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Performance of ASD's oil palm parent material in South Sumatra
The search for elite planting material for Indonesia

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Abstract

A selection program involving oil palm material obtained from ASD (in Costa Rica) is currently being carried out in PT Selapan Jaya's seed garden (in South Sumatra). The program aims to select *dura* female and *pisifera* male parents for generating high-grade *tenera* planting material. Phenotypic values of selection traits are obtained from a set of 90 lines out of a group of 225 *dura* lines (Experiment 1) and from a set of 20 families out of a group of 50 *tenera* x *pisifera* (TxP) families (Experiment 2).

Experiment 3 consists of 425 test cross families, involving all 225 *dura* and all 50 *pisifera* parent palms. Data from the latter experiment provide estimates of the General Combining Ability (GCA) values of the parents of the *dura* lines (Experiment 1) and of the *pisifera* parents of the T×P-families (Experiment 2). The 225 *dura* palms, all of the Deli type, were derived from the main breeding stations in Southeast Asia. The origins of the 50 *pisifera* palms are referred to as AVROS (two generations), Yangambi, La Mé, Dami composite, Ekona, Ghana and Nigeria. Besides data for the conventional target traits, namely bunch yield and oil content, records include auxiliary traits which are associated with light interception (leaf area and crown disease incidence) or with the proportion of photosynthetic vegetative parts of the palms (leaf area/leaf weight ratio, frond dry matter production and palm height). For measuring the height of young palms, a novel technique has been developed that is described in this report.

The phenotypic values of the *dura* lines (Experiment 1) as well as the GCA-values of the parents (Experiment 3) varied considerably. Provided that the heritability is high, such variation offers ample scope for the selection of dura lines as a source of seed palms. Substantial variations were also found among the T×P-families (Experiment 2) and, in particular, among the GCA-values of *pisifera* palms from the six main origins (Experiment 3). Little selection progress was obtained with the second-generation AVROS *pisifera*. The *pisifera* palms of Nigeria origin were superior in terms of oil yield. Interestingly, the two best (elites) from this origin have short stem height, along with other auxiliary traits associated with high harvest index. The report concludes with a detailed account of a new method followed in the selection of *pisifera* parents in particular.

Key words. Elite palms, GCA-values, oil palm, origins, phenotypic values, selection traits, single palm selection

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Introduction

In oil palm, selection of *dura* seed parents and *pisifera* pollen parents should first aim for the main target traits as expressed in their *tenera* offspring, namely bunch yield and oil content in the fruit. Moreover, it makes sense to consider characters that are indirectly associated with (high) oil yield per ha. These are termed auxiliary traits which can be classified into two categories:

(i) traits related to gross CO_2 assimilation and thus to dry matter production

(ii) traits related to the proportion of dry matter incorporated in the economic product (harvest index).

The amount of gross CO_2 assimilation by a palm depends on the size of the light-intercepting leaf surface, i.e. the product of the number of green leaves on the palm and the average area of these leaves. As gross CO_2 assimilation attains its maximum when the canopy is closed, rapid canopy closure is a primary breeding objective. The rate of canopy expansion as well as the final size of the leaf surface can be derived from the logistic growth curve fitted through the area of the youngest leaf as a function of palm age after planting (Breure, 1985). When studying young palms, only the mean of the available leaf area values (as a measure of the extent of light interception) can be considered.

Evidently, optimal light interception requires a low incidence or even absence of crown disease. This common disorder appears as a bending of the newly opened leaves. Its incidence becomes manifest during the period until canopy closure. In this period, the rate of gross CO_2 assimilation strongly depends on the expansion of the light-intercepting crown leaves (Breure, 2003). As a consequence, crown disease is detrimental for dry matter production and, hence, early yield (Breure and Soebagyo, 1991). Various papers reported that the sole method for improvement is to breed for resistance to the disorder (Blaak, 1970; De Berchoux and Gascon, 1963; Breure and Soebagyo, 1991; Sterling and Alvarado, 1996).

Conventionally, a higher harvest index, i.e. the proportion of total dry matter used for the economic product (here oil yield), has been achieved by improving the performance for the target traits (here bunch yield and oil content). Currently, some selection programs also focus on diminishing the production of vegetative dry matter (VDM). In passing it is noted that, since reducing VDM production per se may negatively affect the leaf area and thus photosynthesizing capacity, the reduction of VDM production must be restricted to non-photosynthetic vegetative parts. In terms of standard growth measurements (Corley and Breure, 1982), selection should aim at a high leaf area/leaf weight ratio along with a low leaf dry matter production (LDM) as well as a slow height increment (Breure, 2003). Additional advantages of slow (vertical) stem growth are reduction of harvesting costs and extension of the economic live span of a planting.

