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ASD's oil palm breeding program and its contributions to the oil palm industry

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Abstract

The genetic improvement of the oil palm in tropical America is closely linked to the history and activities of the United Fruit Company, which introduced this species in Central America and several countries in South America in the thirties. The encouraging results from the first commercial plantations in Central America motivated continuous efforts to exchange germplasm with some prestigious breeding programs in Southeast Asia and Africa. Several *dura* and *tenera/pisifera* populations were introduced to Costa Rica starting in 1970. Later, a sample of *dura* populations, AVROS and Ekona pollen and some DxP progenies of the compact population were taken to Honduras. This germplasm now forms the base of the breeding and seed production programs in Central America.

ASD's oil palm breeding program has been focused on three main areas, i) developing of *E. guineensis* varieties, ii) selection of *oleifera* palms to produce interspecific (OxG) hybrids, and iii) the development of compound planting materials by mixing *E. guineensis* and *E. oleifera* genes, better known as compact varieties. This work, initiated four decades ago, has allowed the development of more than ten commercial seed varieties, now occupying about 1.2 million hectares planted in more than 30 countries in America, Asia and Africa.

One of ASD's main achievements has been the commercial consolidation of high density planting materials, compact clones and seed varieties, which offer a unique opportunity to increase oil productivity per hectare. Another important achievement has been the development of stress tolerant seed varieties, such as cold, water deficit and spear rot tolerant materials that allow a little more advancement of the agroecological frontier of the crop.

Background

Ample genetic diversity has been the main strength of ASD's Costa Rica breeding program. The history of this program is closely linked to the diversification efforts of the former United Fruit Company, which in 1926 founded the Lancetilla Experimental Station near Tela on the Atlantic coast of Honduras. Several new tropical crops were introduced to this facility, including the oil palm (starting in the thirties), to study its performance in the America tropics. Seeds of this species were brought in from diverse localities in Southeast Asia and Africa to start the first commercial plantations in the region, mainly in Honduras and Costa Rica.

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New plantations soon followed and toward the end of 1970 there were approximately 12,000 ha planted on the Pacific coast of Costa Rica and 4,000 ha in the Atlantic region of Honduras. The planting material used until 1966 was mainly open pollinated *Dura* Deli seeds coming from Lancetilla, but some seeds were also imported from overseas. From that year on, the open pollinated material was gradually substituted by a mixture of *dura* Deli x Congo *tenera* obtained at the San Alejo plantation near Lancetilla (Richardson 1995).

Following the needs of the expanding crop, several plots were planted to start selecting for superior *dura Deli* palms in order to produce seeds locally. The pollen sources used in Honduras were *teneras* derived from DxP crosses, where both parents were of Yaligimba, Zaire origin. These *teneras* were selected based on yield and bunch characteristics, but its vegetative growth was excessive (Richardson 1995).

Breeding at ASD Costa Rica

Oil palm breeding at ASD has been based at the Coto locality on the South Pacific coast of Costa Rica. The region has a typical tropical climate with diurnal average temperatures between 22 and 35°C, annual rainfall around 4,000 mm, and rather low solar radiation (<360 cal/cm²/day; with the ideal being >400 calories). Soils are of alluvial origin with good natural fertility. All these conditions favor vegetative growth and the stem of traditional varieties may grow up to 70 cm/year with leaves reaching 7-8.5 meters in length. Nevertheless, these conditions are also good for oil palm breeding, since unwanted characters (vegetative or bunch) cannot be masked, which is particularly important when selecting for varieties that can be planted at high densities (short stem and leaves).

Possibly the main strength of ASD's breeding program is its ample collection of *E. guineensis* and *E. oleifera* germplasm. The *oleifera* collection originated from introductions done during the 60s and 70s, from Honduras, Nicaragua, Costa Rica, Panama, Colombia, Suriname and Brazil (Escobar 1981). Nearly 40 localities were prospected collecting more than 350 accessions, some of which were evaluated in OxG progeny trials in 1978 (Sterling et al. 1999). This collection was complemented with the introduction in 2003 of four sources of germplasm from the Taisha area in Ecuador (Table 1). Most of this collection is now planted at Coto.

Table 1. *E. oleifera* germplasm planted at Coto,
Costa Rica (1970-2004)

Origin	*Localities*	*Number of accessions*
Honduras	3	43
Nicaragua	6	43
Costa Rica	7	107
Panamá	12	88
Colombia	5	41
Surinam	3	13
Brazil	7	31
Ecuador	1	4
Total	***44***	***370***

During the 70s, ASD obtained important genetically advanced *guineensis* germplasm by exchanging some *E. oleifera* accessions for *E. guineensis* materials coming from some renowned breeding stations in Africa and Asia: i) *duras* Deli from the Chemara, Harrison & Crosfield, Banting, SOCFIN and MARDI (now MPOB) stations in Malaysia, and Dami, Papua New Guinea; and ii) AVROS *pisifera* from Harrison & Crosfield (Malaysia), Ekona from Unilever (Cameroon); Ghana and Nigeria from the Kade station (Ghana) and the NIFOR station, and La Mé and Yangambi coming from the former IRHO (Ivory Coast). Later, new wild germplasm was introduced from the highlands in Bamenda (Cameroon) and Tanzania, and from several regions in the Ivory Coast, Uganda, Zambia and Malawi (Richardson 1995, Escobar et al.1996, Sterling and Alvarado 2002; Table 2).

Table 2. *E. guineensis* germplasm at the breeding experimental station in Coto, Costa Rica (1970 1996)

Original population	***Accessions***	***Number of palms***
dura Deli (illegitimate)	10	607
dura Deli BPRO	23	2,392
Angola	6	444
dura/tenera (wild)	42	1,594
AVROS	12	1,005
Ekona	14	813
La Mé	5	382
NIFOR	17	1,297
URT	2	189
Yangambi	9	587
Composite	17	1,235
Total	**157**	**10,545**

Initially, the breeding work was concentrated on i) the evaluation of the Malaysia progenies in order to select the best sources of *dura* Deli for seed production, and ii) the performance of OxG progenies to evaluate the *E. oleifera* collection. This work allowed the production of Deli x AVROS seeds in Costa Rica, which were used locally and later exported until the 90s.

