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

Part 1: Improvement of the Vanuatu Tall by mass selection

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Abstract: From 1962 to 2002, at the Saraoutou research station on the island of Santo in Vanuatu, genetic improvement work was undertaken to increase the productivity of coconut plantations, which, through copra exports, were the country's main wealth in the last century. Beginning with two Vanuatu Tall (VTT) populations collected near the station, four mass selection cycles by open pollination or intercrossing have resulted in Elite Vanuatu Tall populations intended for distribution to farmers. The study sums up how the different VTT populations perform in terms of germination rate, flowering precocity, and yield components (copra per nut, number of nuts). It highlights the efficiency of these breeding methods in increasing nut copra content and in reducing within-population variance of phenotypic traits. Flowering precocity, the number of nuts, and consequently copra production per plot, remain highly dependent upon growing conditions, and on the care taken in the nursery. It also confirms that selection too exclusively based on the search for a high copra content is reflected in a drop in the number of nuts and a very slight gain in copra production per palm. Compared to higher-yielding hybrids, the improved VTT populations offer the advantage of being totally tolerant of coconut foliar decay and of being reproducible by farmers themselves. The merits of setting up decentralized seed gardens in the Vanuatu archipelago from improved populations at the research station, or from locally surveyed material, are discussed.

Keywords: Pacific, Vanuatu, coconut, genetic improvement, copra, seeds, heritability, mass selection

Located in the Pacific northeast of New Caledonia, Vanuatu is an archipelago of around 80 islands and islets of volcanic origin straddling the 13th and 22nd parallels, over a distance of about 850 kilometres. Coconut is a traditional crop used by rural populations for highly varied purposes (nutritional, medical, ritual) and for making domestic articles and constructing dwellings. Since 1870, coconut has become a cash crop through exports of a single product, copra, obtained by drying the kernel of the coconut fruit. Throughout the twentieth century, this commodity was the main source of income for the Condominium of the New Hebrides, which became the Republic of Vanuatu after the proclamation of independence in 1980. The latter years of the last century were marked by a slow but steady decline in copra production, though it still reached 29,500 tonnes in 2001, despite record low prices and damage by two cyclones that year. Ninety percent of production is ensured by smallholders farming a few hectares, the rest being supplied by ageing estates. Around half this production is processed locally into oil. These two products, copra and oil, still account for 26% of the country's total export earnings [1].

Agricultural research on coconut is relatively recent in Vanuatu. The Saraoutou research station was founded in 1962 on the island of Santo and placed under the authority of the Institut de recherches pour les huiles et oléagineux (IRHO), then of the Centre de coopération internationale en recherche agronomique pour le développement (CIRAD), a French State-run research establishment, in 1985. In 2002, the coconut research station was integrated into the Vanuatu agricultural research and technical centre (VARTC).

The first research work involved coconut breeding and agronomy, along with the improvement of livestock grazing under coconut [2]. In the context of the 1960s, the aim of research was to increase productivity in coconut plantings, expressed in tonnes of copra per hectare, by improving the yield potential of planting material and developing modern and cost-effective management techniques. The geographical dispersion of Vanuatu and the diversity of its soils and climates would suggest substantial genetic diversity but, until recently, all the Tall coconut populations in the country were grouped under the generic name New Hebrides Tall, then Vanuatu Tall (VTT) after independence. The common trait of these populations is the large number of small nuts, as reported by several observers and scientists as early as the 1960s [3, 4]. The Vanuatu Tall should be classed among coconut palms with high phenotypic variability. Manciot [5] gave the following average values for the different production parameters:

- Number of nuts/palm/year = 88 (c.v. = 44.2 %)
The mass selection improvement programme of the Vanuatu Tall

Initial selection work in the estates (initial generation G0) led to the creation of populations VTT1 and VTT2 (generation G1) by mass selection with open pollination.

We have data available making it possible to evaluate the gain obtained with population VTT2, which descended directly from palms selected in the Leroux estate. Selection focused first of all on copra weight per nut, which had to be over 160 g, and on overall yields, which had to be over 10 kg of copra per palm. Twenty-five palms were chosen and the nuts collected then underwent strict culling in the nursery. For instance, nuts that germinated late and the least vigorous seedlings were eliminated in accordance with protocols drawn up by IRHO [7, 8]. The Leroux estate, and the collection plot in which population VTT2 was planted, were very close to each other and were both located on coral soil.

