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EVALUATION OF COMBINING ABILITY AND GENETIC VARIANCE IN INTROGRESSED WIDIKUM *ELAEIS GUINEENSIS* JACQ. OF CAMEROON USING NORTH CAROLINA II MATING DESIGN

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ABSTRACT

Information on combining abilities and gene action parameters remain critical in oil palm selection/breeding for high yield commercial tenera hybrid. In this study, female families (DA2356D, DA787D, DA507D, and LM7899D) and male families (LM9175T, LM9287T, and LM9927T) were crossed and their progenies planted at Specialized Centre for Oil Palm Research of Cameroon. After 10 years, the resulting progeny test was evaluated in a randomized complete block design with three replications. Oil yield and selected oil palm traits were estimated. ANOVA suggested significant differences among females and males on most studied characters. DA787D and LM7899D were identified as promising good general combiners for yield and yield components, with significant positive general combining abilities (GCA). Female families, mainly DA787D, could be utilized in oil palm breeding programs since they showed potential additive gene effects. Male family LM9287T followed by LM9175T provided good GCA for most of the traits. The Cross DA2356D x LM9287T exhibited best specific combining ability (SCA) for all the yield and yield components. DA787D x LM9927T, DA507D x LM9175T and LM7899D x LM9287T presented good SCA for bunch quality components and height increment of palms. The ratio of $\sigma^2 gca/\sigma^2 sca$, $[\sigma^2 D/\sigma^2 A]^{1/2}$ which was less than unity in some traits and more than unity in others, with low narrow sense heritability estimates, indicated the important role of both additive and non-additive gene actions in the inheritance of these characters, with preponderance of non-additive gene actions. The female × male interaction contributed more to total variation of the expression of different traits.

INTRODUCTION

The main final product of oil palm (*Elæis guineensis* Jacq.) namely crude palm oil (CPO), is used as a food cooking ingredient in most palm oil tropical producer countries of Africa, Southeast Asia and Central and South America. In addition to mesocarp CPO, the extracted endocarp palm kernel oil (PKO) can also be obtained from *E. guineensis* and is commonly used in the cosmetic industry. Palm kernel waste is also used as animal feed (Corley and Tinker, 2003). Indonesia and Malaysia with about 85% production are the major world producers of CPO (Corley and Tinker, 2003). In Africa, major CPO producers are Nigeria, Ghana, Cote d'Ivoire, and Cameroon which currently ranks as the World's 13th largest producer (Hoyle and Levang, 2012). Cameroon government has projected to become an emerging economy country by 2035 and the agricultural sector should play an important role toward achieving this objective. Thus the palm oil production of the country was decided to be and to tackle its current net trade balance issue. Cameroon imports 50,000 tons of palm oil per year. The Cameroon Ministry of Agriculture and Rural Development (MINADER), reported that in the year 2010, the country had produced 230,000 tons of CPO, from oil palm plantations of about 190,000 hectare. Cameroon oil palm materials had played an important role to boost the development of many commercial oil palm varieties and improve the genetic base of breeding programs around the world in oil palm producer countries. In breeding and selection programs, the creation of new hybrid *Tenera*

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varieties in oil palm always imply the need of some major details about genetic structure of the parental lines and their progenies. Information on combining ability is essential to identify superior parents for commercial hybrid seed production. Such information could be derived from some designs such as diallel mating design (Hayman, 1954; Jinks, 1954 ; Griffing, 1956), the line × tester mating design (Kempthorne, 1957) and the North Carolina mating design (Comstock and Robinson, 1948, 1952) crosses.

