Journal of Applied Biosciences 26: 1664 - 1674
ISSN 1997–5902

Assessment of vegetative growth and production of new improved coconut (*Cocos nucifera* L.) hybrids

[Evaluation des caractères végétatifs et de production des nouveaux hybrides de cocotier (*Cocos nucifera* L.) améliorés]

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Original submitted on 21st December 2009. Published online at www.biosciences.elewa.org on February 11, 2010.

ABSTRACT
Objective: to study vegetative growth and production characteristics of three new improved tall coconut hybrids.
Methodology and results: The hybrids were [Rennell Island Tall improved (RIT^+) x West African Tall improved (WAT^+), Polynesia Tall improved (PYT^+) x WAT^+) and PYT^+ x RIT^+]. The hybrid [Malayan Yellow Dwarf (MYD) x WAT^+ or $PB121^+$] was used as control in the experiment. The results showed that tall hybrids have a significantly more developed bulb (177 cm on average) than $PB121^+$ (149.14 cm). The hybrid RIT^+ x WAT^+ was significantly superior ($P<0.001$) to the others with the most robust stem (C150 = 105.61 cm), plant height (872.80 cm), a weak leaf production (NBCF = 10), leaf size (LR = 483.02 cm, SF=24.27 m^2), number of female flowers (30 units), number of nuts on the bunch 22 (14 units), nut size, husk load and meat (useful for fibre and oil production).
Conclusion and application of findings: According to the results, the hybrid RIT^+ x WAT^+ could be recommended to farmers and industrial end-users.

Key words: Coconut, characters, hybrid, improved, production, vegetative.

RESUME
Les caractères végétatifs et de production de 3 nouveaux hybrides de cocotiers grands améliorés [Grand Rennell amélioré (GRL^+) x Grand Ouest Africain amélioré (GOA^+), Grand Polynésie amélioré (GPY^+) x GOA^+) et GPY^+ x GRL^+] ont été observés pour déterminer leurs caractéristiques en vue d'une valorisation adéquate. L'hybride Nain Jaune de Malaisie (NJM) x GOA^+ ou $PB121^+$ a été utilisé comme témoin dans l'expérience. Les résultats ont montré que ces hybrides grands ont un bulbe plus développé (177 cm en moyenne) que le $PB121^+$ (149,14 cm). L'hybride GRL^+ x GOA^+ a été clairement distingué des autres ($P<0,001$) par un stipe plus robuste (C150 = 105,61 cm), une hauteur plus élevée (872,80 cm), une émission foliaire plus faible (NBCF = 10), de grandes feuilles (LR = 483,02 cm,

SF=24,27 m^2), plus de fleurs femelles (30 unités), un grand nombre de noix sur le régime 22 (14 unités), de grosses noix, beaucoup de bourres et d'amende (utile pour les fibres et la production d'huile). Au vu de ces performances, l'hybride GRL$^+$ x GOA$^+$ est recommandé aux paysans et aux industriels.

Mots clés : Amélioré, caractères, cocotier, hybride, production, végétatif.

INTRODUCTION

Coconut tree (*Cocos nucifera* L.) is an oleaginous plant of the intertropical coastal region. It is the most widely cultivated plant in the world (Ohler, 1999). The total agricultural land globally planted with coconut tree was estimated at 12.05 millions hectares, of which 80% are in Asia and the Pacific. About 5.27 % of the total cultivated areas globally are located in Africa (Amrizal, 2003). The coconut tree is a source of fatty acids and many industrial products (Bourdeix *et al*., 2005a). About 10 million small-scale farmers rely on coconuts as their main source of incomes (Moore & Batugal, 2004).

More than 53 cultivars of coconut were introduced in Côte d'Ivoire by the Institute of Research for oil and Oleaginous (IRHO) to allow breeders to develop improved hybrids. The breeding scheme adopted was based on the reciprocal recurrent selection created by Comstock *et al*. (1949). Two approaches to reciprocal recurrent selection were adopted: Tall x Tall and Dwarf x Tall hybrid improvement. The progeny tests implemented at Marc Delorme Research Station in Côte d'Ivoire are used to assess the hybrids. The first generation of hybrids developed was promoted until 1980. The mean yield of these hybrids is about 3 t copra.ha^{-1}.yr^{-1} (in Côte d'Ivoire).

The second generation which is an improvement of the first hybrids was developed by selecting the best parents within the cultivar populations (Bourdeix *et al*., 1989; De Nuce de Lamothe, 1990). The progeny tests of the improved tall x tall hybrids were planted in experimental field at Marc Delorme station in 1995. Physical and chemical characteristics of these hybrids were already evaluated (Konan, 2006; Konan et al., 2008). However, the vegetative and production characteristics of these new hybrids have not yet been studied.

Moreover, some farmers prefer tall coconut varieties producing big nuts with a high oil content and copra. Moreover, tall varieties tolerate water deficits better than the dwarf varieties and the dwarf x tall hybrids (Konan, 1997). Therefore, the present study aimed to determine the vegetative growth and production characteristics of new improved tall coconut hybrids in order to propose better enhanced value of these materials.

