F O N D A M E N T A L

Coconut (*Cocos nucifera L.*) genetic improvement in Vanuatu: Overview of research achievements from 1962 to 2002.

Part 2: Improvement of the Vanuatu Tall by hybridization*

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Abstract: *From 1962 to 2002, at the Saraoutou research station on the island of Santo in Vanuatu, a hybrid creation programme was implemented to improve the productive potential of coconut cultivars. The first stage was to create a collection by introducing around thirty exotic varieties. All those varieties and most of the 60 hybrids created proved to be susceptible to coconut foliar decay, a viral disease transmitted by Myndus taffini and endemic in Vanuatu. Only the Vanuatu Tall populations and two hybrids (Vanuatu Red Dwarf × Vanuatu Tall and Vanuatu Tall × Rennell Island Tall) displayed tolerance enabling their distribution to farmers.*

The author indicates the origin of the parents and the production characteristics of these two hybrids. The Vanuatu Red Dwarf × Vanuatu Tall hybrid expresses good hybrid vigour with a production potential ranging from 2.5 to 3.4 tons per hectare per year. However, it does have several defects: slow germination and a highly irregular final germinated nut rate, susceptibility to cyclones when young, premature nut fall sometimes seen on young palms, and a mediocre copra content (between 135 and 160 g). The Vanuatu Tall × Rennell Island Tall hybrid stands out through its early start to bearing (4 years), its vigour and its good adaptation to cyclones. The copra content of its nuts (between 210 and 245 g) is better than that of the Vanuatu Tall, making copra preparation easier. Its production ranges from 2.5 to 3 tons per hectare per year, which is around 30% better than the improved Vanuatu Tall (Elite Vanuatu Tall). However, dissemination of this hybrid, which can only be produced in centralized seed gardens, is limited by the cost of production and of transport throughout the archipelago. Only large-scale Elite Vanuatu Tall production in decentralized seed gardens would enable a significant improvement in coconut productivity in Vanuatu.

Key words: *Pacific, Vanuatu, coconut, genetic improvement, copra, seednuts, hybrid, virus*

Introduction

In 1962, a coconut palm genetic improvement programme was launched at the Saraoutou research station (now the Vanuatu Agricultural Research and Technical Centre or VARTC) on Santo Island, Republic of Vanuatu, in the southwestern Pacific Ocean. The breeding programme proceeded along two parallel and complementary lines. Firstly, several mass selection cycles and crosses were carried out within and between local Tall populations, called the Vanuatu Tall (international code VTT). This approach proved to be effective in increasing nut copra content. However, flowering precocity, the number of nuts, and consequently copra production per plot, remained highly dependent upon growing conditions and the care taken with seedlings in the nursery. The results of this mass selection were reported in detail in Part I of this article [1].

To overcome the limitations of this method of increasing production potential, hybridization was tested, using the search for tolerance of coconut foliar decay virus as the major constraint.

This article describes the main steps in the hybridization programme, the methods used for assessing the performance of the hybrids, and the main results obtained.

Steps in the hybridization programme

Creation of a collection

To develop hybrids suitable for Vanuatu, the first step was to create a collection of varieties by introducing a number of Dwarf and Tall exotic varieties. The first introductions were made in December 1962 with the Rennell Island Tall (RIT) imported from the Solomon Islands, along with the Niu Leka Dwarf (NLAD), Malayan Yellow Dwarf (MYD), Malayan Red Dwarf (MRD) and Malayan Green Dwarf (MGD) imported from Fiji. The list of exotic varieties introduced in the Saraoutou collection from 1962 to 2002 is given in *table 1*. Most of them were multiplied by hand pollination and are still conserved in the VARTC genebank.

* See Part 1 in: OCL 2004, vol. 11, n° 4-5, p. 354-61.

FONDAMENTAL

Table 1. *List of exotic varieties introduced in the Saraoutou collection from 1962 to 2002.*