Dura *Deli* population

The *duras* Deli have been the palms chosen by most breeding programs in the world to produce commercial seeds. These palms are characterized for having a thick mesocarp, large bunches and high oil content in the bunch. Its main weakness is a rather narrow genetic makeup, since it is normally accepted that they all originate from only four palms (Rosenquist 1985). Due to this fact, the magnitude of the response to selection is low. On the other hand, if we accept that the hereditability of most important characters in oil palm is additive, then it is expected that the major genetic contribution for the development of new varieties will come from the pollen sources (*pisiferas* or *teneras*), but not from the *dura* Deli mother palms.

The breeding of the *dura* Deli palms in Costa Rica can be divided into four cycles or periods, during which the original populations were evaluated and reproduced, and new combinations between different populations were assayed (Table 3).

Table 3. Number of trials, lines and *dura* Deli palms planted at Coto, Costa Rica

Cycle	*Year*	*Trials*	*Lines*	*Palms*	*Origin*[1]
1	1968 to 1980	12	54	4,151	BM, CHE, DM, MAR, SOC
2	1985 to 1992	12	72	5,075	BM, CHE, DM, SOC, BM x CHE, CHE x MAR, CHE x DM, DM x SOC
3	1996 to 2003	10	235	8,917	BM, CHE, DM, MAR, SOC, BM x CHE, CHE x MAR, CHE x DM, DM x MAR
4	2008	12	107	8,061	BM, CHE, DM, MAR, SOC, BM x CHE, CHE x MAR, CHE x DM, DM x MAR
Total		*46*	*468*	*26,204*	

[1] *BM = Banting, CHE = Chemara, DM = Dami, MAR = Mardi, SOC = SOCFIN*

First cycle (1970 to 1980): this period comprises the introduction and consolidation of the so-called original populations obtained from Malaysia and Papua New Guinea, which were previously improved at the original breeding stations. The work was focused on the phenotypic evaluation and selection of superior lines and palms from Banting and Chemara. Based on this first selection, a F_1 population was developed combining the best palms within each original population to establish the first progeny test.

Second cycle (1981 to 1995): during this period, new palms from the original populations were selected; some of them based on the results of the progeny tests. At the same time, phenotypic selection was carried out on the F_1 population. Later, new *dura* Deli F_1 and F_2 populations were established and the second series of progeny tests were planted, where palms of Banting, Chemara, Dami and MARDI were evaluated.

Third cycle (1996 a 2003): the phenotypic evaluations and progeny tests from the two previous cycles permitted the establishment of a new cycle of evaluation of *dura* Deli F_1 and F_2 palms. Most of the families used came from *selfings* meant to stabilize the different *dura* Deli lines. At the same time, 225 lines from several populations were planted in Indonesia to follow their phenotypic behavior and the performance of their progenies (Breure 2002, 2006).

Fourth cycle (2004 to 2009): contains the evaluation of the behavior of all the *dura* Deli families, based on their phenotype and the results of the progeny tests established in Indonesia. A fourth selection cycle was initiated by planting the *selfings* of *duras* that included 89 superior palms, which will be evaluated again in progeny trials in Indonesia.

Breure (2006) compared the phenotypic performance of four of ASD's *dura* Deli populations planted in Sumatra, Indonesia in 1996. Stems were shorter in the Dami derivatives and the Dami and Mardi populations were less vigorous (lower leaf area per palm). In additions, bunch yield was similar in the four groups, but oil to bunch was superior in the Chemara and MARDI origins (Table 4).

Table 4. Characteristics of four *dura* Deli populations planted in Indonesia

Population	Lines	FFB (kg)	M/F (%)	O/M (%)	O/B (%)	SH (cm)	LA (m^2)
Dami	45	97	62.7	46.0	19.5	256	6.41
Chemara	24	97	63.3	51.0	21.5	286	6.75
H & Crosfield	8	95	64.6	47.7	20.4	289	6.84
Mardi	5	92	63.3	52.2	22.9	277	6.40
Average*	90	96	63.0	48.0	20.3	269	6.55
CV (%)		10.2	3.6	6.7	8.3	13.0	7.6

* *The general mean includes all dura Deli origins, Breure (2006). FFB = fresh fruit bunches/palm/year; M/F= mesocarp to fruit; O/M = oil to mesocarp; O/B = oil to bunch; SH = stem height at 5 years; LA = leaf area at 5 years; VC = variation coefficient*

The *dura* Deli palms introduced from Asia were selected in Costa Rica based on bunch oil content, which was effectively achieved through four selection cycles in several populations. The best response was obtained on the second filial generation (F_2) in the Banting population, where a 3.7% oil increase was achieved. On the Chemara and Socfin populations, the increments were lower (2.4% and 2.6% respectively). No response was obtained in the Dami and Mardi populations on the F_1, but it is possible that this will change in the F_2. On the other hand, when the Chemara and Banting populations were combined, bunch oil content did not change, which implies a high degree of genetic purity in both populations (Table 5).

Considering the narrow genetic base of the *dura* Deli populations, it can be argued that not much improvement can be obtained in terms of oil content. However, it is still possible that some progress can be achieved by combining the best palms with African *duras* from other origins like Tanzania, Bamenda and Angola.

Table 5. Bunch oil content and selection gain obtained in several *dura* Deli generations compared with the original populations. Coto, Costa Rica

Population	Lines	Palms	Oil/bunch (%)	Selection gain (%)
Chemara	**6**	**354**	**20.4**	
F_1	33	1,026	21.7	1.3
F_2	63	1,264	22.8	2.4
F_1 x F_2	4	63	19.2	
Banting	**3**	**175**	**18.1**	
F_1	35	475	19.5	1.4
F_2	12	215	21.8	3.7
Dami	**20**	**1,621**	**20.6**	
F_1	116	2,387	20.4	
Mardi	**1**	**59**	**23.7**	
F_1	11	302	23.1	
Socfin	**3**	**146**	**19.4**	
F_1	13	356	22.4	3.0
F_2	1	8	22.0	2.6
Chemara x Banting				
F_1	17	524	20.1	
F_2	11	140	20.8	

More than 7,000 *dura* Deli palms were planted in 2008 in order to select new mothers. The palms that originated this population (fourth cycle) were selected due to their high oil/bunch content (Table 6). The progenies of a group of 89 superior palms are particularly important due to their high oil quality. It is expected that the new generation of *dura* Deli mother palms will have a mean oil content not less than 25.2%, which implies an increase on the average of 4.6%, which is superior to that found in the original populations and the three previous selection cycles (Tables 5 and 6).