MATERIALS AND METHODS

Plant material: Four hybrids that descended from the following crossings were studied:

(1) Rennell Island Tall improved (RIT$^+$) x West African Tall improved (WAT$^+$);

(2) Polynesia Tall improved (PYT$^+$) x West African Tall improved (WAT$^+$);

(3) Rennell Island Tall improved (RIT$^+$) x Polynesia Tall improved (PYT$^+$);

(4) Malayan Yellow Dwarf (MYD) x West African Tall improved (WAT$^+$) or PB121$^+$ used as control. It was developed in Côte d'Ivoire and is reported to be the most widely grown hybrid in the world (Bourdeix et al., 2005). For each hybrid, 10 trees were randomly chosen and analysed making a total population of 40 trees.

Experimental methods (table 1): The field experiment started in 1995 on field No. 051 at Marc Delorme Port-Bouët Research station of the Centre National de Recherché Agronomique (CNRA, Côte d'Ivoire). Ten (10) hybrids were planted on this field. Plants were arranged in a completely randomised design with two repetitions. The plant density is 143 trees per hectare.

A ladder was used to climb the coconut trees to reach the foliar circlet. A machete was used to cut leaves and inflorescences, which were measured on the ground using a band meter and a slide foot. At the laboratory, a balance was used to weigh the nuts and its components. The meat (white flesh) was dried in a drier before determining copra quantity. First, the nuts were broken; then the meat (white flesh) was sampled in the equatorial zone. The samples must have the same size for the nuts of the same hybrid. The meat fragments obtained were weighed then dried in the drier at 105°C for 48 hours in aluminium containers. The dried meat was weighed to determine copra quantity at 6 % of moisture.

Vegetative characters: On each coconut tree, the stem, the leaves and the inflorescence characteristics were observed. On the stem, the plant height (HS), the root bulb circumference 20 cm from the ground (C20), the stem circumference 150 cm from the ground (C150) and the number of leaves scars between one and two meter (s) were measured.

Concerning the leaf and the inflorescence, measures were done on the ones of rank 25. The leaf rachis length (LR), the leaf petiole length (LP), the leaf petiole thickness (EP), the leaf petiole width (LGP), the number of leaflets down one side of the leaf (NBF), the leaflet length (LF), the leaflet width (LGF) and the foliar theoretical surface (SF=2 x NBF x LF x LGF) were measured on the leaf. The axis length (ILA), the peduncle length (ILP), the peduncle circumference (ICP), the spikelets length (ILE), the distance between the point of spikelet insertion and the insertion of the first fruit (ILPRF), the spikelets number (NBE), the number of spikelets with female flowers (NBFF), and the number of spikelets without female flowers (NBESF) were determined on the inflorescence.

Production characters: The number of female flowers on the inflorescence bore by the number 10 leaf (NBFF), the number of bunches per tree (NBR) and the number of nuts on the bunch 22 (NBN22) were the yield characters assessed. Nuts physical parameters were also determined including the entire fruit weight (MNE), the husk weight (MB), the fruit weight without husk (MND), the shell weight (MCQ), the meat weight (MALB), the water weight (ME) and the percentage of copra per nut (Q). On each tree, four mature nuts (so, 40 nuts per hybrid) were collected and kept in a store for 15 days to achieve their maturation before measuring these physical parameters.

Statistical analysis: An analysis of variance with two classification criteria was carried out using the software SPSS vs. 9.0. The Student Newman-Keuls test was used to compare mean values of the parameters assessed in the different hybrids. Correlation coefficients were calculated to determine the relations between vegetative and production characters analyzed; the agromorphological relationships between the hybrids were determined using cluster analysis method, and Principal components analysis (PCA) was used to further describe the hybrids. The last analyses were conducted using the software XLSTAT vs. 7.1.

Table 1: Abbreviations for the different variables assessed on coconut hybrids in Côte d'Ivoire.

C20	: Bulb circumference 20 cm from the ground	MB	: Husk weight
C150	: Stem circumference 150 cm above ground	MCP	: Copra weight
EP	: Leaf petiole thickness	MCQ	: Shell weight
HS	: Stem height	ME	: water weight
ILA	: Inflorescence axis length	MND	: Fruit weight without husk
ICP	: Peduncle circumference	MNE	: Fruit weight
ILE	: Spikelets length	NBCF	: Number of leaves scars between one and two meter (s)
ILP	: Peduncle length	NBE	: Spikelets number
ILPRF	: distance between the point of spikelet insertion and the insertion of the first fruit	NBEF	: Number of spikelets with female flowers
LR	: Leaf rachis length	NBESF	: Number of spikelets without female flowers
LP	: Leaf petiole length	NBF	: number of leaflets down one side of the leaf
LGF	: Leaflet width	NBR	: number of bunches per tree
LGP	: Leaf petiole width	NBN22	: number of nuts on the bunch 22
LF	: Leaflet length	SF	: Foliar theoretical surface
MALB	: Meat weight	Q	: Percentage of copra per nut