When the palms in the selection program are young, unconventional recording methods are required to evaluate the following traits:

(i) palm height; (ii) VDM production.

With regard to palm height, the conventional reference point on the stem, i.e. the height of the base of a specified leaf in the spiral of the youngest fully-opened frond, measures the height of the growing point one to two years before the date of observation. Despite the reference point, this period depends on the rate of leaf production, which varies considerably among palms. This makes height records unreliable, particularly in young palms where vertical stem growth only starts about three years after field planting. Thus, in the present experiments a novel method to estimate the height of the growing point was used (see Materials and methods).

In oil palm the measurement of VDM production is confined to the above-ground vegetative parts, i.e. LDM and trunk dry matter (TDM). In the present report the production of LDM is considered, excluding TDM. The latter requires measuring trunk volume, for which trunk diameter and annual height increment should be observed. These two records were not available for the palms under study. LDM provides a slight, but relatively constant, underestimate of VDM. (N.B. The trunk represents only about 15% of the total above-ground vegetative dry matter).

The three experiments in this report are related to each other. Experiments 1 and 2 provide data of the sources of female and male parents, respectively. Experiment 3 provides data on the offspring from the parents of these parental sources. Experiment 1 consists of a set of 90 *dura* lines, which was the first sub-group planted from a total group of 225 lines. They originate from several, locally occurring families, all of the Deli type (for details, see Materials and methods). Experiment 2 consists of the first set of 20 *tenera* × *pisifera* families (say: T×P-families), from a group of 50 families, from distinct origins. Experiment 3 consists of 425 *dura* × *pisifera* families (D×P-families), resulting from crosses between the 225 *dura* and 50 *pisifera* palms from above.

Per experiment, data on the target traits and the auxiliary traits were obtained. Auxiliary traits are known to have moderate heritability, particularly those associated with the architecture of the palm, such as leaf area/leaf weight ratio. Among the target traits, bunch yield is especially known to have low heritability (Breure and Corley, 1983). Reasonably, line and family evaluation may be expected to benefit from extra information about their parents, as obtained from Experiment 3. Indeed, the data generated by these D×P-families offer the opportunity to estimate the general combining ability (GCA) values of the parents of the *dura* lines used in Experiment 1 and of the *pisifera* parents of the T×P-families used in Experiment 2. The statistical analysis of Experiment 3 also yields interaction effects of *dura* and *pisifera* parents. In a quantitative genetic context such effects are termed specific combining ability (SCA).

The main aim of the study is to report on the variation found in the selection traits among the phenotypic values of the *dura* lines (Experiment 1) and the T×P-families (Experiment 2), which are the sources of, respectively, the female and male parents of the palm material to be produced. Also of importance is the variation in the GCA-values of their parents. Based on both phenotypic values and GCA-values of the selection traits, the final objective is to identify the best (elite) sources of parent palms for seed production. The report concludes with an analysis of the most promising origin of *pisifera* male parents.

Materials and methods

The genetic material, derived from 225 *dura* and 50 *pisifera* palms, was introduced from ASD in Costa Rica. The 225*dura* parent palms were selfed; the 50 *pisifera* palms were cloned and used in T × P crosses. Due to poor germination of seed resulting from some crosses, 200 *dura* lines (out of 225 lines) and 36 T×P-families (out of 50 families) were planted. From test crosses involving all 225 *dura* and all 50 *pisifera* parents, 425 D×P-families were generated. Between 1996 and 1998, a total of 661 entries (200 + 36 + 425) were planted in South Sumatra, at a density of 135 palms/ha (for details, see Breure, 1998).

The 225 parents of the *dura* lines (i.e. selfings of ASD's *dura* palms) are all of the Deli type. They originate from several, locally occurring families that ASD obtained from the breeding programs of Dami (117 *dura* palms), Chemara (68), Harrisons & Crosfield (18), MARDI (7), Socfin (2), along with families due to crosses between palms in ASD's Harrisons & Crosfield (HC) and Chemara families (13).

