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Compact Seeds and Clones and their Potential for High Density Planting

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Abstract

The possibility of using segregants from several compact backcross populations for the development of high-density seed varieties and clones is now a reality; recent results from various trials planted in 1998 confirmed that the compact character of slow stem growth and short leaves has been successfully fixed in several segregant populations. However, the highest average reduction of yearly trunk increment was found in the second backcross generation (43 cm/year vs. 65 cm/year of the *'guineensis'* DxP tester). Besides this, the reduction in leaf length was also outstanding (574 cm vs. 730 cm of the *'guineensis'* DxP tester).

Comparisons between backcross cycles showed that the successive concentration of the most desirable *'guineensis'* genes at the expense of the dilution of the *'oleifera'* genes made the compact character less evident: nearly half of the value of the character was lost in the third backcross cycle when compared with the *'guineensis'* DxP tester (trunk increment reduction of 22 cm/year attained in the second cycle vs. only 11 cm/year difference during the third cycle). The same tendency was observed with leaf length; the compact palms of the second cycle showed an average reduction of 156 cm as compared to 80 cm in palms of the third backcross cycle. These results indicate that probably only two backcross cycles can be practiced when combining *'oleifera'* and *'guineensis'* genes looking for special characters such as slow trunk growth and shorter leaves for high density planting. Initial field performance with semi-commercial plots indicates that early high yields can be successfully combined with the compact character.

Introduction

The compact trait concept refers to special palms of any genetic origin showing slow trunk growth with short leaves. The latter characteristic is determinant for high density planting, since shorter leaves will allow planting more palms per hectare while maintaining the same leaf overlap (interplant competition); this possibility will certainly result in a real production increase due to more palms per area at the same level of productivity per palm obtained at the standard density of 143 palms per hectare. However, palm breeders are always seeking to concentrate high yielding genes; thus, potential productivity per palm is also an important factor for even higher yields when combined with high-density planting.

Breeding for reduced trunk growth and shorter leaves continues to be a priority aimed at prolonging the economic life span of commercial plantations and increasing the planting density. Apart from the materials derived from the slow-growing *'Dumpy'* palm discovered by Jagoe

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(1952), individual palms from the population named PS1 originated from *'guineensis'* wild germplasm collected in Nigeria in 1975-76, showed outstanding characteristics such as 11 to 20% more bunch oil content than conventional varieties. The yield potential of the best PS1 were between 7.4 and 9.7 tons of oil per ha, and crosses of the so-called *'Population 12'* were up to 45% smaller with 11% shorter leaves than the control, allowing the possibility for high-density planting at 170 palms/ha (Rajanaidu et al., 1999).

However, Sharma (1999) described the PS1 palms as having a high number of small bunches with small fruits, and some selfings showed reduced trunk height: 1.30 to 1.36 m compared with 1.75 to 2.06 m for the control, but its fresh fruit bunch (FFB) production was rather low, probably due to inbreeding depression. The same author suggested incorporating genes into PS1 materials from other advanced breeding populations to improve some of PS1 deficiencies.

Sterling, et al. (1987) reported on the phenotypic characteristics of an exceptional segregant from an OxG hybrid open-pollinated with *guineensis*, known as the original compact palm (OCP). More recently Escobar and Alvarado (2004) indicated that populations derived from three successive backcross cycles of the OCP showed consistently slow trunk growth and short leaves. This paper summarizes the latest results of a series of trials planted in 1998 as part of the compact breeding program by ASD de Costa Rica, S. A., aimed at consolidating the production of seed varieties and clones for high-density planting.

Materials and methods

Trials in Costa Rica

A series of field trials were planted in 1998 in Coto, Costa Rica, as part of the second backcross cycle (BC_2) of the compact breeding program by ASD de Costa Rica, S. A., described in detail by Escobar and Alvarado (2004). This paper focuses on the results of the recombination of selected BC_2 compact palms that were intercrossed to generate an F_1generation known as BC_2F_1.

Five trials were planted in June 1998, using a randomized block design with four replications and 12 palms per plot, to evaluate 23 F_1 compact progenies of the second backcross cycle (BC_2F_1) and 17 progenies of the third backcross cycle (BC_3). Two *'guineensis'* DxP varieties, Deli x AVROS and Deli x Ekona, were used in each experiment as controls (5 progenies and 240 palms of each variety). All trials were planted at 160 palms per hectare and the yield and growth data from all trials were pooled for statistic analysis. Parameter averages were used for comparisons between compact populations and the DxP tester (Table 1).