Depending on the reproductive biology of the plant (self- or cross-pollination method), these mating design methods can be used to determine general combining ability (GCA) and specific combining ability (SCA) of population lines. Apart from GCA and SCA, the gene effect and genetic variance components estimate can be also obtained from these mating design methods (Singh and Chaudhary, 1985; Breure and Konimor, 1992; Cruz and Ragazzi, 1994; Petrovic, 1998; Hossein and Aziz, 1998; Hede *et al*., 1999; Konak *et al*., 1999; Chokan, 1999; Dumortier and Konimor, 1999; Kushairi and Rajanaidu, 2000; Venkatesh *et al*., 2001; Kenga *et al*.,2004; Musa, 2004; Noh *et al*., 2012). Falconer and Mackey (1996) reported that the differences in GCA are mainly due to the additive genetic effects while differences in SCA are attributed to the no-nadditive dominance and other types of epistasis. In the current study, therefore, an attempt was made to generate information on the new 3rd selection cycle material of oil palm introgressed *Dura* x *Tenera* (D x T) progeny test population of 4 female families crossed with 3 male families using North Carolina II mating design. The objectives were to estimate the general combining ability (GCA), the specific combining ability (SCA) and the gene effects for oil palm yield, yield components and some economically important agronomic traits under the climate conditions of Cameroon.

MATERIALS AND METHODS

The experiment was conducted at the Specialized Centre for Oil Palm Research (CEREPAH) of Cameroon from 2004 to 2014. The research center is located in the littoral region, between 3° 46 and 4° 01 N latitude and between 9° 44 and 10°04 E longitude, at less than 200 m above sea level. It is characterized by Guinean equatorial climate with four seasons. During the research period, 2730.49 mm of annual mean rainfall, 27.36 °C of annual mean temperature with maximum and minimum of 30.81°C and 23.95°C of temperature respectively and 1334 hours of annual mean sunshine were recorded. A total of 12 progenies of oil palm Deli *Dura* x La Mé *Tenera* (DxT) were planted in experimental plots. The Dabou *Dura* materials family originating from the National Centre for Agronomic Research (CNRA) in Ivory Coast Breeding Programme were used as female parents. The male parents were the La Mé *Tenera* family, the descendants of the crosses between Widikum from CEREPAH-Cameroon and La Mé. The materials were crossed using North Carolina Mating Design II (NCM II) (Comstock and Robinson, 1948, 1952). NCM II is a nested design, where each male is mated to a number of same females in a set. It can be used to estimate genetic variance components, that is, additive and dominance variances and narrow-sense heritability. In addition, combining ability effect can also be evaluated. The progenies were created by randomly crossing each of the 3 male *Tenera* (LM9175T, LM9287T and LM9927T) with one set of 4 female *Dura* (DA2356D, DA787D, DA507D, LM7899D).

Data Collection

Data collection was carried out for bunch yield (2008–2014), bunch quality components (2011–2014), and one round vegetative measurement (2011). The bunch yield components were fresh fruit bunch (FFB) and bunch number (BN). The bunch quality components included spikelet weight (SpW), average fruit weight (AFW), kernel to fruit ratio (K/F), kernel to bunch ratio (K/B), oil yield (OY) and kernel yield (KY) which were investigated following the method of Mandal and Kochu (2008); while the vegetative trait assessed was palm height increment (HT).

Statistical Analysis

The data collection was based on individual palm basis and was computed using the Statistical Analysis System (SAS) program. Simple statistics for each trait such as Mean, Standard Error (SE), and Standard Deviation (SD) were determined. Analyses of variance (ANOVA) among traits were also carried out by SAS program. GCA and SCA and standard errors of the estimates were determined by the following formula (Singh and Chaudhary, 1985):

GCA (females) = Yi../rt – Y…/rlt
GCA (Males) = Y.j./rl – Y…/rlt
SCA= Yij./r – Yi../rt – Y.j./rl + Y…/rlt
SE (GCA for female)= $(Me/rt)^{1/2}$
SE (GCA for male)= $(Me/rl)^{1/2}$
SE (SCA)= $(Me/r)^{1/2}$
SE (GCAi – GCAi') female= $(2Me/rt)^{1/2}$
SE (GCAj – GCAj') male= $(2Me/rl)^{1/2}$
SE (SCAij – SCAi'j')= $(2Me/r)^{½}$

Where, Yi..= Total of the ith female, Y.j.= Total of the jth male, Y…= Grand total, r, l and

t = number of replications, females and males, respectively, SE= Standard error of the estimate and Me= Error mean square

The significance of GCA and SCA effects were tested by dividing the corresponding GCA and SCA values by their respective standard error and comparing the obtained t with tabular t-value at error degree of freedom.