Variety name	Code	Date of first planting (Plot)	Origin	Donor
Dwarf varieties				
Aromatic Green Dwarf	AROD	1983 (P31)	Thailand	Sawi research station, Thailand
Brazilian Green Dwarf	BGD	1975 (P50)	Brazil	Marc-Delorme station, IC
Cameroon Red Dwarf	CRD	1967 (P31), 1983 (P31)	Kribi, Cameroon	Marc-Delorme station, IC
Catigan Green Dwarf	CATD	1983 (P31)	Philippines	PCA-Zamboanga, Philippines
Kiribati Green Dwarf	KIGD	1991 (P50)	Butaritari, Kiribati	–
Madang Brown Dwarf	MBD	1983 (P31)	Madang, PNG	Marc-Delorme station, IC
Malayan Green Dwarf †	MGD	1964 (P02)	Malaysia	Fiji
Malayan Red Dwarf	MRD	1964 (P02), 1967 (P31)	Malaysia	Fiji
Malayan Yellow Dwarf	MYD	1964 (P02), 1967 (P31)	Malaysia	Fiji
Malayan Yellow Dwarf	MYD	1967 (P31), 1974 (P50)	Malaysia via Ghana	Marc-Delorme station, IC
Niu Leka Dwarf	NLAD	1964 (P02)	Fiji	Taveuni, Fiji
Pilipog Green Dwarf	PILD	1983 (P31)	Philippines	PCA-Zamboanga, Philippines
Samoan Red Dwarf †	SRD	1968 (P41)	Samoa	–
Samoan Yellow Dwarf	SYD	1968 (P41)	Samoa	–
Tacunan Green Dwarf	TACD	1983 (P31)	Philippines	PCA-Zamboanga, Philippines
Thailand Green Dwarf	THD	1983 (P31)	Thailand	Sawi research station, Thailand
Vanuatu Red Dwarf	VRD	1974 (P01)	Samoa (?)	Jacquier, Malo Island, Vanuatu
Tall varieties				
Baybay Tall	BAYT	1983 (P40)	Baybay, Philippines	PCA-Zamboanga, Philippines
Gazelle Peninsula Tall	GPT	1985 (P30)	Gazelle Peninsula, PNG	Keravat station, PNG
Karkar Tall	KKT	1985 (P30)	Karkar Island, PNG	Bubia station, PNG
Malayan Tall	MLT	1967 (P30)	Malaysia	Yandina, Solomon Islands
Markham Valley Tall †	MVT	1969 (P43)	Markham Valley, PNG	–
New Caledonia Tall	NCT	1987 (P20)	Ouvea, New Caledonia	–
Rangiroa Tall	RGT	1967 (P00)	Rangiroa, French Polynesia	–
Rennell Island Tall	RIT	1964 (P02), 1968 (P40/41) †	Rennell Island, Solomon Islands	–
Rotuman Tall	RTMT	1969 (P41)	Rotuma, Fiji	–
Solomon Island Tall †	SIT	1968 (P41)	Yandina , Solomon Islands	–
Solomon Is. Tall Nendo	SIT	1987 (P00)	Nendo Island, Solomon Islands	–
Solomon Is. Tall Reef	SIT	1987 (P00)	Reef Island, Solomons Islands	–
Tagnanan Tall	TAGT	1983 (P40)	Tagnanan, Philippines	PCA-Zamboanga, Philippines
Tagnanan Tall	TAGT	1983 (P40)	Tagnanan Est. Inc., Philippines	–
Tonga Tall	TONT	1969 (P41)	Tonga	–
West African Tall	WAT06	1966 (P31)	Ouidah, Benin	Marc-Delorme station, IC

† this variety does not exist anymore in the VARTC collection; PNG = Papua New Guinea; IC = Ivory Coast.

Creation of hybrids

Starting in 1968, numerous crosses were carried out, mainly by hand pollination, with palms in the collection or with imported pollen. Some hybrids were also created abroad at the Marc Delorme Station in Ivory Coast or at the Yandina Estate in the Solomons, and the hybrid seeds were imported into Vanuatu. In all, 60 different hybrids were planted out at Saraoutou from 1968 to 2002 (*figure 1*).

Discovery of coconut foliar decay disease

In 1965, eighteen months after the first exotic varieties had been planted out, a previously unseen wilt appeared on the Malayan Red Dwarf (MRD) and, later, on the other exotic varieties and hybrids, while the local Tall (VTT) remained unaffected. The symptoms of this disease, called coconut foliar decay (CFD), were first described in 1980 by Calvez *et al.* [2] and a review of the epidemiology and the characteristics of the virus was published recently [3].

On the MRD, which is one of the most susceptible varieties, the first symptoms are a yellowing of leaflets at the base of middle fronds and lateral necrosis on the petioles of affected fronds. These fronds die prematurely, hanging from the petiole down through the crown (*figure 2*). Then, the other upper fronds turn yellow then brown, and die. Susceptible cultivars succumb to the disease between one and two years after symptoms appear.

A small, circular single-stranded DNA was shown to be associated with CFD [4]. The nucleotide sequence of the DNA was determined. It was confirmed that the virus represented a new taxonomic group and it has been tentatively assigned to the genus *Nanovirus* [5, 6]. The plant-hopper *Myndus taffini* was shown to be the vector of CFD virus [7]. This insect has a breeding host, *Hibiscus tiliaceus* (or burao), a local shrub, very common in Pacific countries. However, the disease has never been reported outside Vanuatu [8].

Remission of symptoms has sometimes been observed on individual palms of susceptible cultivars 1 or 2 years after symptoms developed. Those palms then appeared to remain disease-free even if exposed to high infection pressure in the field [9]. The mechanisms of remission and of acquired immunity remain unknown.

There are two efficient ways of controlling this disease. The first is to remove of the insect breeding host, *H. tiliaceus*, for several hundred metres around the cultivation area. This strategy has been successfully

			Dwarfs									Talls														
	Variety name	**Code**	CRD	KIND	MBD	MRD	MYD	NLAD	PILD	SYD	VRD	BBT	FJT	GPT	KIT	MLT	MVT	RGT	RIT	RTMT	SMOT	SIT	TAGT	TONT	VTT	WAT
Dwarfs	Brazilian Green Dwarf	BGD						X			X			X	P			P	X		P				X	I
	Cameroon Red Dwarf	CRD												X			X		X	X	P					I
	Kinabalan Green Dwarf	KIND																							P	
	Madang Brown Dwarf	MBD												X	P		X		X	X						
	Malayan Red Dwarf	MRD											I	X	P	P	X	P	X	X	P			X		P
	Malayan Yellow Dwarf	MYD												X	P		X		X	X	P	X		X	I	I
	Niu Leka Dwarf	NLAD																						X	P	
	Pilipog Green Dwarf	PILD																							X	
	Samoan Yellow Dwarf	SYD																			P			X	X	
	Vanuatu Red Dwarf	VRD																							X	
Talls	Baybay Tall	BBT																							X	
	Fiji Tall	FJT																								
	Gazelle Peninsula Tall	GPT																	X							
	Kiribati Tall	KIT																								
	Malayan Tall	MLT																							X	
	Markham Valley Tall	MVT																								
	Rangiroa Tall	RGT																								
	Rennell Island Tall	RIT																				X		X	X	X
	Rotuman Tall	RTMT																							X	
	Samoan Tall	SMOT																								
	Solomon Island Tall	SIT																							X	
	Tagnanan Tall	TAGT																							X	
	Tonga Tall	TONT																								
	Vanuatu Tall	VTT																								X

Legend: Crossing (X) carried out with Saraoutou germplasm; (P) with imported pollen; (I) abroad, seeds imported

Figure 1. *Hybrids planted at Saraoutou from 1968 to 2002.*

applied at Saraoutou for the conservation of susceptible cultivars in collections and trials, and inside a few large commercial plantations on Santo, but cannot be extended to the whole area cultivated by smallholders. The second is to use CFD virus-tolerant cultivars.

