil (kg/palm)
Cowan				
10/5568.	156.2	26.4	17.1	26.7
12/1/9264.	143.2	27.4	18.9	27.1
13/301	138.0	34.7	24.0	33.1
23/8799	118.5	25.4	18.6	22.0
23/10281	126.4	28.9	21.5	27.2
23/10294	140.8	23.4	16.5	23.2
26/0932 (Deli)	254.6	24.8	18.3	46.6
26/5767 (Deli)	225.0	27.6	18.5	41.6
29/6459	193.7	27.2	19.4	37.6
38/4163	183.4	26.4	17.3	31.7
39/3459	180.0	26.5	17.7	31.9
44/10419	124.7	26.2	17.1	21.3
Mean	165.4	27.1	18.7	30.8
Ndian				
3AR/0744	132.9	32.0	20.8	27.6
3B/9607	127.3	28.8	21.1	26.9
3B/10045	131.4	22.8	21.7	28.5
4/1/7109.	141.1	32.6	19.3	27.2
14/6605	126.2	36.0	21.2	26.7
15/6201	146.1	28.1	21.8	31.9
Mean	134.2	30.1	21.0	28.1

TABLE 11. FIRST GENERATION *TENERA* PARENTS SELECTED AT COWAN AND NDIAN ESTATES

	Mean annual yield of FFB (kg/palm)	Oil/bunch (%)	Oil/ fruit (%)	Oil (kg/palm)
Cowan				
13/3402	133.5	35.9	21.5	28.7
23/4889	151.6	37.3	24.9	37.7
23/6266	141.6	49.2	26.4	37.4
23/7521	145.2	43.8	27.1	39.3
23/8887	132.8	49.9	29.8	39.6
23/9889	151.0	41.1	31.6	47.7
23/10166	123.8	39.4	24.5	30.3
23/10215 'A'	146.9	37.7	26.7	39.2
23/10249	147.1	34.6	22.4	32.9
23/10283	136.7	50.0	25.1	34.3
23/10297	140.7	41.3	25.7	36.2
23/102103	150.5	34.4	23.1	34.8
38/0401	191.0	35.8	26.8	51.2
Mean	145.6	40.8	25.8	37.6
Ndian				
3AR/0809	136.5	47.5	31.7	43.3
3AR/1004	129.0	40.7	20.4	26.3
3AR/4105	129.1	43.1	26.2	33.8
3AR/4212	123.9	37.9	26.0	32.2
3AR/7207	122.6	36.9	22.2	27.2
3AR7239	130.8	46.0	31.8	41.6
3B/9858	131.2	45.4	30.7	40.3
14/6710	146.4	42.9	29.0	42.5
14/7902	154.9	38.1	23.8	36.9
22/4402	127.7	37.1	24.2	30.9
22/4712	126.2	41.7	23.6	29.8
Mean	132.6	41.6	26.3	35.0

The second generation of the breeding whose trials were planted from 1966 to 1971 was marked by the introgression of new oil palm genetic resources from the highlands of Bamenda (Cameroon), Aba and Calabar (Nigeria) (*Figure 4)* and Angola (*Figure 5)* natural oil palm genetic resources maintained at NIFOR and materials received on exchange basis from IRHO, Ecuador and Malaysia.

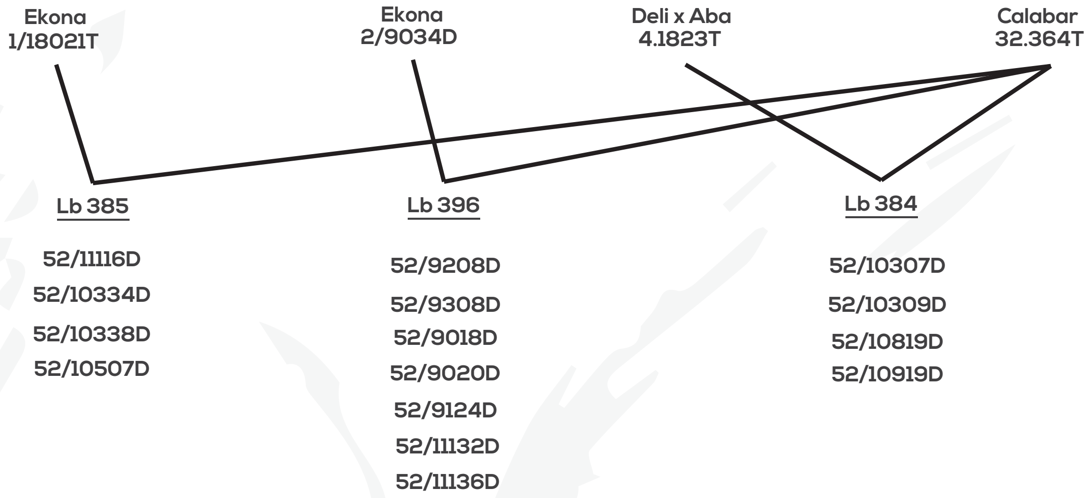


Figure 4. Introduction of Aba and Calabar materials in the Lobe (or Pamol) breeding programme.

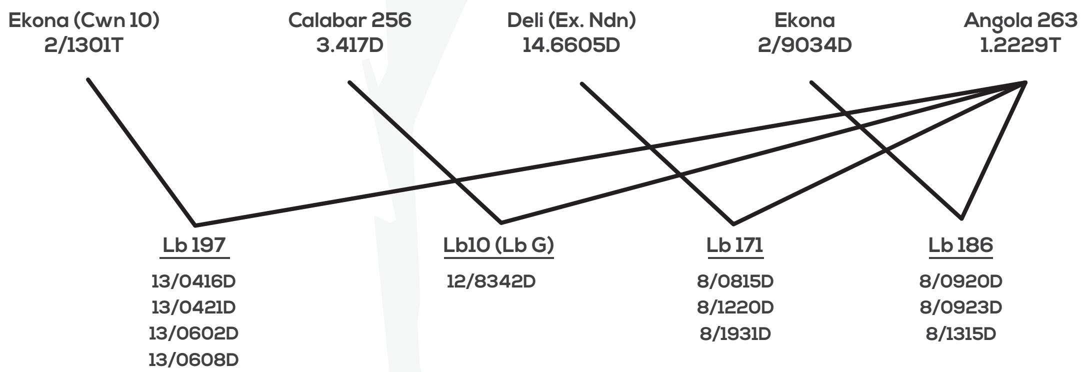


Figure 5. Introduction of Angola materials in the Lobe (or Pamol) breeding programme.

The breeding of oil palm in Pamol is now in the third generation. The main objectives have been to conserve and improve palms of Ekona origin and to test progenies of crosses between *pisifera* selected in the F2 and elite Lobe *dura* as well as some Bamenda *dura* selected for slow height increment and moderate FFB yield. The 3rd generation started in 1987, and field establishment of trials was carried out in 1990 and 1991. Two other programmes were conducted concomitantly focusing on the improvement of the resistance to *Fusarium* wilt and of fresh fruit bunch yield.

The first programme evaluates the resistance (or tolerance) to *Fusarium* wilt of progenies from crosses between *tenera* 2/2311 resistant to *Fusarium* wilt (Index 47) and its descendants at Lobe and between Bg 312/3 (Index 46) and its descendants at Binga (DRC) (*Figure 6*). *Tenera* 2/2.311 and Bg 312/3 appear to transmit a high degree of wilt resistance (or tolerance) to their offspring. In addition, the best *pisifera* at Lobe come from the selfing of 2/2311T.

The second programme involved crosses between elite *dura* from Dami (PNG) and elite *tenera* from Lobe. Yield recording and bunch analysis have been completed, but statistical analysis of data obtained has not been completed that would allow the selection of elite *dura*, *pisifera* and *tenera* for seed production and further breeding.

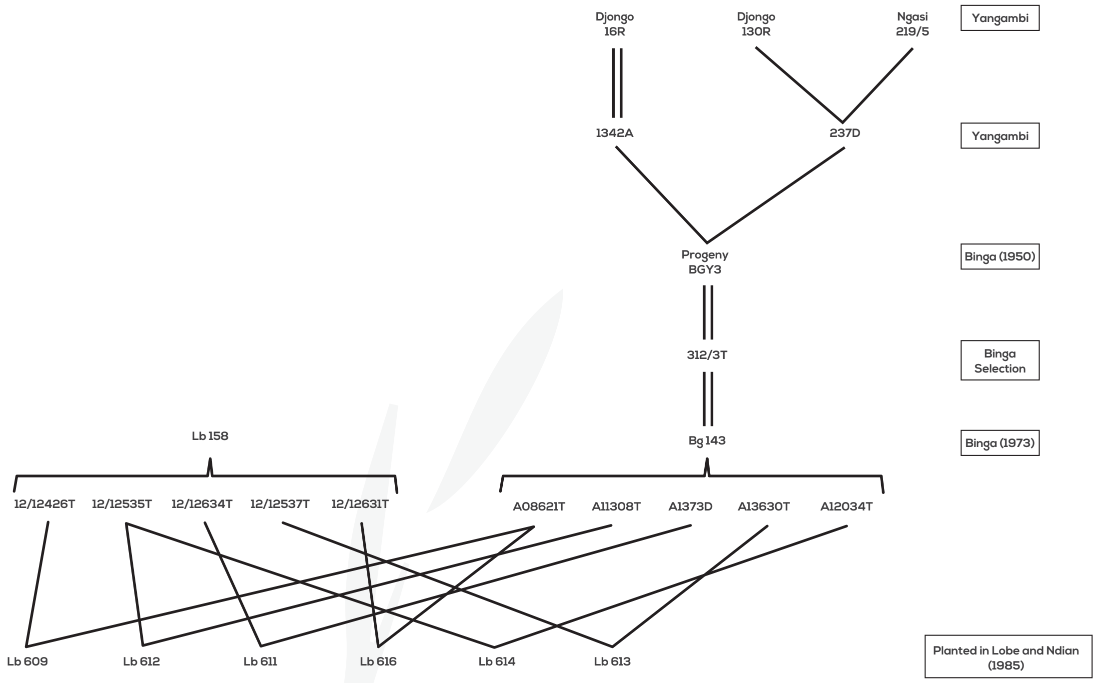


Figure 6. Pedigree of Binga parents used in the combined breeding programme planted, Lobe in 1985.

Oil palm germplasm maintained by Pamol

Pamol oil palm germplasm is composed of remnants of the 18 *dura* and twenty-four 24 *tenera* mainly of Ekona and Cowan origins from the 1951 selection and of selected genotypes from their progenies. In the early 1960s the germplasm was enriched with new oil palm resources derived from the exploration of local natural oil palm groves or obtained through exchanges with other research institutions. The most noticeable acquisitions include:

i. Bamenda (highlands of Cameroon) natural oil palm collections

ii. Aba, Ufuma, Calabar (*Figure 7*), Angola natural oil palm grooves resources, and Malaysia materials obtained from NIFOR

iii. Malaysia materials received through exchanges with the Sabah breeding programme and the Oil Palm Genetic Laboratory (OPGL) (*Figure 8)*

iv. 10 progenies received on an exchange basis from IRHO (Benin and Côte-d' Ivoire) included the famous L2T x D10D (planted in 1965)

v. Progenies obtained through exchanges with INEAC and Yaligimba (DRC - former Zaïre) and Ecuador (Rosenquist *et al.* 1990).

These different origins confer to the Pamol breeding programme a wide genetic base on which breeders are capitalising. In fact, the breeding strategy at Lobe was designed to exploit the complementarity that exists between the various African origins and within-origins for species improvement. The strategy will be further refined on the basis of a relatively recent grouping of breeding and African materials found by Cochard *et al.* (2009).

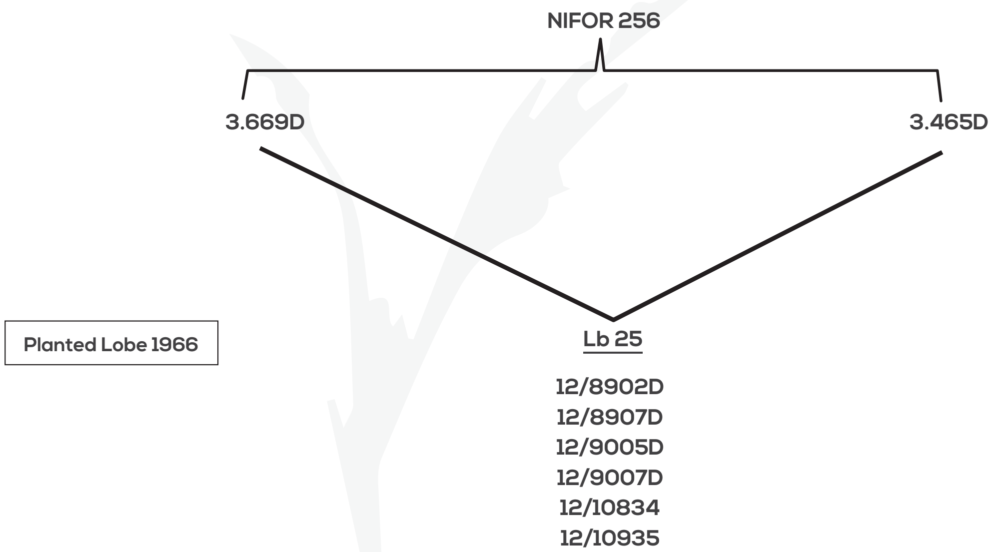


Figure 7. Ancestry of Calabar materials of Pamol breeding programme.

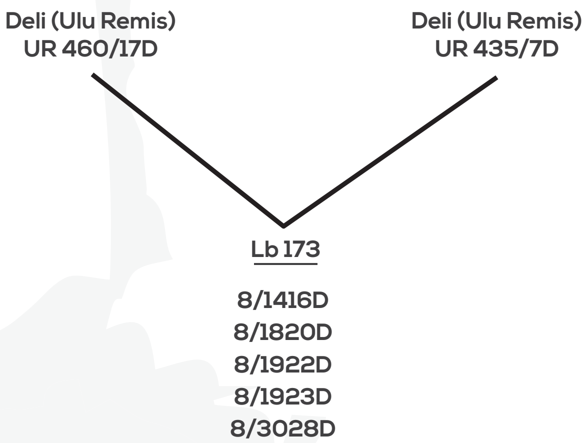


Figure 8. Malaysian Deli dura parents in the Lobe breeding programme.

Records were collected for over 5,000 *tenera* and 6,000 *dura* palms from more than 300 progenies. At the end of the second generation of breeding in 1982, 332 high productive *dura*, 23 *pisifera*, and considerable number of elite *tenera* were selected for future breeding programmes. Some of the selected *dura* were selfed and some of the *pisifera* progenies were tested for seed production.