The genetic components were determined as follow:

Cov H.S. (female) = $(M_l – M_{lxt})$ / r x t
Cov H.S. (male) = $(M_t - M_{lxt})$ / r x l
Cov H.S. (average) = $1/r(2lt-l-t)\{[((l-t)M_l + (t-1)M_t) / (l + t – 2)] – M_{lxt}\}$

Cov F.S. $=\{[(M_l – M_e)+(M_t – M_e)+(M_{lxt} – M_e)]/3r\}+[6rCovHS_{(average)} –r(l-t)CovHS_{(average)}] /3r$

Additive genetic variance (σ^2_A), dominance genetic variance (σ^2_D), narrow sense heritability (h^2_{ns}), broad sense heritability (h^2_{bs}) and average degree of dominance were estimated as below (Singh and Chaudhary, 1985):

σ^2_A= [4/(1 +F)] σ^2gca = [4/(1 +F)] $CovHS_{(average)}$
σ^2_D= [4/(1 +F)^2] σ^2sca =[4/(1 +F)^2] $CovHS_{(average)}$
Average degree of dominance= $(\sigma^2_D/ \sigma^2 A)^{1/2}$

Where, σ^2gca= Estimate of GCA variance, σ^2sca= Estimate of SCA variance, σ^2_P= Estimate of phenotypic variance (plot basis) and F= Inbreeding coefficient, which was considered as zero because both lines and testers were non-inbred. In addition, it was assumed that the epistasis variance is negligible. The proportional contribution in percent of females, males, and their interaction to the total variance was determined by dividing the corresponding sum of square value by the sum of square of crosses value.

RESULTS AND DISCUSSION

Combining ability

The ANOVA for yield and yield components, vegetative trait and bunch quality components (Table 1) showed significant differences between tested crosses for all of the traits, except for height increment (HT) of palm trees and spikelet weight of bunches (SpW). High significant differences were observed among *Dura* female parents and *Tenera* male parents for all the studied traits except for spikelet weight (SpW) and fresh fruit bunch (FFB) respectively, indicating the existence of genetic variability among *Dura* female and *Tenera* male parents used as experimental oil palm materials in this study. This observation is sufficient evidence for breeding and selection of improved oil palm parent candidates for these characters except for height trait. Similar findings in variability were reported by Okwuagwu *et al*. (2008).

General combining ability (GCA) estimates for bunch yield and yield components (Table 2) revealed that, regarding their combining effect importance among female parent families, DA787D was the best general combiner for all yield and yield component traits and LM7899D occupied the second position, since positive significant GCA values for fresh fruit bunch (FFB) and bunch number (BN) were recorded from these parents. Among male family parents, LM9287T was obtained as a good general combiner for number of bunch per palm, while LM9175T was recorded as good general combiner for oil yield per palm. Noh *et al*. (2012) and Okwuagwu (1996) also reported on GCA from yield components of oil palm population using North Carolina Mating Design I method and diallel excluding reciprocal and self method respectively. The GCA estimates for a character such as height increment (HT) was negative and non significant for most of *Dura* female and *Tenera* male parents: DA787D, DA507D, LM7899D and LM9175T, LM9927T respectively (Table 3). Negative values of combining abilities are preferred by breeders when considering the selection criteria of this height character in plant breeding. In oil palm, shorter palm height is desirable to increase oil palm estate productivity by reducing the production costs of the plantation. Thus these parents were good general combiners. The results indicated that among *Dura* female parent families, DA2356D recorded positive significant GCA for average fruit weight (AFW), and kernel to fruit ratio (K/F) whereas LM7899D had significant positive GCA effect for oil bunch and kernel yield (KY). Regarding the *Tenera* male parents, LM9287 Tpresented high significant positive GCA for all the studied bunch quality components, except for spikelet weight (SpW) (Table 3). This suggested that these parent families are good general combiners for these traits.