The origins of the 50 *pisifera* pollen parents include 15 AVROS *pisifera* palms, namely ASD's first-generation (HC) as well as second-generation (C9212) palms (6 versus 9); and *pisifera* palms from Yangambi (4) and La Mé (1; note that one palm is not representative of the performance of the origin). Finally, other new origins for Indonesia are included, viz. Dami composite (5), Ekona (10) and two other entries, GHA 608 (6) and GHA 648 (9). The GHA entries were developed at the Nigerian Institute for Oil Palm Research (NIFOR) and introduced to Costa Rica from the Kade Oil Palm Research Centre in Ghana. GHA 648, being a selfing containing the female parent of GHA 608, is of Calabar origin, while the male parent of GHA 608 is derived from Ufuma and Aba origins. These three origins have a long history of selection, starting from grove palms in Eastern Nigeria (Sparnaaij et al., 1963; Van der Vossen, 1974). In the present report, the *pisifera*palms of these two African entries are referred to as Ghana (GHA 648) and Nigeria (GHA 608) origins.

The ancestry of the Dami composite involves, on the female side, Banting (BM) families BM 29 and BM 31. Both these families originate from pollinating Dumpy Deli E206 2/4 by Serdang fertile *pisifera* SP29/36 (BM 29) and by IRHO*pisifera* 38/32 (BM 31). On the male side, BM 119 (AVROS) *tenera* and UR 435/1 (Ulu Remis) *dura* are involved in the ancestry. The origin of the AVROS, Ekona, Yangambi and La Mé *pisifera* are described in detail by Corley and Tinker (2003).

Experiment 1

In January 1996, the first set of 90 dura lines were planted in South Sumatra with four replicates and 16 palms per plot. These 90 lines trace back to palms from the breeding programs at Dami (45 lines), Chemara (24), Harrisons & Crosfield (8), MARDI (5), Socfin (1), and to lines and families due to selfings and crosses between palms selected at ASD in the Chemara and Harrisons & Crosfield origins (7).

Experiment 2

In April 1996, the set of 20 full-sib T×P-families were planted with four replicates and 16 palms per plot. These families (from an entire group of 36) were obtained by pollinating 20 elite *tenera* palms with one *pisifera* palm belonging to the same family (sib-mating). The origins of the 20 *pisifera* male parents were AVROS (3), Dami composite (5), Ekona (5), Nigeria (3) and Ghana (4). They were derived from a total of 12 T×T- families at ASD (from some families more than one*pisifera* was obtained).

Experiment 3

In January 1997, the set of 425 D×P-families were planted with three replicates and 16 palms per plot. Each of the three replicates was comprised of small blocks of nine progenies that were grouped on the same two main soil series (cf. Breure and Foster, 2003). The crossing scheme used to generate the families was according to an alpha design (Patterson et al., 1978) with incomplete blocks. Each *dura* palm (to be considered as a treatment) was pollinated by two different *pisifera*palms. Each *pisifera* palm (replacing the incomplete blocks) pollinated nine different *dura* palms. Reference is made to Breure and Verdooren (1995) for the rationale of this design, described by the following parameters: v=225, b=50, r=2 and k=9.

Data were used to estimate the general combining abilities (GCA) or breeding values of the parents (cf. Breure and Bos, 1992) as well as the actual performance of the D×P-families adjusted for block effect. In the present paper the general mean is added to the main parent effects; the sums obtained are referred to as GCA-values.

Ablation, the standard practice in the experimental area of removing the first inflorescences of each palm, was carried out in 10 monthly rounds (Experiments 1 and 2) and in 18 monthly rounds (Experiment 3) from the start of flowering.

Observations, data recording and measurements

Bunch yield was recorded in Experiment 1 from July 1998 to June 2003 (5 years), in Experiment 2 from July 1998 to January 2004 (5.5 years) and in Experiment 3 from July 1999 to January 2004 (4.5 years). In Experiment 3, the number and sex of the ablated inflorescences were recorded.

In all experiments, a sample of bunches was analyzed for the components of oil and kernel content, following the modified method of Blaak et al. (1963). The modification was mainly that percentage oil/mesocarp was determined by the cold extraction method (Blaak, 1970). Another novelty is that instead of sampling a fixed weight or a fixed number of fruits, as described by Rao et al. (1983), a fixed-volume method was used. In the latter method the total number of fertile fruits from the spikelet sample of one bunch is divided into eight lots, while a fixed volume is taken (randomly drawn) from one lot. The mean fruit weight obtained from the fixed-volume method approximates the actual mean fruit weight in a more reliable way than the conventional sampling methods.

Standard leaf measurements (Corley et al., 1971; Hardon et al., 1969) were taken in Experiments 1 and 2 on marked leaves opening in June 1998, 1999, 2000, 2001 and 2002, and in Experiment 3 on leaves opening in February 1998, 1999, 2000, 2001, 2002 and 2003. The annual number of leaves produced per palm was recorded between the above-mentioned dates of leaf opening (4 years).