African *duras*

Some *dura* and *tenera* wild populations (Table 2) with oil content similar to *duras* Deli can be used as mother palms, and in new combinations. These populations have also shown stress tolerance, particularly to water deficit and low temperatures. In progeny tests, most descendants of Bamenda, Tanzania and Angola mother palms have shown excellent yields (FFB), oil/bunch content and reduced vegetative growth (Alvarado and Sterling 2004; Table 7). Tanzania progenies are particularly outstanding in terms of oil to mesocarp and kernel to bunch (Bulgarelli and Sterling 2000).

Table 6. Oil/bunch in superior *dura* Deli palms selected for planting in 2008 and the original populations

Population	Selected palms	Selection 2008	Oil/bunch (%) original population	Difference
Chemara	39	26.1	20.4	5.7
Banting	2	25.6	18.1	7.5
Dami	18	24.4	20.6	3.8
Mardi	8	25.8	23.7	2.1
Socfin	3	24.3	19.4	4.9
Chemara x Banting	4	23.8	19.2	4.6
Chemara x Dami	3	26.3	20.5	5.8
Chemara x Mardi	7	25.8	22.0	3.8
Dami x Mardi	5	25.1	22.0	3.1
Average (89 palms)		***25.2***	***20.7***	***4.6***

Some descendants of the African *duras* have also shown tolerance to spear rot (Chinchilla et al. 2006). Several of these wild *duras* were collected in the highlands of the countries of origin (800-1,200 masl), and they have behaved quite well in similar conditions in Ethiopia and other East African countries (Richardson and Chaves 1986, Blaak and Sterling 1996, Alvarado and Sterling 2004). At the moment, 21 families of the Bamenda F_2, Tanzania F_2 and Angola F_1origins are being evaluated in order to produce a new generation of mother palms. The intense phenotypic selection will allow improvement of the characteristics of these populations, particularly those of Tanzania origin (high yields of FFB and oil to bunch) (Table 8).

Pollen sources

Pisifera palms are used as pollen sources in DxP crosses in oil palm breeding programs since these palms do not usually produce normal fruits. *Pisiferas* derived from the AVROS population have normally been used to produce the Deli x AVROS variety in Malaysia and Indonesia. This same variety was also sold by ASD starting in 1975.

Table 7. Characteristics of several DxP progenies using African *duras* as mother palms. Coto, Costa Rica, planting in 1994

Female	Male	FFB (kg)	SH (cm)	LL (cm)	M/F (%)	O/M (%)	O/B (%)
Deli	AVROS	167	244	730	69.9	51.3	24.8
Bamenda	Ekona	153	150	642	72.9	47.8	24.1
Tanzania	Ekona	155	175	664	73.4	51.4	22.8
Angola	Ekona	173	204	665	71.2	48.0	21.8
Average		**160**	**176**	**657**	**72.5**	**49.1**	**22.9**
Bamenda	Ghana	131	156	626	61.0	42.7	18.0
Tanzania	Ghana	170	172	662	65.2	49.5	23.2
Angola	Ghana	176	201	691	65.4	52.5	25.3
Average		**159**	**176**	**660**	**63.9**	**48.2**	**22.2**

Female = mother palm; Male = pollen source, SH = stem height at six years, LL= leaf length at six years; M/F = mesocarp to fruit; O/M = oil to mesocarp; O/B = oil to bunch

The superior characteristics of this variety were documented by Corley (2003). Results in Costa Rica showed that the AVROS source was superior to derivatives of Ulu Remis *teneras*, another popular *pisifera* population in Malaysia (Richardson 1995). These *pisiferas* transmit to their progenies good yield characteristics, but also vigorous vegetative growth, which makes the Deli x AVROS variety not suitable for many environments. Mainly in tropical America, this old variety is being gradually substituted by others with a less vigorous growth.

Apart from the Deli x AVROS variety, some breeding stations also developed others like Deli x Ghana in Kade, Ghana; Deli x Ekona, produced by Unilever, Cameroon, and Deli x La Mé (IRHO, Ivory Coast) (Sterling and Alvarado 2002). All these materials were evaluated in Costa Rica where the advantages of the Ghana (shorter leaves) and Ekona (high oil content) varieties were noted (Sterling and Alvarado 1995).

TxP[2] trials using second and third generation varieties of Ghana, Ekona and new pollen sources were established in Costa Rica and Indonesia (Table 9). Four lines were superior to the AVROS pollen source and the Ghana population stood out for its high oil content in the bunch (31.2 %). The derivatives of the Dami composite, Ekona and Nigeria had shorter stems at six years of age (141, 147 and 130 cm respectively) (Breure 2006).

[2] *Ténera* by *pisifera* crosses that generate 50% *pisiferas* (pollen sources)

Table 8. Yield and growth characteristics of several African *duras*

Population	Year planted	Lines	Palms	FFB (kg)	SH (cm)	LL (cm)	M/F (%)	O/M (%)	O/B (%)
Bamenda									
Original population	1968	9	219	nd	nd	nd	40.5	44.3	12.5
F_1 population	1994	12	93	104.6	59	474	42.8	41.8	12.3
F_1 selected	1994	4	8	124.5	62	509	44.4	47.7	14.6
F_2 population	2006	8	1,618						
Tanzania									
Original population	1978	4	96	nd	nd	nd	55.7	50.1	20.2
F_1 population	1994	11	251	177.1	68	522	53.3	49.6	18.5
F_1 selected	1994	4	6	181.8	67	521	58.6	55.7	23.9
F_2 population	2006	8	1,053	nd	nd	nd	nd	nd	nd
Angola									
Original population	1981	1	60	nd	nd	nd	59.5	47.4	17.0
Selected	1981	6	6	82.1	nd	nd	59.3	47.3	17.3
F_1 population	2004	5	350	77.7	nd	nd	55.2	46.3	18.4

nd = data not available; FFB = fresh fruit bunches; SH = stem height at four years, LL = leaf length at four years; M/F = mesocarp to fruit; O/M = oil to mesocarp; O/B = oil to bunch

The commercial DxP derivatives with Nigeria *pisiferas* showed excellent fruit yield, high oil content and reduced height in the progeny trial in Indonesia. The Ghana pollen sources transmitted high oil content and short leaves, and the composite Dami *pisiferas* transmitted high oil content and reduced vegetative growth (Breure 2002 and 2006) (Table 10). Based on these results, ASD now favors commercial seed production using Ghana and Nigeria pollen sources.