Estimates of seed production in Africa

Our estimates of African oil palm seed production are of about 50 million yearly, varying from 4 million in Ghana to 13 million in Cameroon. Côte-d'Ivoire, Benin and Nigeria seed production potentials represent 20%, 22% and 24% of the continent potential, respectively. Detailed information on seed production has been provided by Nigerian and Cameroonian seed producers. An invited speaker at the current ISOPB Seminar 2016 from PalmElit the commercial arm of Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD) of France who joint ventured seed production at Pobé in Benin, , will elaborate on the oil palm seed production in Benin. Côte-d'Ivoire did not respond to this point because of tight schedule in the local and overseas supplies of germinated seeds.

NIFOR Oil palm seed production in Nigeria

The 1,804 *dura* parent trees are derived from selfings of NIFOR locally selected *dura* and Deli *dura* and the 101 *pisifera* from selfings of the *tenera* parents, all of good GCA or specific combining ability (SCA). The current seed production potential is more than 7 million sprouted seeds. A greater percentage of the pollen donor trees come from the early 1960s plantings. They are too tall and are inaccessible even to a double aluminum ladder. The age distribution of the NIFOR seed gardens is presented in (*Table 12)*.

TABLE 12. AGE PROFILE OF NIFOR SEED GARDENS

Field No.	Number of *dura*	Number of *pisifera*	Year planted
2	421	3	1966
16	4	-	1964
54	1,172	30	2000
47	4	-	1987
37	211	11	1988
25	-	14	1963
34	-	11	1962
46	-	32	1964
Total	**1,804**	**101**	

Every year, the production of dry seeds is far above national demand. However, germination of dry seeds depends on paid orders to avoid heavy losses such as those encountered in 2010 and 2015 as shown in the (*Table 13)*.

TABLE 13. NIFOR SEED PRODUCTION AND SUPPLIES OF SPROUTED SEEDS IN 2010-2015

Year seeds	Number of dry seeds	Number of sprouted seeds	Number of supplied
2010	6,916,405	2,062,436	1,339,240
2011	7,016,190	1,291,730	1,007,712
2012	4,244,724	1,472,693	1,168,936
2013	6,413,982	4,756,819	4,572,114
2014	7,197,283	4,017,073	3,903,383
2015	6,017,415	3,071,420	1,762,613
Total	**37,805,999**	**16,672,171**	**13,753,998**

With the conclusion of the second cycle breeding programme and the ageing of first selection cycle genitors, NIFOR is focusing on the establishment of new seed gardens to meet the future demand by growers for oil palm DxP seeds. Therefore, 50-hectare seed gardens will be established by year 2019 including 10 hectares already planted in May 2016. NIFOR seed production potential will move to 15 million dry seeds per annum.

Constraints facing seed production in the NIFOR include (i) labour shortage, (ii) insufficient funding for oil palm breeding, and (iii) lack of collaboration with other research institutes for work and laboratory equipment sharing mostly in molecular biology that could relatively ease the selection of parental genotypes of the third selection cycle.

Oil palm seed production in Cameroon

Oil palm seed production at La Dibamba

Total quantities of seed produced in the last 6 years varied from 1.4 million in 2010 to 4.4 million in 2012 (mean = 2.4 million), 15 to 62% of which were tolerant to *Fusarium* wilt *(Table 14)*. The fluctuations observed are indicative of the variations in the financial resources allocated to the activity. As a result, only 2/3 of the available parent palms are currently used. About USD 1,700,000 were granted recently by both the Cameroon Government and African Development Bank (AfDB) to boost seed production in La Dibamba who expecting to reach a production of 5,000,000 dry seeds/year from 2018 using 1,921 *dura* mother oil palms and 83 *pisifera* (pollen donors) *(Table 16)*.

TABLE 14. YEARLY SEED PRODUCTION AT LA DIBAMBA FROM 2010 TO 2015

Year	*Fusarium* wilt-tolerant	Standard	Total
2010	892,821	549,531	1,442, 352
2011	1,210,525	1,626,943	2,837,468
2012	2,489,704	1,905,179	4,394,883
2013	576,001	817,654	1, 493,655
2014	382,061	2,124,491	2,506,552
2015	316,903	1,195,212	1,512,115

TABLE 15. *DURA* AND *PISIFERA* PROGENIES AND PALMS FOR SEED PRODUCTION AT LA DIBAMBA

Parent oil palm	*Fusarium* wilt-tolerant seeds		Standard seeds		Total	
	Number of progenies	Number of palms	Number of progenies	Number of palms	Number of progenies	Number of palms
Dura	16	1,251	9	670	25	1,921
Pisifera	3	53	9	30	11	83

Oil palm seed production at Pamol Lobe

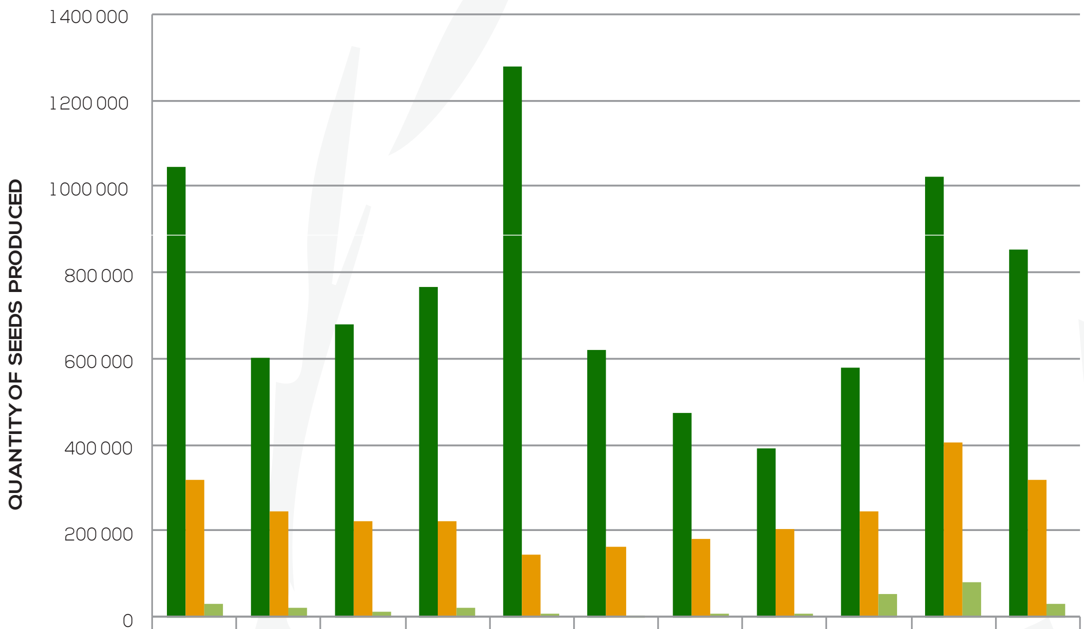
The seed gardens consist of 487 *dura* and 10 *pisifera* of the second generation. *Tables 16* and *17* show the *dura* progenies selected for production of *Fusarium* wilt-resistant and cold-tolerant (highlands) seeds, respectively. Details of the 10 *pisifera* selected for seed production are shown in *Table 18*. Quantities of dry seeds produced yearly from 2006 to July 2016 show fluctuations from one year to another. The average annual production was 1,012,000 including 748 000 standard seeds, 237,000 *Fusarium* wilt-resistant and 27,000 cold-tolerant (BD x P) seeds *(Figure 9)*. There is a production potential of 2.922 million dry seeds comprising 1.230 million standard seeds, 1.590 million *Fusarium* wilt-resistant seeds and 102,000 cold-tolerant (BD x P) seeds. This potential is not, however, realised because not all the selected palms are currently used for seed production.

TABLE 16. PARENTAGE, PERFORMANCE AND *FUSARIUM* WILT-RESISTANCE INDICES OF PROGENIES SELECTED FOR PRODUCTION OF *FUSARIUM* WILT-RESISTANT SEEDS IN THE LOBE BREEDING PROGRAM

Progeny	Parentage	Origin	No of *dura* palms	Performance of *dura*		
				FFB kg/palm/yr	% Oil/bunch	Wilt index
Lb 10	3.417D x 1.2229T	Calabar x Angola	1	109.2	17.1	42
Lb 130	3AR/7239T x 2/2311T	Ekona x Ekona	23	101.2	18.9	41
Lb 136	3AR/7239T x 2/2311T	Ekona x Ekona	4	105	18	90
Lb 158	2/2311T SELFED	Ekona Selfed	8	110	17.2	47
Lb 200	3AR/7239T x 2/2809T	Ekona x Ekona	3	85.9	16.1	51
Lb 214	2/5622T SELFED	Ekona Selfed	3	77.3	12.2	50
Lb 235	37/1649D x 31.4958T	Deli(NDN) x INEAC	31	87.3	19.7	65
Lb 240	2/2319D x 31.4958T	Ekona x INEAC	27	104.6	18.9	70
Lb 242	24.16.12T x 70.14.208D	Yangambi x Yangambi	31	92.5	18.2	77
Lb 244	35/2718D x 31.4958T	Deli INEAC x INEAC	9	99.9	19.8	86
Lb 256	2/1301T x 1/10920T	Ekona x Ekona	1	103.4	17.9	68
Lb 261	4-26-10T x 24-16-12T	Yaligimba x Yaligimba	3	75.1	18.5	64
Lb 263	4-26-10T x 74.11.25.5T	Yaligimba x Yaligimba	26	94.5	21.8	91
Lb 267	2/5622T SELFED	Ekona Selfed	21	77.3	12.2	57
Lb 323	2/11308D x 2/10323T	Ekona x Ekona	12	118	19.2	73
Lb 328	L2T x D10D	Lame x Dabou Deli	18	123	18.5	53
Lb 344	2/1301T x 2/2311T	Ekona x Ekona	8	105	19	52
Lb 349	35/1609T x 35/0911T	(Deli Dumpy x Ekona) x (Deli x Ekona)	10	104	15.8	49
Lb 376	2/2311T SELFED	Ekona Selfed	26	110	17.2	47
Total			**265**			
Mean				99.1	17.7	62

TABLE 17. ORIGIN AND PERFORMANCE OF PROGENIES SELECTED FOR PRODUCTION OF COLD-TOLERANT (HIGHLANDS) SEEDS FROM BAMENDA *DURA* [BD] IN THE PAMOL LOBE BREEDING PROGRAMME

Progeny	Origin	FFB/palm/yr	% O/B		Number of *dura* used
			Dura	*Tenera*	
Lb 274	Mankon 1	85.0	12.4	13.5	3
Lb 275	Meta 2	82.3	16.0	21.5	3
Lb 278	Meta 5	90.7	12.9	20.4	1
Lb 294	Batibo 21	77.6	13.6	19.9	1
Lb 296	Batibo 23	85.8	12.5	22.2	2
Lb 297	Widikum 24	79.2	15.2	20.0	3
Lb 298	Widikum 25	83.9	12.3	15.8	2
Lb 300	Bamenda 32	78.2	16.7	22.2	2
Mean		82.8	14.0	19.4	
Total					**17**



	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016 AS OF JULY
STANDARD SEEDS (DxP)	1 045 52	605 924	681 627	768 314	1 280 73	622 759	477 883	391 506	582 988	1 026 90	855 035
WILT RESISTANT SEEDS (DxP)	318 704	248 407	225 386	226 255	144 269	163 865	182 902	204 443	246 941	406 991	320 000
BDxP	34 277	24 996	12 663	24 283	10 415	6 858	9 727	9 033	54 749	84 041	31 393

Figure 9. Dry seed productions for the past 10 years.

TABLE 18. ORIGIN AND PARENTAGE OF PISIFERA SELECTED FOR SEED PRODUCTION

Progeny	Parentage	Origin	Palm number	Group
CWN 3	23/10215Ts	Ekona	2/0114P 2/0110P	A
NDN212	3AR/7239Ts	Ekona	2/11023P 2/7118P	B
Lb 158	2/2311Ts	Ekona	12/12433P 12/12440P 12/12640P 12/12428P 52/6210P	E
Lb 135	1,2229T x 1,2215P	Angola x Angola	12/2709P	H

CONCLUSION

African oil palm research centres have long time contributed to oil palm breeding efforts despite the fact that the main provider of palm oil to locals was natural oil palm groves. Efforts are still made to improve continent production of palm oil with limited financial and qualified human resources. Creating an African oil palm research board could lead to harmonizing current divergent or duplicated breeding programmes to sharing of work, to exchange of experiences, and most importantly, to convincing country decision makers of the necessity to secure production of edible vegetable oils and fats via oil palm cultivation. Prospects for further oil palm improvement exist thanks to exchanges of existing oil palm germplasm and collection of new genetic resources from natural oil palm groves. Availability of improved planting materials constitutes a limiting factor to oil palm development in Africa. Only 6 countries out of about 20 of the African oil palm belt produce oil palm seeds. In fact, the efforts of African countries efforts to augment seed production potentials and to narrow the gap between the potentials and the current productions are recognized by their African oil palm seed producers.

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SESSION 2

P6

Oil Palm Breeding and Seed Production in MPOB

Marhalil, M; Rajanaidu, N; Mohd Din, A; Suzana, M; Zulkifli, Y; Fadila, A and Kushairi, A

Malaysian Palm Oil Board (MPOB), 6, Persiaran Institusi, Bandar Baru Bangi, 43000 Kajang, Selangor, Malaysia.
E-mail: marhalil@mpob.gov.my

ABSTRACT

Discovery of the inheritance of shell in 1941 and the subsequent cultivation of DxP as the planting material provided the impetus for the expansion of the oil palm industry throughout the world. The sustainability of the oil palm industry requires both the availability of high quality planting material and its continuous improvement. Selection of palms for seed production relies on strict selection criteria, based on progeny testing results as well as family and individual phenotypes evaluation. Continuous breeding work in MPOB (Malaysian Palm Oil Board) through the evaluation and utilisation of a parental line acquired since the 1930s gave rise to a promising good quality breeding material for research and seed production purpose. Seed production aims to achieve high productivity from selected palms to maintain high selection intensity. Also, the introduction of exotic oil palm germplasm gave rise to short planting material and yielding oil up to 9 t/ha/yr. It also contributes to broadening the narrow genetic base of the current planting materials.

Keywords: oil palm, performance, seed production, germplasm.

INTRODUCTION

The oil palm industry of the Far East is growing rapidly, especially in Malaysia. Since 1966 the region has become the largest palm oil producer that once Nigeria and exporting as much palm oil as the whole of West Africa. Until now, the oil palm plantation in Malaysia had expanded successfully. In 2014, 5.39 million hectares in Malaysia are planted with oil palm and producing 19.67 million tonnes of crude palm oil (CPO) and 2.28 tonnes of palm kernel oil. The export of palm oil products is important to Malaysia over the last two years 2013 and 2014 and export values were RM 61.3 and RM 63.6 billion, respectively (MPOB, 2015). It is vital that the Malaysian oil palm industry remain competitive against other oils and fats.