Table 1. Mean squares analysis of variance in North Carolina II mating design for various characters of oil palm D x T progeny test (2004-2014) population from Cameroon research Center (CEREPAH)

Sources of variation	Degrees of freedom	Mean squares								
		Yield components			Vegetative trait	Bunch quality components				
		FFB	BN	OY	HT	SpW	AFW	K/F	K/B	KY
Replication	2	26.65	1.63	0.39	21.95	2.16	0.04	9.22	13.33	0.63
Cross	11	394.54*	9.54**	1.29*	45.89ns	3.87ns	2.19**	591.44**	282.07**	8.75**
Female	3	727.03**	12.58**	2.36**	41.81ns	2.56ns	1.35*	256.47*	125.77*	2.91*
Male	2	446.15ns	11.45**	1.89*	37.85ns	5.99*	8.55**	2623.56**	1223.90**	36.13**
Female x Male	6	211.09ns	7.38**	0.56ns	50.60ns	3.81ns	0.49ns	81.54ns	46.27ns	2.54*
Error	22	148.83	1.11	0.47	21.25	1.63	0.41	59.58	32.35	0.81

* , **: Significant at 0.05 and 0.01 probability levels, respectively; ns: Non-significant; df: degree of freedom.
FFB: Fresh fruit bunch yield; BN: Bunch number; HT: Height increment; AFW:Average Fruit Weight
SpW:Spikelet weight; K/F:Kernel to Fruit;K/B: Kernel to Bunch; KY:Kernel yield; OY: Oil yield.

Table 2. General combining ability (GCA) estimates for yield and yield components for *Dura* female and *Tenera* male parent family of progeny test (2004-2014)

Female N°	Family Parentage	FFB	BN	OY
Dura1	DA2356D	-2.73	-0.60*	-0.30
Dura2	DA787D	9.77**	1.47**	0.53**
Dura3	DA507	-11.09**	-1.24**	-0.56**
Dura4	LM7899D	4.05*	0.37*	0.33
SE(GCA)		3.40	0.31	0.20
SE(GCAi-GCAj)		5.75	0.50	0.32
Male N°	Family Parentage			
Tenera1	LM9175T	4.11	0.02	0.35*
Tenera2	LM9287T	2.89	0.96**	0.09
Tenera3	LM9927T	-7.01**	-0.99**	-0.43**
SE(GCA)		2.78	0.25	0.16
SE(GCAi-GCAj)		4.98	0.43	0.28

*, **: Significant at 0.05 and 0.01 probability levels, respectively(t-test value)
FFB: Fresh fruit bunch yield; BN: Bunch number; OY: oil yield SE (gca) = Standard error ofgeneral combining ability effect and SE (gcai - gcaj) = Standard error ofthe difference ofgeneral combining abilityeffects

Table 3. General combining ability (GCA) estimates for vegetative and bunch quality components for *dura* female and *tenera* male parent family of progeny test (2004-2014)

Female Nº	Family Parentage	HT	AFW	SpW	K/F	K/B	KY
Dura1	DA2356D	3.15*	0.38*	0.76	4.15*	2.38	0.35
Dura2	DA787D	-0.40	-0.46**	-0.49	-7.84**	-5.49**	-0.34
Dura3	DA507D	-1.55	0.26	-0.1	2.02	0.77	-0.61*
Dura4	LM7899D	-1.21	-0.17	-0.17	1.67	2.34	0.60*
SE(GCA)		1.33	0.18	0.37	2.15	1.60	0.26
SE(GCAi-GCAj)		2.17	0.30	0.60	3.64	2.68	0.43
Male Nº	Family Parentage						
Tenera1	LM9175T	-0.29	-0.89**	0.25	-9.75**	-6.40**	-0.79**
Tenera2	LM9287T	1.90*	0.80**	-0.80**	17.01**	11.64**	1.99**
Tenera3	LM9927T	-1.61	0.09	0.55*	-7.26**	-5.25**	-1.20**
SE(GCA)		1.09	0.14	0.31	1.75	1.31	0.21
SE(GCAi-GCAj)		1.88	0.26	0.52	3.15	2.32	0.37