Richardson and Alvarado (2003) noted the good bunch and oil yields of the Nigeria population introduced to Costa Rica. The Ghana and Nigeria progenitors come from seeds collected in several regions of Nigeria. Descendants of the so-called 851 and 853 populations selected at the Kade research station in Ghana were introduced to Costa Rica around 1980. The Ghana population, named GHA648 in Costa Rica, originated in Calabar. The original Nigeria line GHA608 has broader genetic variability since it has genes from three different populations: Calabar, Ufuma and Aba (Fig. 1).

Table 9. Characteristics of five TxP lines evaluated in Indonesia as potential pollen sources

Origin	**Lines**	**FFB (kg)**	**M/F (%)**	**O/M (%)**	**O/B (%)**	**S/H (%)**	**LA (m²)**
AVROS	3	67	86.3	47.5	22.5	184	6.80
Dami composite	5	90	83.2	53.2	27.4	141	5.67
Ekona	5	91	81.2	55.9	25.6	147	7.34
Ghana	4	86	85.4	55.1	31.2	204	6.08
Nigeria	3	89	85.1	54.5	26.2	130	6.59
Media	***20***	***86***	***83.9***	***53.6***	***26.8***	***160***	***6.48***
CV (%)		11.0	3.0	3.1	3.0	28.0	12.4

FFB = fresh fruit bunches; M/F = mesocarp to fruit; O/M = oil to mesocarp; O/B = oil to bunch; SH = stem height at six years of age, LA = leaf area at six years of age (Breure 2006)

Some Nigeria descendants segregate *virescens* fruits and this characteristic is associated with precocity. ASD is now selecting *pisifera* palms whose descendants are high yielders with 100% *virescens* bunches. *Dura* x *tenera* (DxT) crosses are done to fix the *virescens* character and to evaluate the yield potential of the selected *virescens teneras*.

Table 10. Characteristics of seven pollen sources (*pisiferas*) at the progeny tests in Indonesia

Origin	Lines	FFB (kg)	M/F (%)	O/M (%)	O/B (%)	Oil (kg/p/y)	S/H (%)	RL (cm)	LA (m²)
AVROS	15	117	81.5	49.1	26.4	30.9	152	381	5.19
Yangambi	4	121	75.8	53.3	27.3	32.9	145	380	4.94
La Mé	1	116	76.4	50.5	25.5	29.6	131	390	4.79
Dami Composite	5	118	79.7	49.6	26.2	31.1	124	358	4.57
Ekona	10	121	77.9	51.6	26.1	31.8	130	382	5.05
Ghana	9	119	78.8	51.0	27.2	32.4	147	375	4.89
Nigeria	6	127	80.0	51.6	26.9	34.2	136	379	5.32
Mean	50	120	79.4	50.7	26.6	31.9	141	377	5.04
CV (%)		4.5	3.1	3.2	3.1	5.4	10.5	3.4	6.3

M/F=mesocarp to fruit; O/M=oil to mesocarp; O/B=oil to bunch; kg/p/y= oil/palm/year, SH=stem height, 6 years, RL=rachis length, 6 years, LA=leaf area at six years

The evaluation of the DxT progenies will allow determination of the potential of the commercial *tenera* segregates, and at the same time will verify the purity of the parents with respect to the *virescens* character (homozygous or heterozygous). *Selfing* of a homozygous *tenera-virescens*, high yielding palm will permit the acquisition of *pisifera* palms to eventually produce a 100% *virescens* variety. Results from the progeny test planted in 2005 show that fruit yield in the two families of the best *tenera virescens* palms was superior to the test variety, Deli x AVROS, indicating that it is possible to develop high yielding 100% *virescens* DxP varieties (Table 11).

Table 11. Characteristics of the Deli x Nigeria *virescens* progenies. Coto, Costa Rica (*tenera s*egregates in the DxT lines)

Cross	Lines	FFB (kg)	M/F (%)	O/M (%)	O/B (%)	O/ha (t)
Deli x Nigeria DxT	12	146.7	82.5	43.9	27.2	5.8
Deli x Nigeria (best) DxT	2	167.3	82.9	48.5	30.0	7.2
Deli x AVROS		121.9	86.0	47.0	29.9	5.2

FFB = fresh fruit bunches; M/F = mesocarp to fruit; O/M = oil to mesocarp; O/B = oil to bunch; O/ha = oil per ha

OxG hybrids (*E. oleifera* x *E. guineensis*)

The rich *E. oleifera* collection started in 1970 (Escobar 1981) called the attention of many oil palm breeders in Asia and Africa who wanted to include this species in their breeding programs in order to improve oil quality, stem growth and disease tolerance. By exchanging this germplasm, ASD obtained highly valuable already improved *guineensis* materials. Besides this, and based on extensive field data, ASD also initiated the production of OxG hybrids using as pollen sources the composite compact and the Ghana populations (Escobar and Alvarado 2004, Alvarado et al. 2007).

The renewed interest on the OxG hybrids has come from their tolerance to spear rots in tropical America. ASD tested several OxG crosses of diverse origin in an area on the Atlantic coast of Panama, where spear rots where known to occur. The tolerance of these materials was expressed as fewer palms with symptoms (0.2 %) and fewer palms dead (3.8%: deaths probably associated with spear rot attacks). The Deli x AVROS variety had an incidence of 2% and 11.1 % were dead at the moment of the evaluation when palms were eight years old. A sample of the *oleifera* population showed no diseased palms, indicating that the resistance genes came from the *oleifera* mother palms (Table 12); Chinchilla et al. 2006).