Novel for this study is the indirect determination of palm height, using equipment described by Breure and Verdooren (1995). Palm height is determined to the point of insertion of the first leaflets on leaves that opened in June 2003 (Experiment 1) or in February 2001 (Experiment 2). This measurement includes the length of the petiole. To correct for it properly, measurements were taken about two months after leaf opening when the petiole had reached its final size. Height values were then obtained by subtracting the petiole length, which was estimated as 0.3 times the rachis length; the latter was measured within the framework of standard leaf records later on. The estimated plot values of the petiole length were highly correlated with the actual values (r = 0.82), as found from measurements of rachis and petiole length on a sample of fronds. In Experiment 3, the actual height of the base of the leaf that opened in February 2002 was measured in December 2004 (when the base was exposed due to routine leaf pruning).

Incidence of crown disease was recorded as the percentage of affected palms, while the severity was scored on the set of the eight youngest opened leaves (the youngest leaf in each of the eight spirals) at four-month intervals, using score 0 (absence of symptoms) to 3 (severe symptoms). Recording continued until crown disease was no longer observed.

General combining ability (GCA) values were calculated according to the method described by Breure and Verdooren (1995).

Selection traits

The above records were used to obtain the following selection traits (cf. Breure and Verdooren, 1995):

- *Bunch yield* (kg/palm/year).
- *Percentages*: m*esocarp/fruit*, o*il/mesocarp*, and o*il/bunch*.
- *Oil yield* (kg/palm/year) - the product of bunch yield and percentage Oil/bunch.
- *Bunch Index* - here calculated as the ratio of bunch dry matter production to the sum of bunch and leaf dry matter production. Leaf dry matter (kg/palm/year) is calculated as the product of the annual number of leaves produced and the mean weight of the two leaves, opening at the start and end of the year of recording. This trait ignores trunk dry matter.
- *Mean leaf area* (m^2).
- *Mean leaf area/leaf weight ratio*.
- *Height* (cm) - at the level of the growing point.
- *Incidence of crown disease*. Only the incidence is reported in the present paper; severity is a criterion for individual palm selection.

For each trait, variation was quantified as standard deviation (s.d.) as well as the (scale-independent) coefficient of variation (CV), i.e. the standard deviation as a percentage of the mean.

Results and discussion

Dura female parents

Table 1 presents, in the upper panel, the overall results obtained from the 90 *dura* lines in Experiment 1, along with data for each of the four main origins. As indicated by the minima, the maxima and the coefficients of variation, there is clearly wide variation in performance among the 90 *dura* lines, and among the *dura* lines within each of the main origins (see the standard deviations within the four origins). The variation is manifest in the phenotypic values of the target traits of bunch yield and oil content as well as in the values of the auxiliary traits: bunch index, height, leaf area, leaf area/leaf weight ratio and crown disease incidence.

Conventionally, *dura* selection in Southeast Asian breeding programs was mainly directed at bunch yield and oil content. This policy can be traced back in the data patterns. For example, all four origins have nearly similar values of bunch yield and percentage mesocarp/fruit. The origins differ, however, with regard to the oil/mesocarp percentage. The latter was relatively low for the Dami origin (46.0%) against 51.0% for Chemara, 47.7% for H&C and 52.2% for MARDI. This discrepancy between Dami and the other origins is in line with other investigations on *dura* material at ASD (A. Alvarado, pers. comm.). It reflects the emphasis on oil content in the Chemara and MARDI selection programs, in contrast with those of Dami and H&C at that time. Also in contrast to the selection goal of the three other origins is that the Dami selection was focused on auxiliary traits, such as (high) bunch index and (slow) height increment (cf. Breure et al., 1987). Relatively favorable values were obtained for these two traits in the Dami origin, with a mean bunch index of 0.399 and a mean height of 256 cm compared with averages of 0.380 (bunch index) and 284 cm (height) across the other three origins. The undeniable conclusion is that some progress has been achieved in the Dami origin.

As shown by the coefficients of variation (CV), the phenotypic values from the dura lines in Experiment 1 are more variable for each trait than the GCA-values from their *dura* parents, as found in Experiment 3 (cf. Table 1 versus 2). Higher variation among the *dura* lines is not surprising, since selfing tends to expose genetic variation. Selfing is indeed an effective tool when one wants to select (or to eliminate) extreme genotypes.