Fresh fruit bunch yields were recorded during the first four years of harvesting in all trials described in table 1. Trunk height increments were estimated from two successive height measurements to frond number 41, at 53 (3 years and 5 months) and 68 months (5 years and 8 months) after planting, and leaf lengths (petiole + rachis) were measured at 68 months (5 years and 8 months) after the date of planting.

Table 1. Number of compact progenies evaluated in five experiments planted in 1998, Coto, Costa Rica

Trial code	BC_2F_1		BC_3	
	Progenies	Palms	Progenies	Palms
98.1A	10	480	1	48
98.1B	10	480	1	48
98.1C	1	48	4	192
98.1D	1	48	8	384
98.1E	1	48	3	144
Total	23	1,104	17	816
Deli x AVROS	5	240		
Deli x Ekona	5	240		

BC = backcross

An average of 35 bunches were analyzed to characterize progeny during the first 4-7 years of age, according to the method described by Blaak et al. (1963) and revised by Rao et al. (1983).

The mean annual rainfall in Coto, Costa Rica, is 4,070 mm, with higher records in La Niña years. In this location there are only two months with rainfall below 100 mm and hence the water deficit is very mild or nil. Mean monthly temperatures are within a suitable range for oil palm (minimum 20-22 °C and maximum 31-34 °C), but sunlight is rather low for 4 to 6 months (<15 Mj/m^2). The soils in the Coto region are deep; fine loams, moderately to poorly drained alluvial soils (Aeric Endoaquepts and Fluvaquentic Eutrudepts). The percent of base saturation is high and dominated by calcium inherited from the parent material. Despite medium levels of potassium in these soils, its availability to plants is low due to very high calcium and magnesium contents. In spite of limiting factors such as poor soil drainage and some nutritional deficiencies and imbalances, the high humidity and low sunlight in Coto favor vigorous oil palm growth.

Trial in Ecuador

A semi-commercial trial was planted in January 2003, near Quininde in Esmeraldas province in the Pacific zone of Ecuador, to evaluate five compact BC_2 crosses and one BC_2 F_1 cross at 160 palms per hectare and 70 palms per plot with two replications (140 palms per compact variety). Three *'guineensis'* conventional DxP varieties (Deli x AVROS, Deli x La Mé and Deli x Ghana) were planted in the experiment as controls at 143 palms per ha (156 palms of each variety), to compare yield and growth with the compact crosses. Fresh fruit bunch yield (FFB) was recorded every fortnight during the first two production years. Leaf length (rachis plus petiole) was recorded at 42 months after field planting date (in 36 palms per/plot).

In normal years, mean annual rainfall in the area is 3,200 mm, but its distribution is quite poor as rainfall is less than 100 mm for 4 to 6 months. The average annual water deficit for normal years is estimated at 200 mm, but it may go up to 350 mm in particular years. In El Niño years, total annual rainfall increases to 5,600 mm and the water deficit is normally nil. In normal years, the mean monthly minimum temperature drops below 19° C at night in the dry season (August to November). During that time a heavy cloud cover is also common in the region that reduces sunlight levels significantly (<1,000 hours per year), and FFB yields are therefore diminished.

The soils in the region of Quininde are mostly deep, medium-textured, well-structured and well drained volcanic soils (Typic Haplustands). However, soil fertility is moderate to poor in spite of the relatively high organic matter content and, phosphorus availability is very low due to high P fixation by the allophone, the proportion of which is high in the clay fraction. Some potassium fixation may also occur in these soils.

Besides the above limitations, it is important to note that *Sagalassa valida* is a widespread soil-borne pest in the Pacific region of Ecuador, whose larvae can cause serious damage to the palm root system and reduce yields severely.

Results and discussion

The main objective of the compact breeding program is to develop high-density varieties, trying to get at least the same productivity per plant of fresh fruit bunches (FFB) than conventional *'guineensis'* varieties from various origins. However, the high oil content values frequently observed in compact palm bunches provides an opportunity to increase oil yield output per hectare as well.

Nevertheless, the discussion of the results of this paper will focus mainly on two vegetative parameters: trunk increment in cm/year and leaf length (petiole + rachis). The authors consider the latter as fundamental in seeking high density planting. Theoretically reducing leaf length by one meter will allow increasing density to 170 palms per hectare, and two meters reduction would allow up to 200 or more palms per hectare. Certainly, there are several other considerations to take into account when discussing the subject of high density planting, such as leaf area, leaf area index, canopy development, light interception and photosynthesis rate; although these aspects are not dealt with this paper on compact palms, considerable research is being carried out on the agronomy, physiology and growth of compact seed varieties and clones and will be reported in future papers.