Searching for CFD-tolerant cultivars

The Vanuatu Tall populations have never shown any severe symptoms or succumbed to CFD disease. Some slight symptoms (yellow spots on the leaves) have been observed in very rare cases but the palms always recovered. Using cloned sequences as probes, Hanold *et al.* [10] showed that the VTT contains CFD virus DNA and is susceptible to infection by the causal agent; the VTT can therefore be considered perfectly tolerant, rather than resistant to CFD virus.

For the other varieties, and for the hybrids, screening for CFD virus susceptibility was done by planting palms in a field where they were exposed to high natural infection pressure *i.e.* in an area with a high density of *H. tiliaceus* around the plot. At least four years' exposure to CFD virus in the field was necessary to judge whether an unaffected coconut type (after the susceptible MRD control had been affected) was likely to prove highly tolerant. A complementary test was developed by Julia [11] for a more rapid evaluation. Nursery seedlings were raised in cages where they were exposed to 1 500 *Myndus taffini* insects captured in the field, but sometimes the artificially inoculated palms recovered, making susceptibility to the disease difficult to assess (nursery effect). However, for each variety, a good correlation was shown between the susceptibility observed in the field and the expression of early symptoms on young seedlings.

The results of these experiments were published [11, 12] and can be summarized as follows: for Dwarfs, the MRD and MYD were the most susceptible varieties and the Vanuatu Red Dwarf (VRD) showed a high level of tolerance. The most susceptible Tall was the Markham Valley Tall introduced from Papua New Guinea. The other Tall and Dwarf varieties showed intermediate levels of susceptibility. All the hybrids were more or less susceptible (*table 2*), except the Vanuatu Tall × Rennell Island Tall (VTT × RIT) and the Vanuatu Red Dwarf × Vanuatu Tall (VRD × VTT), which displayed a high level of tolerance. For the VTT × RIT hybrid, a very small percentage of palms (3.5%, 13 years after planting in trial GC1) expressed slight CFD symptoms, but all of them recovered. As for VRD × VTT, no diseased palms were recorded in on-station trials. Rare cases of attacks in farmers' fields have been reported.

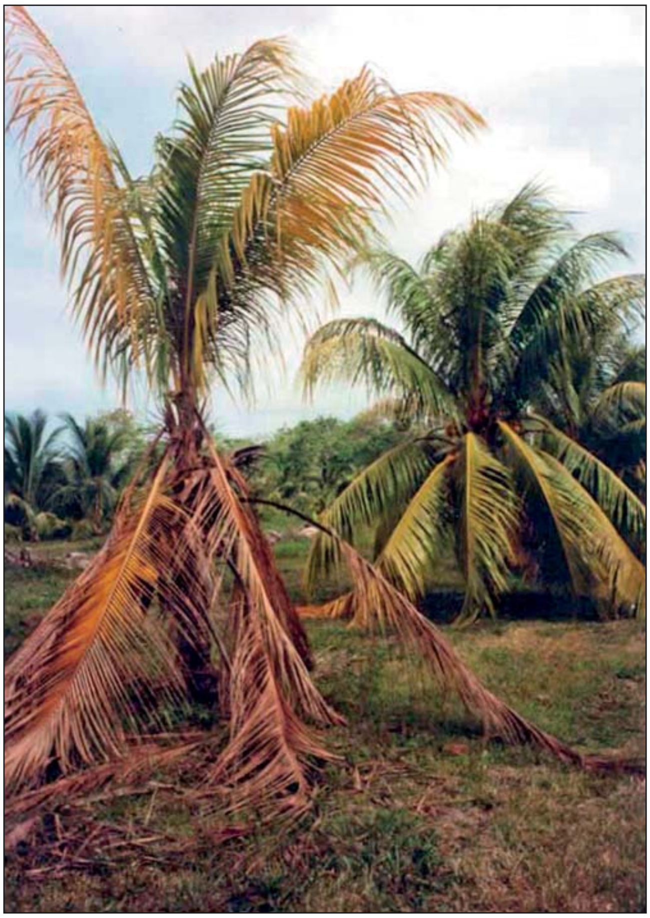

Figure 2. *In the foreground, severe symptoms of Coconut Foliar Decay on a Malayan Red Dwarf; in the background, unaffected palm. Photo J.P. Labouisse.*

Table 2. *Results of screening 16 cultivars for CFD virus tolerance in collection plot P01, 27 years after planting (1975-2002).*

Rank	Cultivar	Number of palms observed	% palms killed by CFD
1	VTT × RIT	34	0
2	VTT × NLAD	39	2.5
3	RTMT × VTT	30	3.3
4	SRD × VTT	33	9.0
5	SYD × VTT	32	12.5
6	MYD × VTT	25	32.0
7	BGD × VTT	29	37.9
8	MRD × RTMT	20	40.0
9	SIT × VTT	29	51.7
10	CRD × NLAD	33	54.5
11	RIT	25	56.0
12	CRD × WAT	16	56.2
13	MYD × WAT	10	60.0
14	MYD × RIT	23	60.6
15	MRD	32	62.5
16	BGD × WAT	21	71.5
17	MYD × SIT	15	80.0
18	BGD × RIT	27	88.9
19	MYD	14	92.8

Once these results had been obtained, the breeding programme focused on assessing the performance of the VTT × RIT and VRD × VTT hybrids, and on improving their tolerance of CFD virus.