RESULTS

Vegetative characters: There were differences amongst the hybrids in some vegetative characters (table 2). The tall x tall hybrids' bulbs were better than the control (PB121$^+$). The bulb size ranged from 165.02 cm to 194.98 cm for tall x tall hybrids compared to 149.14 cm for the control. However, the hybrids PYT$^+$ x WAT$^+$ and RIT$^+$ x PYT$^+$ were not significantly different from the control hybrid PB 121$^+$ in the aspect of stem circumference at 150 cm above the ground (C150), plant height (HS), leaf rachis length (LR), the number of spikelets with female flowers (NBEF) and the foliar theoretical surface (SF=2 x NBF x LF x LGF). Only the hybrid RIT+ x WAT+ was clearly distinguished, and it showed bigger stem (105.65 cm), vast leaves (SF = 24.27 m^2, LR = 483.02 cm), many spikelets (30 spikelets) and a high plant height (872.80 cm) than the other hybrids (table 2).

No significant difference was detected amongst the three hybrids tested concerning the leaflet width (LGF); the spikelets number (NBE) and the distance between the point of spikelet insertion and the insertion of the first fruit (ILPRF) (table 2). However, tall hybrids petioles were longer than for the control hybrid. The petiole length varied from 168.35 cm (RIT+ x PYT+) to 161.9 cm (RIT+ x WAT+) while the length of the petiole of the control hybrid was 149.41 cm.

Peduncles and spikelets of tall hybrids were comparatively longer than those of the control hybrid PB 121+ (table 2), but not significantly different among the tall hybrids. Concerning the peduncle circumference (ICP), the hybrid RIT+ x WAT+ was superior (9.83 cm) to hybrids RIT+ x PYT+ (8.95 cm) and PB 121+ (8.53 cm) but not to the hybrid PYT+ x WAT+ (9.42 cm). Inflorescence axis length (ILA) of hybrid RIT+ x WAT+ (45.31 cm) was also superior to the control one (40.75 cm) but was not significantly different to the hybrids RIT+ x WAT+ (42.94 cm) and RIT+ x PYT+ (41.83 cm). The number of leaves scars, which varied from 10 to 15 units, structured the hybrids into three groups. The hybrid RIT+ x WAT+ (10 units) was grouped together with the hybrid PYT+ x WAT+ (10 units) and the hybrids PYT+ x RIT+ (12 units) and MYD x WAT+ (15 units) formed the second and the third group, respectively.

Table 2: Comparison of improved coconut hybrids for vegetative characteristics in experimental field

		Hybrids			
	Variable[1]	MYD x WAT+ (T)	RIT+ x WAT+	PYT+ x WAT+	PYT+ x RIT+
Stem	C20 (cm)	149,14±11,97 a	194,98±19,85 c	171,03±18,37 b	165,09±22,98ab
	C150 (cm)	86,50±2,25 a	105,61±8,81b	93,47±4,59 a	87,42±11,64a
	HS (cm)	746,40±47,91ab	872,80±39c	766,4±52,37b	703,10±69,04a
	NBCF	15±0,82 c	10±0,74a	10±1,45a	12±1,93b
Leaf	LP (cm)	149,41±4,41 a	161,9±6,83 b	166,15±14,6 b	168,35±13,28 b
	LGP (cm)	8,02±0,34 ab	9,09±0,49 c	8,39±0,54 b	7,74±0,58 a
	EP (cm)	3,35±0,20 a	4,13±0,40 b	3,40±0,20 a	3,26±0,25 a
	LR (cm)	456,70±25,69 a	483,02±21,55 b	452,63±20,46 a	429,04±34,42 a
	NBF	113,30±2,79a	124,30±2,58b	116,80±4,69a	115±4,94 a
	LGF (cm)	6,75±0,43a	6,92±0,51a	6,69±0,56a	6,37±0,51a
	LF (cm)	139,86±2,95b	141,04±8,26b	135,80±4,30ab	131,80±7,27a
	SF (m2)	21,37±1,36a	24,27±2,39b	21,21±1,83a	19,38±2,72a
Inflorescence	ILP (cm)	57,81±5,26 a	71,083±5,49 b	64,99±7,16 b	64,75±5,88 b
	ICP (cm)	8,53±0,86 a	9,83±0,56 c	9,42±0,46b bc	8,95±1,14 ab
	ILA (cm)	40,75±1,90 a	42,94±4,48 ab	45,31±4,42 b	41,83±3,15 ab
	NBE	41,20±4,47 a	42,20±5,43 a	41,10±3,63 a	43,40 ± 6,06 a
	NBESF	18,70±4,60 b	12,40±5,87 a	21,50±3,87 b	22,50±9,44 b
	NBFF	22,50±7,72 a	29,80±8,11 b	19,60±1,35 a	20,90±5,32 a
	ILE (cm)	39,89±4,60 a	52,96±3,42 b	48,91±4,50 b	47,65±8,81 b
	ILPRF (cm)	8,42±2,83 a	9,42±0,96 a	8,36±1,38 a	8,24±1,59 a

[1] Variables are described in table 1. Means with different letters are different at $P < 0.05$ using Newman - Keuls test.