Backcrossing cycles

Escobar and Alvarado (2004), reported on the gradual improvement of yield and bunch characteristics of compact populations through backcrossing, but at the expense of the gradual dilution of genes of the original compact palm (OCP). It was clearly demonstrated that the third back cross cycle (BC_3) gave the best recombinants in terms of fresh bunches (FFB) and oil yield, but its trunk growth was higher and its leaves were not as short as the BC_2 palms.

Recombination of selected BC_2 palms gave origin to the BC_2F_1 population, which showed outstanding compact characteristics when compared with the BC_3 generation. In the latter population, nearly half of the desired compact trait was lost (Table 1). The average trunk increment difference between the BC_2F_1 generation and the DxP tester was 22 cm per year and almost double the difference observed in the BC_3 population, both results were significant ($P<0.05$). On the other hand, the leaf length difference of the BC_2F_1 palms with the control was 156 cm; this difference was again significant ($P<0.05$) and nearly two times the difference found in the comparison of the BC_3 population with the DxP tester (Table 2).

Table 2. Comparison between the second and third backcross compact populations

Population	Proge-nies	Palms	FFB	BN	BW	O/ha	Ti	Ti dif.	LL	LL dif.
BC_2F_1	23	1,104	117.3	17.9	6.6	5.4	43	(22)	574	(156)
BC_3	17	816	134.6	18.3	7.6	6.6	54	(11)	650	(80)
DxP Tester	10	480	129.3	14.3	9.1	5.7	65		730	
LSD $_{(P<0.05)}$			23.4	3	0.3	1.5	6		32	

BC = backcross cycle; FFB = fresh fruit bunch production in kg/palm/year; BN = bunch number/palm/year; BW = bunch weight in kg; O/ha = oil production in tons/ha/year; Ti = trunk increment in cm/year; Ti dif. = trunk increment difference with the DxP tester in cm. LL = leaf length in cm; LL dif. = leaf length difference with the DxP tester in cm.

Although the BC_2F_1 and BC_3 FFB/palm /year production averages were not statistically different from the DxP tester average, there was a tendency of the BC_3 compact palms to yield more FFB than the BC_2F_1 palms and the DxP tester in most of the yield parameters, except that bunches were smaller than the control: bunch weight 7.6 kg vs. 9.1 kg (Table 2).

These results suggest that seed production could focus on the reproduction of BC_3 progenies despite losing almost half of the compact trait. However, differences between BC_3 crosses, derived by crossing selected BC_2 palms with tested *'guineensis'* from different origins, prove that the compact trait can be substantially recovered (Table 3). For instance, a good option could be using selected Deli *dura* crossed with the best compact BC_2F_1 *pisiferas*, since this type of cross out-yielded the DxP tester (6.3 vs. 5.7 tons oil/ha/year) and had the shortest leaves of all the BC_3 progenies tested: 93 cm difference with the control. This leaf length difference of 12.7% with the DxP tester indicates that a Deli x Compact cross can be planted at 170 palms/ha as pointed out by Rajanaidu et al. (1999).

The possibility of using elite compact BC_2F_1 palms showing very short leaves can lead to increasing planting density per hectare even more. That is the case of progenies derived from pisiferas 150P, 212P and 73P, which showed no significant differences in oil yield with the control, but significant leaf length differences, ranging from 141 to 168 cm, with significant slow trunk increments (Table 4).

Table 3. Yield and vegetative differences between compact progenies of the third back cross cycle (BC_3)

BC_3 Cross Type	Proge-nies	Palms	FFB	BN	BW	O/ha	Ti	Ti dif.	LL	LL dif.
Compact x AVROS	3	144	134.9	18.4	7.4	6.6	56	(9)	657	(73)
Deli x Compact	8	384	122.7	14.5	8.6	6.3	59	(6)	637	(93)
Compact x Ekona	4	192	158.8	24.0	6.6	7.5	47	(19)	664	(67)
Compact x La Me	2	96	127.6	20.8	6.2	6.1	46	(19)	658	(72)
BC_3 Population	17	816	134.6	18.3	7.6	6.6	54	(11)	650	(80)
DxP Tester	10	480	129.3	14.3	9.1	5.7	65		730	
LSD $_{(P<0.05)}$			23.4	3	0.3	1.5	6		32	

BC = backcross cycle; FFB = fresh fruit bunch production in kg/palm/year; BN = bunch number/palm/year; BW = bunch weight in kg; O/ha = oil production in tons/ha/year; Ti = trunk increment in cm/year; Ti dif. = trunk increment difference with the DxP tester in cm. LL = leaf length in cm; LL dif. = leaf length difference with the DxP tester in cm.