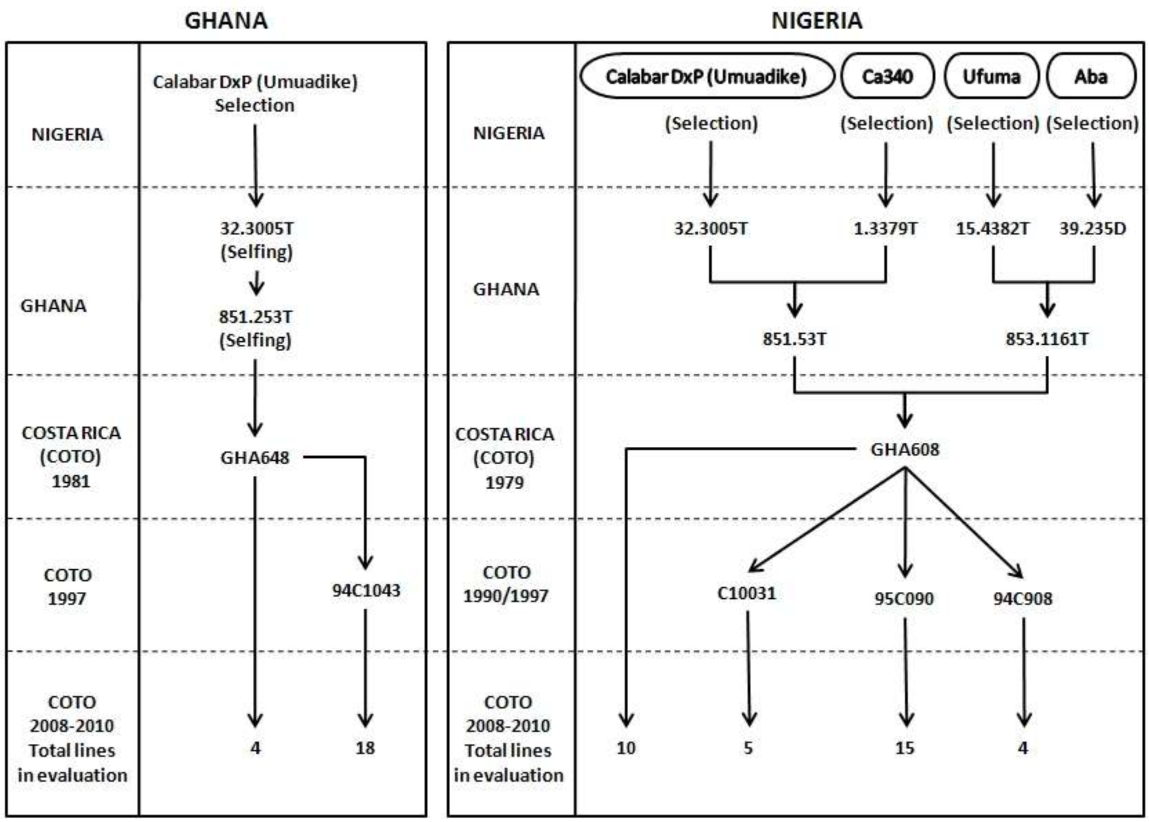

Fig. 1. Genealogy of the Ghana and Nigeria populations introduced to Costa Rica

The results of the progeny tests (1978-1998) and observation plots, plus the tolerance to spear rot motivated ASD to produce OxG commercial seeds of two of such hybrids starting in 2007. The first of these hybrids called Amazon (ASD Costa Rica 2007) is derived from seeds of *E. oleifera* palms originally collected in Manaos, Brazil, and selected for their high oil content. These palms were crossed with *pisiferas* compacts. The other hybrid, called Brunca, is the result of the cross of *E. oleifera* from Costa Rica, Panama and Colombia (selected for its high bunch yield) with Ghana pollen.

Table 12. Incidence of spear rots in 8-years old palms of several origins (*E. oleifera* and *E. guineensis).* Changuinola (Panama**)**

Origin	Palms	CD/CSR	PC (%)	Dead palms
BC_1 F_1 compacts	781	3.1	0.1	9.9
OxG hybrids	869	1.2	0.2	3.6
E. oleifera	91	0	0	2.1
Deli x AVROS	451	15.7	2	11.1
Total	**2,197**	**4.8**	**0.5**	**7.3**

CD/CSR = crown disease/common spear rot; PC= spear rot (pudrición del cogollo)

The Amazon hybrid planted at Coto in 1993 has shown slow stem growth and leaves whose length is comparable to *guineensis* varieties, so it can be planted at the normal density of 143 palms/ha (Table 13). During anthesis, feminine inflorescences of this hybrid are at least 25% exposed (free of fibers), which facilitates natural pollination (fruit set is high with pollen coming from nearby *guineensis* commercial lots). Nevertheless, the male inflorescences of this hybrid only produce 5-10 grams of pollen, which is rather low when compared to *guineensis* (15-20 grams) and this fact could put some limits on natural pollination in large commercial plantations.

Table 13. Vegetative characteristics of the first generation OxG Amazon compact OxG hybrids at 14 years of age

Material	LL (cm)	PxS (cm^2)	SH (m)
Amazon	697	22.0	2.6
Deli x AVROS (*guineensis*)	704	26.7	6.9

LL = leaf length; PxS = petiole cross section; SH = stem height

The Amazon hybrid shows good yields of fresh fruit and oil (Table 14). It is expected that the new generation of Amazon will have an industrial oil extraction rate superior to 20%, which will be the result of using new *oleiferas* from Manaos and compact *pisiferas* that transmit genes for higher oil content. The *teneras* of the new compact population reach high oil bunch content (22-30%), which can be transmitted to the hybrid descendants through the sister *pisiferas*.

Table 14. Bunch composition and yield potential of the first generation OxG Amazon compact hybrid (n = 42 palms)

Material	FFB (kg)	BW (kg)	BN	FF/B (%)	PF/B (%)	F/B (%)	M/F (%)	O/M (%)	OER (%)	O/ha (t)
Amazon	227.5	18.5	12.3	42.2	15.5	57.7	67.0	44.9	15.7	5.1
Deli x AVROS	174.8	21.3	8.2	68.2	2.5	70.7	87.9	47.8	24.3	6.2

FFB = fresh fruit bunches; BW = bunch weight; BN = bunch number/palm/year; FF/B = fertile fruits/bunch; PF/B = parthenocarpic fruits with oil/bunch; F/B = total of fruits/ bunch; M/F = mesocarp to fruit; O/M = oil to mesocarp; OER = estimated industrial oil extraction rate, % oil to bunch x 0.87; O/ha = oil/ha (calculated with the OER).

The Brunca hybrid uses Ghana pollen. This variety was evaluated on plots in East Ecuador, where its behavior has been superior to other hybrids due to its good bunch conformation (fruit set) with no assisted pollination and no incidence of spear rot so far. Nearby *guineensis* plots may be supplying pollen for the hybrid, but there are tests in progress to determine compatibility and amount of pollen produced by the hybrid, so it can be predicted whether assisted pollination will be needed in large commercial lots.