Production characters: The hybrid RIT+ x WAT+, with 30 flowers, presented significantly more female flowers (NBFF) than the two other tall x tall hybrids tested PYT+ x WAT+ and RIT+ x GPY+. These last hybrids had 20 and 21 female flowers, respectively, and were statistically identical to the control hybrid PB 121+ (23 female flowers) for this character.

With regard to the number of nuts on the bunch 22 (NBN22), the hybrids RIT+ x WAT+ and PYT+ x WAT+ presented the same performance as the control hybrid PB121+ (table 3). Compared to t the hybrids RIT+ x WAT+ and PYT+ x WAT+, RIT+ x PYT+ had fewer nuts on the bunch 22 (8 nuts). In general, tall x tall hybrids produced nuts that were bigger than those of the control hybrid (table 3). However, the control hybrid PB121+ (276.25 g) and the hybrids PYT+ x WAT+ (319 g) and RIT+ x PYT+ (357.48 g) provided statistically identical husk weight. Only the hybrid RIT+ x WAT+ (405 g) differed significantly from the others. Tall coconut hybrids fruit components (shell and meat) were statistically heavy to those of the control hybrid, but their copra weights were statistically identical. The hybrid RIT+ x WAT+ fruit components were significantly superior to the control hybrid PB 121+ (table 3).

Table 3: Comparison of improved coconut hybrids for production characteristics in experimental field.

	Hybrids			
Variable	MYD x WAT+ (T)	RIT+ x WAT+	PYT+ x WAT+	PYT+ x RIT+
NBR	15,30 ± 1,25 a	16,40 ± 1,58 a	14,80 ± 1,55 a	15,20 ± 1,69 a
NBFF	22,50 ± 7,72 a	30,40 ± 8,44 b	19,60 ± 1,35 a	20,90 ± 5,32 a
NBN22	11,30 ± 3,47 ab	13,50 ± 4,20 b	12,20 ± 5,18 b	8 ± 1,41 a
MNE (g)	782,50 ± 113,22 a	1148,75 ± 157,72 b	956,25 ± 244,54 b	1072,08 ± 205,46 b
MND (g)	506,25 ± 71,26 a	743,75 ± 113,54 b	638,75 ± 199,52 b	714,58 ± 143,24 b
MB (g)	276,25 ± 60,51a	405 ± 62,69 b	319 ± 68 a	357,48 ± 104,90 ab
MCQ (g)	95 ± 13,44 a	161,25 ± 21,61 c	132,5 ± 31,84 b	170,35 ± 35,39 c
ME (g)	98,75 ± 32,52 a	166,25 ± 67,20 a	141,25 ± 79,51a	168,33 ± 56,25a
MALB (g)	312,50 ± 34,36 a	426,25 ± 45,66 b	368,75 ± 96,33 ab	392,92 ± 72,04 b
MCP (g)	163,51 ± 29,53 a	240,35 ± 38,91 b	196,46 ± 66,13 ab	213,47 ± 62,75ab
Q (%)	24 ± 3,45 a	24,53 ± 3,41a	23,89 ± 4,34 a	23,59 ± 4,06a

Means with different letters are different at $P < 0.05$ using Newman - Keuls test.

Relations between production and vegetative characters: Correlation analysis revealed strong relationships among vegetative and production characters (table 4). The number of female flowers (NBFF) was positively and significantly correlated to the number of spikelets with female flowers (NBEF) amongst the hybrids. Correlations coefficients were 0.99 or 1.

The number of female flowers (NBFF) was negatively correlated to the number of leaves' scars (NBCF) amongst the hybrids RIT+ x WAT+ and PYT+ x WAT+. The coefficients of correlation recorded between these variables were, respectively - 0.87 and - 0.70. With hybrid RIT+ x PYT+, the number of nuts on the bunch 22 (NBN22) increased with the number of leaves scars and the correlation coefficient between these two characters was 0.77.

Positive correlations between the inflorescence peduncle length (ILP) and the whole fruit weight (MNE) (r = 0.74) in the first way, and the inflorescence peduncle circumference (ICP) and the number of female flowers (NBFF) (r = 0.82) in the second way, showed that more female flowers and heavier fruits were carried by inflorescences with developed peduncles. Negative relationship was observed between fruit components (copra, meat, nut without husk) and the spikelets number (NBE) (table 4). Amongst the control hybrid PB 121+ and the hybrid RIT+ x PYT+, the number of female flowers (NBFF) increased with the spikelets length (ILE) with correlation coefficients of 0.78 and 0.80, respectively. Significantly high and positive correlations were observed between the number of female flowers (NBFF) and the number of spikelets (NBE) amongst the hybrids RIT+ x WAT+ (r = 0.85) and PB 121+ (r = 0.70). The number of female flowers (NBFF) were also positively correlated to the distance between the point of spikelet insertion and the insertion of the first fruit (ILPRF) on hybrids RIT+ x PYT+ (r = 0.76) and RIT+ x WAT+ (r = 0.73). High and significant correlation between the bulb circumference 20 cm from the ground (C20) and the fruit water weight (ME) (r = 0.74), was also recorded on hybrid PYT+ x WAT+.