Compact *ortet* selection

Cloning elite compact BC_2F_1 *tenera* palms is without a doubt the most efficient way of reproducing the compact trait when seeking high density planting. Phenotypic characteristics of recently selected top compact *tenera* palms are shown in table 5. All palms showed significant and outstanding FFB/palm/year production, with bunches that were smaller but more numerous than those of the DxP tester. In terms of oil to bunch (O/B) these compact palms had higher levels, particularly palm 645T with 38.4% O/B.

In seeking high density planting using clones, the compact *ortets* listed in table 5 have outstanding short leaves compared with the DxP tester; their leaf length difference ranged from 173 to 242 cm. Escobar and Alvarado (2004) indicated that the leaf length (cm) correlation between *ortets* and their respective clones was significant (r^2=0.791, $P<0.05$), thus, the probability of reproducing the short leaves of the *ortets* listed in table 5 is high. With a clone derived from palm 698T (Table 5) with leaves 242 cm shorter than the leaves of the DxP tester, planting at 200 or more palms per ha would be now a reality.

The first commercial plantings with ASD compact clones were carried out in Costa Rica, Nicaragua and Venezuela in 2003. Since then, a total of 996 hectares have been planted in seven countries in Latin America, with most of this area in Costa Rica (66.1%).

Although commercial yield records are not yet available because the palms are still too young, some interesting data on the leaf length of a particular commercial clone in Costa Rica show how the compact trait becomes evident even during the early stage of the plantations (Table 6).

Table 4. Second backcross cycle (BC_2) progeny test results - compact *pisifera* selection

Male	Proge-nies	Palms	FFB	BN	BW	O/ha	Ti	Ti dif.	LL	LL dif.
C9235:404P	3	144	109.4	17.2	6.4	4.4	34	(31)	536	(194)
C9269:119P	5	240	107.9	18.5	5.8	5.1	38	(27)	557	(173)
PTC9001:150P*	4	192	127.9	20.4	6.3	6.1	44	(21)	574	(156)
C9232:232P	5	240	116.6	16.4	7.1	5.2	49	(16)	593	(137)
C9236:75P	4	192	127.1	17.8	7.2	6.1	48	(17)	603	(127)
C9269:212P	1	48	134.8	20.3	6.7	6.1	36	(29)	589	(141)
C9269:73P	1	48	137.1	20.5	6.7	6.6	45	(20)	563	(168)
BC_2F_1 Population	23	1,104	117.3	17.9	6.6	5.4	43	(22)	574	(156)
DxP Tester	10	480	129.3	14.3	9.1	5.7	65		730	
LSD $_{(P<0.05)}$			23.4	3	0.3	1.5	6		32	

* Clonal pisifera, BC = backcross cycle; FFB = fresh fruit bunch production in kg/palm/year; BN = bunch number/palm/year; BW = bunch weight in kg; O/ha = oil production in tons/ha/year; Ti = trunk increment in cm/year; Ti dif. = trunk increment difference with the DxP tester in cm. LL = leaf length in cm; LL dif. = leaf length difference with the DxP tester in cm.

The difference in leaf length between the commercial clone Sergio and the DxP variety was already 133 cm after 24 months from the date of field planting, and increased to 171 cm when the palms were 38 months old. Based on this result, a difference 1.8 to 2.0 m in leaf length is expected by the time the palms will reach their maximum vegetative growth (6-8 years from planting). With this large a difference and considering the same leaf overlap as with normal DxP varieties in commercial plantations, this particular clone could well be planted at 273 palms/ha.

Table 5. Superior second backcross cycle compact *tenera* segregants selected for cloning

Cross	Palm	FFB	BN	BW	O/B	Ti	Ti dif.	LL	LL dif.
C95-15922	645T	198.3	28.3	7.0	38.4	50	15	557	173
C96-2270	632T	188.8	27.2	6.9	34.7	31	34	549	181
C95-15921	324T	173.9	30.4	5.7	34.1	35	31	552	178
C96-2270	698T	196.4	26.1	7.5	28.3	30	36	488	242
BC_2F_1 Population		117.3	17.9	6.6	28.7	43	(22)	574	(156)
DxP Tester		129.3	14.3	9.1	27.5	65		730	
LSD $_{(P<0.05)}$		23.4	3	0.3	1.5	6		32	

BC = backcross cycle; FFB = fresh fruit bunch production in kg/palm/year; BN = bunch number/palm/year; BW = bunch weight in kg; O/B = oil to bunch (%); Ti = trunk increment in cm/year; Ti dif. = trunk increment difference with the DxP tester in cm. LL = leaf length in cm; LL dif. = leaf length difference with the DxP tester in cm.