*, **: Significant at 0.05 and 0.01 probability levels, respectively (t-test value) HT: Height increment; AFW: Average Fruit Weight; SpW: Spikelet Weight; K/F: Kernel to Fruit ratio; K/B: Kernel to Bunch ratio; KY: Kernel yield SE (gca)= Standard error ofgeneral combining ability effect and SE (gcai - gcaj)= Standard error ofthe difference ofgeneral combining ability effects

Table 4. Specific combining ability (SCA) estimates for yield and yield components for cross combination *dura* female and *tenera* male parent family of progeny test (2004-2014) in CEREPAH-Cameroon

Crosses	Progeny	FFB	BN	OY
D1 x T1	LM21864	-2.38	-0.3	-0.13
D1 x T2	LM21728	11.28*	1.87**	0.51
D1 x T3	LM21787	-8.90*	-1.57**	-0.38
D2 x T1	LM21761	-0.52	-0.32	-0.02
D2 x T2	LM22130	-5.85	-1.11**	-0.23
D2 x T3	LM21867	6.38	1.43**	0.24
D3 x T1	LM22001	1.94	1.06*	0.18
D3 x T2	LM21881	-8.29*	-1.64**	-0.54*
D3 x T3	LM21706	6.31	0.58	0.37
D4 x T1	LM22534	0.96	-0.44	-0.03
D4 x T2	LM21790	2.82	0.88*	0.26
D4 x T3	LM21839	-3.78	-0.45	-0.23
SE (SCA)		4.81	0.44	0.28
SE ($SCA_{ij} – SCA_{kl}$)		9.96	0.86	0.56

SE (sca)= Standard error ofspecific combining ability effect and SE (sca_{ij} - sca_{kl}) = Standard error ofthe difference ofspecific combining ability effects; D..= Dura palm and T..= Tenera palm with experimental number
FFB: Fresh fruit bunch yield; BN: Bunch number; OY: oil yield

Table 5. Specific combining ability (SCA) estimates for vegetative trait and bunch quality components for cross combinations of *dura* female and *tenera* male parent families of progeny test (2004-2014) in CEREPAH-Cameroon

Crosses	Offsprings	HT	AFW	SpW	K/F	K/B	KY
D1 x T1	LM21864	-3.28*	-0.17	0.09	-1.49	-0.89	-0.39
D1 x T2	LM21728	6.01**	0.06	-0.62	3.38	2.55	1.17**
D1 x T3	LM21787	-2.73	0.11	0.53	-1.89	-1.66	-0.78*
D2 x T1	LM21761	0.06	0.48*	0.82	8.27**	6.05**	0.94**
D2 x T2	LM22130	-2.02	-0.07	0.29	-5.94*	-4.78*	-1.01**
D2 x T3	LM21867	1.96	-0.41	-1.11*	-2.33	-1.27	0.07
D3 x T1	LM22001	-1.22	-0.53*	-1.01*	-4.09	-2.63	-0.11
D3 x T2	LM21881	0.01	0.17	1.37**	1.90	1.72	-0.54
D3 x T3	LM21706	1.21	0.36	-0.36	2.20	0.91	0.65*
D4 x T1	LM22534	4.44*	0.22	0.10	-2.69	-2.52	-0.44
D4 x T2	LM21790	-4.00*	-0.16	-1.04*	0.67	0.51	0.38
D4 x T3	LM21839	-0.44	-0.06	0.94*	2.02	2.02	0.06
SE (SCA)		1.88	0.25	0.53	3.04	2.26	0.36
SE ($SCA_{ij} – SCA_{kl}$)		3.76	0.52	1.04	6.30	4.64	0.74