Table 4: Significant correlations between vegetative and production characters studied on the hybrids

Hybrid	Variable	Correlation coefficient (r)
MYD x WAT+ (T)	NBFF/NBEF	1
	NBFF/ILE	0,78
	NBFF/NBE	0,85
RIT+ x WAT+	NBFF/NBEF	0,99
	NBFF/NBCF	-0,87
	NBFF/NBE	0,70
	NBFF/ILPRF	0,73
PYT+ x WAT+	NBFF/NBEF	1
	NBCF/NBFF	-0,70
	C20/ME	0,74
PYT+ x RIT+	NBFF/NBEF	1
	NBCF/NBN22	0,77
	ILP/PNE	0,74
	ICP/NBFF	0,76
	NBE/MCP	-0,77
	NBE/MALB	-0,85
	NBE/MND	-0,75
	NBFF/ILE	0,80
	NBFF/ILPRF	0,82

Principal component analysis (PCA) and hierarchical classification analysis (HCA): The vegetative and production relationships (figure 1) constructed from the population showed two main clusters of hybrids. The hybrid RIT+ x WAT+ constituted the first cluster. The second cluster included the two other tall x tall hybrids (RIT+ x PYT+, PYT+ x WAT+) and the control hybrid PB 121+. In the second group, hybrids are further grouped in two subgroups. The first subgroup comprised of the hybrids RIT+ x PYT+ and PYT+ x WAT+ and the control hybrid was isolated in the second subgroup (figure 2).
The PCA (figure 1) on the whole vegetative and production characters indicated that the first two principal components were adequate in explaining the variation between the hybrids assessed. These two principal components accounted for 53.35 % of the vegetative and production variation (table 5). The first component described 36.25 % of the total variation. It was mainly formed by five vegetative characters (bulb circumference 20 cm from the ground, stem circumference 150 cm above ground, leaf petiole thickness, number of leaflets down one side of the leaf and peduncle length) and two physical traits of the nut (fruit weight and fruit weight without husk. The second component explained 17.10 % of the total variation. This component was essentially defined by two leaf characters (LGF, SF) and two physical traits of the nut (MALB, ME) (table 5). In general, the PCA result confirmed those obtained with cluster analysis. The hybrid RIT+ x WAT+ in the cluster I formed a distinct group. In the same way, the two subgroups distinguished in the cluster II were confirmed. The first subgroup contained the hybrids RIT+ x PYT+ and PYT+ x WAT+ while the control hybrid formed the second one. According to this organisation, the tall x tall hybrids were characterized as follows:
(i) the hybrid RIT+ x WAT+ was distinguished by a large bulb circumference, large stem circumference, thick petiole , high number of leaflets, high peduncle length, heavy fruit, wide leaflets, high foliar surface, low meat weight and water.
(ii) the hybrids RIT+ x PYT+ and PYT+ x WAT+ were mainly characterized by fine leaflets, low foliar surface, high meat weight and water.

Table 5: Eigen values and correlation matrix between characters analysis and the principal components of the PCA.