Early performance of campact seed varieties

The main objective of any breeding program is to raise the productivity of oil per palm and per hectare, but high-density planting promises a production increase due to the possibility of planting more palms with the same productivity obtained at the standard density of 143 palms per hectare.

Table 6. Leaf length difference between a BC_1 clone and DxP variety in 2003 commercial plantings in Costa Rica

	Leaf length (cm) /age after planting			
	At 24 months	LL dif.	At 38 months	LL dif.
Clone Sergio	259	-133	377	-171
DxP variety	392		548	

LL dif. = leaf length difference with the DxP variety.

Early results from a small planting of compact varieties in Ecuador are showing specifically the advantage of planting high-density varieties at 160 palms per hectare (Table 7). The average FFB production per hectare observed during the first two years of harvesting this trial compared with other yield averages from other producing regions in the world is not relevant for the purpose of this paper, but to the discussion of increased production due to high-density planting.

Table 7. Yield and growth characteristics of BC_2F_1 crosses in Las Maravillas, Ecuador, planted in 2003

Cross	Type	Density (palms/ha)	FFB (t/ha/year)	FFB dif.	FFB (kg/palm/yr)	BN	BW	LL	LL dif.
Comp x Comp	BC_2F_1	160	9.7	-17%	60.6	17	3.7	432	-85
Comp x Ghana	BC_2	160	14.4	23%	90.0	18	5.1	429	-88
Comp x AVROS	BC_2	160	12.6	7%	78.4	15	5.4	442	-75
Comp x Ekona	BC_2	160	11.7	-1%	72.8	20	3.6	481	-36
Deli x Comp 1	BC_2	160	13.9	18%	86.6	22	3.9	446	-71
Deli x Comp 2	BC_2	160	12.6	7%	78.4	19	4.1	498	-19
Control	DxP	143	11.8		82.2	17	4.7	517	

BC = backcross cycle; FFB = fresh fruit bunch production in kg/palm/year; BN = bunch number/palm/year; BW = bunch weight in kg; LL = leaf length in cm; LL dif. = leaf length difference with the DxP tester in cm.
Comp = Compact

At a density of 160 palms/ha the expected production increase shall be at least 12% more than with the conventional density of 143 palms per hectare. Not all compact varieties achieved this level; in particular, the pure compact BC_2F_1 variety produced even less (-17%) compared with the DxP control, but this type of cross is not commercially produced at present, as discussed in previous sections. The rest of BC_2 varieties out-yielded the DxP control with the exception of the Compact x Ekona cross, which yielded slightly less than the control (-1%).

Two crosses were outstanding: Compact x Ghana and Deli x Compact 1, producing 23% and 18% more than the control respectively; these varieties exceeded the expected 12% production increase due to high-density planting. On the other hand, the varieties Compact x AVROS and Deli x Compact 2 showed only a 7% yield increase over the control DxP. These differences between crosses are related to the specific combining ability of the parental palms, and are an indication that certain compact crosses will not be commercial if the yield expectation is not achieved, despite having short leaves. Finally, it is interesting to point out that the average leaf lengths of the best crosses Compact x Ghana and Deli x Compact 1 were 71 to 88 cm shorter than the DxP control, and their FFB productivity per palm was very similar to the control DxP *'guineensis'*, hence, their yield superiorities were indeed due to the high density.

Conclusions

1. The compact trait: slow trunk growth and short leaves, as initially conceived when the original compact palm (OCP) was selected in 1970, is less evident after the second cycle of backcrossing to selected *guineensis* palms of different origins.
2. The selection of compact palms for seed production shall concentrate in populations F1, F_2, F_3, … resulting from the recombination of elite palms of the second backcross cycle (BC_2), because of their reduced annual trunk increments and short leaves.
3. An alternative to produce high-density compact seed varieties shall result from selected BC_2F_1 mother palms crossed to proven *'guineensis' pisiferas*, which indeed correspond to a third backcrossing cycle (BC_3) type of palms. Another possibility is to cross selected Dura palms with pollen from Compact palms. These Compact seed varieties shall be planted at 160-170 palms per hectare.
4. Cloning by tissue culture offers an opportunity to mass reproduce elite compact *tenera* palms, allowing an increase in planting density to 200 or more palms per hectare.

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