Therefore, the choice of planting material is important to ensure the production of high yield with good oil quality so that it is profitable and economically beneficial to the oil palm industry. The selection programme of parental materials should focus on traits which are important to improve the productivity of oil palm such as oil yield, height and bunch index. The problem with our present variety is that they are selected on narrow genetic base (Rajanaidu, 1994a). The current planting material is *tenera* hybrid (DxP) which is the cross between *dura* mother palms and *pisifera* pollen.

In 2009, global seed production was estimated at 490 million (Kushairi *et al.*, 2010) against the Malaysia requirement is about 80 million based on a planting density of 148 palms ha^{-1} and request for 200 seeds ha^{-1} (allowing for 25% losses). If based on 300 seeds ha^{-1}, Rajanaidu and Jalani (1999) quoted a higher demand for 120 million seeds. Indonesia (250 million), Malaysia (132 million), Papua New Guinea (30 million) and Costa Rica (30 million) were the main producers and capable of exporting a large quantity. The demand in the oil palm growing regions, namely, Asia-Pacific, Africa and Central/ South America, has been plateaued.

The DxP *(Dura* x *Pisifera)* planting material

Malaysia oil palm *dura* x *pisifera* (DxP) hybrid seeds are largely based on Deli *dura* selections at various research centres, such as Chemara, Banting, Department of Agriculture, Malaysia (DOA)/Malaysian Agricultural Research and Development Institute (MARDI)/Malaysian Palm Oil Board (MPOB), Dami, Socfindo and Dabou. The main sources of *pisifera*s are AVROS, NIFOR (Calabar), Ekona, Yangambi and La Mé. The oil palm DxP seed production capacity in Malaysia increased marginally from 50 million in 1995 to 88 million in 2008 and 132 million in 2009 (Kushairi *et al.*, 2010). Currently, the number of producers also increased to meet the demands of the DxP seeds.

Since Malaysian *dura* or the female parent always been a Deli descendant which believed were raised from just four Deli palms, the genetic base is very narrow. In the case of *pisifera* or the male parents are derived from a limited number of breeding populations. Most seed producers, in practice, use only a few *pisifera* palms for seed production. Hence, the populations of the palms that currently used as males are probably of a narrow genetic base but less restricted than that of the Deli descendants.

An introduction of new oil palm germplasm is very important to broaden the current genetic base of oil palm planting materials both in *dura* and *pisifera*. The narrow genetic base has improvement bunch yield and its components, average bunch weight and bunch number (Okwuagwu, 1996). To widen the genetic base of breeding material, MPOB (at that time known as PORIM-Palm Oil Research Institute of Malaysia) started to collect oil palm genetic materials from African countries such as Nigeria, Cameroon, The Democratic Republic of the Congo, Tanzania, Madagascar, Angola, Senegal, Gambia, Sierra Leone, Guinea and Ghana. In 1973, MPOB (still MARDI-Malaysian Agricultural Research and Development Institute, at the time of collection) and NIFOR (Nigerian Institute for Oil Palms Research) jointly collected oil palm germplasm from the wild and semi-wild palm groves of Nigeria. This was the first expedition to collect oil palm germplasm by Malaysia and then continued in the Western and Central Africa and Madagascar in 1984. Currently, MPOB had collected germplasm collections from more than 20 countries from Africa and South America (Rajanaidu and Jalani, 1994a, b, c).

MPOB Oil Palm Breeding Programme

MPOB involvement in the oil palm breeding already started in the early 1930s. MPOB was under a number of different managements; from the Department of Agriculture of Malaya (DoA) to Malaysia Agricultural Research Development Institute (Mardi), then Palm Oil Research Institute Malaysia (PORIM) in 1979 and lastly known as Malaysian Palm Oil Board (MPOB) in 2000.

Our advance breeding materials were benefited through active participation in Malaysian oil palm breeding collaboration programmes such as the Cooperative Breeding Scheme (CBS) in 1957 and Sabah Breeding Programme (SBP) in 1964. To date, MPOB DxP planting materials have been widely planted in Malaysia. The performance of MPOB parental and DxP planting materials was discussed.

Dura lines

The origin of MPOB oil palm parental palms for seed production is the result of long time effort of research and development. It all started in the 1930s with the planting of Elmina *dura* in FES Serdang in Field 3A and 4 during DoA era at that time (MPOB only known after 2000). Involvement in CBS in 1957, Sabah Breeding Programme (SBP) in 1964 and other individual and collaborative oil palm breeding programmes with the main aim for the improvement of existing oil palm breeding materials resulted in the acquisition of MPOB *dura* lines.

The MPOB earliest *dura* parental materials involved Elmina (*e.g.* E152 and E206), Johore Labis (*e.g.* JL 4107, and JL 1407) Ulu Remis (e.g. UR27.9 and UR 413/13) and some Socfin materials as the first generation of BPRO *dura*s. They were the results of programmes done by DoA, Guthrie and Socfin in the early Malaysian oil palm breeding programme. Materials were planted in Federal Experimental Station (FES), Fields 3A and 4 at Serdang, Selangor and Jerangau between 1930 to 1952. Elmina was known for their low stature, the Dumpy E206. The E206 was only 335 cm tall as compared with 518 cm for 'normal' Elmina palms. The Dumpy families were more uniform in yield and other characters as compared to the tall progeny lines (Hartley, 1988). The F2 progenies were planted in genetic blocks at Serdang in 1966 (Rajanaidu *et al.*, 1990) and in collaborative trials with plantation companies. The interest in Elmina materials is so great that very few of other Deli *Dura* involved in the testing. Most of the early MPOB *Tenera* (DxP/DxT) breeding work only related to the Elmina progenies.

Despite that, in order to increase genetic variability, legitimate progenies of Serdang Avenue (S.Av) materials which were planted in Elaeis Estate in 1931 been brought to MPOB. Some interesting characteristics of the Serdang Avenue *Dura* palms were higher yielding and higher kernel to fruit percentage than those of the commercial Deli (Hartley, 1988). In the later generations of materials developed from this population, genes of Serdang Avenue palms 5, 7 and 23 were found in many of the best progenies (Breure *et al.*, 1982). Through the Sabah Breeding Programme shows that Banting *Dura*s (ex Chemara ex Serdang palm – 5,7 and 23) had high yields. The Serdang Avenue *Dura*s had higher oil to bunch (O/B) than the Elmina *Dura*s. However, their progenies when crossed to AVROS *Pisifera* had comparable O/B values (Rosenquist, 1985).

As time goes by, improvement programme was carried-out using these sets of *dura*. Benefited from Malaysia oil palm collaborative programme, the Sabah Breeding Programme in 1964, the second cycle of BPRO; a mixture of *duras* including UR(D) (Trial 0.46, JL (Trials 0.37, 0.41, 0.45), Klanang Bahru (KB), Highlands Estate (HE, HEZE, HEZG), Banting (BD), Serdang Avenue (Serd.), Tumbuk E, Gunung Melayu (GM) (Trials 0.39 and 0.45) was obtained. The SBP aim was to produce high yielding planting materials suitable for the Sabah agroclimatic conditions (Rajanaidu *et al*., 1985). The breeding materials for the programme were acquired through exchange between four Malaysian [Chemara, HMPB, Socfin and Federal Department of Agriculture (now managed by MPOB)] and three African participants (West African Institute for Oil Palm Research (WAIFOR), Unilever Nigeria and Unilever Cameroon). The SBP was established using reciprocal recurrent selection (RRS) by Hartley for Sabah state in 1964 (Corley and Tinker, 2003). A cross section of the SBP materials was distributed to the participating agencies for their own use (Rajanaidu *et al*., 1985).

The materials of the third cycle were the continuation of the second cycle and planted mainly in Serdang in Trial 0.80, 0.81 and 0.82 and some in Kluang. The fourth cycle showed a wider distribution of *dura*s especially in MPOB research station in Kluang, Hulu Paka, Lahad Datu, Sessang, Keratong and Bangi and some agencies under joint trial basis. The latest as the fifth cycle of these materials was currently used as parental material for seed production.

The performance of *dura* as stated is shown in *Tables 1* and *2*. These were the performance of Deli *dura* from 2 generations of Elmina descendants (F4 and F5 for Elmina *dura*) originated from the 1931 FES's *dura*. Also shown the performance of Serdang Avenue (S.Av) *dura* which were planted in the same trials. Best progenies then selected using family and individual palm selection (FIPS) for the next generation.

TABLE 1. PERFORMANCE OF *DURA* PROGENIES (F4) PLANTED IN 0.212 KLUANG, JOHOR

No	Progeny	Origin	FFB (t/ha/yr	ABW (kg)	MFW (%)	M/F (%)	S/F (%)	O/DM (%)	O/B (%)
1	MS 3459	Banting *Dura*	9.27	9.60	9.34	59.21	34.05	76.12	19.02
2	MS 3489	Banting *Dura*	12.96	11.41	8.93	60.61	32.01	76.80	18.84
		Mean	**11.12**	**10.51**	**9.13**	**59.91**	**33.03**	**76.46**	**18.93**
3	MS 3225	Elmina *Dura*	14.60	14.13	12.13	61.21	30.74	74.70	15.23
4	MS 3288	Elmina *Dura*	13.51	15.78	10.63	59.18	31.60	76.51	16.85
5	MS 3338	Elmina *Dura*	15.69	13.11	12.05	61.21	32.18	76.31	18.22
6	MS 3358	Elmina *Dura*	14.39	13.55	11.30	59.58	32.65	75.73	16.89
7	MS 3385	Elmina *Dura*	12.40	11.47	13.16	58.89	33.48	75.86	17.37
8	MS 3428	Elmina *Dura*	11.66	12.28	14.56	59.19	32.47	75.83	16.36
9	MS 3485	Elmina *Dura*	11.98	12.54	11.67	61.96	30.51	75.63	18.15
10	MS 3509	Elmina *Dura*	17.72	14.18	12.37	60.03	32.79	76.64	18.33
		Mean	**14.00**	**13.38**	**12.23**	**60.16**	**32.05**	**75.90**	**17.17**
11	MS 3493	Johor Labis *Dura*	**11.01**	**10.74**	**10.79**	**57.40**	**32.48**	**74.01**	**14.50**
12	MS 3336	Ulu Remis *Dura*	14.09	13.07	12.91	57.46	34.33	72.16	15.71
13	MS 3415	Ulu Remis *Dura*	16.61	11.72	14.86	56.56	36.31	73.04	15.11
		Mean	**15.35**	**12.39**	**13.89**	**57.01**	**35.32**	**72.60**	**15.41**
	Overall Mean		**13.89**	**12.83**	**12.11**	**59.44**	**32.63**	**75.27**	**16.80**

Notes: Planted in 1986; 148 palms/ha;
FFB-Fresh fruit bunch; ABW-average bunch weight; MFW-mean fruit weight;
M/F-mesocarp to fruit ratio; S/F-shell to fruit ratio;
O/DM-oil to dry mesocarp; O/B-oil to bunch ratio.

TABLE 2. PERFORMANCE OF *DURA* PROGENIES (F5) PLANTED IN 0.400 KLUANG, JOHOR

No	Progeny	Origin	FFB (t/ha/yr)	ABW (kg)	MFW (%)	M/F (%)	S/F (%)	O/DM (%)	O/B (%)
1	PK 2540	Banting *Dura*	7.34	9.07	10.56	57.25	34.86	73.69	18.69
2	PK 2694	Banting *Dura*	10.89	9.98	9.05	63.95	29.46	72.51	19.59
3	PK 2714	Banting *Dura*	15.10	12.97	11.76	63.32	30.00	74.58	19.01
4	PK 2728	Banting *Dura*	19.47	15.22	12.27	61.44	31.50	70.79	15.00
5	PK 2811	Banting *Dura*	10.00	9.13	11.88	61.35	32.01	69.81	16.44
6	PK 2821	Banting *Dura*	8.62	9.47	9.74	64.16	29.47	70.11	18.38
7	PK 2882	Banting *Dura*	19.58	16.10	8.65	74.78	14.88	70.64	19.53
8	PK 2883	Banting *Dura*	9.90	9.62	10.43	64.10	29.67	72.68	19.54
9	PK 2891	Banting *Dura*	11.48	11.64	10.50	67.87	26.85	70.40	17.44
		Mean	**12.49**	**11.47**	**10.54**	**64.25**	**28.74**	**71.69**	**18.18**
10	PK 2547	Elmina *Dura*	18.48	15.32	11.45	64.67	30.77	72.14	15.49
11	PK 2626	Elmina *Dura*	15.37	15.06	15.03	65.81	27.94	75.92	19.65
12	PK 2649	Elmina *Dura*	14.83	14.93	13.33	60.09	31.94	72.10	16.57
13	PK 2660	Elmina *Dura*	15.13	12.58	14.18	62.78	30.92	72.23	18.20
14	PK 2687	Elmina *Dura*	14.03	16.38	11.60	64.56	28.35	74.51	18.22
15	PK 2704	Elmina *Dura*	14.58	15.32	12.24	62.73	30.04	75.41	18.15
16	PK 2709	Elmina *Dura*	19.22	14.63	11.31	60.36	33.32	72.79	17.32
17	PK 2713	Elmina *Dura*	10.95	10.98	13.43	55.77	37.01	74.99	16.20
18	PK 2724	Elmina *Dura*	19.97	15.02	11.00	58.26	34.70	71.55	16.17
19	PK 2748	Elmina *Dura*	17.02	15.62	12.30	61.63	30.88	72.23	16.95
20	PK 2764	Elmina *Dura*	13.61	12.76	10.40	62.29	31.37	72.93	18.17
21	PK 2775	Elmina *Dura*	20.88	15.90	14.81	63.06	30.88	75.31	19.82
22	PK 2776	Elmina *Dura*	18.45	14.21	11.46	60.42	32.19	74.08	18.41
23	PK 2791	Elmina *Dura*	9.95	12.70	14.70	64.10	28.55	75.51	19.51
24	PK 2801	Elmina *Dura*	22.19	14.63	11.71	57.78	33.82	74.71	17.71
25	PK 2810	Elmina *Dura*	16.15	14.70	12.24	63.15	29.85	76.73	20.27
26	PK 2813	Elmina *Dura*	13.65	16.38	12.84	66.22	27.21	77.07	20.28
27	PK 2816	Elmina *Dura*	16.01	14.93	14.53	62.40	31.12	77.22	19.62
28	PK 2817	Elmina *Dura*	16.93	11.13	13.91	58.97	34.29	72.20	15.30
29	PK 2828	Elmina *Dura*	19.13	17.92	13.61	61.66	31.05	74.34	17.45
30	PK 2831	Elmina *Dura*	17.94	17.37	12.52	65.19	28.50	75.12	18.46
31	PK 2836	Elmina *Dura*	12.19	15.19	13.33	64.34	29.29	76.69	19.06
32	PK 2837	Elmina *Dura*	15.51	13.89	14.65	61.74	31.86	74.63	17.58
33	PK 2840	Elmina *Dura*	17.66	13.20	11.40	60.76	31.82	75.63	19.14
34	PK 2860	Elmina *Dura*	10.95	12.70	12.48	55.91	34.94	73.82	16.07
35	PK 2890	Elmina *Dura*	16.51	13.10	10.70	62.29	31.56	71.92	17.02
36	PK 2938	Elmina *Dura*	15.79	11.73	15.00	62.03	31.66	71.26	16.54
37	PK 2961	Elmina *Dura*	20.15	16.25	13.31	69.94	20.57	77.93	24.09
		Mean	**16.19**	**14.45**	**12.84**	**62.10**	**30.94**	**74.32**	**18.12**
40	PK 2767	Ulu Remis *Dura*	18.71	15.76	12.63	55.38	34.99	71.11	15.39
41	PK 2802	Ulu Remis *Dura*	11.86	14.43	11.13	54.99	36.98	68.88	14.17
42	PK 2822	Ulu Remis *Dura*	16.21	10.81	16.41	60.54	31.95	68.35	16.25
43	PK 2849	Ulu Remis *Dura*	15.84	13.68	14.46	62.02	30.68	74.29	19.48
		Mean	**13.52**	**12.56**	**14.45**	**58.71**	**33.28**	**70.17**	**16.01**
	Overall Mean		**15.04**	**13.56**	**12.58**	**62.08**	**30.81**	**73.19**	**17.84**

Notes: Planted in 2000; 148 palms/ha;
FFB-Fresh fruit bunches; ABW-average bunch weight; MFW-mean fruit weight;
M/F-mesocarp to fruit ratio; S/F-shell to fruit ratio; O/DM-oil to dry mesocarp;
O/B-oil to bunch ratio.