	Axe1	Axe 2	Axe 3	Axe 4	Axe 5	Axe 6	Axe 7	Axe 8
Eigen value	11,238	5,303	2,291	1,886	1,695	1,431	1,182	1,048
Variation (%)	36,253	17,105	7,391	6,084	5,467	4,615	3,811	3,381
% cumulative	36,253	53,358	60,749	66,833	72,300	76,915	80,726	84,107
C20	0,866*	-0,023	-0,091	-0,151	0,061	0,114	-0,053	-0,063
C150	0,796*	-0,345	-0,165	-0,056	0,023	0,107	-0,016	-0,099
HS	0,552	-0,559	-0,237	-0,101	-0,066	0,106	0,096	-0,042
NBCF	-0,683	0,032	0,451	0,264	-0,085	-0,062	-0,047	0,081
LP	0,365	0,484	-0,038	-0,302	0,329	0,235	-0,165	0,325
LGP	0,666	-0,514	-0,243	0,031	-0,225	0,022	-0,070	-0,006
EP	0,739*	-0,419	-0,053	0,060	-0,134	0,000	-0,201	0,084
LR	0,674	-0,342	0,332	-0,101	-0,020	-0,082	-0,409	0,090
NBF	0,793*	-0,104	0,076	-0,171	-0,232	0,186	-0,095	-0,274
LGF	0,211	-0,638*	-0,183	-0,016	-0,373	0,207	0,219	0,093
LF	0,457	-0,450	0,169	0,180	0,018	-0,108	-0,294	0,568*
SF	0,617	-0,614*	-0,031	0,011	-0,303	0,173	-0,016	0,187
ILP	0,733*	0,340	0,019	-0,089	0,284	0,093	0,011	0,026
ICP	0,696	-0,078	-0,055	-0,144	0,266	0,246	0,065	0,059
ILA	0,362	0,247	-0,050	-0,446	0,435	-0,094	-0,168	0,037
INBE	-0,031	-0,028	-0,158	0,601	0,476	0,501*	-0,225	-0,034
NBESF	-0,651	0,316	-0,344	-0,069	-0,005	0,510*	-0,139	0,176
NBEF	0,635	-0,338	0,239	0,477	0,328	-0,174	-0,013	-0,201
ILE	0,688	0,139	-0,048	-0,194	0,278	-0,183	0,349	-0,034
ILPRF	0,400	-0,049	0,355	-0,215	0,076	-0,330	0,283	0,399
NBFF	0,643	-0,344	0,232	0,466	0,331	-0,174	-0,009	-0,201
NBR	0,232	-0,313	0,172	0,138	0,252	0,331	0,654*	0,204
NBN22	0,170	-0,428	0,161	-0,585*	0,172	0,033	-0,090	-0,353
MNE	0,760*	0,562	-0,154	0,146	-0,174	-0,101	0,016	0,011
MND	0,705*	0,661	0,065	0,102	-0,149	-0,006	-0,002	0,003
MB	0,658	0,227	-0,527	0,187	-0,173	-0,254	0,047	0,024
MCQ	0,590	0,551	-0,445	0,206	-0,023	-0,015	0,128	-0,008
ME	0,566	0,683*	0,095	0,063	-0,113	-0,123	-0,134	0,067
MALB	0,684	0,617*	0,212	0,062	-0,189	0,110	0,038	-0,050
MCP	0,674	0,509	0,350	0,094	-0,268	0,209	0,056	-0,058
Q	0,179	0,220	0,794	-0,053	-0,230	0,402	0,049	-0,085

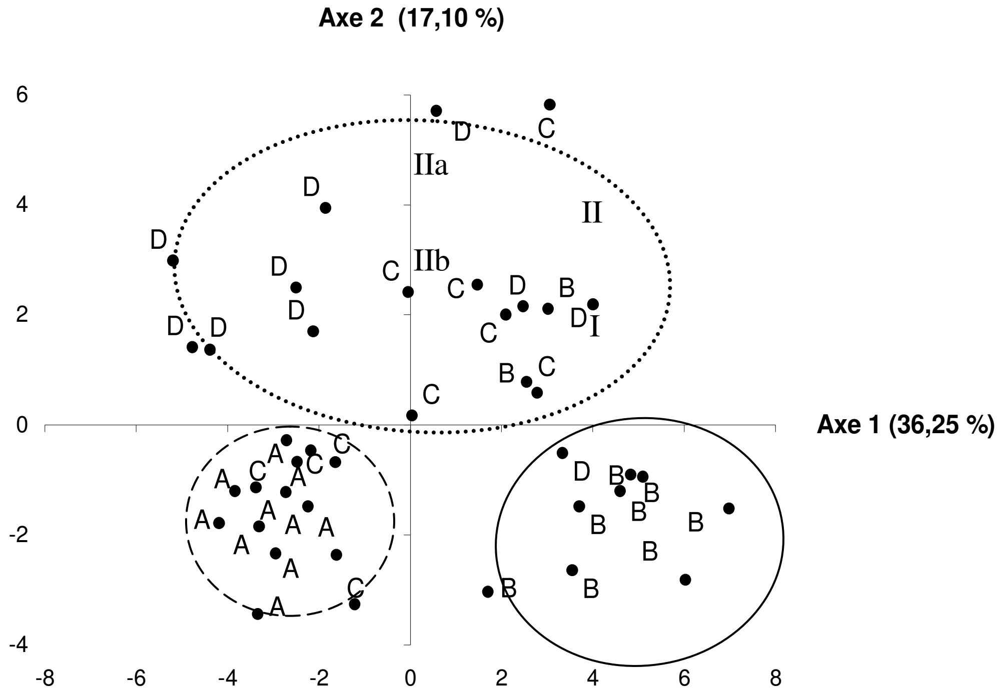
* Variables mostly correlated to the component

DISCUSSION

Assessment of vegetative characters shows that tall x tall coconut hybrids developed more robust bulbs than the control hybrid PB121+. This character was probably inherited from their two tall parents. Indeed, tall coconut trees are characterized by very well developed root bulb. This character confers to tall coconut trees the resistance needed to violent winds and/or drought (De Nuce & Wuidart, 1982; Konan, 1997).