Another factor is related to the crossing design used to obtain the material planted in Experiment 3. In this design, each *pisifera* parent pollinated nine *dura* palms. In contrast, each *dura* parent was pollinated by only two *pisifera* palms. The low number of crosses per *dura* palm renders parental selection based on GCA-values less reliable for the *dura* than for the *pisifera* parents. Reasonably, the GCA-values of the *dura* palms, as estimated in the present study, may to a great extent bear upon the *pisifera* parents and include *dura* × *pisifera* interaction, termed specific combining ability (SCA). Both factors favour the emphasis of selection on phenotypic values of the *dura* lines.

Table 1. Overall means, minima, maxima, and coefficients of variation of the phenotypic values with respect to the selection traits. The upper panel provides results from the 90 *dura* lines (Expt. 1), along with the means and standard deviations per main origin. The lower panel provides the results of the 20 *tenera* × *pisifera* families (Expt. 2), along with the means and ranges per origin. The lowest line presents data from Family 13 of the Nigeria origin

Parental sources	**Bunch yield (kg/palm per year)**	**% Mesocarp/ fruit**	**% Oil/ mesocarp**	**% Oil / bunch**	**Bunch index**	**Height (cm)**	**Leaf area (m^2)**	**Leaf area /leaf weight ratio**	**% Crown disease**
Dura lines (Expt.1)									
Mean (*n*=90)	96	63.0	48.0	20.3	0.389	269	6.55	2.69	30.1
Minimun	73	56.9	41.4	16.1	0.261	195	5.28	2.12	0
Maximun	125	68.7	55.0	24.0	0.470	354	7.67	3.07	98.4
CV (%)*	**10.2**	**3.6**	**6.7**	**8.3**	**10.0**	**13.0**	**7.6**	**7.9**	**85.1**
Dami (*n*=45)	97	62.7	**46**	19.5	**0.399**	**256**	6.41	2.71	40.7
s.d.**	9.0	2.5	2.0	1.4	0.035	9.0	0.46	0.36	27
Chemara (*n*=24)	97	63.3	**51**	21.5	**0.379**	**286**	6.75	2.66	13.2
s.d.	10.0	1.7	1.9	1.3	0.046	13.0	0.5	0.3	17.5
H&C (*n*=8)	95	64.6	**47.7**	20.4	**0.373**	**289**	6.84	2.57	33.6
s.d.	13.0	1.2	3.0	1.4	0.037	7.0	0.5	0.4	18.6
Mardi (*n*=5)	92	63.3	**52.2**	22.9	**0.387**	**277**	6.40	2.76	25.9
s.d.	5.0	2.9	1.7	1.0	0.022	6.0	0.3	0.3	7.9
TxP families (Expt. 2)									
Mean (*n*=20)	86	83.9	53.6	26.8	0.419	160	6.48	2.97	19.3
Minimum	63	77.4	47.1	21.4	0.330	116	4.44	2.14	0
Maximum	98	88.7	57.6	32.3	0.469	223	7.98	3.43	62.5
CV (%)	**11.0**	**3.0**	**3.1**	**3.0**	**13.2**	**28.0**	**12.4**	**10.4**	**83.5**
AVROS (*n*=3)	**67**	86.3	47.5	**22.5**	0.367	**184**	6.8	3.04	42.2
Range	63-69	82.7-88.7	47.1-48.2	21.4-24.6	0.330-0.401	176-193	6.45-7.03	2.95-3.08	12.5-62.5
Dami comp (*n*=5)	**90**	83.2	53.2	**27.4**	0.418	**141**	5.67	2.71	19.5
Range	85-93	81.0-84.5	51.8-54.0	24.8-29.5	0.401-0.437	133-164	4.44-6.21	2.14-2.95	10.9-33.3
Ekona (*n*=5)	**91**	81.2	55.9	**25.6**	0.424	**147**	7.34	3.08	7.8
Range	86-94	77.4-86.9	53.8-57.3	24.5-26.5	0.404-0.469	137-169	6.41-7.98	2.82-3.40	0.0-14.1
Ghana (*n*=4)	**86**	85.4	55.1	**31.2**	0.428	**204**	6.08	2.76	11.3
Range	79-93	83.1-87.3	53.8-57.3	30.5-32.3	0.415-0.445	193-223	5.65-6.46	2.71-2.84	4.7-17.2
Nigeria (*n*=3)	**89**	85.1	54.5	**26.2**	0.453	**130**	6.59	3.42	26.0
Range	78-98	83.3-86.4	52.2-57.6	25.1-27.5	0.434-0.469	116-142	6.40-6.74	3.41-3.43	10.9-35.9
Family 13	**98**	85.5	57.6	**27.5**	0.469	**116**	6.74	3.43	10.9

* CV (%) = coeficient of variation (s.d./mean x 100); ** s.d. = standard deviation

Selection of *dura* seed palms

After identification of attractive sources of female parents (Experiment 1), the search within these sources focuses on individual palms in order to generate desirable *dura* × *pisifera* planting material. The procedure to select individual *dura* palms within favorite *dura* lines is as follows.