Hardon *et al.* (1987) estimated that selection progress in the second and subsequent generations was about 10-15% per generation. However, only a small improvement being seen from the F4 to F5 for this Elmina *dura*. Many factors might influence this and one of it was due to inbreeding. Soh *et al.* (1981) also considered that the low yields and poor F/B seen in pure Dumpy material might be due to inbreeding during the experiment to compare Deli x *pisifera* crosses with Dumpy x *pisifera* for height.

Tenera/pisifera lines

The first cycle of MPOB's *tenera/pisifera* started with AVROS (AV:1107, 10/119) where the seeds of *tenera* x *pisifera* were imported to Malaysia as BM119. The BM119 was planted at trial 0.45 Klanang Bahru Estate in 1957. Besides AVROS, the other *teneras/pisiferas* include Ulu Remis (UR 374/16, WAIFOR 52.3105, W(T)1, and Pamol *pisifera* (PP 11/8770). A *tenera* palms S31.10 and fertile *pisiferas*, S29.39 and S36.21 were selected for further breeding. Selfs of S31.10 gave rise to the 43/S27B (fertile *pisifera*). All these materials benefited from SBP in 1964.

Various sources of *pisiferas* were planted in Trials 0.79 (AVROS), 0.98 (LC(T), W(T), UR(T), LN(T), 0.109 (20A/43, AVROS KB4/4, IRHO1039 & 646, LC(T)4, W(T)9, 0.110 ((LN(T), UR(T), AVROS KB), 0.111 (WAIFOR, UR(T), 0.114 (LN(T)), KB AVROS) and 0.127 (UR(T), (W(T)) in F.E. S. Serdang. The most known and utilized *pisifera* source in MPOB was the AVROS from trial 0.79. Potential families related to the selected *pisifera* from this trial then brought forward to another generation and planted in trial 0.174 and 0.182 in Kluang Johor as the third cycle. Others were planted in Trials 0.159, 0.235 (WAIFOR, UR(T), 0.243 (Soc. L2(T)), 0.246 (W(T)1 and 0.268 (HE1138, LC(T), NP5, IRHO 646 & 640). It later goes through various testing and potential and promising *tenera* and *pisifera* were crosses and progenies derived were planted latter in trial 0.394 and 0.395 in 2000 at Hulu Paka Terengganu and Kluang Johor. It was the fourth cycle for the AVROS.

During this time, the introduction of new sets of *pisifera* was carried out. They were planted in Trial 0.361 (Nigerian Pop. 12), 0.337 (Nigerian Pop. 12), Trial 0.394 and 0.395 (Nigerian Pop. 12 and Yangambi 718 of Felda).

The performances of *pisifera* AVROS for 2 generation is shown in *Tables 3* and *4*.

TABLE 3. PERFORMANCE OF TXT PROGENIES AVROS DESCENDANTS (F3) PLANTED IN 0.174 KLUANG, JOHOR

No	Progeny	Origin	FFB (t/ha/yr)	ABW (kg)	MFW (g)	M/F (%)	S/F (%)	O/DM (%)	O/B (%)	OY (t/ha/yr)
1	MS 1255	AVROS F3	20.60	11.20	11.75	83.51	8.98	78.47	26.13	3.87
2	MS 1258	AVROS F3	21.62	11.51	11.74	82.07	9.57	78.88	28.62	4.24
3	MS 1259	AVROS F3	18.71	9.55	10.28	83.24	8.72	78.87	25.45	3.77
4	MS 1284	AVROS F3	17.76	10.85	9.95	84.09	9.23	76.88	25.53	3.78
5	MS 1288	AVROS F3	21.76	10.36	10.68	84.88	8.33	78.74	28.55	4.23
6	MS 1407	AVROS F3	17.78	10.75	11.00	83.29	8.95	79.57	28.62	4.24
7	MS 1408	AVROS F3	21.89	10.97	12.23	83.68	9.04	79.23	28.08	4.16
8	MS 1410	AVROS F3	14.72	10.70	8.49	81.93	9.82	80.43	27.97	4.14
9	MS 1436	AVROS F3	19.66	11.06	11.01	84.13	9.52	79.18	27.13	4.02
10	MS 1437	AVROS F3	19.16	11.18	12.95	83.01	8.90	79.85	27.46	4.06
11	MS 1438	AVROS F3	20.44	9.89	11.14	81.04	9.63	78.32	24.22	3.58
12	MS 1439	AVROS F3	20.77	9.98	10.48	83.53	9.42	77.46	25.16	3.72
13	MS 1443	AVROS F3	17.53	10.49	13.01	83.83	9.03	79.24	27.39	4.05
14	MS 1444	AVROS F3	17.66	10.37	10.78	84.03	9.70	78.83	27.75	4.11
15	MS 1445	AVROS F3	26.17	11.41	9.75	85.39	7.81	77.34	23.69	3.51
16	MS 1457	AVROS F3	24.28	9.60	8.01	85.10	8.49	78.53	28.61	4.23
17	MS 1458	AVROS F3	21.99	11.04	10.11	86.51	7.52	79.26	28.57	4.23
18	MS 1459	AVROS F3	23.46	9.98	11.56	83.41	9.40	77.57	25.25	3.74
	Mean		**20.33**	**10.60**	**10.83**	**83.70**	**9.00**	**78.70**	**26.90**	**3.98**

Notes: Planted in 1981; 148 palms/ha;
FFB-Fresh fruit bunches; ABW-average bunch weight; MFW-mean fruit weight; M/F-mesocarp to fruit ratio; S/F-shell to fruit ratio; O/DM-oil to dry mesocarp; O/B-oil to bunch ratio; OY-oil yield.

TABLE 4. PERFORMANCE OF TXP PROGENIES AVROS DESCENDANTS (F4) PLANTED IN 0.395 KLUANG, JOHOR

No	Progeny	Origin	Cross	MFW (g)	M/F (%)	S/F (%)	O/DM (%)	O/B (%)	OY (t/ha/yr)
1	PK 2827	AVROS F4	TxP	12.49	85.24	8.71	76.97	28.51	3.19
2	PK 2829	AVROS F4	TxP	11.08	83.28	9.34	75.85	25.90	4.25
3	PK 2856	AVROS F4	TxP	13.23	83.99	8.56	77.45	26.30	4.22
	Mean			**12.27**	**84.17**	**8.87**	**76.76**	**26.90**	**3.89**

Notes: Planted in 2000; 148 palms/ha;
MFW-mean fruit weight; M/F-mesocarp to fruit ratio; S/F-shell to fruit ratio; O/DM-oil to dry mesocarp; O/B-oil to bunch ratio; OY-oil yield

Performance of DxP Progeny Testing

Progeny testing trial is necessary to evaluate the performance of *dura* and *pisifera* combinations used for seed production. The yield and bunch analysis performance of the second 2nd generation of AVROS progeny test is shown in *Table 5*.

TABLE 5. PERFORMANCE OF DXP PROGENY TEST OF 2ND GENERATION AVROS IN FIELD 7 HIGHLAND ESTATE

No	Progeny	Crosstype	FFB (kg/ha/yr)	ABW (kg)	MFW (g)	M/F (%)	S/F (%)	O/DM (%)	O/B (%)	OY (kg/ha/yr)
1	MS 888	DxP	175.88	14.749	12.14	82.10	9.88	74.44	25.13	46.54
2	MS 914	DxP	150.63	12.192	12.08	83.04	9.29	72.22	24.97	44.62
3	MS 972	DxP	200.78	15.114	11.69	79.48	11.57	75.02	25.42	53.31
4	MS 892	DxP	161.12	14.483	11.52	80.28	10.99	76.09	25.94	43.00
5	MS 907	DxP	169.53	14.132	11.63	76.15	14.03	75.22	22.80	41.09
6	MS 908	DxP	185.17	15.936	10.35	77.10	12.82	74.23	24.52	48.64
7	MS 879	DxP	176.48	15.563	9.89	80.63	10.11	76.84	25.27	46.30
8	MS 886	DxP	165.14	14.146	10.69	81.92	9.88	76.32	26.03	44.58
9	MS 896	DxP	157.52	13.203	9.78	82.47	9.71	74.20	25.58	42.18
10	MS 895	DxP	189.89	14.792	11.76	82.60	9.59	72.70	25.59	54.52
11	MS 965	DxP	162.88	16.003	11.54	81.35	10.49	76.39	26.87	52.47
12	MS 983	DxP	166.88	14.776	11.10	81.08	10.03	74.45	25.77	45.01
13	MS 891	DxP	202.48	15.453	10.05	76.87	12.87	74.70	24.80	52.61
14	MS 915	DxP	176.62	13.848	10.89	80.85	11.16	76.20	24.23	46.40
15	MS 940	DxP	148.1	15.589	9.34	80.76	10.79	74.89	24.13	37.71
16	MS 911	DxP	143.96	15.383	11.41	83.93	8.27	76.36	28.58	41.94
17	MS 955	DxP	175.24	13.61	9.63	79.38	12.42	70.91	22.27	42.48
18	MS 973	DxP	137.1	17.33	10.67	79.19	11.94	75.74	23.10	31.67
19	MS 916	DxP	158.9	13.709	10.54	79.77	12.24	74.56	23.85	41.64
20	MS 956	DxP	162.52	14.68	12.73	78.18	13.43	73.86	23.58	41.19
21	MS 958	DxP	186.54	16.619	11.89	79.11	11.66	77.47	24.77	49.73
22	MS 883	DxP	166.13	13.276	11.55	83.25	9.54	75.65	27.37	47.58
23	MS 910	DxP	182.15	15.264	12.77	82.48	9.64	74.19	25.79	49.34
24	MS 912	DxP	174.28	13.703	12.16	81.47	10.22	74.06	26.13	45.34
25	MS 975	DxP Sc	167.05	15.939	11.95	78.42	11.73	73.10	24.15	42.01
26	MS 977	DxP Sc	164.97	18.61	11.55	78.46	11.76	72.56	23.52	40.72
27	MS 985	DxP Sc	149.78	15.605	12.60	81.36	10.14	74.36	26.59	43.53
	Mean		**168.80**	**14.95**	**11.25**	**80.43**	**10.97**	**74.69**	**25.06**	**45.04**

Notes: Planted in 1977 FFB-Fresh fruit bunches; ABW-average bunch weight; MFW-mean fruit weight; M/F-mesocarp to fruit ratio; S/F-shell to fruit ratio; O/DM-oil to dry mesocarp; O/B-oil to bunch ratio; OY-oil yield; Sc-standard cross.

Through this DxP progeny testing we are able to evaluate both MPOB *dura* and *pisifera*. The DxP planting materials mostly derived from Serdang Avenue palms, Elmina (E) based *dura*s and their intercrosses for *dura* improvement. The *pisifera*s were based on BM 119 or AVROS which were derived from the famous Djongo palm planted at Eala Botanic Gardens, Zaire. The TxT crosses of BM119 were planted at the Federal Experimental Station, Serdang in Trial 0.79 in November, 1965. Results showed that both MPOB *dura* and *pisifera* combination can yield up to 15-6% higher than the DxP standard cross. The best DxP progeny in term of oil yield was from progeny 972 (UR32/1 x UR293/2; E211) an intercrossed/Hybrid *dura* had good oil yield averaging 53.3 kg p^{-1} yr^{-1}.

Another DxP progenies testing trial involving the next generation of *dura* Elmina was laid out in Keratong *(Table 6)*. The Deli *dura* materials were the descendants of Elmina and Serdang Avenue palms planted at Serdang in 1966. The male parents were the AVROS *pisiferas*, the 'F3' of BM 119 from PORIM Research Station Kluang Johor. The mean performance of the *pisifera*s showed that the grand mean for FFB was 131.62 kg/palm/yr, with mean BNO of 8.66 bunches/p/yr and mean ABW of 15.60 kg/p/yr. AVROS 0.174/247 gave the highest *tenera* FFB yield of 143.90 kg/p/yr, more than 9% above the grand mean. AVROS 0.182/308) exhibited the highest oil to bunch ratio (O/B) with 26.23%.