The hybrid RIT+ x WAT+ has greater stem circumference 150 cm from the ground than its two parents RIT and WAT that were described by De Nuce & Wuidart (1979). This performance suggests heterosis effect (Bourdeix, 1989). Consequently, this hybrid is an excellent plant material for regions with extensive dry seasons since the robust stem of tall coconut trees facilitates water accumulation for use during periods of water deficiency (Konan *et al*., 2006). The hybrids (RIT+ x WAT+ and PYT+ x WAT+) with robust stem showed more developed bulbs and tall plants. These hybrids have less foliar scars than the hybrids MYD x WAT+

and PYT⁺ x RIT⁺, which were characterized by a low plant height. These results are similar to those of Konan *et al*. (2006). According to Le Saint *et al*. (1983) fast leaf production can explain the more reduced distance between scars observed with the hybrids MYD x WAT⁺ and RIT⁺ x PYT⁺. Otherwise, the ascendant Polynesia Tall of the hybrid RIT⁺ x PYT⁺ is characterized by fast leaf production (De Nuce & Wuidart, 1979). This character possibly has a strong heritability that was expressed in the hybrid. This behavior could also indicate more efficient assimilation of nitrogen element by the hybrids MYD x WAT⁺ and RIT⁺ x PYT⁺. Achuthan and Sreedharan (1983) demonstrated that leaf production increased with nitrogen element application. With the control hybrid PB121+, the fast foliar emission would have been inherited with the female parent Malayan Yellow Dwarf. In general, dwarf coconut trees give out one leaf on average per month compared to 45 days for the tall genotypes.



A → MYD x WAT⁺ (control); **B** → RIT⁺ x WAT⁺**; C** → PYT⁺ x WAT⁺**; D**→ PYT⁺ x RIT⁺

Figure 1: Principal components analysis ordination of 40 coconut hybrid plants showing the groups identified based on shared agromorphological characteristics.

The hybrid RIT⁺ x PYT⁺ has low plant height. This character was certainly inherited from the parent Polynesia tall (PYT), which is characterized by low height according to De Nuce & Wuidart (1979).

The hybrids tall x tall presented longer leaflets compared to the control hybrid. They would have also inherited this character from their parents. Indeed, tall coconut trees generally possess big leaves with longer leaflets than the dwarf trees (N'cho *et al*., 1988). The high foliar surfaces of tall hybrids enhance chlorophyll exchange resulting in better development of tall coconut hybrid tree organs (stem, leaves and fruits). Concerning the inflorescence, the hybrids' spikelets number is similar to that of their parents PYT and WAT (De Nuce & Wuidart, 1979).

The peduncle and spikelet lengths of the control hybrid were lower than for the three tall hybrids tested. This characteristic of the control hybrid (MYD x WAT⁺) is inherited from the Malaysia Yellow dwarf parent (MYD). Indeed, MYD is characterized by a short peduncle and spikelet (Le Saint et *al*., 1983). The small size of the control hybrid peduncle, corresponding to insufficient insertion space, constitutes an obstacle to development of nuts. On the other hand, the tall x tall hybrids can produce more big nuts due to their long peduncles. However, due to the heavy bunch weight, these nuts are more likely to fall down prematurely (De Nuce & Rognon, 1977). Based on their similarity with the control hybrid on the aspects of vegetative measurements (rachis length and theoretical foliar surface), the tall hybrids (PYT^+ x WAT^+ and RIT^+ x PYT^+) could be planted at a density of 160 trees.ha^{-1} (as the control hybrid) instead of the recommended 143 trees.ha^{-1}.

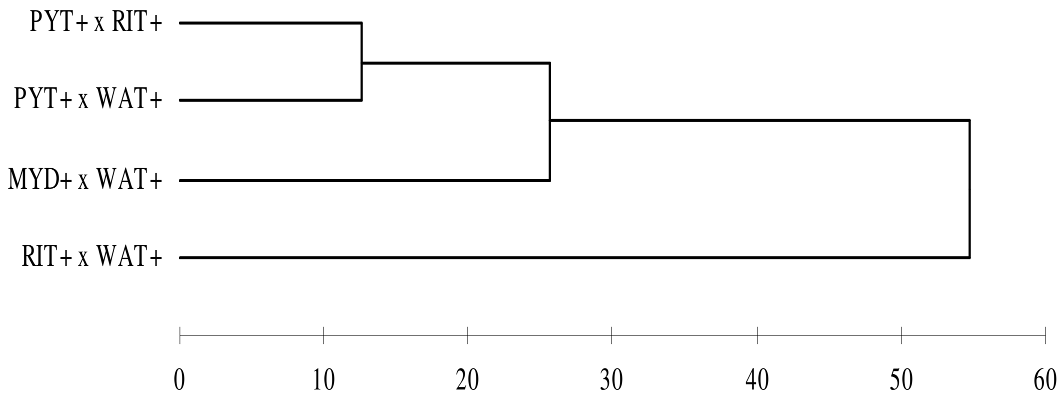


Fig. 2: Cluster analysis of vegetative and production relationships among four improved coconut hybrids in Côte d'Ivoire.