First of all, low-yielding palms as well as palms with severe incidence of crown disease, and/or excessive height, and/or undesirable visual characteristics (sterile fruit, boron deficiency, etc.) are excluded. For the remaining palms, individual records of fruit components are listed. Palms with high mesocarp/fruit percentage and high oil/mesocarp percentage are subjected to additional bunch analysis. Eventually, the aim is to select palms on the basis of bunch yield and on the basis of an analysis of at least six bunches per palm. Selection also requires favorable values for auxiliary traits, in particular a high leaf area/leaf weight ratio and a small stem height.

Pisifera pollen parents

The lower panel of Table 1 presents the mean phenotypic values for the 20 T×P-families of Experiment 2, along with the data patterns for their five origins. With respect to the target traits, the coefficient of variation (CV) for bunch yield (kg/palm/year) is 11% in Experiment 2, against 10.2 % for the *dura* lines of Experiment 1. Both values are nearly similar, whereas the CV values of the three components of extraction rate are all lower for the T×P-families (percentage mesocarp to fruit: 3.6 % versus 3.0 %; percentage oil to mesocarp: 6.7 % versus 3.1 %; percentage oil to bunch: 8.3 % versus 3.0 %, as found in Experiments 1 and 2, respectively). By contrast, the CV values of the auxiliary traits are clearly higher in the T×P-families (bunch index: 10.0% versus 13.2 %; height (cm): 13 % versus 28 %; leaf area (m^2): 7.6 % versus 12.4 %; leaf area/leaf weight ratio: 7.9 % versus 10.4 %, as found in Experiments 1 and 2, respectively). As stated before, selfing generates diversity among the *dura* lines of Experiment 1. For the pronounced variation in vegetative growth of the T×P-families, the diversity among the (five) distinct origins of Experiment 2 may be responsible. Further, the four new origins introduced to Indonesia (Dami composite, Ekona, Ghana and Nigeria) are superior to the widely-used AVROS origin, both with regard to the target traits and auxiliary traits. Clearly, the palms of the AVROS origin are relatively tall (184 cm), with the highest incidence of crown disease (42.2 %), along with the lowest values for bunch index, bunch yield and oil content, as target traits.

The superiority of the newly-introduced origins over the AVROS *pisifera* palms is confirmed by the GCA-values obtained from Experiment 3, which are presented in the lower panel of Table 2. For two reasons, the results of Experiment 3 are more suitable for evaluating the origins of the *pisifera* palms than those of Experiment 2:

(i) Experiment 3 consists of a higher number of tested *pisifera* palms than Experiment 2 (50 versus 20 palms).

(ii) The GCA-values from Experiment 3 more validly assess the relative performances of the origins than the phenotypic values of the T×P- families from Experiment 2. In the latter the contribution of the *tenera* parent to performance cannot be excluded.

Table 2. Overall means, minima, maxima, and coefficients of variation of GCA-values per trait of all 225 *dura* and 50 *pisifera* parents of Experiment 3, along with the mean values per origin of the parents of the *dura* lines from Experiment 1 and all 50 *pisifera* palms. Per *pisifera* origin, the trait values of the palm with the highest value for oil yield (or elite palm) are presented