TABLE 6. PERFORMANCE OF DXP PROGENY TEST OF 3RD GENERATION AVROS IN KERATONG, PAHANG

No	Progeny	Crosstype	FFB (kg/ha/yr)	ABW (kg)	M/F (%)	S/F (%)	O/DM (%)	O/B (%)
1	01PK1389	DxP	73.24	9.38	82.16	9.85	76.71	25.30
2	01PK1396	DxP	98.01	9.53	79.78	10.44	79.63	27.44
3	01PK1397	DxP	78.34	9.15	78.50	10.73	77.36	25.93
4	02PK1106	DxP	77.96	8.30	84.93	7.53	78.39	28.02
5	02PK1384	DxP	77.04	8.01	81.20	10.07	78.87	26.18
6	02PK1387	DxP	70.11	8.00	81.87	8.40	78.55	27.82
7	02PK1388	DxP	65.68	8.00	85.37	7.12	77.82	24.12
8	03PK1283	DxP	39.56	6.62	78.62	10.84	77.83	25.54
9	03PK1297	DxP	81.82	8.85	79.76	10.70	79.83	27.20
10	04PK1179	DxP	79.95	9.49	80.46	10.42	77.30	26.03
11	04PK1269	DxP	72.24	8.32	77.54	12.74	76.37	25.10
12	04PK1399	DxP	84.24	8.24	76.71	12.88	77.94	24.37
13	04PK1400	DxP	83.57	9.22	79.00	10.40	77.71	24.65
14	04PK1401	DxP	70.34	9.82	81.08	9.42	78.05	26.51
15	04PK1403	DxP	31.58	7.35	84.50	6.83	76.43	16.80
16	04PK1404	DxP	40.82	7.01	98.80	0.36	79.69	18.27
17	05PK1291	DxP	55.98	8.57	76.29	13.32	76.98	25.54
18	05PK1379	DxP	67.66	8.22	78.94	16.66	79.24	24.96
19	05PK1380	DxP	70.70	7.85	78.89	12.53	78.72	27.15
20	05PK1381	DxP	83.17	9.24	77.19	12.08	78.51	26.05
21	05PK1382	DxP	77.15	9.30	83.35	8.49	80.20	28.84
22	06PK1097	DxP	60.41	7.41	80.25	9.48	76.23	24.81
23	06PK1418	DxP	79.59	7.88	82.86	7.51	78.30	26.61
24	06PK1421	DxP	56.57	7.35	86.18	7.67	76.36	27.43
25	06PK1424	DxP	65.44	7.70	86.52	7.07	79.33	27.87
26	06PK1436	DxP	63.77	7.25	85.28	8.53	79.81	27.78
27	07PK1241	DxP	53.71	6.65	75.29	18.42	76.37	22.62
28	07PK1250	DxP	52.94	8.01	81.83	8.70	78.76	26.53
29	07PK1253	DxP	85.90	9.05	83.47	8.53	77.47	27.74
30	07PK1275	DxP	82.95	7.74	78.99	11.82	79.54	28.88
31	07PK1405	DxP	87.01	8.43	80.25	9.14	77.50	25.66
32	07PK1407	DxP	77.85	9.41	83.38	8.51	78.32	23.31
33	07PK1414	DxP	48.35	6.84	81.96	9.09	77.12	23.86
34	08PK1182	DxP	59.05	8.55	78.19	12.07	80.23	27.02
35	08PK1188	DxP	79.68	9.32	79.13	11.36	77.41	24.57
36	08PK1196	DxP	84.25	9.56	78.56	11.14	79.06	26.32
37	09PK1321	DxP	65.40	8.54	84.40	8.00	77.34	26.21
38	09PK1348	DxP	78.83	7.87	83.30	7.63	77.72	27.61
39	09PK1358	DxP	53.63	8.25	82.95	8.94	78.60	27.16
40	10PK1266	DxP	75.30	8.48	81.65	9.82	78.54	28.10
41	10PK1267	DxP	72.41	9.67	77.21	11.88	78.42	23.72
42	10PK1272	DxP	72.18	8.49	75.86	12.32	77.76	24.20
43	11PK1278	DxP	63.10	8.38	81.38	10.35	80.43	28.83
44	11PK1279	DxP	73.06	7.33	81.64	10.01	77.87	27.29
45	11PK1280	DxP	74.09	8.62	83.55	8.91	78.08	27.44
46	12PK1270	DxP	84.36	8.24	84.21	8.70	78.72	27.40
47	12PK1273	DxP	82.19	8.69	80.94	10.06	78.26	25.85
48	12PK1274	DxP	71.06	8.22	81.54	9.60	73.99	23.01
49	13PK1467	DxP	66.23	7.07	85.44	7.19	77.72	27.40
50	PK 1158 SC	DxP SC	45.52	6.83	81.74	9.23	77.81	25.50
	MEAN		**72.19**	**8.37**	**81.10**	**10.00**	**78.26**	**26.37**

Notes: Planted in 1994
FFB-Fresh fruit bunches; ABW-average bunch weight; MFW-mean fruit weight;
M/F-mesocarp to fruit ratio; S/F-shell to fruit ratio; O/DM-oil to dry mesocarp;
O/B-oil to bunch ratio; OY-oil yield; Sc-standard cross DxP.

In general, few improvements were made in both *dura* and *pisifera*. Since the *dura* was descendants of Deli, the AVROS *pisifera* originated from a single plant selected at the Eala Botanical Garden of Yangambi, it has been described by Rosenquist (1986, 1992) as breeding populations of restricted origin (BPRO), a practice that heightens the risk of decreased genetic diversity in commercial oil palm production. Therefore, continued reliance on the exploitation of both *dura* and narrow selection of *pisifera* has resulted limit breeding progress.

Therefore, an introduction of new oil palm germplasm is very important to broaden the current genetic base thus increase the probability of yield improvement. One of the germplasm populations which was known to the Malaysian oil palm industry was the Nigeria Population 12. It has high yield and slower vertical growth thus been used in developing dwarf planting materials. The MPOB-Nigerian Population 12 material is known for its high yielding and exceptional slow vertical increment (Rajanaidu *et al.*, 1998).

The first attempt to incorporate germplasm from MPOB collection was with the release of PORIM Series 1 (PS1) in 1994 (Rajanaidu *et al.*, 2008). It used Nigerian *dura* as the new introduction to the MPOB DxP during that time. PS1 is known for dwarfness. The population 12 is known for low height increment of 30-40 cm per year. Deli *dura* x MPOB Nigeria *tenera* crosses yield more than 200 kg/p/yr as compared to the DxP control with 180 kg/p/yr (Rajanaidu *et al.*, 1998; 1999). The oil to bunch of *tenera* is about 28% and the palms are at least 30% shorter than Deli x AVROS control.

Results by Kushairi *et al.* (2003) showed the performance of PS1 planting materials. The trial at MPOB shows that at the third year of harvesting, FFB yield could reach up to 30 t ha^{-1} and the O/B was 25.9%, ranging from 23.66% to 28.90%. Hence, PS1 planting material has the potential to produce 7.7 t ha^{-1} of oil yield. Palm height of PS1 material is shorter, 40 cm yr^{-1} compared to current planting material with 45-75 cm yr^{-1}. Generally, PS1 was superior in most bunch quality components such as oil to bunch ratio (O/B), fruit to bunch (F/B), oil to dry mesocarp (O/DM), oil yield and total economic product (TEP) compared to PS2. The final product (TEP), besides being dependent on the bunch quality traits was heavily influenced by FFB yield. Mean TEP of the PS1 progenies was 45.40 kg $palm^{-1}$ yr^{-1} that ranged from 40.81 to 50.65 kg $palm^{-1}$ yr^{-1}.

The latest progress for DxP improvement was in 2004 with a trial planted with progenies of Deli *dura* x Nigerian *pisifera* in Sungai Papan, Kota Tinggi, Johor *(Table 7.)* The *pisifera* palms 'F_1' are the offspring of Nigeria population 12 materials planted in 1994 whereas the Deli *dura* materials used are sourced from various *dura* improvement programme in the 1960s and mostly from OPGL oil palm breeding programme. The fifth year mean yield of 33 DxP progenies was 232.5 kg (31 t/ha/yr) and the best progeny yielded 267.7 kg (36 t/ha/yr) with oil yield at 8.7 t/ha and the total economic product (TEP) amounting to 10.5 t/ha. The best oil/bunch (O/B) of this DxP population was 31.3% with oil extraction rate at 27%. The height increment of the progeny was 38 cm/yr compared to the AVROS at 47 cm/yr. There were also a number of progenies with TEP of 8.7 t/ha exhibiting height increments of 28 cm per year. The latest DxP improvement programme gave promising results which benefited commercial production of planting materials in the industry.

TABLE 7. PERFORMANCE OF DXP PROGENY TEST (MALE) OF NEW INTRODUCTION NIGERIAN *PISIFERA* IN KOTA TINGGI, JOHOR

No	Male	Crosstype	FFB (kg/ha/yr)	ABW (kg)	MFW (g)	M/F (%)	S/F (%)	O/DM (%)	O/B (%)	OY (t/ha/yr)	HT (m)
1	P01	DxP	28.76	11.2	10.77	83.21	11.57	79.32	28.28	8.19	2.39
2	P02	DxP	26.41	11.92	12.96	80.96	12.52	79.01	26.61	6.93	2.13
3	P03	DxP	27.79	11.99	11.57	84.61	10.69	81.11	29.41	8.04	2.31
4	P04	DxP	24.41	10.76	12.08	81.31	11.28	78.47	26.01	6.26	1.73
5	P05	DxP	24.28	11.51	12.63	81.17	12.9	77.54	25.15	5.99	2.07
6	P06	DxP	26.60	12.79	15.28	80.91	12.39	81.09	27.63	7.38	1.88
7	P07	DxP	26.27	10.28	12.42	78.92	14.5	79.6	27.35	7.18	2.56
8	P08	DxP	25.91	11.09	11.57	82.56	11.3	79.53	27.74	7.19	2.01
9	P09	DxP	26.97	11.32	11.3	83.62	10.592	80.86	28.58	7.73	1.97
10	P10	DxP	23.64	12.45	14.57	78.85	13.29	81.12	28.32	6.88	2.78
	Mean		**26.10**	**11.53**	**12.52**	**81.61**	**12.10**	**79.77**	**27.51**	**7.18**	**2.18**

Notes: Planted in 2004
FFB-Fresh fruit bunches; ABW-average bunch weight; MFW-mean fruit weight;
M/F-mesocarp to fruit ratio; S/F-shell to fruit ratio; O/DM-oil to dry mesocarp;
O/B-oil to bunch ratio; OY-oil yield; Ht-height.

CONCLUSION

Identifying good and promising *dura* and *pisifera* combinations is one of the measures taken to improve current DxP planting materials. This improvement can only be realized if breeders have knowledge and access to a quality breeding material. Introduction of germplam into the programme might be one way to improve current DxP planting materials to broaden the narrow genetic base.

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Evolution of Oil Palm Breeding Strategies/ Approaches and Development of Commercial Planting Materials in Applied Agricultural Resources Sdn Bhd

Wong, C K; Choo, C N; Wong, W C; Ng, W J; Kumar, K; Aida, N; Chin, S; Melody, M; Teo, C J; Farouq, R I L H and Tan, C C

Applied Agricultural Resources Sdn Bhd, No. 11 Jalan Teknologi 3/6, Taman Sains Selangor 1, Kota Damansara, 47810 Petaling Jaya, Selangor, Malaysia. Tel: +603-6151 7924, Fax: +603-61517081
E-mail: aarsb@aarsb.com.my

ABSTRACT

Oil palm breeding strategies centre on modified recurrent selection (also more commonly known among oil palm breeders as FIPs, acronym for Family-Individual Palm Selection) or modified reciprocal recurrent selection (MRRS). However, advanced crop improvement tools, *e.g.* tissue culture, advanced statistics, and molecular marker, have been integrated not only into oil palm breeding program, but also production of planting materials. Hence, AAR's oil palm breeding program is inclusive of development of tools and knowledge, followed by research execution for variety development, vice-versa, which eventually leads to the release of seed or tissue culture varieties. In this manuscript, two specific trials shall be highlighted as they serve the components of tools-knowledge development during the execution of research for variety development. The results of these two trials appraised (1) two strategies of production of commercial DxP seeds, *i.e.* selfs *dura*s or clonal *dura*s as mother palms; and (2) the necessity of DxP testing after MRRS; in AAR breeding materials.

Keywords: oil palm, breeding strategies, commercial planting materials.

INTRODUCTION

Overview of Applied Agricultural Resources Sdn Bhd (AAR) Oil Palm Breeding Program

AAR Oil Palm Breeding Research is inclusive of development of tools and knowledge, followed by research execution for variety development, or vice-versa. The tools and knowledge refers to, but not exhaustive, (1) Germplasm collection, (2) Oil Palm Breeding Techniques *e.g.* controlled pollination, (3) Classical & Quantitative Genetics, (4) Traits Analyses & Data Collection, Processing, Summarizing and Storage, (5) Trial Management e.g. quality control checks, (6) Statistics *e.g.* experimental design, data analysis, and prediction of performance, (7) Tissue Culture Technique *e.g.* cloning of *dura*, *tenera*, and *pisifera*, (8) Molecular breeding *e.g.* Molecular Assisted Selection, and Genomewide Selection and (9) Cytogenetics *e.g.* Ploidy Level. These tools and knowledge were used to execute AAR Main Breeding Program and Clonal Performance Evaluation Program, which focus mainly on the oil yield trait, and Auxiliary Breeding Program, which focus on traits like long bunch stalk, big fruit, oil quality, small palm stature and *Ganoderma* sp. Tolerance. Alongside these breeding programs, ortets are selected. Often, during the execution of breeding program, apart from the end results of the release of commercial varieties, specific tools and knowledge relevant to AAR breeding program are enhanced by consciously embedding objective of such while designing the experiment.

Evolution of Breeding Strategies/Approaches and Development of Commercial Planting Materials in AAR

AAR oil palm breeding research has progressed continuously for more than 50 years starting from Highland Research Unit. This year, AAR is celebrating its 30th anniversary. In the 1980's, Dr Soh Aik Chin, the lead oil palm breeder, had developed and released AA DxP as commercial planting materials. The maternal lineage of AA DxP was Deli (Breeding Population of Restricted Origin (BPRO) of Ulu Remis, Ulu Bernam, Dabou and their intercrosses) while the paternal lineage of AA DxP was Dumpy AVROS, which is a lineage of a backcross (on the level of population) event with AVROS, of the Dumpy Deli – Serdang Avenue – AVROS palms. Apart from its high yields (defined by the era), the prominent feature of AA DxP was 10-15% shorter in height compared to Deli – AVROS DxP. The breeding approach in selection of *pisifera* then was mimicking animal breeding, like, the approach of choosing the sire for milking ability, which progressively becoming more well known as family and individual palm selection: The *pisifera*-family is being selected through inferring its performance by the *tenera*-sib performance, while the choice of *pisifera* within the selected *pisifera*-family is being selected based on DxP progeny testing.

AA Hybrida I was subsequently released as commercial planting materials in 2004, replacing AA DxP. Though, since 1998, semi-commercial testing of AA Hybrida I (term as AAR 2nd generation DxP then), was initiated. The lead breeder was Dr Soh Aik Chin still, assisted mainly by Mr Hor Thim Yoon and subsequently by Mr Wong Choo Kien, who was responsible for the commercialization of AA Hybrida I. AA Hybrida I had maternal lineage of BPRO Ulu Remis Deli, Ulu Bernam Deli and Ulu Remis – Dabou intercross Deli. While the paternal lineage of AA Hybrida I was Dumpy Yangambi AVROS$_{158}$, which is an intercross of Dumpy AVROS and Yangambi AVROS. In the course of developing the AAR 2nd generation DxP, Dumpy AVROS of a generation more advanced then the paternal lineage of AA DxP were also tested simultaneously, yet it was observed inferior against Dumpy Yangambi AVROS.