HT: Height increment; AFW: Average Fruit Weight; SpW: Spikelet Weight; K/F: Kernel to Fruit; K/B: Kernel to Bunch; KY: Kernel yield. SE (sca)= Standard error of specific combining ability effect and SE (sca_{ij} - sca_{kl}) = Standard error ofthe difference of specific combining ability effects
D..= Dura palm and T..= Tenera palm with experimental number

Therefore, the expression of the bunch quality components is controlled by additive gene action in these parent families.Thus they can be utilized in seed production programs and other breeding purposes. Noh *et al*. (2012) noted GCA from fresh fruit bunch yield and oil to bunch ratio.

The SCA estimates and their significant levels (tested at 5% and 1%) of *Dura* female parent families and *Tenera*male parent families for oil palm yield components and oil palm vegetative trait and bunch quality componentsare presented in Table 4 and Table 5 respectively.

Table 6. Estimates of genetic components for the measured yield and yield component charactersin D x T oil palm progeny test population (2004-2014) of CEREPAH-Cameroon

Estimates of parameters	FFB	BN	OY
σ^2_{gca}	7.91	0.09	0.03
σ^2_{sca}	20.75	2.09	0.03
σ^2_A	31.65	0.37	0.13
σ^2_D	83.02	8.36	0.12
$\sigma^2_{gca}/\sigma^2_{sca}$	0.38	0.04	1.04
$[\sigma^2_D/\sigma^2_A]^{1/2}$	1.62	4.74	0.98
h^2_{NS}	12.01	3.78	17.65
h^2_{BS}	43.52	88.73	34.62

σ^2_A: additive genetic variance, σ^2_D: dominance genetic variance, h^2_{NS}: narrow sense heritability, h^2_{BS}: broad sense heritability, σ^2_{gca} : estimate of GCA variance,σ^2_{sca}: estimate of SCA variance, $\sigma^2_{gca}/\sigma^2_{sca}$: ratio of variance of general to specific combining ability, $[\sigma^2_D/\sigma^2_A]^{1/2}$: degree of dominance

FFB: Fresh fruit bunch yield; BN: Bunch number; OY: oil yield.

Table 7. Estimates of genetic components for the measured vegetative traits and bunch quality component characters in D x T oil palm progeny test population (2004-2014) of CEREPAH-Cameroon

Estimates of parameters	HT	SpW	AFW	K/F	K/B	KY
σ^2_{gca}	-	0.002	0.07	22.00	10.17	0.27
σ^2_{sca}	9.78	0.73	0.03	7.32	4.64	0.58
σ^2_A	-	0.01	0.29	87.98	40.69	1.07
σ^2_D	39.14	2.91	0.11	29.28	18.56	2.30
$\sigma^2_{gca}/\sigma^2_{sca}$	-	0.003	2.75	3.00	2.19	0.46
$[\sigma^2_D/\sigma^2_A]^{1/2}$	-	17.85	0.60	0.58	0.68	1.47
h^2_{NS}	-	0.20	36.45	49.75	44.42	25.57
h^2_{BS}	64.81	64.15	49.68	66.31	64.68	80.59

σ^2_A: additive genetic variance, σ^2_D: dominance genetic variance, h^2_{NS}: narrow sense heritability, h^2_{BS}: broad sense heritability, σ^2_{gca} : estimate of GCA variance, σ^2_{sca}: estimate of SCA variance, $\sigma^2_{gca}/\sigma^2_{sca}$: ratio of variance of general to specific combining ability, $[\sigma^2_D/\sigma^2_A]^{1/2}$: degree of dominance

HT: Height increment; SpW: Spikelet Weight; AFW: Average Fruit Weight; K/F: Kernel to Fruit; K/B: Kernel to Bunch; KY: Kernel yield