Parental sources	**Bunch yield (kg/palm per year)**	**% Mesocarp/ fruit**	**% Oil/ mesocarp**	**% Oil / bunch**	**Oil yield (kg/palm per year)**	**Bunch index**	**Height (cm)**	**Leaf area (m^2)**	**Leaf area /weight**	**Rachis lenght (cm)**
Dura parents										
Mean, *n*=225	120	79.4	50.7	26.6	31.9	0.534	141	5.04	2.70	377
Minimum	100	73.6	43.6	21.0	24.3	0.473	111	4.32	2.30	339
Maximum	130	85.1	55.0	29.5	38.2	0.592	179	5.88	2.89	421
CV (%)	6.0	2.5	3.4	5.2	8.0	3.6	8.9	5.4	3.6	3.6
Parents of Expt. 1										
CV (%)	**6.7**	**2.3**	**2.5**	**4.9**	**8.2**	**4.3**	**9.2**	**5.2**	**3.5**	**3.7**
Dami *n*=45	122	79.9	50.3	26.7	28.1	0.538	139	5.01	2.68	373
Chemara *n*=24	117	79.4	51.3	26.8	27.7	0.519	148	5.19	2.70	392
H & C (*n*=8)	122	78.9	51.1	26.9	28.3	0.524	150	5.23	2.64	386
Mardi (*n*=5)	120	81.5	53.4	28.0	29.4	0.541	133	5.00	2.72	375
Pisifera parents										
Mean (*n*=50)	120	79.4	50.7	26.6	31.9	0.534	141	5.04	2.70	377
Minimum	109	71.1	47.7	24.8	27.6	0.488	108	4.19	2.49	344
Maximum	135	83.8	54.0	28.0	35.6	0.570	173	5.69	2.95	423
CV (%)	4.5	3.1	3.2	3.1	5.4	3.6	10.5	6.3	3.9	3.4
AVROS	**117**	81.5	49.1	26.4	**30.9**	0.518	152	5.19	2.68	381
Elite	123	83.4	49.6	26.2	32.2	0.511	165	5.53	2.66	387
-HC (*n*=6)	**116**	81.0	**49.3**	26.3	30.7	**0.529**	153	**4.98**	2.69	**373**
-C9212 *n*=4	**118**	81.8	**49.0**	26.4	31.1	**0.512**	151	**5.34**	2.67	**385**
Yangambi (*n*=4)	**121**	75.8	53.3	27.3	**32.9**	0.528	145	4.94	2.68	380
Elite	120	74.0	53.8	27.8	33.3	0.523	139	4.67	2.75	377
La Mé (*n*=1)	116	76.4	50.5	25.5	29.6	0.554	131	4.79	2.79	390
Dami comp *n*=5	**118**	79.7	49.6	26.2	**31.1**	0.541	124	4.57	2.58	358
Elite	123	79.4	49.4	26.9	33.1	0.534	125	4.88	2.54	364

Ekona *n*=10	**121**	77.9	51.6	26.1	**31.8**	0.541	130	5.05	2.74	382
Elite	128	76.2	52.4	26.9	34.4	0.547	134	5.33	2.74	383
Ghana *n*=9	119	78.8	51.0	27.2	**32.4**	0.535	**147**	**4.89**	**2.64**	**375**
Elite	128	81.6	50.2	27.6	35.1	0.544	173	5.22	2.74	383
Nigeria *n*=6	**127**	80.0	51.6	26.9	**34.2**	0.553	**136**	**5.32**	**2.87**	**379**
Elite-1	128	79.7	53.6	27.8	**35.6**	**0.570**	**114**	**5.03**	**2.89**	**368**
Elite-2	**135**	81.7	50.5	26.3	35.6	0.551	**122**	**5.69**	2.88	**389**

When looking at the GCA-values of oil yield per origin, one must conclude that the Nigeria origin, a new introduction originating from Kade Oil Palm Research Centre in Ghana, is superior. Its oil yield amounts to 34.2 kg/palm/year, whereas the average of the other five main origins amounts to 31.8 kg/palm/year. When comparing the two entries from Kade (the Nigeria and Ghana origins), it is interesting to note that the Nigeria origin combines high oil yield with attractive levels for auxiliary traits, namely, low height (being 136 and 147 cm for *pisifera* palms of the Nigeria and Ghana origin, respectively) and high leaf area/leaf weight ratio (2.87 and 2.64). For the Ghana origin, on the other hand, the GCA-values of leaf area and rachis length (4.89 m^2 and 375 cm, respectively) are lower, implying that a slightly higher planting density can be adopted for Ghana-derived planting material. Hence, the oil yield per ha of Ghana material is expected to be even higher than what could be estimated on an individual palm basis, as presented in Table 2.

Within the AVROS origin a comparison can be made between the six first-generation AVROS *pisifera* (HC) and the nine second-generation AVROS *pisifera* (C9212). The GCA-values of target traits as bunch yield and percentage oil/ mesocarp for HC and C9212, as presented in Table 2, are nearly similar (116 versus 118 kg/palm/year and 49.3% versus 49.0 %, respectively). One may therefore infer that virtually no selection progress was attained by ASD. However, the superiority of the C9212 palms over the HC palms regarding leaf area (5.34 m^2 versus 4.98 m^2) and rachis length (385 cm versus 373 cm) should be noted. This indicates that planting material derived from the C9212 *pisifera* is more vigorous and, therefore, more competitive for light.