Assessing the agronomic performance of the Vanuatu Tall × Rennell Island Tall hybrid

Characteristics of the Rennell Island Tall parent

The RIT is one of the most remarkable cultivars of the Pacific, through its origin, the characteristics of its fruit and its genetic combining ability. The RIT comes from Rennell, an island measuring 75 km by 10, about 200 km due south of Guadalcanal in the Solomon Islands archipelago. According to Foale [13], the true-to-type RIT is found mainly in the centre of the island and around Lake Tenganno. The RIT was described by Whitehead from Foale's observations [14], and by de Nucé *et al.* [15]. This palm gives one of the largest coconut fruits in the world. In the VARTC collection, the average weight of a whole fruit, calculated over a 4-year period (1994-1997), was 1742.8 ± 226.6 kg[1] and the fresh albumen weight was 576.3 ± 65.6 g. One RIT palm produced around 64.6 ± 19.2 nuts per year. According to these data, annual production was about 18.6 kg of copra per palm. The RIT has been widely used in many breeding programmes to increase nut copra content [16]. The MRD × RIT hybrid is a high-yielding cultivar and is produced in many countries of the Pacific region for dissemination to farmers.

The RIT is susceptible to CFD virus. Nine years after planting in trial GC1, 27.1% of the palms had been affected by the disease [17]. In collection plot P01, 28 years after planting, 56% of RIT palms had died from this disease *(table 2)*. To improve the level of RIT and VTT × RIT tolerance of CFD virus, unaffected RIT palms in the collection were self-pollinated and the progenies planted in a field exposed to high infection pressure. After 10 years, all the progenies were affected but the percentage of diseased palms within each of them varied from 11% to 96%. Many palms recovered, but only three progenies expressed good tolerance of CFD virus, with no or very few palms succumbing to the disease (0% for 2 progenies, 4% for the third). We used pollen from those three progenies to create a second generation of VTT × RIT hybrids that we presumed to be more tolerant of CFD virus than those created with an unselected RIT parent.

On-station trials

The performance of the RIT × VTT hybrid was assessed at different periods, in the collection and trial plots at the Saraoutou research station. The characteristics of the site (climate, soil) and the observation methods were detailed in Part I of this article. *Table 3* gives the main characteristics of the trials and collections, for which data will be examined in the following sections. The palms are planted in a 9-metre equilateral triangle design, which corresponds to a planting density of 143 palms per hectare.

The origins of the hybrid parents are given in *table 4*. For trial GC29, we used pollen from a Rennell Island Tall palm selected for better tolerance of CFD virus.

Germination rate

In all the trials, the VTT × RIT hybrid displayed very rapid germination, as did the VTT. The cumulative germinated fruit curves were similar. In trial GC1, the VTT × RIT hybrid germinated a little more rapidly than the VTT,

[1] Data in the text are "mean ± standard deviation".

Table 3. *Simplified description of trials with the VTT × RIT hybrid.*

Trial number	Planting date	Treatments compared	Experimental design	Soil
Trial GC1	3/1969	VTT × RIT VTT (G1)* RIT MRD × RIT Diverse Tall × Tall hybrids	Balanced incomplete blocks 2 replications	Plateau
Trial GC14	6/1982	VTT × RIT Improved VTT (G2)*	Balanced lattices 4 × 4 5 replications	Plateau
Trial GC29	4/1998	VTT × RIT Elite VTT (G4)*	5 Fisher blocks (1 incomplete)	Plateau

* for VTT, the generation is mentioned in brackets (see Part I for details).

Table 4. *Origin of the VTT × RIT hybrid parents used in the trials.*

Type	Female parent	Origin of female parent	Male parent	Origin of male parent
Trial GC1	VTT of Leroux Plantation (G0)*	–	RIT pollen imported from Yandina (SI)	Rennell Island
Trial GC14	40 palms of VTT1 (G1)* 20 palms of VTT2 (G1)*	Surrenda Plantation and Leroux Plantation	15 RIT selected for productivity, good copra content and unaffected by CFD	Hand pollination of RIT imported from Rennell Island in 1962
Trial GC29	18 progenies of VTT (G2)*	Selfing of 7 VTT1 palms and 11 VTT2 palms selected for good performance	15 RIT palms taken from 3 unaffected progenies	Selfing of 3 unaffected RIT palms

* for VTT, the generation is mentioned in brackets (see Part I for details).

with 50% of germinated fruits 77 days after sowing as opposed to 84 for the VTT. The Rennell Tall in the same trial took 98 days.
As observed for most hybrids, the nature of the female parent (here the VTT) seemed decisive and determined germination characteristics.

Flowering precocity

In each trial, we found that the hybrid revealed a very similar performance to the VTT (*figure 3*). This suggests that the difference in precocity between the trials mainly depended on the environment (planting date, rainfall, etc.). In trial GC29, on plateau soil, palm growth was excellent and the precocity of the VTT × RIT hybrid was remarkable: the first flowers appeared after 30 months, as opposed to 33 months for the Elite VTT. Three years after planting, 75% of the hybrid palms bore flowers. Under those conditions, the first harvest took place 4 years after planting.