The breeding approach leading to the commercial planting material of AA Hybrida I was family and individual palm selection but was more keenly being referred as modified recurrent selection, in order to be in line with plant breeding terminology on breeding-selection methodologies. By then, obvious grouping of Deli and Non-deli had already been well acknowledged and progeny testing often refer to Deli x Non-deli. Tapping into the technological maturity of oil palm tissue culture then (late 90's) where research has been conducted since 1982, multiple Deli *dura*s featured in DxP testing were cloned simultaneously with the envision of the possibility of clonal seeds production. The good *dura* clones (defined by DxP progey test) were selected for semi-clonal seed production. Since 2012, all seeds sold in AAR were semi-clonal seeds which were then named AA Hybrida IS. The additional "S" added to AA Hybrida I is the acronym for semi-clonal.

Modified reciprocal recurrent selection (MRRS) was adopted in AAR where numerous DxT crosses of various lineages of Deli x Non-Deli were planted, 2-3 years before AA Hybrida I become commercially available. The corresponding selfs of the DxT crosses were planted 2-3 years earlier than the DxT crosses. The conclusive results of AAR's 1st set of modified reciprocal recurrent selection were drawn in year 2010 after 8 years of data collection. A few top DxT crosses of high yields and small palm stature were identified. Immediate commercialization (to produce DxP seeds using all the corresponding selfs *dura*s and the *pisifera*s, though they are already available, as how the MRRS suggested) did not happen, instead DxP testing is proposed (somewhat like modified recurrent selection), in view of the variability that could potentially become a disadvantage – an undesirable trait to the planters, and selection of better *pisifera*s among the selfs *pisifera*s, in order to meet the improvement targeted (2% annually). The commercial DxPs produced from these selected *pisifera*s are AA Hybrida II, the lineage are Ulu Remis or Ulu Bernam Deli x Dumpy AVROS La Me and Ulu Remis or Ulu Bernam Deli x Dumpy Yangambi AVROS$_{138}$. Sharing the same aspiration as AA Hybrida IS, AA Hybrida IIS will replace AA Hybrida II, when the relevant clonal *dura*s are ready.

Genomewide Selection was applied on Dumpy Yangambi AVROS$_{158}$ intercrosses (a generation ahead of Dumpy Yangambi AVROS$_{158}$ in AA Hybrida I). Genomewide Selection has enabled the selection of *pisifera*s within this new generation relatively quickly and the DxP released from this strategy is expected to be part of AA Hybrida II and possibly AA Hybrida III.

While DxP testing were on-going for the selection of *pisifera*s of AA Hybrida II, AAR 2nd set of MRRS were laid. The intercrosses of the parents of the top few DxTs in the 1st set of MRRS, which still maintained the grouping structure of Deli x Deli and Non-deli x non-deli, were serving as parents to AAR 2nd set of MRRS. The lineage involved was mainly Ulu Remis – Ulu Bernam Deli x Dumpy Yangambi AVROS Nifor. The "canon" like events of DxP testing of previous generation and DxT testing new generation at similar period is expected to be adopted for the coming variety development to speed up the program, in order not to reduce the speed of variety development. Such practice if persevere, will reduce a variety time span to the next improved variety to an expected 10 years.

Two trials will be further discussed, highlighting some findings that answer two queries among oil palm breeders: (1) Who serves as better mother: Clonal *dura* or selfs *dura*? (2) Can better *Pisifera*s be identified through DxP testing after MRRS? Nevertheless, the results are specific to AAR germplasms and breeding materials, hence, do not override contradictory findings of other groups.

Who serves as better mother: Clonal *dura* or selfs *dura*?

In commercial production of DxP seeds, the mother palms are commonly selfs palms or sib-mated palms of tested *dura*s. When the cloning technology matures, the mother palms used in DxP seed production could be clones of tested *dura*s. In genetics theories, early generation selfings generates recombinants with variance depending on the heterozygosity of the palms being selfed, while cloning aims to reproduce the exact copy of the genotype.

Commercial production of DxP seeds aims to reproduce desirable genotypes in large quantity based on progeny test results, and, in most cases, the bottleneck to large amount of seeds production rests on the number of mother palms. Both selfs and clonal *dura* mother palms can meet the later aim. The following discussion shall address which serves as better mother: clonal *dura* or selfs *dura*, given that both share the same parent, *i.e.* apart from being clone, the ortet is also selfed to produce the selfs *dura*.

Methods and Materials

Four *dura* ramets belonging to one clone were crossed with a *pisifera*; *i.e.* D_{ramet}xP. Four selfs *dura*s generated from the ortet that produce the said *dura* ramets, were also crossed with the same *pisifera*; i.e. D_{selfs}xP. As reference, the ortet is also crossed with the same *pisifera*; *i.e.* D_{ortet}xP. In total, there were 9 crosses and were planted in a trial following the experimental design Randomized Complete Block at 3 replications, with plot size of 16 palms, in year 2011, in Paloh, Johor. Data of fresh fruit bunch (FFB), bunch number (BNo) and bunch weight (BW) were collected 30 months after field planting, *i.e.* January 2014.

Results and Discussion

There were two years of FFB, BNo and BW. The trial is still on going. The average of the two years results of the DortetxP of FFB, BNo and BW were 112 kg/palm/year, 20.1 bunches/year and 5.5 kg/bunch respectively. In the same period, the 4 DselfsxPs produced 106.3 kg FFB/palm/year, 17.9 bunches/year and 6.1 kg/bunch while the 4 DrametxPs 118.8 kg FFB/palm/year, 21.0 bunches/year, 5.6 kg/bunch.

As expected, variation among D_{ramet}xP crosses was lesser than variation among D_{selfs}xP crosses *(Table 1)*. Should similar trend persist, to bulk reproduce a cross, D_{ramet}xP is desirable, for the sake of uniformity. These were early results and they are not conclusive yet. Joko *et al.* (2011) conducted similar experiment, comparing the D_{selfs}xPs and DrametxPs and concluded that there was no statistical difference between the two. While Zulhermana *et al.* (2011), instead of using *dura* clones, used *pisifera* clones to compare the performance of semi clonal seeds and conventional seeds; *i.e.* DxP_{ramet} and DxP and found no statistical difference among the two also.

Better *pisiferas* through DxP testing after Modified Recriprocal Recurrent Selection

Depending on the nature of the parental population, DxPs created using the selfs from the parents to the selected DxTs, with maternal and paternal lines well separated, were subjected to trial, in order to select better *pisiferas* among the selfs. Based on the pedigree of parents used in the MRRS breeding program in AAR, DxP testing is proposed after DxT testing because the parental background of the paternal were early generation of introgressions of different non-deli groups.

Methods and Materials

Four *pisifera* selfs were mated with 2 to 4 *dura* selfs in which the parents to the selfs were also the parents of a selected DxT cross, with maternal and paternal lines well separated. In total, there were 11 crosses and were planted in a trial following the experimental design Randomized Complete Block at 3 replications, with plot size of 16 palms, in year 2011, in Paloh, Johor. Data of fresh fruit bunch (FFB), bunch number (BNo) and bunch weight (BW) were collected 30 months after field planting, *i.e.* January 2014.

Results and Discussion

There were two years of FFB, BNo and BW *(Table 2)*. The trial is still on going. The best *pisifera*, which was determined by the simple averages of DxP results of FFB, BNo and BW grouped by *pisifera* type, were 113.8 kg/p/year, 21.7 bunches/year and 5.2 kg/bunch. The 2nd rank pisifera yielded 99.3 kg FFB/p/year, 19.6 bunches/year and 5.0 kg/bunch whereas the 3rd rank *pisifera* 88.8 kg FFB/p/year, 17.4 bunches/year and 5.1 kg/bunch and the 4th rank *pisifera* 78.4 kg FFB/p/year, 15.6 bunches/year and 4.9 kg/bunch. These results suggested that the *pisiferas* were different based on DxP progeny test, though they were selfs. Should similar trend persist, the necessity for DxP progeny test is evident, if only the top *pisiferas* (defined by the genetic improvement targeted) are used in commercial seed production. These were early results and they are not conclusive. Nouy *et al.* 1988 had proven the feasibility to recapture the performance of DxT crosses, by creating DxP from the corresponding selfs, and serve as commercial DxP seeds. Nevertheless, they also showed differences among the *pisifera* used (defined by general combining ability). Therefore, the necessity to DxP progeny test with the aim for seed production is dependent on the breeding population, the heterozygosity level, and the genetic improvement desired.

CONCLUSION

Many breeding research findings strongly suggest that their findings are usually population specific typically on quantitative traits *e.g.* QTL-mapping, though simple trait might not be straightforward either. Oil palm breeding program is slow due to the perennial nature of the crop. Often, an oil palm breeder had a breeding program inherited from the previous breeder. Therefore, good record keeping cannot be overemphasized in order to make sense of the breeding program so that it could be creatively and precisely integrated with advanced knowledge, tools and technology with the ultimate goal of variety release and seed production always at the back of our mind.

TABLE 1. AVERAGE RESULTS (JAN 2014 - DEC 2015) OF FRESH FRUIT BUNCH (FFB) (KG/PALM/YEAR), BUNCH NUMBER (BNO) (NO./YEAR) AND BUNCH WEIGHT (BW) (KG) OF 4 D_{SELFS}XPS, 4 D_{RAMET}XPS AND A D_{ORTET}XP. THE *PISIFERA* IS COMMON ACROSS ALL CROSSES

No.	Cross Type	No of Reps	FFB	BNo	BW
1	$D_{self1}xP$	3	112.0	19.4	5.7
2	$D_{self2}xP$	3	98.8	19.2	5.1
3	$D_{self3}xP$	3	93.9	12.3	7.6
4	$D_{self4}xP$	3	120.5	20.5	5.9
5	$D_{ramet1}xP$	3	115.7	20.9	5.5
6	$D_{ramet2}xP$	3	120.4	21.0	5.8
7	$D_{ramet3}xP$	3	119.5	21.1	5.6
8	$D_{ramet4}xP$	3	119.6	21.2	5.6
9	$D_{ortet}xP$	3	112.0	20.1	5.5

TABLE 2. AVERAGE RESULTS (JAN 2014 - DEC 2015) OF FRESH FRUIT BUNCH (FFB) (KG/PALM/YEAR), BUNCH NUMBER (BNO) (NO./YEAR) AND BUNCH WEIGHT (BW) (KG) OF $D_{SELFS}XP_{SELFS}$. THE PARENTS TO THE SELFS WERE ALSO THE PARENTS OF A SELECTED DXT CROSS, WITH MATERNAL AND PATERNAL LINES WELL SEPARATED

No.	Cross Type	No of Reps	FFB	BNo	BW
1	$D_{self1}xP_{self1}$	3	77.6	15.1	5.1
2	$D_{self2}xP_{self1}$	3	79.1	16.1	4.6
	Average by P_{self1}		**78.4**	**15.6**	**4.9**
3	$D_{self1}xP_{self2}$	3	77.1	15.1	5.1
4	$D_{self2}xP_{self2}$	3	75.3	15.3	4.9
5	$D_{self3}xP_{self2}$	3	111.1	20.5	5.4
6	$D_{self4}xP_{self2}$	3	91.9	18.5	4.9
	Average by P_{self2}		**88.8**	**17.4**	**5.1**
7	$D_{self5}xP_{self3}$	3	94.9	19.2	4.9
8	$D_{self1}xP_{self3}$	3	117.4	21.5	5.4
9	$D_{self2}xP_{self3}$	3	85.6	18.1	4.7
	Average by P_{self3}		**99.3**	**19.6**	**5.0**
10	$D_{self1}xP_{self4}$	3	113.5	21.3	5.3
11	$D_{self4}xP_{self4}$	3	114.1	22.2	5.1
	Average by P_{self4}		**113.8**	**21.7**	**5.2**

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P8

The Journey: Oil Palm Breeding and Seed Production in Felda Global Ventures

Tan Joon Sheong[1*]; Leao Ling Jiun[1]; Suthashinikisan Krishnan[1] and Sharifah Shahrul Rabiah Syed Alwee[1]

[1]Felda Global Ventures Research and Development Sdn Bhd
* Corresponding Author: js.tan@feldaglobal.com

Felda Global Ventures (FGV) had been involved in oil palm breeding programme since the early 1960. This is made possible with the germplasms materials release by MPOB and to date, FGV have the second largest oil palm germplasm collect after MPOB. All these materials are located within Tun Razak Agricultural Research Centre (also commonly known as PPPTR). Over a period of 45 years of breeding history. FGV has assembled a comprehensive set of advanced breeding materials encompassing all major *dura* and *tenera* / *pisifera* populations. Throughout these period, FGV had released Felda Yangambi planting material in 2002 and an improvised version Felda Yangambi ML161 in the subsequent years. The breeding programme did not stop here, Felda 3-way DxP was released in the early 2010. Since 2009, FGV through its subsidiary company, Felda Agricultural Services Sdn Bhd (FASSB) has emerged as one of the top seed producer in Malaysia, producing 23 - 26 million per annum and commanding more than 43% of the Malaysian seed market in 2015. To date FASSB has sold over 330 million seeds of Felda Yangambi and 4.9 million seeds of Felda 3-way. Felda Yangambi is Felda Deli *dura* x Felda Yangambi; the latter improved over three generation from a few crosses received from IRHO (now CIRAD, who in turn obtained the material from Yangambi in Congo). Felda 3-way is completely developed within FGV starting from selections from MPOB's Nigerian prospections of 1973. Oil extraction rate (OER) at FGV mills has also proven FGV materials to be one of the toppers in the industry, the OER ranging from 23.03% to 24.15% at a FPI mill in East Malaysia with more than 95% only FGV materials in 2016. Further development of planting materials at FGV is now harnessing marker-assisted breeding (MAB) to be integrated in FGV's breeding programme.

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Translating the Oil Palm Genome Information into Precision Agriculture Breeding Practices

Nathan Lakey[1]; Rajinder Singh[2]; Meilina Ong Abdullah[2]; Eng-Ti Leslie Low[2]; Leslie C-L Ooi[2]; Rajanaidu Nookiah[2]; Steven W Smith[1]; Jared M Ordway[1]; Robert A Martienssen[3] and Ravigadevi Sambanthamurthi[2]

[1]Orion Genomics, St. Louis, MO, USA
[2]Malaysian Palm Oil Board (MPOB), 6, Persiaran Institusi, 43000, Kajang, Selangor, Malaysia
[3]HHMI-GBMF Cold Spring Harbor Laboratory, Cold Spring Harbor, New York

ABSTRACT

In 2013, a team led by MPOB reported the reference genome sequences of *E. guineensis* and *E. oleifera*. This milestone rapidly resulted in the identification of the genetic basis of three traits critical to the oil palm industry. The discovery of the *VIR* gene, responsible for oil palm fruit colour, facilitates the use of marker assisted selection (or *VIR* gene testing) in the development of elite breeding lines with a natural color indicator for fruit ripening. The identification of *Karma*, a transposon inserted into the *MANTLED* gene, whose DNA methylation state controls the *MANTLED* phenotype, paves the way for epigenetic testing of nursery material to identify and cull somaclonal palms destined to yield unproductive abnormal fruits years after field planting. Finally, the discovery of the *SHELL* gene, responsible for increased yields in tenera hybrids, allows genetic testing and culling of non-*tenera* (low-yielding) palms at the nursery stage, thus enabling the exclusive field planting of the higher yielding *tenera* palms. *SHELL* gene testing will also allow for improved efficiency in breeding programmes, especially in the development of male *pisifera* lines. A recently published study, led by MPOB, involving over 10,000 tested palms and seedlings within 51 independent planting sites and nearby nurseries throughout Malaysia demonstrated that a novel molecular precision agriculture approach incorporating comprehensive *SHELL* gene testing will result in a significant increase in oil yield from existing planted area. This form of molecular precision agriculture will increase wealth creation among Malaysia's poorest farmers, while also growing plantation profitability, gross national income and national tax revenues. These discoveries made in the Malaysian Oil Palm Genome Programme, and more to come, are already helping to achieve sustainability for the most important oil crop worldwide.