Table 8. Proportional contribution of females, males and their interactions to total variance for the various studied traits in D x T Oil palm progeny test (2004-2014) from CEREPAH-Cameroon

Contribution of	df	HT	FFB	BN	SpW	AFW	K/F	K/B	KY	OY
Females	3	24.85	50.26	35.96	18.02	16.82	11.83	12.16	9.08	49.85
Males	2	15.00	20.56	21.83	28.18	71.08	80.65	78.89	75.08	26.53
Female x Male	6	60.15	29.18	42.21	53.80	12.10	7.52	8.95	15.84	23.62

HT: Height increment; FFB: Fresh fruit bunch yield; BN: Bunch number; SpW: Spikelet Weight; AFW: Average Fruit Weight; K/F: Kernel to Fruit; K/B: Kernel to Bunch; KY: Kernel yield; OY: Oil yield.

Both negative and positive significant estimates of SCA effects were observed among the family crosses. DA2356D x LM9287T) was assumed to be a potential good specific combinerfor fresh fruit bunch (FFB)and number of bunches (BN). In addition, the result showed also that DA787D x LM9927T, DA507D x LM9175Tand LM7899D x LM9287Tcan also be considered as family crosses with good SCA effects for bunch number (BN). High significant SCA effects of the crosses indicate theextent of deviation in performance of the considered cross combinations from that predicted on the basis of the general combining abilities of parents involved in crosses. Thus these crosses with high positive and significant estimates of SCA effect could be selected for their specific combining ability and exploited in oil palm improvement breeding programs. Concerning the plant height, family Cross LM7899D x LM9287T was good specific combiner, followed byDA2356D x LM9175T, whereas, the cross DA2356D x LM9287T was found to be the poor specific combination with its high tendency to increase the height increment of palm trees. DA787D × LM9175T exhibited significant SCA effectsfor most traits such as average fruit weight (AFW), kernel to fruit ratio (K/F), kernel to bunch ratio (K/B), and kernel yield (KY). Thus, this cross was considered for good specific combinations. Findings on significance of GCA and SCA for traits were noted by Breure and Konimor (1992). The existence of both positive and negative SCA effects in oil palm crosses has also been reported by Noh *et al*. (2012). However, high general combining ability for trait, will not always produce high SCA for the same trait in the same parent (Hossein and Aziz, 1998).

Gene Action, Degree of Dominance and Contribution to the Total Variance

The results on specific combining ability variance (σ^2sca) and the general combining ability (σ^2gca) estimatesas well as their ratio (σ^2gca / σ^2sca) for yield components (Table 6) indicated that, the general combining ability variance estimate (σ^2gca) was lower than the estimate of variance due to the specific combining ability variance (σ^2sca) for all yield components. This emphasized that, non-additive gene action is possibly controlling these characters. With regards to palm oil yield traits, σ^2gca was slightly greater than specific combining ability variance (σ^2sca), indicating that additive gene actions were important in controlling palm oil yield traits in the studied population. Dominance genetic variance was larger than additive genetic variance for yield component traits. These results are confirmed by the ratio of the general combining ability variance to the specific combining ability variance (σ^2gca/σ^2sca) from which smaller values than unity were recorded, and by the degree of dominance which produces values greater than unity except for palm oil yield (Table 6). Therefore, it can be assumed that the inheritance of these studied yield component characters was controlled by the main role of non-additive gene effects. This suggests that, the base population of this study was a heterozygote oil palm breeding population. In addition selection for improved performance of hybrids can be operated by the breeding program. Table 7 presents the variance due to general and specific combining ability for bunch quality components and vegetative traits. It is noted that, the general combining ability variance (σ^2gca) was lower than specific combining ability variance (σ^2sca) for all studied characters except for average fruit weight (AFW), kernel to fruit ratio (K/F), and kernel to bunch ratio (K/B), indicating the main role of non-additive gene action in the expression of most of the studied characters. In contrast, for AFW, K/F, K/B, the expression of these traits was controlled by additive gene action. These results are supported by ratio of general combining ability variance to specific combining ability variance (σ^2gca / σ^2sca) which produced smaller values than unity, and by the degree of dominance $(\sigma^2_D / \sigma^2_A)^{1/2}$ which also recorded values smaller than unity except for SpW and KY. It was observed that the gene action process for bunch quality component characters, was more controlled by non-additive gene effects. Thus, potential presence of heterosis in the studied population to release superior improved oil palm hybrid can also be found. However, the results showed negative additive and dominance genetic variance for some studied traits. The estimates of the genetic components of variance for these characters were set to zero based on expected mean squares.