There are good opportunities to even improve the OxG hybrids in terms of vegetative growth and oil production closing the gap between them and the *guineensis* varieties. Improving the *oleifera* mother palms depends on the existing genetic variability and making the appropriate combinations to concentrate the desired genes: less rachis in the bunch, <12%; higher fruit weight, >10 g; more mesocarp to fruit, >60% and higher oil to bunch, >12%.

Table 15 summarizes the bunch characteristics of ASD's *oleifera* palms. The Taisha and Manaos palms show higher fruit weights (9-11 g and 7- 11 g respectively). The Taisha population also shows good bunch composition (61-63 % fertile fruits), high mesocarp to fruit ratios (64%) and less rachis in the bunch. Oil to bunch is particularly high in the Manaos population (9-10%).

Table 15. Bunch characteristics in several *E. oleifera* populations

Origin	Palms	F (g)	FF/B (%)	F/B (%)	M/F (%)	O/MF (%)	O/B (%)
CR/Pam/Col F_1	364	3.1	46.0	64.2	43.9	17.4	5.8
CR/Pam/Col F_2	79	2.9	43.7	62.5	44.5	15.8	5.2
CR/Pam/Col F_2 Sel 08	18	2.9	46.1	63.4	45.6	19.5	6.7
Taisha (Ecuador)	146	8.9	61.0	67.0	64.3	11.8	5.2
Taisha sel 2008	8	11.0	63.1	67.4	64.4	13.7	5.9
Manaos	245	11.5	16.5	33.7	43.8	28.2	5.5
Manaos F_1	122	7.4	36.7	59.2	42.8	28.1	9.1
Manaos F_1 sel 2008	20	7.6	43.3	62.9	44.7	31.1	10.1
Surinam	9	2.4	64.8	65.4	51.4	12.1	4.0
Coari[1]	34		nd	nd	nd	20.5	nd
Cenipalma[2]	26		nd	54-59	30-55	26-43	1.4-13

[1] *Corredor, J. (Palmeiras S.A.), 2008, personal communication*

[2] *Rey, L. et al. 2004*

Composite population: CR = Costa Rica; Pan = Panama , Col = Colombia; F_1 and F_2 = filial generations; FF = fertile fruits in the bunch; F/B= total fruit in the bunch; M/F = mesocarp in the fertile fruit; O/MF = oil in mesocarp of fertile fruits; O/B= oil to bunch; nd = no data available. Bunch analysis done at 3-5 years on the populations CR/Pan/Col F_2, Taisha and Manaos; F_1 at 8-10 years for Manaos and 10-12 years in CR/Pan/Col F_1

The Taisha *oleiferas* were brought from Ecuador in 2003. Besides the characteristics mentioned above, the fruits are of the *virescens* type, but oil content in the mesocarp is relatively poor (Table 15).

Varieties for high density planting

The varieties for high density planting (compact) originated from a backcross program started more than 35 years ago using an exceptional OxG hybrid (Sterling et al. 1987). This program has given rise to varieties characterized by slow stem growth, short leaves and high oil content. Compact clones have also been produced using the best compact palms as *ortets* (Escobar and Alvarado 2004, Alvarado et al. 2007). Results from several experiments planted between 1978 and 1991 showed that growth characteristics of these compact palms are regulated by a reduced number of genes that are easily inherited: the compact character is fixed when combined with most *guineensis* materials.

Based on this knowledge, it was possible to stabilize growth and increase bunch oil content on the first generations of the compact palms: the second backcross BC_2, kept the average growth observed on the first backcross BC_1, and bunch oil content increased with respect to Deli x AVROS (26.2 vs. 25.6%) (Escobar and Alvarado 2004).

These characteristics were kept and improved in the recombinant generation of the second backcross BC_2F_1, where bunch oil reached 29.8% (27.4% for AVROS). However, on the third backcross (BC_3) vegetative growth was more vigorous due to a gene dilution effect from the recombination; which means that only two backcrossing cycles were enough to fix the compact character, whose frequency is higher in the subpopulations F_1 and F_2 (Escobar and Alvarado 2004; Table 16).

Table 16. Characteristics of several compact populations through three backcrosses (*tenera* segregates)

Type	Palms	FFB (%)	SH (cm)	LL (cm)	M/F (%)	O/MF (%)	O/B (%)	O/ha (t)
BC_1	567	114.1	43.0	497.0	78.1	43.5	21.1	3.4
AVROS DxP	48	147.5	79.0	570.0	80.5	44.8	23.0	4.8
BC_1F_1	530	129.0	79.0	416.0	78.3	42.6	22.5	4.2
BC_2	2,330	152.9	53.0	497.0	82.0	47.3	26.2	5.7
AVROS DxP	561	175.1	79.0	570.0	81.5	44.9	25.6	6.4
BC_1F_1	2,329	134.6	51.0	487.0	84.2	53.8	29.8	5.7
AVROS DxP	140	158.6	86.0	637.0	85.7	46.0	27.4	6.2
BC_3	1,088	167.0	92.0	583.0	81.0	49.9	27.7	6.6
AVROS DxP	32	180.2	113.0	682.0	85.4	45.7	25.9	6.7

BC = backcross; F = filial generation; FFB = kg/fresh bunches/palm/year; SH = stem height; LL= leaf length; M/F= mesocarp to fruit; O/M= oil to mesocarp; O/B = oil to bunch; O/ha = oil/ha/year

The BC_1F_2 population has short leaves and very good bunch oil content. Some progenies can generate varieties that can be planted at high densities (170 or more palms/ha) and 'supercompact' *ortets* (superior palms used for cloning) with the potential to be planted at 200 palms/ha. The descendants of the BC_2F_1 population are expected to have high oil content, since this was an important selection criterion (Table 17).

Table 17. Bunch characteristics of *dura* (D) and *tenera* (T) compact palms selected for the new generation planted in 2008

Population	Palms	M/F (%)	O/M (%)	O/B (%)
BC_1F_2 D	8	57.5	46.6	19.0
BC_1F_2 T	6	80.8	48.5	25.8
BC_2F_1 D	14	61.8	53.8	23.5
BC_2F_1T	8	86.5	53.7	30.8

BC = backcross; F = filial generation; M/F = mesocarp to fruit; O/M = oil to mesocarp;O/B = oil to bunch; O/ha = oil/ha/year

Compact clones

The ASD's cloning program started in 1980. During these 25 years, tissue culture technology, procedures to select superior palms (*ortets*) and *ramet* hardening techniques have been depurated (Escobar and Alvarado 2004, Alvarado et al. 2007). The first commercial plots were planted in 2002 aimed at selecting the most promising compact clones. Data from the first three years of commercial production in a sample of seven lots (250 ha) that include clones with different characteristics and behavior show that these have on average lower initial yields than seed varieties. Table 18 compares the performance of two clones with the Deli x Nigeria variety.