Description of the palm

The VTT × RIT hybrid has a thicker stem and a larger bole than the VTT (*figure 4*). Given these characteristics, it is fairly tolerant of strong winds, as is the VTT. The bunch is borne by a long, thick peduncle. The fruits are large, egg-shaped and green, greenish brown, or reddish brown in colour. Most of them inherited a sort of nipple from the RIT parent, on the opposite side of the fruit from the peduncle (*figure 5*).

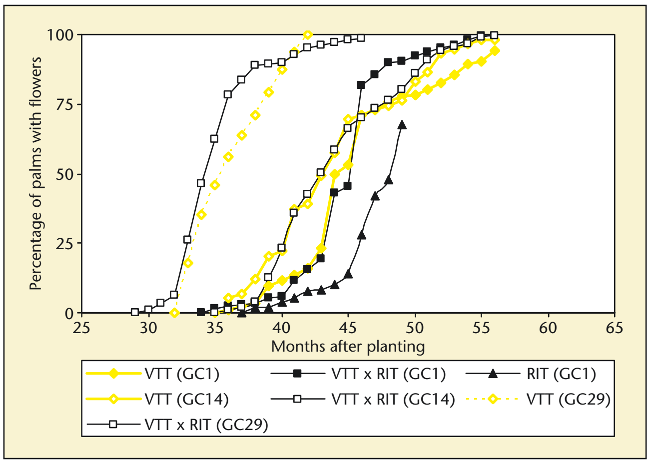

Figure 3. *Flowering of the VTT and the VTT × RIT hybrid in trials GC1, GC14 and GC29.*

Yield characteristics

The trial results are summarized in *table 5*.
In trials GC1 and GC14, the first harvest took place four and a half years after planting, and the number of nuts was not significantly different for

Figure 4. *Young 5-years-old VTT × RIT hybrid palm (with 1meter rule). Photo J.P. Labouisse.*

Figure 5. *Bunch of the VTT × RIT hybrid. Photo J.P. Labouisse.*

Table 5. *Comparison of production data (annual means) for the VTT and the VTT × RIT hybrid.*

	GC1[b]		GC14[b]		GC29[c]	
	VTT	VTT × RIT	VTT	VTT × RIT	Elite VTT	VTT × RIT
Number of bunches/palm	_[a]	_[a]	11.9	11.8	12.1	13.2
Number of fruits/palm	83.6	84.2	82.5	89.1	79.9	104.5
Copra/nut (g)	173.6	209.8	197.0	240.2	203.1	213.2
Copra/palm (kg)	14.5	17.8	16.2	21.4	16.2	22.3
Copra/ hectare (t)	2.1	2.5	2.3	3.1	2.3	3.2

[a] not determined.
[b] means calculated from year 5 to year 12 after planting.
[c] means calculated for year 5 only.

the VTT and the VTT × RIT hybrid. In trial GC1, the copra content of the hybrid nut was significantly higher (+ 21%) than the VTT copra content. Production calculated from year 5 to year 12 was 22% higher for the hybrid. This trial suffered from drought in years 9 and 10, and from cyclone Gordon in year 10 (January 1979). Similarly, in trial GC14, due to a higher copra content, hybrid production was significantly higher (+ 31%) than VTT production. In trial GC 29, the first harvest took place 4 years after planting. In this trial, the hybrid was very promising with a yield of 3.2 tons per hectare as opposed to 2.3 tons for the Elite VTT (+ 39%) in the fifth year after planting.
For the VTT, copra content was significantly higher in trial GC29 than in trials GC14 and GC1. This was the result of the mass selection process applied to the Vanuatu Tall, as described in Part I. For the VTT × RIT hybrid, copra content was lower in trial GC29 than in trial GC14. The reason could have been that the RIT parents in GC29 were chosen for their tolerance of CFD virus, whereas the RIT parents in GC14 were only chosen for their high copra content.

Assessment of the agronomic performance of the Vanuatu Red Dwarf × Vanuatu Tall hybrid

Characteristics of the Vanuatu Red Dwarf parent

The Vanuatu Red Dwarf was collected in 1973 at the Jacquier Plantation set up on Malo, a small island south of Santo Island. There is no evidence that this variety originated from Vanuatu because, when it was collected, it was not widespread in the country at all. According to some unpublished documents, it was introduced from Samoa at the beginning of the twentieth century by a returning Melanesian worker who had been recruited by a German plantation company operating in the country before World War I.
Whatever its origin is, the VRD is well adapted to the ecology of Vanuatu and is highly tolerant of CFD virus, even though some slight symptoms have occasionally been observed. It is tolerant of strong winds, when compared to other Dwarfs. In the VARTC field genebank, in 1999, cyclone DANI toppled 4% of the VRD palms, as opposed to 100% of the Malayan Yellow Dwarfs (the palms were broken at the bottom of the stem).
The Vanuatu Red Dwarf has a rather thin stem and no bole. The leaves are yellowish. This variety bears numerous small bright orange fruits. In the VARTC collection, the average weight of the whole fruit, calculated over a 4-year period (1997-2000), was 0.692 ± 0.195 kg, and the fresh meat weight was 261.1 ± 60.5 g. The copra content was 117.7 ± 33.1 g.
In 1985, a study by Chant showed that the VRD has a very slow germination speed and a low, irregular germination rate [18]. Germination started between 70 and 100 days after sowing, as opposed to 30 days for the Malayan Yellow Dwarf (MYD). The average germination rate was 43%, but high variability was recorded (22 to 68%) depending on the origin of the nuts, the nutrition of the palm and the stage of maturity. The VRD bore its first flower 26 months after planting (21 months for the MYD) and 50% of the palms had flowers after 32 months (25 months for the MYD). In the VARTC genebank, the annual number of nuts was over 100, and yield was about 12 kg of copra/palm/year.
However, due to the low copra content of its nuts, the VRD is not used for copra production. It is mainly planted as an ornamental in parks and gardens.