Comparison of the mean cumulative yields of the Nigeria progenies and the AVROS progenies (see Table 3; 77.3 versus 71.2 t/ha) emphasizes the progress in performance made with ASD's novel (Nigeria) material compared with the widely-used AVROS material. This was also observed by Ang et al. (2005). The superior yield of the Nigeria material was evident from the second year of production (13.6 t/ha).

The progenies derived from the Ekona and Nigeria origins are the most precocious, as can be concluded from the relatively high number of female inflorescences removed (ablation) during months 6 to 18 and months 19 to 24 after planting (Table 3). When a more restricted period of ablation is applied, as is normal in favourable environments, the yield performance may be even higher during the first year of production than observed in Experiment 3.

Table 3. Mean annual and cumulative yield (FFB) of *dura* x *pisifera* progenies derived from six *pisifera* origins for the first 4.5 years of production, along with the number of female inflorescences removed per palm during the periods 6 - 18 and 19 - 24 months after planting. Experiment 3

Pisifera origins	Number of progenies	Mean yield (tons FFB/ha)[1] (years of production)					Mean number of female inflorescences removed/palm[1] (months after planting)		
		1	**2**	**3**	**3-4.5**	**Total**	**6-18**	**19-24**	**Total**
AVROS	131	6.0	12.1	16.5	36.7	**71.2**	0.22	2.85	3.07
YANGAMBI	25	7.0	13.4	19.1	33.9	73.4	0.24	3.44	3.68
DAMI Comp.	45	6.6	12.5	18.9	33.8	71.9	0.28	3.49	3.77
EKONA	90	6.8	12.9	19.2	34.8	73.8	0.34	3.87	**4.21**
GHANA	72	6.9	12.4	19.2	34.0	72.6	0.26	3.47	3.73
NIGERIA	55	6.5	**13.6**	20.9	36.3	**77.3**	0.33	3.70	**4.03**

[1] Adjusted for block effect

The low overall yield level achieved in Experiment 3 compared with that reported by Ang et al. (2005) with the same families is, despite the less favourable climatic conditions in South Sumatra, probably due to the low rate of fertilizer applied in the trial areas (cf. Breure and Foster, 2003).

Elite *pisifera*

The potential of an origin can be shown best by the elite *pisifera* palm in the origin. Since the main interest is oil production, the highest GCA- value for oil yield within an origin is used as a criterion. To obtain a general profile for each elite *pisifera*palm, the GCA or breeding values of all other traits are also considered (see the lower panel of Table 2).

Clearly, Elite-1 *pisifera* of the Nigeria origin combines the highest values of oil yield (35.6 kg/palm/year), bunch index (0.570) and leaf area/leaf weight ratio (2.89) with the lowest value for stem height (114 cm). All these traits are associated with a high harvest index. Note also the palm's low value for leaf area (5.03 m^2) in comparison with the average for the whole Nigeria group (5.32 m^2) and also its relatively low value of rachis length (368 cm versus 379 cm for the average of the group).

Interestingly, this elite *pisifera* palm is the male parent of family 13. Family 13 (see the bottom line of Table 1) is characterized by the highest bunch yield, above average oil extraction rate, and the lowest palm height among all 20 families in Experiment 2. Due to both GCA-values of the *pisifera* male parent and the phenotypic values of its T×P full-sib family offspring (Experiment 2), family 13 of the Nigeria origin is considered to be the most promising source of *pisifera* male parents to be used for seed production. Elite-2 *pisifera* from this origin shows by far the highest bunch yield (135 kg/palm/year) across all *pisifera* tested with low height values. Its leaf area (5.69 m²) and rachis length (389 cm) are, however, substantially higher than for Elite-1 *pisifera*.

Selection of *pisifera* pollen parents

Dura × *pisifera* planting material derived from *pisifera* palms in family 13 is expected to show considerable improvement in the most important traits: oil yield, harvest index and height. The candidate pollen parents in this family must still be tested, as done in Experiment 3. From the difference in GCA-values between the mean of the six Nigeria palms and the two elite palms within the origin (see Table 2), one may infer that there is ample scope for response to selection in family 13.

The only proven pollen parents are the clones of the *pisifera* palms tested in Experiment 3. Unfortunately, these clones cannot yet be used for generating planting material. The reason is that the correct identity of the *pisifera* ramets planted in South Sumatra must still be checked by DNA fingerprinting of the *pisifera ortets* at ASD in Costa Rica.

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