Table 18. Yield (tons of FFB) in several compact clones and the Deli x Nigeria seed variety. Coto and Palmar, Costa Rica (first three years)

Year	Mean of 12 clones	Best two clones	Deli x Nigeria
1	2.0	2.9	3.8
2	10.9	14.1	15.1
3	19.2	30.6	31.6
Total	32.1	47.6	50.5
OER	-	28.4%	24.2%
Oil/ha total	-	13.5t	12.2t

TEI= estimated oil extraction rate: % oil in bunch x 0.87

The added value of the compact clones is the possibility of planting them at much higher densities than standard commercial seed varieties. In a density trial planted in 2005, two clones (Tornado and Fran) outyielded the Deli x AVROS seed variety during the first years of production (Table 19). The compact character (shorter leaves and stems) gives a clear advantage to these clones, which seem to increase with age. Initially (palms under two years of age), the difference in leaf length with respect to the *guineensis* seed variety was 0.2-1.0 meter. For compact materials (seed varieties and clones) compared with the *guineensis* control at nine years of age, these differences were 1.5-2 meters and 2.5-3 meters respectively. Stem height increments with age behaved similarly: the difference in stem height between compact and *guineensis* materials in nine year old palms was larger than two meters.

Table 19. Yield and growth of two compact clones planted at different densities in 2005, Coto, Costa Rica

Clone	Density (plants/ha)	First year Yield (t/ha)	Leaf length (36 months, cm)
Tornado	205	12.4	394
Tornado	235	16.3	397
Average		14.4	395
Fran	180	17.0	460
Fran	205	19.7	456
Average		18.3	458
Deli x AVROS	143	9.0	480

Commercial seed production and productivity of ASD planting materials

The selection criteria for *dura* Deli mother palms in ASD are based on DxP progeny test results, where lines with high general combining ability are chosen. Selection of individual palms is based on high heritable bunch characteristics, such as mesocarp to fruit, oil to mesocarp and oil to bunch ratios, and is complemented with data on bunch yield and growth (stem height and leaf length). SIRIM standards (Sharma 2006) are used for reference. ASD uses more than 4,000 superior *dura* Deli mother palms from the third selection cycle. Oil yield potential for all these palms is superior to SIRIM standards (Table 20).

The Tanzania (*guineensis*) mother palms and the composite compact origin surpass the SIRIM standards, but the Bamenda origin has lower mesocarp to fruit, oil to dry mesocarp and oil to bunch ratios. This population is stress tolerant (cold and some diseases), but is still going through the first selection cycle, so much progress is expected due to its ample genetic variation.

The *oleifera* mother palms have bunch characteristics below SIRIM standards in terms of oil production, which is normal for this species when compared with *guineensis*; however, fresh bunch yield is higher than those standards SIRIM (Table 20).

Table 20. Characteristics of the different populations of mother palms used by ASD in its commercial seed producing program (2009)

Variable	*Deli*	Tanza-nia	Bamenda	Compact	*Oleifera* Brazil	*Oleifera* Central America	SIRIM
FFB	168	180	176	190	240	220	>150
B	24.0	25.7	25.2	27.2	34.3	31.5	
M/F	65.5	54.3	41.0	59.2	42.7	44.5	>55
O/M	44.2	52.3	43.2	54.2	28.2	18.5	
O/MD	77.0	79.5	72.4	81.3	48.8	40.4	>75
O/B	20.8	19.9	12.2	23.2	9.1	6.2	>18
O/ha	5.0	5.1	3.1	6.3	3.1	1.9	
Evaluation (years)	4	5	5	3	1	1	
Mother palms	4,000	70	20	450	120	150	

B = bunch weight, kg; FFB = fresh fruit bunches, kg/palm/year ; M/F= mesocarp to fruit, %; O/M= oil to mesocarp, %; O/Dm = oil to dry mesocarp, %; O/B= oil to bunch, %; O/ha = oil,/t/ha

Between 1986 and 2008, ASD commercialized more than 213 million seeds around the world, representing about 1.2 million hectares. The high demand for ASD seed has been supported by the results obtained in progeny trials and in commercial plantations. Deli x AVROS and Deli x Ekona were the main varieties sold before 2001; but in recent years, other varieties such as Deli x Ghana, Deli x Nigeria and the those for high density planting (Compacts) have taken the lead (Table 21).

Data from the Oil World report (2009) shows Costa Rica is very well positioned in terms of productivity when compared with three other major palm oil producing countries in tropical America. These data tell much about the yield potential of ASD's planting materials since all plantations in Costa Rica were established with these varieties (Table 22).

Table 21. Area planted with ASD's oil palm varieties during the period 1986 to 2008

Variety	America	Asia	Africa	Hectares (thousands) Total
Deli x AVROS	160.6	280.9	0.3	441.8
Deli x Ghana	130.0	119.3	6.0	255.2
Deli x Nigeria	63.6	190.5	2.7	256.8
Deli x Ekona	70.2	47.1	0.7	118.0
Deli x La Mé	58.9	39.6	1.5	100.0
Deli x Yangambi	13.9	9.2	0.7	23.8
Compacts	34.9	14.0	0.0	48.9
Tanzania x Ekona	1.9	1.3	1.5	4.7
Bamenda x Ekona	0.8	0.5	0.7	2.0
Evolution	0.8	1.0	0.0	1.8
Others*	0.6	0.6	0.4	1.6
Total	536.2	704.1	14.4	1,254.6

*Bamenda x AVROS and Tanzania x AVROS

Improvement in productivity of ASD varieties can also be seen on the historical yield curves of one of the plantations in Costa Rica (Fig. 2) where the genetic composition of the planting materials have been changing and can be divided into three periods. Yield improvement in these lots was due to better agronomical practices, but also to the effect of parental selection. The following are the three groups of palms with clearly different yields records (Fig. 2):

Lots planted before 1985: 5,800 ha including DxT (*dura x tenera*) varieties planted before 1977 and the Deli x AVROS variety of first introduction and first F_1 selection

Lots planted between 1985 and 1994 (3,200 ha) that include a high proportion of Deli x AVROS palm descendants of the first two F_1 selections. Other materials are the Deli x Ekona and Deli x Calabar varieties (this last one was a mixture of the new Deli x Ghana and Deli x Nigeria varieties).