INTRODUCTION

Translation of agricultural research from primary findings into applications with fundamental real-world impacts is inherently a laborious process requiring multiple years of focused effort. Advances begin as basic scientific discoveries made in research settings that are then rigorously validated to demonstrate applicability across the crop industry being studied. Extensive development work then goes into pinpointing the most effective technologies and methods to translate the discoveries into robust applications that address the challenge at hand. Finally, the work culminates in the implementation of these advances in a way that can best address the needs of the industry.

A strong example of this process is provided by the oil palm translational research led by a partnership between the Malaysian Palm Oil Board, Orion Genomics and Cold Spring Harbor Laboratory. A cornerstone of this work was the 2013 publication of the reference genome sequences of the African oil palm *E. guineensis* and the South American oil palm *E. oleifera*. Using a combination of next-generation sequencing strategies and Sanger sequencing of bacterial artificial chromosomes, the published reference genome of *E. guineensis* (AVROS *pisifera* fruit form) included 1.535 Gb assembled sequence, of the total estimated 1.8 Gb oil palm genome size, and it predicted at least 34,802 oil palm genes [1]. Since then, the team has continuously improved upon the initial reference genome, increasing the genetically mapped genome space from 0.658 Gb to 1.299 Gb and decreasing the percentage of internally mapped gaps from 31.1% to 3.6%. The availability of the reference genome has rapidly resulted in the discovery of the molecular basis of three of the most critical traits in the oil palm industry: namely the shell thickness trait responsible for *dura*, *tenera* and *pisifera* fruit form phenotypes; the virescens fruit color trait; and the *mantled* abnormality trait associated with somaclonal propagation.

The *Shell* Gene Controls Fruit form Phenotype and Oil Yield

Conventional breeding for palm oil production throughout southeast Asia is based on the planting of hybrid *tenera* fruit form palms. This is accomplished by crossing thick shelled *dura* maternal palms to shell-less, typically female sterile, *pisifera* paternal palms to produce hybrid offspring with the preferred *tenera* phenotype. Fruit from *tenera* palms yield substantially more oil than either parent, a classic example of single-gene heterosis (or single gene hybrid vigor). However, absolute control over these crosses is often difficult to achieve in real world settings, and unintentional planting of non-*tenera* palms for commercial production decreases yield. The team utilized a combination of strategies to pinpoint the *SHELL* gene. Genotyping of restriction fragment length polymorphism (RFLP), simple sequence repeat (SSR) and single nucleotide polymorphism (SNP) markers in 240 F_1 progeny derived from a controlled self-pollination of the Nigerian *tenera* accession T128, and grown over two decades in plantations throughout Malaysia, placed the locus within a defined T128 linkage group that mapped to a 3.4 Mb scaffold of the reference *E. guineensis* genome. Further focused SNP mapping identified recombinant breakpoints pinpointing a 450 Kb genetic interval on chromosome 2. Homozygosity mapping was then performed utilizing an AVROS pedigree involving carefully controlled crosses of AVROS *pisifera* (homozygous mutant) and *tenera* (heterozygous) palms over five decades. Next generation sequencing of *pisifera* palms allowed the mapping of a single homozygous gene *(SHELL)* within the genetic interval, and PCR based sequencing of the gene in 336 T128 accessions and 334 independent palms of known fruit form phenotype confirmed its identity and revealed the responsible genetic mutations within these populations [2].

The *SHELL* gene encodes a type II MADS-box transcription factor homologous to *Arabidopsis SEEDSTICK*, which controls ovule, seed and lignified endocarp differentiation [3-5], and rice *OsMADS13*, which controls ovule differentiation and female fertility [6]. Expression of *SHELL* is high in the outer layers of the developing kernel in *dura* fruits, consistent with its function in regulating the formation of the heavily lignified shell surrounding the fruit kernel [2]. MADS box genes are master regulators of plant floral organ identity, and they are grouped into one of several families based on the specific domain structures of the proteins they encode [7]. Type II MADS box proteins include a highly conserved MADS box domain that is essential for dimerization and DNA binding, I and K domains that provide a level of specificity to each protein's function and a C domain required for transcription regulatory activity. These proteins each function by interacting with different MADS box family proteins. This heterodimerization is required for binding to DNA regulatory regions of the genes whose expression they control. The combination of different MADS box proteins expressed within a particular tissue type and developmental stage, the interaction combinations possible among different family members, and the identities of the target genes regulated by a specific heterodimeric MADS box protein pair all contribute to the specific flower and fruit development regulatory function of any particular MADS box gene.

Five independent, but closely related, mutations within the *SHELL* MADS box domain have been identified. While *dura* fruit form palms are homozygous wildtype at all *SHELL* nucleotide positions, palms that are heterozygous for any one of the five mutations are *tenera* fruit form. Furthermore, palms that are homozygous mutant for any one of the five mutations (or compound heterozygous with different mutations on each of the two chromosomes) are *pisifera* fruit form. The first mutations to be discovered included the Congo-derived AVROS (sh^{AVROS}) mutation resulting in an asparagine substitution of a highly conserved lysine residue, as well as the Nigerian T128-derived sh^{MPOB} mutation resulting in proline substitution of a leucine residue two amino acids N-terminal to the sh^{AVROS} position [2]. In a survey of 13 smallholder planting sites or nurseries that supply these sites throughout Malaysia, the team recently reported the identification of three additional low frequency mutations within the *SHELL* MADS box domain. These include the sh^{MPOB2} lysine-to-glutamine substitution six amino acids N-terminal to sh^{MPOB}, the sh^{MPOB3} alanine-aspartate substitution 10 amino acids C-terminal to sh^{AVROS} and the sh^{MPOB4} lysine-to-asparagine substitution of the same amino acid altered by the sh^{MPOB2} mutation [8]. Across all surveyed sites, 10,224 palms or seedlings were genotyped. 89.3% (n = 9,130) were found to be heterozygous for one of the five *SHELL* mutations, and therefore *tenera* fruit form type. *Tenera* palms or seedlings heterozygous for either sh^{AVROS} or sh^{MPOB} were found in all sites surveyed, and heterozygosity for either of these two alleles accounted for 97.42% (n = 8,885) of observed heterozygous genotypes (and, therefore, *tenera* phenotypes). The other three mutant alleles were detected only in subsets of surveyed sites and at relatively low frequencies. The sh^{MPOB2} (detected in 7 of 13 sites), sh^{MPOB3} (detected in 7 of 13 sites) and sh^{MPOB4} (detected in 2 of 13 sites) mutations accounted for 1.62%, 0.93% and 0.02% of observed heterozygous genotypes, respectively [8]. However, it should be noted that these represent overall frequencies across all surveyed sites. Although overall frequencies of these additional mutant alleles are low, their importance is underscored by the findings that they can be present at significant frequency within specific sites. To further verify the correlation between these mutations and fruit form phenotype, the team sampled mature fruit form phenotyped palms from sites in which each of the mutations were detected (n = 512; 56 *dura*, 34 *pisifera* and 422 *tenera*), and genotypes were determined by PCR amplicon-based

Sanger DNA sequencing. After resolution of rare discordances (2.9%) by resampling and blinded phenotyping and genotyping, the five *SHELL* mutations accounted for 100% of the observed *tenera* and *pisifera* phenotypes [8]. All 422 *tenera* palms were heterozygous for one (and only one) of the five reported mutant *SHELL* alleles, and each mutation was observed as heterozygous in at least 2 *tenera* palms. Of the 34 *pisifera* palms genotyped, 33 were homozygous for the sh^{AVROS} allele while one palm was compound heterozygous for both the sh^{AVROS} and sh^{MPOB2} alleles. Finally, all 56 *dura* palms were homozygous wildtype at all nucleotide positions. Therefore, while it remains possible that additional mutations of *SHELL* may be present in unique commercial populations and may contribute to fruit form phenotype, these findings demonstrate that these five mutations account for all phenotypes within these surveyed populations, and they indicate that potential additional mutations would likely account for an exceptionally small portion of *tenera* phenotypes in commercial palm oil production populations. As described in more detail below, the discovery of *SHELL* and the mutations underlying fruit form phenotype has now been developed into applications that will allow the industry to identify non-*tenera* contamination at the early nursery stage, thus avoiding the unwanted investments of resources into previously unidentified lower yielding non-*tenera* palms.

The *VIR* Gene Controls Fruit Colour

Oil palm fruit exocarp colour can be an indicator of fruit ripeness, and therefore is important in terms of harvesting and oil yield. The majority of oil palms produce either *nigrescens* or *virescens* fruit type [9]. *Nigrescens* fruits are usually deep violet to black at the apex when unripe, with minimal change in colour of the apex upon ripening, while *virescens* fruits are green when unripe, and change to orange when the bunch matures, due to accumulation of carotenoids [10]. This colour change is advantageous in that harvesters can more easily identify ripe bunches without relying on fruits on the ground, thus reducing yield loss due to detached fruits or harvesting of unripe bunches. In 2014, the team reported the identification of the *VIRESCENS* gene *(VIR)*, as well as five dominant-negative mutations responsible for the advantageous virescens fruit colour phenotype [11]. Again utilizing the T128 self-pollination pedigree, as well as additional palms from six independent crosses, a genetic linkage map for the fruit colour trait was constructed. In RFLP, SSR and SNP genotyping efforts similar to those used to identify *SHELL*, the *VIR* locus was mapped to a linkage group on chromosome 1. Mapping of markers flanking the locus localized the interval to a specific assembly scaffold of the reference genome, and additional mapping ultimately narrowed the interval to a region containing four potential candidate genes. A combination of next generation sequencing and PCR-based candidate gene Sanger DNA sequencing within a panel of palms phenotyped for fruit colour identified a R2R3-MYB transcription factor gene, with homology to *Lilium LhMYB12* and *Arabidopsis PAP1*, that was homozygous wildtype in *nigrescens* palms but, in *virescens* palms, was heterozygous or homozygous for a nonsense mutation in the final exon of the gene. To further validate the identity of the *VIR* gene, and to identify additional mutant alleles, the entire gene was sequenced in 139 samplings from six independent breeding populations (DT35, DT38, DP454, TT108, AVROS and MPOB PK575), as well as 440 samplings from various germplasm collections (Angola, Madagascar, Tanzania, Ghana, Congo, Cameroon and Nigeria). In breeding populations, all 52 *virescens* palms (and none of the 87 *nigrescens* palms) were either heterozygous or homozygous for the VIR exon 3 nonsense mutation identified within the T128 population. However, four additional

VIR mutations were identified in the germplasm collections, each resulting in a remarkably similar C-terminal truncation of the *VIR* protein. Overall, the *VIR* genotype of the five variants were concordant with fruit colour phenotype in >99% of the 787 palms analyzed [11]. R2R3-MYB proteins are members of regulatory networks controlling development, metabolism and responses to biotic and abiotic stresses [12]. Specifically, LhMYB12 and PAP1 control accumulation of anthocyanins by regulation of biosynthetic gene expression [13-15], implying that the *VIR* truncation mutations result in a dominant-negative function linked to anthocyanin deficiencies via impaired regulation of downstream anthocyanin biosynthetic target genes. This model is supported by whole transcriptome gene expression profiling in *nigrescens* and *virescens* fruit [11].

The discovery of the *VIR* gene and the mutations responsible for the *virescens* fruit colour phenotype will have important impacts on oil palm breeding through the development of genetic testing for fruit colour prior to planting. Testing will allow seedlings that are heterozygous for the dominant-negative mutation to be differentiated from those that are homozygous. Along with *SHELL* testing, this will allow breeders to develop paternal *pisifera* lines that are homozygous for the advantage variant for use in introgression of the desirable *virescens* trait into elite breeding materials.

Bad Karma Underlies *Mantled* Somaclonal Abnormality

The discoveries of *SHELL* and *VIR* directly impact conventional oil palm breeding. However, somaclonal propagation of high performing palms is also an attractive route to increase yields in commercial populations. Ramets (clones) of high-yielding *tenera* ortets can potentially provide 30% increases in yield relative even to the preferred seed derived *tenera* hybrid [16]. However, cloning of oil palm requires up to ~3 years of cell culture of immature apex leaf tissue and plantlet regeneration on hormone-supplemented media. During this time, somaclonal variation arises due to the induction of somatic cells into pluripotent state, resulting in clones that are genetically identical, yet can display phenotypes that differ between each other and to the parent ortet. For this reason, somaclonal abnormality has long been believed to be a largely epigenetic, rather than genetic, phenomenon [16-20]. Central to oil palm somaclonal propagation is the *mantled* abnormality. The abnormality arises at variable and previously unpredictable rates among independent cloning events. In clones that become *mantled*, staminodes of pistillate flowers and stamens of staminate flowers develop as pseudocarpels, often resulting in sterile parthenocarpic flowers with abortive fruit and very low oil yields [21]. The time and expense of the somaclonal process, compounded by the years required to determine whether cloned palms produce normal or *mantled* fruits, have dramatically limited the use of somaclonal propagation in the oil palm industry.