On-station trials

The performance of the VRD × VTT was assessed in several trials whose main characteristics are presented in *table 6*. From 1992 to 1996, 7 trials were planted at VARTC under a regional research project (PRAP – Pacific Regional Agricultural Programme). During this project, thirty-one Dwarf × Tall hybrids were compared with two controls: VRD × VTT and MRD × RIT.

Germination rate

The VRD × VTT hybrid has inherited a low germination speed and an irregular germination rate from the VRD. In trial GC12, germination of the hybrid started 70 days after sowing and reached a maximum rate of 60% after 6 months. In trial GC16, germination started 75 days after sowing and reached a maximum rate of 46% after 194 days. In the PRAP trials, germination occurred between 35 and 70 days after sowing and

Table 6. *Simplified description of trials with the VRD × VTT hybrid.*

Type	Planting date	Treatments compared	Experimental design	Soil
Trial GC12	1/1980	VRD × VTT MRD Diverse VRD × Tall hybrids	Fisher blocks 6 replications 143 palms/ha	Coral
Trial GC16	1982 & 1984	VRD × VTT (16 progenies)	Balanced lattices 4 × 4 5 replications 160 palms/ha	Plateau
Trial CC12	1987	VRD × VTT	Fertilization trial 160 palms/ha	Coral
PRAP trials (GC21 to GC27)	From 1992 to 1996	VRD × VTT Diverse Dwarf × Tall hybrids	Fisher blocks 160 palms/ha	Plateau

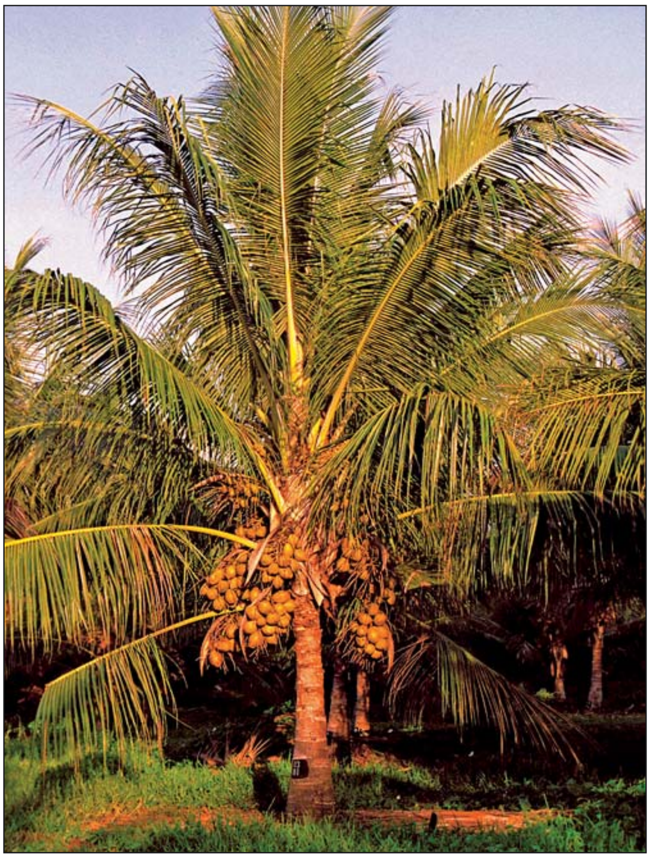

Figure 7. *An 8-years-old VRD × VTT hybrid palm. Photo R. Bourdeix.*

the maximum rate fluctuated between 15% and 80%, depending on the trials. Factors that might explain such germination variability remain unknown, even though the nutritional status of the mother palm and the stage of nut ripeness have been suspected.

Flowering precocity

In trial GC12, on coral soil, the first flowers appeared 35 months after planting and 50% of the palms bore flowers 42 months after planting. In GC16 and in the PRAP trials, planted on fertile plateau soil, flowers appeared earlier as shown in *figure 6*. Under the best planting conditions (trial GC27), the flower opened 26 months after planting and 50% of palms bore flowers 31 months after planting. However, in these PRAP trials, we found that the other Dwarf × Tall hybrids were often more precocious (by 2 or 3 months) than the VRD × VTT. This difference could be explained by the latter's low germination speed. VRD × VTT seedlings were less developed when they were taken from the nursery to be planted in the field with the other hybrids.
These results suggest that VRD × VTT flowering precocity depends on the environment and the stage of seedling development when planted in the field. In most of the cases, the first significant harvest took place 4 years after planting.

Description of the palm

The stem of the VRD × VTT is shorter and thinner than the VTT stem and has a bole of medium size (*figure 7*). This stem is moderately tolerant of strong winds, especially during the period from 5 to 7 years after planting, when the palm is not yet deeply anchored in the soil. During cyclone Dani, 15.4% of the 6-year-old palms were blown over. The bunch has a long, thin peduncle that bears a large number of reddish brown fruits (*figure 8*).