Lots planted after 1995 (4,700 ha), that include the new Deli x Ghana and Deli x Nigeria varieties. The mother palms that originated these lots came from the best *dura* Deli planted after 1990.

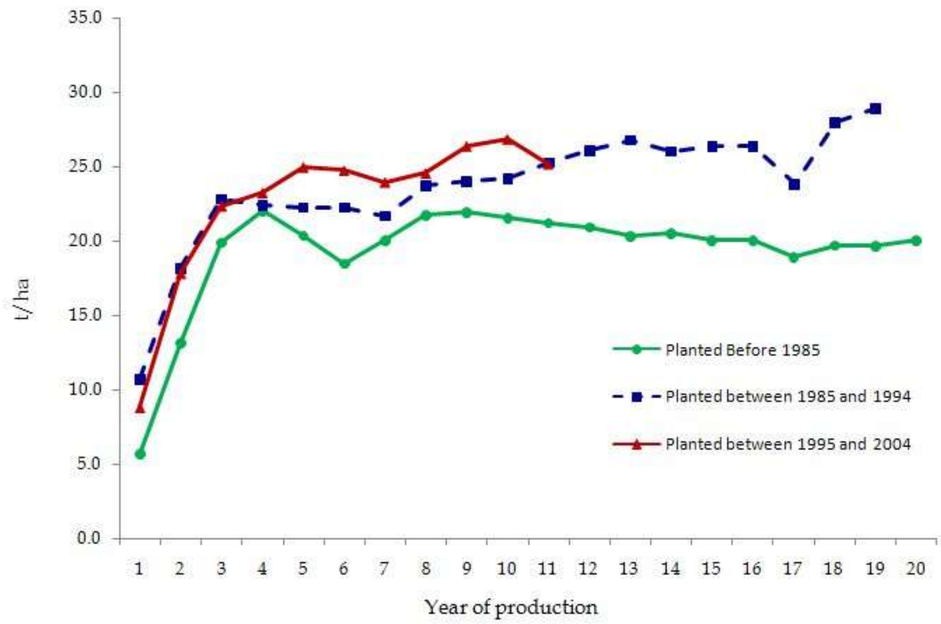

Fig. 2. Yield improvement (fresh fruit bunches) associated with the use of new varieties. Coto, Costa Rica**.**

Table 22. Area planted and annual crude oil annual yield on the main oil palm producing countries in tropical America during the years 2006 to 2008)

Country	Hectares (thousands)	Oil (thousands of tons)	t/ha
Colombia	311	742	3.7
Ecuador	223	388	1.9
Honduras	94	222	2.9
Costa rica	55	197	4.2

Source: Oil World 2009; t/ha = tons of oil/ha/year

It has been evident that the initial behavior of the new Ghana and Nigeria varieties has been better than the previous AVROS and Calabar generations in the planting done between 1995 and 2004 (Fig. 3).

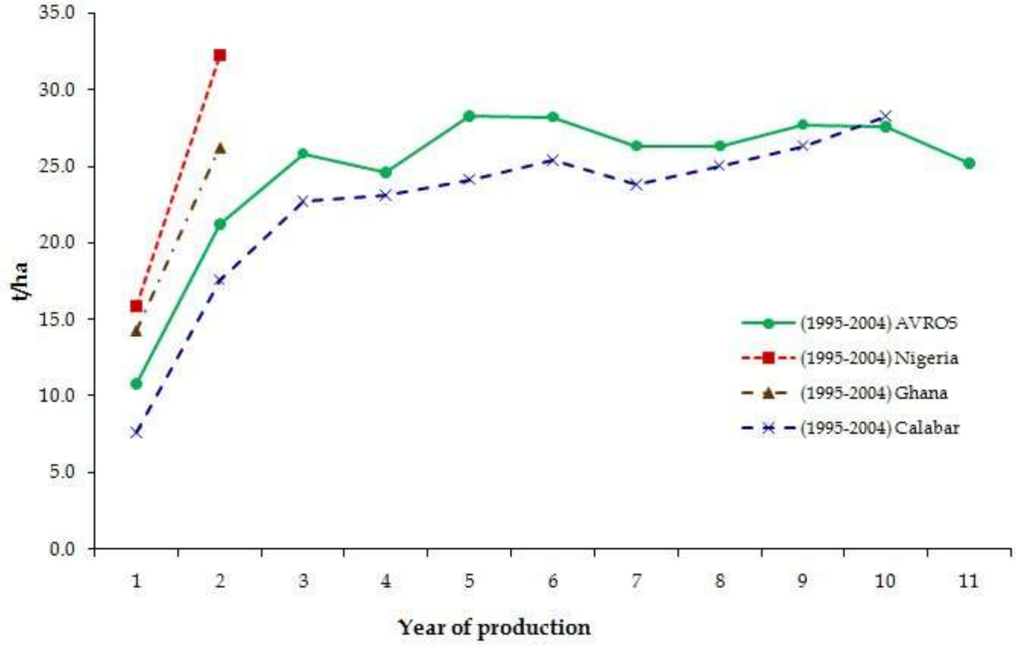

Fig. 3. Yield (fresh fruit bunches) changes in commercial lots planted with different varieties. Different planting years.

Conclusions

ASD Costa Rica has been doing oil palm breeding for more than 40 years now, during which the ample genetic resources gathered have allowed the development of many innovative planting materials. Selection of superior palms within the *dura* Deli and african *duras* populations, and the evaluation of diverse pollen sources have originated more than ten commercial varieties. The new varieties for high density planting (compacts) are particularly outstanding in terms of oil production and reduced vegetative growth that permit an optimum use of available land. The new compact clones developed from the best compact palms keep the promise of a real revolution of the whole oil palm industry in the future.

Novel planting materials such as 100% *virescens* and stress tolerant varieties will give new impulse to the industry by facilitating harvesting or opening of new lands for planting. The new OxG hybrids that retain some of the best characteristics of both *guineensis* (i.e. oil yield) and *oleifera* (i.e. oil quality and disease tolerance) are also finding their way within the industry.

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