To address this problem, the team took a genome-wide epigenetic profiling approach to identify the underlying cause of the *mantled* abnormality. Again owing to the availability of the *E. guineensis* reference genome, the team constructed a DNA microarray capable of globally monitoring the unique portion of the oil palm genome. Using Orion Genomics' *MethylScope* technology, the team constructed genome-wide DNA methylation maps for multiple ortets, *mantled* ramets and normal ramets representing multiple clonal lineages from each of four independent industry sources. Remarkably, the approach pinpointed a single locus of the genome that had undergone loss of DNA methylation (hypomethylation) in *mantled* ramets, yet maintained high levels of DNA methylation in ortets and normal ramets [22]. Mapping this locus back to the reference genome revealed that the hypomethylated region overlaps a *Karma* retrotransposon embedded within a large intron 5 of the *EgDEF1* B-class MADS-box transcription factor gene. EgDEF1 is homologous to *Antrirhinum majus DEFICIENS (DEF)* and *Arabidopsis APETALA3 (AP3)* [20, 23, 24]. The epigenetic hypomethylation defect (referred to as *Bad Karma*) was validated by whole genome bisulfite sequencing, clone-based bisulfite sequencing and qPCR-base quantitative DNA methylation assays and was found to occur in leaf and fruits of *mantled* ramets regardless of industry source or clonal lineage, while ortets and ramets producing normal fruits maintained high DNA methylation density across the *Karma* element (referred to as *Good Karma*). Furthermore, the extent of *Bad Karma* in fruits from abnormal ramets displaying revertant normal fruits was inversely correlated with the proportion of normal fruits produced by the revertant ramets. The team went on to demonstrate that the effect of *Bad Karma* is to unmask a mRNA splice site at the 5' end of the *Karma* retrotransposon. In ramets producing normal fruit, splicing of the full length *EgDEF1* mRNA transcript (*cDEF1* [20]) occurs normally. However, in ramets producing mantled fruits (those with *Bad Karma*), abnormal splicing of *EgDEF1* exon 5 into the Karma retrotransposon results in a *mantled*-specific aberrant transcript encoding a truncated, presumably dominate-negative, form of the *EgDEF1* protein at stages 3-5 of female inflorescence development. A previously identified alternative *EgDEF1* transcript (*tDEF1* [20]) was expressed at identical levels in both normal and mantled female inflorescences throughout inflorescence development [22].

The ability to test for *Bad Karma* at the early plantlet stage and cull those destined to become *mantled* ramets will have a clear impact on the implementation of somaclonal propagation in the oil palm industry. Without the negative impact of unpredictable mantling among adult ramets, somaclonal propagation is poised to facilitate the introduction of higher performing clones and further optimize yield and land utilization.

Impact on Precision Agriculture

While the gains in basic scientific understanding achieved by the above reviewed discoveries are substantial, the true value of these advances will be measured in terms of their direct applicability, availability and impact on the oil palm industry. Orion Biosains, Sdn Bhd, located in Puchong, Selangor, offers genetic/epigenetic testing services to the oil palm industry (https://orionbiosains.com). The company's SureSawit *SHELL* test, licensed from MPOB, is the first commercially available genotyping test for the industry. Based on the *SHELL* discoveries described above, industry members are able to sample material using a Sample Collection Kit provided by Orion Biosains. The kit includes patented barcoded leaf punch and tag devices allowing the user to simply take a small leaf punch sample and tag the seedling or adult palms with the associated removable barcode tag. These punches are shipped to Orion Biosains for high-throughput genetic testing using custom automation and the Douglas Scientific Intellicycler and IntelliQube systems. The company has the capacity to genetically test and report phenotype predictions on millions of palms per year. Orion Biosains is currently in the final stages of implementing SureSawit-*KARMA* epigenetic testing to predict risk of future *mantled* somaclonal abnormality. This will then be followed by implementation in the near future of SureSawit-*VIR* genetic testing for the prediction fruit colour phenotype.

An example of the real world impact of genetic testing in the oil palm industry is provided by the study mentioned above addressing non-*tenera* contamination rates among 13 independent smallholder planting sites and the nurseries that supply them throughout Malaysia [8]. This broad and extensive sampling (10,224 palms or seedlings) allowed the first direct assessment of non-*tenera* contamination in commercial populations. Samples were first tested by genetic assays for the more abundant sh^{AVROS} and sh^{MPOB} alleles. All samples that were found to be wildtype for both these nucleotide positions were then Sanger DNA sequenced (*SHELL* exon 1, encoding the MADS-box domain) to provide absolute confidence in the scoring of *dura* contaminant samples. Notably, every site analyzed had some level of unexpected non-*tenera* contamination, with per-site rates ranging from as low as 2.5% to as high as 23.1%. Across all sites, non-*tenera* contamination was directly measured to be 10.7% (95% confidence interval: 10.1%-11.9%). To account for differences in region-specific planting area, contamination rates from each region were then weighted by each region's total oil palm planted area, resulting in a national weighted average independent planting site contamination rate of 10.9% (8.1% *dura* and 2.8% *pisifera*). To assess the economic impact of *SHELL* genetic testing in the independent sector (estimated 3.9 million palms plated each year), a 48-parameter, four-stage economic model involving variables associated with breeders, nurseries, planting sites and mills was constructed [8]. Planted area managed by independent planters were set at 2015 levels and assumed average planting density of 143 palms per hectare. Mass CPO, PKO and PKC for baseline and *SHELL* testing scenarios were computed by mass balance equations reported in the open access publication [8]. Selling prices of CPO and PKO at a future date were predicted using a regression of monthly closing prices from January 1995 through April 2015 (CPO) and from January 1996 – April 2015 (PKO), as described [8]. Based on economic modeling, *SHELL* genetic testing would increase gross national income, industry income and government tax income as low yielding contaminant palms are replaced by high yielding *tenera* palms. At steady state, *SHELL* gene DNA testing in the independent sector alone (representing only 15% of oil palm planted area) would add RM 1.05 billion to Malaysian GNI annually (or RM 272 in gains per screened palm-including all *tenera* and non-*tenera* palms tested), RM 0.693 billion of increased production annually to oil palm industry members (or RM 180 per screened palm) and RM 0.26 billion of increased tax receipts annually (or RM 68 in new taxes per screened palm).

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FIELD VISITS

PT SOCFINDO AEK LOBA

Principle Director:
Mr Harold Owen Williams

www.socfindo.co.id

Aek Loba Plantation is a largest oil palm plantation of PT Socfin Indonesia; it is located in Asahan, North Sumatera, Indonesia. The estate regroups two locations: Aek Loba area with 8824.64 ha (99°32'56.41"-99°43'15.75" East and 2°35'27.89"-2°39'58.52" North) and Padang Pulo area with 1208.41 ha (99°26'57.93"-99°30'7.43" East and 2°36'53.96"-2°40'25.832" North). It is operated by two units namely Aek Loba commercial plantation and Aek Loba Seed Production.

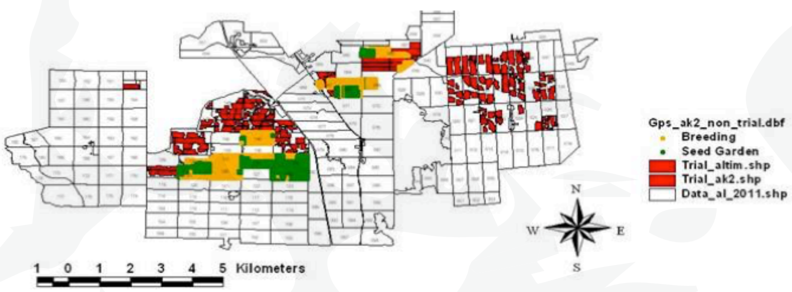
The commercial plantation is divided into eight field divisions and has one palm oil mill. It is administrated by one manager supported by two chief assistants, eight field assistants, one head of factory and six technical assistants and supported by 1500 workers. In 2015, it produced 54.912.89 t of CPO and 10.072.55 t of kernel.

The Aek Loba Seed Production unit (ALSP) is sub divided into two sections namely breeding and seed production. All of its fields are integrated to the Aek Loba commercial plantation areas. Two breeding projects are currently running: the Aek Loba Timur project and the Aek Kuasan II project. The Aek Loba Timur project regroups 342.3 ha of genetic trial, planted between 1995 and 2003, which tests 114 group A parents and 112 group B parents for a total of over 420 DxP/T crosses. The main origins tested were Deli Dabou and Deli Bangun Bandar as well as La Mé, Yangambi and NIFOR. It impacted on seed production since 2003.

The Aek Kuasan II project regroups 425.9 ha of genetic trial, planted between 2005 and 2013, which tests 149 new group A parents and 124 new group B parents for a total of 660 DxP/T crosses. The main origins tested are Deli Dabou, Deli Bangun Bandar, Deli Dami as well as La Me, Yangambi, Ekona, Yaligimba and Avros as well as recombination intra Group A and intra Group Bits impact on seed production should occur by 2020.

Aek Kuasan II project also consists in the setup of genetic gardens which consists of a collection of introductions of new origins, a seed garden and parental garden. The Collection area represents 59.76 ha with 688 families coming from Pamol, Brabanta, Sierra Leone, Yaligimba, Cameroon and Angola: the latter are prospection of Indonesian/Malaysian joint research teams. The Parental Garden group A area represents 84.03 ha with 168 family, Parental Garden group B area represents 98.04 ha with 605 family, Seed Garden group A area represents 115.43 ha with 406 family and Seed Garden B area represents 52.25 ha with 290 family.

Aek Loba Seed Production also have several facilities such as a seed production office, a seed processing unit, a bunch and oil analysis laboratory, a pollen preparation laboratory and a pollinator office. Aek Loba Seed Production is run by one manager supported by two assistants and 177 workers. It started to produce oil palm seeds in 2008, and until know its potential of production can reach 50 million seeds per year.



Map of genetic material in Aek Loba Plantation.

ASD BAKRIE

Director:
Mr Atok Herdrayanto

www.asd-bakrie.com

ASD-Bakrie Indonesia Oil Palm Seed (ASD-Bakrie) develop new high quality planting materials which is adapted to local microclimate. With its home base in Kisaran, North Sumatera, ASD-Bakrie helps business to find, develop and manage the process to produce high quality yield oil palm seeds to helps their client' businesses more profitable.

Formed in 2008, PT ASD-Bakrie Indonesia Oil Palm Seed has been set forth to expand their production quantity until 20 million seeds per year. ASD-Bakrie is now principally engaged in research, plant breeding, seed production and processing, sales and marketing of oil palm seed. ASD-Bakrie promotes greater financial return and opportunity among partners by enabling them to understand, manage and protect their oil palm plantation.

The cultivation of oil palm in America is linked to the history of the United Fruit Company, which introduced and spread this species throughout tropical America in the early 20th century. Thus the breeding program in ASD oil palm in Costa Rica, which now has more than 40 years of existence, during which has been formed and enriched a diverse genebank *Elaeis guineensis* and *E. oleifera*. As a result, it has a great capacity to innovate and create new varieties, adaptable to many environments and can meet particular needs. Efforts to improve oil palm in ASD have focused on three areas: i) development of *E. guineensis* varieties, ii) selection of *oleifera* palms for the production of interspecific hybrids and iii) the development of composite materials or mixtures gene of *E. guineensis* and *E. oleifera*.

The fruits of this program have been consolidating over 10 varieties 'guineensis', with which they have planted more than 1.7 million hectares in major palm regions around the world. Besides this, the program has created its exclusive varieties and clones of high density, characterised by slow growth and short leaves trunk. In addition, ASD has offered to market new varieties tolerant to adverse weather conditions such as low temperatures and water deficit. Part of this effort also led to create a novel hybrid OxG (Amazon), which has agronomic characteristics and tolerance to rots the upper whorl other hybrids available on the market.

CLOSING REMARKS by

DR N RAJANAIDU

Vice President of International Society for Oil Palm Breeders (ISOPB)

Dear Colleagues,

This international seminar on oil palm breeding seed production and field visits was organised by ISOPB, IOPRI and MPOB. These three organisations provided considerable assistance in terms of human resources, time and materials to make this seminar a success. We express our appreciation to Socfindo and Bakrie for permission to visit their field trials and for their hospitality. We thank Orion Biosains for their Gold sponsorship.

We had field visits on the 29 September 2016 and the seminar today on 30 September 2016. We deliberated eight papers on oil palm breeding and seed production and a paper on precision agriculture using oil palm genome information by Orion Biosains emphasising the use of DNA-based technology to oil palm breeding. The rest of the papers covered conventional oil palm breeding and seed production.

ASD Costa Rica programme emphasized the use of both *Elaeis guineensis* and *Oleifera* germplasm to develop compact planting materials which are amenable to high density planting. To date, ASD has marketed 30 million seeds of compact variety. Their breeding programme emphasizes higher oil yield, tolerance to diseases and slow dehiscence and high olein content.

IOPRI is one of the major oil palm seed producers in Indonesia. It collaborated with CIRAD at the early stages and utilised RRS Breeding Scheme to produce high yielding planting material. IOPRI's main selection criteria are high oil yield, *Ganoderma* tolerance, OG hybrids, acquisition of new germplasm and the application of molecular markers in their breeding programmes.

Socfindo too uses RRS Scheme to identify best parental combinations to produce high FFB, OER, low height and canopy growth. The programme also emphasizes breeding for disease resistance for *Ganoderma*, *Fusarium*, and bud rot. Socfindo /CIRAD collaborate closely in the field of oil palm breeding, tissue culture and molecular marker assisted selection.

AAR programme is known for oil palm clonal propagation and large scale planting of clones in the field. The commercial DxP seed production is based on the use of d*ura* clones/*dura* selfs as mother palms. AAR *pisifera*s are derived from Dumpy Yangambi x Dumpy AVROS crosses.

MPOB has outlined Serdang Avenue and Elmina Deli *dura* and AVROS improvement programmes. The progeny tests are based on NCM1 mating design and the results are documented. MPOB has the largest oil palm germplasm collection in the world (*E. guineensis* and *E. oleifera*). It has developed PS 1.1 planting material using the MPOB Nigerian population 12. PS 1.1 is known for high oil yield and dwarfness.

Asian Agri breeding programme utilises extensive Deli *dura* and *pisifera* populations. They have Chemara, Banting, MARDI, SOCFIN, ASD Deli *dura*s and *pisifera*s population of AVROS BM119 and Dami, Ekona, Calabar, Yangambi and La Me. AA has one of the largest DxP progeny test trial which has been used to estimate GCA and SCA values for the *dura* and *pisifera* parents.

Felda Global Ventures (FGV) is one of the largest oil palm seed producers in Malaysia. They have extensive oil palm breeding programme involving *guineensis*, *oleifera* and interspecific backcrosses. FGV is known to produce DxP planting materials based on 3-way crosses where hybrid *dura*s are crossed to Yangambi *pisifera* (ML161).

ISOPB wish to thank members of organising committees in Malaysia and Indonesia for their time and effort. We look forward to meet in Malaysia for the next ISOPB seminar which will be held in Kuala Lumpur in 2017 coinciding with MPOB International Palm Oil Congress (PIPOC).

Thank you.

NOTES

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SureSawit *SHELL* - precisely determine the *tenera, dura,* and *pisifera* fruit form of a seedling, nursery palm or field planted palm.

SureSawit *VIR* (available 2017) - enables early differentiation of *virescens* from *nigrescens* fruits, allowing selection for desired future fruit color.

SureSawit *KARMA* (available 2016) - predicts potential abnormalities of somoclonal variants that could lead to the mantled fruit form.

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Unit E-6-3A, 4th Floor, Block E, SetiaWalk, Persian Wawasan, Pusat Bandar Puchong, 47160 Puchong, Selangor
Tel: 03 5879 1711, Fax: 03 5879 1712 www.orionbiosains.com

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