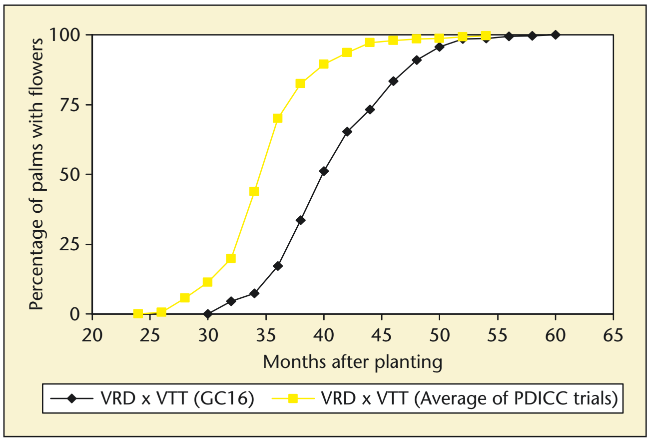

Figure 6. *VRD × VTT hybrid flowering.*

Production

The production data for the trial are summarized in *table 7*.
In trial GC12, the first hybrid yields were disrupted by cyclone Nigel which passed over the station in January 1985. This trial was prematurely halted.
In trial GC16, the hybrid yields were greatly improved. But this was probably the result of a high level of selection applied to the VTT parents, which had the following characteristics: very large number of fruits (167 fruits per palm on average) and high copra content (203 g per nut on average). The average theoretical yield of these outstanding VTT palms was 4.7 tons per hectare!
The performance of the hybrid obtained through the PDICC trials was more difficult to analyse. These trials were severely affected during the first years of production by cyclones Dani and Ella in 1999, and cyclones Paula and Sosé in 2001. Moreover, from the beginning of 2000, all the palms in these trials were infected by a fungus, C*orticium penicillatum*. The older leaves dried and fell prematurely, and production was seriously affected.

Seednut supplies to growers, and recorded performances

From 1979 to 1982, the first generation of VTT × RIT hybrids was disseminated to farmers on a very small scale (a dozen farms). A very few

Figure 8. *Bunch of a VRD × VTT hybrid. Photo J.P. Labouisse.*

Table 7. *Production data for the VRD × VTT hybrid in different trials.*

	GC12[b]	GC16[c]	GC22[c]	CC12[c]
Number of bunches/palm	_ [a]	12.6	8.6	10.3
Number of fruits/palm	80.2	146.7	89.3	114.3
Copra/nut (g)	133.0	146.8	167.8	142.1
Copra/palm (kg)	10.7	21.5	15.0	16.2
Copra/ hectare (t)	1.5	3.4	2.4	2.6

[a] not determined.
[b] calculated from year 6 to year 8.
[c] calculated from year 5 to year 11.

number of them had been reported to be affected by CFD virus (actually they recovered), so, when the Coconut Development Project (*Kokonas Devlopmen Projek* or KDP) started in 1982, the VRD × VTT hybrid was preferred to the VTT × RIT. During that project (1982-1993), farmers planted around 300 hectares with the VRD × VTT hybrid [19]. This hybrid was observed for 2 years in 8 demonstration plots in comparison with the Elite VTT [20]. The performance of the VTT × RIT was only recorded in one farmer's field in comparison with the Elite VTT and the VRD × RIT. The data are presented in *table 8*. The yield observed for both hybrids was 28% higher than VTT yield.

Performance for copra processing

In 2000, we conducted a series of experiments to assess the labour required for copra preparation [21]. The data are presented in *table 9*. The VTT × RIT hybrid required more time to extract the kernel from one nut, but ultimately this hybrid required less labour than the Elite VTT (– 8%) and the VRD × VTT hybrid (– 45%) to prepare one ton of copra.

Table 8. *Annual performance of the hybrids recorded in farmers' fields in comparison with the elite VTT. Means calculated over a two-year period.*

		Fruits/palm	Copra/nut (g)	Copra/ha (t)
Means of data recorded for 8 on-farm trials	Elite VTT	68.7	200.2	1.9
	VRD × VTT	100.1	156.4	2.4
Data recorded for 1 on-farm trial	Elite VTT	90.5	152.9	1.9
	VRD × VTT	115.8	141.8	2.5
	VTT × RIT	86.3	220.7	2.6

After extraction, the kernel of the cultivars was loaded into a hot-air dryer for 48 hours. At the same time, samples were taken and dried in a laboratory oven in order to determine the percentage of dry matter. The results are presented in *table 10*. VRD × VTT kernel had the highest initial water content (55%) but it dried more rapidly (because of the lower kernel thickness). The quantity of copra obtained at the end of the drying process was higher for the VTT compared to the VTT × RIT (+ 4.5%) and the VRD × VTT (+ 12.5%). The difference in copra weight between the laboratory and the hot-air drier resulted from losses during dryer loading/unloading and during the drying process.

We also determined the oil content from kernel samples using the Soxhlet method with hexane as the solvent. The oil content was not significantly different for the three cultivars, varying from 65.3% to 66.2% of dry matter.

Discussion

Generally speaking, hybridization between coconut varieties has led in many cases to considerable genetic progress. In Vanuatu, the susceptibility of exotic ecotypes to CFD virus has considerably restricted the range of hybrid combinations that can be adapted to local conditions. Whilst the VTT is totally tolerant, it transmits that tolerance very imperfectly to its hybrids. Out of 60 hybrids tested, 13 had VTT as a parent, and among the latter, only two displayed a level of tolerance making it possible to consider them for distribution to farmers.

The VTT × RIT hybrid stands out through its precocity, its vigour and its good adaptation to cyclones. When compared to the VTT, the copra content of its nuts is better and the number of nuts produced per year is slightly larger. The difference in production with the VTT is significant but remains modest for a Tall × Tall hybrid. For instance, in Ivory Coast, yields of the WAT × RIT and WAT × VTT hybrids are more than double those of the local West African Tall (WAT) [22]. This moderate heterosis observed in the hybrid might be explained by the limited genetic distance between the VTT and RIT parents. Indeed, despite dissimilar phenotypic traits, we showed with molecular markers that these varieties are genetically close and, along with the New Caledonia Tall and Solomon Island Tall, form the same sub-group among the Melanesian Tall coconut palms [23]. However, this hybrid still represents true genetic progress compared to the VTT, through its higher yield and a reduction in the work time required to prepare copra.