Negative estimates of genetic components of variance for some characters were reported by Mather and Jinks (1982). Although additive genetic variance was present for some characters under study, dominance genetic variance was much larger than additive genetic variance for all of the traits except AFW, SpW, K/F, K/B indicating that dominance gene effects were more important than additive gene effects in controlling palm oil yield trait. Thus a favorable oil palm hybrid breeding program can be established for this studied oil palm breeding population. Selection efficiency is related to the magnitude of heritability. In this study, low estimates of narrow-sense heritability were observed for most of the studied traits. However, the results showed moderate to high estimates of broad-sense heritability for height increment (HT), bunch number (BN), Spikelet weight (SpW), kernel to fruit ratio (K/F), kernel to bunch ratio (K/B), and Kernel yield (Table 7). Moderate and high broad-sense heritability were also reported for yield components in oil palm (Okoye *et al*., 2009; Okwuagwu *et al*., 2008). As concerns the proportional contribution of females, males and their interaction for nine studied traits (Table 8), females played important role towards fresh fruit bunch yield (50.26%) and palm oil yield (49.85%) indicating predominant maternal (*Dura*) influence for these traits. Males were more important for average fruit weight (71.08%), kernel to fruit ratio (80.65%), kernel to bunch ratio (78.89%) and kernel yield (75.08%). Thisindicatesthe main role of paternal (*Tenera*) influencefor these traits. The contribution of maternal and paternal interaction (*Dura* female parentx*Tenera* maleparent) was high for height increment of palm trees (60.15%), bunch number (42.21%) andspikelet weight (53.80%). These results showed thatthe *Tenera* male parent families contributed more to the total sum square. Thus, *Tenera* male parentbrought much variation in the expression of the studied population traits.

Conclusion

The results of this study revealed that, from the studied oil palm populations, several crosses are highly promising to breed new oil palm cultivars possessing genetic factors for bunch quality characters and high yield and yield component potential. The results also indicated that among female parent families, DA787D was the best general combiner for all yield and yield component traits followed by LM7899D which recorded positive significant GCA values for fresh fruit bunch (FFB) and bunch number (BN). However, among male parent families, LM9287Tfollowed by LM9175T were recorded as good general combiners for number of bunch per palm. Thus, these *Dura* female and *Tenera* male parent families possess the potential to be utilized in seed production programs and for other breeding purposes. Cross family DA2356D x LM9287T showed the best specific combiner effect for all the yield and yield components. In addition, DA787D x LM9927T, DA507D x LM9175T and LM7899D x LM9287T showed good specific combiners for bunch quality component and height increment of palms. These crosses with highly positive and significant estimates of SCA effect could be selected for use in oil palm improvement breeding programs. The σ^2gca / σ^2sca and $(\sigma^2_D/ \sigma^2_A)^{1/2}$ estimates with relative low ratios and low estimates of h^2_{ns} supported the involvement of both additive and non-additive gene effects with preponderance of non-additive gene actions. The females × males interaction contributed more to the variation of the expression of the different traits. Hence, the information from this study may possibly be useful for Cameroon oil palm research center to develop new high yielding varieties.

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Con ict of interest

The authors declare no con ict of interest.

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