The hybrid RIT^+ x WAT^+ had the highest number of spikelets with female flowers. It would have inherited this character from the parent WAT that possesses more spikelets with female flowers than the parent RIT (De Nuce *et al*., 1983).

A high number of female flowers observed per inflorescence could explain the elevated number of nuts on the bunch 22 of RIT+ x WAT+. This yield potential was maintained until maturity of the nuts. The identical number of spikelets for the three hybrids studied means that they have the same yield potentiality. Konan et al. (2006) identified the number of spikelets as a yield index. However, the hybrid RIT^+ x WAT^+, which produces more female flowers, is superior to the other hybrids.

The weight of the nuts and its main components (shell, water, meat, copra) amongst tall x tall hybrids were determined to be superior to those of the control hybrid $PB121^+$. The performances of tall hybrids are the results of a good heritability of yield characters from their tall parents.

Indeed, De Nuce & Wuidart (1979) reported high weights of the fruit and its components concerning the populations WAT, PYT and RIT. Among the tall x tall hybrid, RIT^+ x WAT^+, with its most elevated weight of nuts and components would be more close to the parent RIT (maternal effect). Konan *et al*. (2006) showed the same relation between this hybrid and its parent RIT. The weight of the nuts and its main components obtained for the control hybrid and RIT^+ x WAT^+ were lower than those reported by Bourdeix et al. (2005 b). Experimental conditions could explain this variation. Quencez & De Taffin (1981) indicated that potassium fertilization influences the coconut tree yield potential. However, at the experimental site, land fertilization and plant sanitary maintenance were not regular in the past 10 years. This situation must have reduced the yield potential of the material tested.

Fast foliar emission observed with the hybrids $PB121^+$ and RIT^+ x PYT^+ would increase the yield potential, as every leaf should carry an inflorescence to its axil (Konan et al., 2006). De Nuce & Rognon (1977) explain the difference of yield production observed between the coconut trees by the influence of leaf size, inflorescences and the environment. This observation is particular relevant with hybrid RIT^+ x WAT^+. With a slow leaf production, this hybrid is better prepared to develop big leaves and to produce numerous female flowers that develop into nuts. Due to its well-developed vegetative system, the hybrid RIT^+ x WAT^+ appears well acclimated than the others hybrids. Correlation analysis revealed negative and positive correlations between some morphological and production characters. N'cho *et al*. (1993) explained negative correlations by direct causal relations between organs in competition for a limited quantity of resources (nitrogen, hormones, carbon assimilated) or by a ling growth. Negative correlations were observed between the number of spikelets with female flowers and the number of spikelets without female flowers, the number of female flowers and the number of foliar scars and between the number of bunch per tree and the nut weight.

The production of hormone by an organ, which initiates the development of another, could explain positive correlations observed between morphological and production characters like the number of foliar scars and the number of nuts on the bunch 22 and between the number of female flowers and the spikelets length. The inflorescences with more developed peduncles carry more female flowers. Such behavior explains the predisposition of the peduncle to support a high number of nuts.

PCA and cluster analyses of agromorphological characters indicated that it is possible to distinguish tall x tall coconut hybrids, particularly hybrids PYT^{+} x WAT^{+} and RIT^{+} x PYT^{+} from the hybrid RIT^{+} x WAT^{+}. The hybrids PYT^{+} x WAT^{+} and RIT^{+} x PYT^{+} are very similar, certainly because of the dominance of the shared female parent PYT (maternal effect). These two hybrids were also closely related to the control hybrid PB 121^{+}with regard to leaf traits (EP, LR, NBF, SF), the stem height, the stem circumference 150 cm from the ground, the peduncle circumference, the number of spikelets without female flower and the number of spikelets with female flowers. They have also the same number of female flowers per inflorescence. On the other hand, the hybrid RIT^{+} x WAT^{+} is clearly different. In spite of the utilization of the same male parent in the crossings RIT^{+} x WAT^{+}, MYD x WAT^{+} and PYT^{+} x WAT^{+}, some differences were noted between the hybrids tested. This observation would most likely be due to the lower paternal effect in comparison to the maternal parents.

CONCLUSION

This study aimed to evaluate the vegetative and production characters of tall-improved coconut hybrids in order to propose better valorisation of these materials. In general, the tall x tall hybrids showed similar yield production than the control hybrid regarding the number of bunch per tree and the number of nuts on the bunch 22. However, they produced bigger nuts with heavier components than the control hybrid. Specifically, the hybrid RIT^{+} x WAT^{+} is characterized by elevated weight of copra, husk and meat. According to these results, the hybrid RIT^{+} x WAT^{+} can be recommended to the farmers for producing big nuts. Furthermore, since this hybrid has a vegetative development close to the control hybrid, it could be planted at a higher density of 160 trees/ha (as the control hybrid) instead of the currently recommended 143 trees/ha. The husk, the shell and the meat of the hybrids RIT^{+} x WAT^{+} and PYT^{+} x RIT^{+} would appear to be appropriate for an industrial transformation

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