Unlike the VTT, it has the drawback of not being reproducible by farmers from their own plantation. It can only be reproduced in centralized seed gardens, as RIT parents cannot be maintained in a smallholder environment because they succumb to CFD virus. In addition, the mother palms (VTT) rapidly reach a considerable height, thereby reducing the working life of the seed garden and making work less easy than with Dwarf × Tall hybrids. All this makes it more expensive to produce and disseminate this hybrid than the improved VTT.

Table 9. *Evaluation of the labour required for fruit splitting and kernel extraction. Number of fruits and time required to prepare one ton of copra.*

	Time for processing 1000 fruits (hours)			Kernel weight of 1000 fruits (kg)	Copra content of one fruit (g)	Number of fruits needed to obtain 1 t copra	Time to prepare 1 t copra (hours)
	Fruit splitting	Kernel extraction	Total				
Elite VTT	1.22	3.56	4.78	342	192.2	5204	25
VTT × RIT	1.28	4.22	5.50	456	238.2	4198	23
VRD × VTT	1.33	3.58	4.89	305	146.0	6849	33

Table 10. *Quantity of copra obtained after drying 100 weight units of kernel in a laboratory oven and in a copra dryer.*

	Thickness of kernel (mm)	In laboratory		In copra dryer		
		Percentage of water in kernel	Theoretical weight of copra (6% moisture)	Weight of dried kernel after 48 hours	% water in dried kernel	Theoretical weight with 6% moisture (copra)
Elite VTT	12.6	47.2	56.2	50.0	12.2	46.7
VTT × RIT	12.8	50.9	52.2	48.1	12.6	44.7
VRD × VTT	12.0	55.0	47.9	43.6	10.5	41.5

For its part, the VRD × VTT hybrid displays good hybrid vigour, though it remains average in relation to that found in Dwarf × Tall hybrids. However, it does have some defects. The first is slow germination and a highly irregular and often low final germinated nut rate. This holds back its distribution to farmers in nut form. In addition, as the female parent is a Vanuatu Red Dwarf with very small nuts, farmers who are used to selecting the largest nuts from their plantation, are reticent to set up and maintain seed beds for such small nuts over a long period. The hybrid can therefore only be distributed in seedling form, usually raised in polybags, from the central VARTC nursery or from regional nurseries supervised by agriculture technicians. This considerably increases planting material and transport costs. The second defect is susceptibility to cyclones, which results in the uprooting or breakage of a not insubstantial number of young palms, but also, and especially, in substantial immature nut fall. Premature nut fall is sometimes seen in young palms without it being attributable to a cyclone. The factor(s) causing it has (have) not been clearly established. Such nut fall may be due to a transient nutrition imbalance, an excessive fruit-set rate or low intrinsic peduncle resistance. This is reflected in highly variable yields depending on environmental conditions. The third defect is the mediocre quantity of copra obtained from one nut, which increases work time when preparing copra. Lastly, other elements of assessment were recorded during field surveys [20]. Whilst farmers say they are satisfied with precocity and with young palm yields, they often express the fear that this high productivity will not be maintained in the long term and they have doubts about the longevity of the palms which, in their view, would be shorter than for the local Tall. Experimentally, we lack the hindsight required to judge the validity of those arguments.

Table 11. *Summary of the main characteristics of the elite VTT, VTT × RIT and VRD × VTT and the constraints for seednut production.*

	Unit	**Elite VTT**	**VTT x RIT**	**VRD x VTT**
Recommended planting density	palms/ha	143	143	160
Tolerance of CFD		total	high	high
Tolerance of strong winds		high	high	medium
Germination				
50% germinated nuts after sowing	days	60-80	60-80	70-200
Final germination rate	%	90	80	40-80
Flowering				
First flowers after planting	months	30-35	30-35	26-35
50% palms bearing flowers	months	35-40	35-40	31-40
Yield				
Number of nuts/palm/year		75-85	80-90	90-140
Nut copra content	g	190-205	210-245	135-160
Copra/ palm/year	kg	15-17	18-21	16-21
Copra/ hectare	t	2.1-2.4	2.5-3.0	2.5-3.4
Number of fruits to obtain 1 t copra		5000	4300	6800
Seednut production				
Self multiplication by farmers		yes	no	no
Decentralization of seed gardens		yes	no	difficult
Supplying seeds to farmers		yes	yes	difficult
Cost of seednut production		low	high	high

Conclusion

The comparative characteristics of the Elite Vanuatu Tall and of its two hybrids are summarized in *table 11*. We have added the production constraints of the planting material, which are important aspects that need to be taken into account by developers.

In view of the defects of the VRD × VTT hybrid, its production was halted in 1996. Since that date, emphasis has been placed on the second generation of the VTT × RIT hybrid selected for better CFD tolerance. To date, after 5 years in the field, that hybrid has shown no signs of CFD attack, be it on-station or on-farm. Its precocity and yields are highly satisfactory. However, dissemination of this hybrid will always be limited by seedling production and transport costs, due to the need for centralized seed gardens.

Large-scale use of the Elite VTT produced in decentralized seed gardens combined with improved nursery and plantation management techniques are the main ways of increasing coconut productivity in Vanuatu in the short and medium terms.

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