Table 1 shows that the production components of population VTT2 were largely improved when compared to the original population. Nut copra content (C/N) was improved by 26%, the number of nuts (NN) by 37% and total yields by 71%. The coefficients of variation for these parameters decreased. For lack of a “non-selected” control to compare with VTT2 in the same collection plot, it was not possible to determine the share attributable to the environment, management methods, palm age or the effect of culling (in the field and at the nursery stage) in the improvement of these components. However, the production potential of the Vanuatu Tall had already been revealed, along with the possibility of substantially increasing copra weight per nut.

However, several authors [6, 9, 10] showed that mass selection with open pollination, when compared to hybridization, was not particularly efficient in terms of genetic progress and also entailed major risks:

- Given the high negative correlation existing between the “number of nuts” and “copra weight per nut” traits, selection limited to a search for larger nuts could work against an increase in copra yields.
- During strong periods of growth in the hot season, the bunch emission rate accelerates, and high-yielding mother palms could adopt an autogamous reproduction system. As coconut palms have a heterozygous genome, their progenies would display a depressive inbreeding effect, which would be reflected in their lower average performance when compared to the parental population.

Thus, right from the second generation, mass selection was used with intercrossing. After a period of yield observations, the best palms in a population were crossed with each other. This required the hand pollination technique, which is much more labour-intensive than selection with open pollination, but more efficient in terms of the expected genetic progress. At Saraoutou, the risk of inbreeding was reduced by taking parents from two distinct populations, VTT1 and VTT2, though they are genetically close. The progenies obtained were tested in two comparative trials (GC2 and GC9), and formed generation G2.

Table 1. Annual production means for palms in the Leroux plantation and its progeny.

<table>
<thead>
<tr>
<th>Leroux Plantation</th>
<th>Generation G0</th>
<th>(1963-1965)</th>
<th>NN</th>
<th>C/N</th>
<th>C/A</th>
<th>C/ha</th>
<th>NN</th>
<th>C/N</th>
<th>C/A</th>
<th>C/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>205 palms observed during 1 years</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (Min-Max)</td>
<td>68.5</td>
<td>159.2 g (62-223)</td>
<td>9432 g</td>
<td>1.35 t</td>
<td>93.7</td>
<td>175.2 g (125-235)</td>
<td>1614 g</td>
<td>2.3 t</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard deviation</td>
<td>31.2</td>
<td>23.8</td>
<td>3962 g</td>
<td>36.2</td>
<td>22.8</td>
<td>5874</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>VTT2 Generation G1</th>
<th>(1973-1976)</th>
<th>290 palms observed during 4 years</th>
<th>NN</th>
<th>C/N</th>
<th>C/A</th>
<th>C/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (Min-Max)</td>
<td>45.6</td>
<td>18.5</td>
<td>42.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard deviation</td>
<td>38.6</td>
<td>36.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NN: number of nuts; C/N: copra per nut; C/A: copra per palm; C/ha: copra per hectare (density 143 palms/hectare); C.V: coefficient of variation

Figure 1. Surunda estate in 2003. Collection site for VTT1 in 1963. Photo J.P. Labrousse.

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<table>
<thead>
<tr>
<th>Traits</th>
<th>Non-selected</th>
<th>VTT2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of nuts/bunch</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Number of bunches/year</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Number of flowers/bunch</td>
<td>43</td>
<td>43</td>
</tr>
<tr>
<td>Copra weight/nut</td>
<td>148 g</td>
<td>148 g</td>
</tr>
</tbody>
</table>

C.V. (%)        34.5  34.5
Means(Min-Max)  139.2 g (62-223) 139.2 g (62-223)
Standard deviation 25.8  25.8

Comparison of the number of nuts, copra weight per nut, and copra content per hectare in VTT1 and VTT2 (1973-1976).
A new selection cycle was undertaken, leading to the creation of the Elite A seed garden using seednuts from palms in trial GC9. Initially, culling was based on the germination rate and seedling vigour in the nursery. Then, at the adult stage, the least productive palms in the seed garden were eliminated to promote more favourable combinations. The seednuts produced in Elite A seed garden (generation G4) are currently distributed to growers in Vanuatu.

More recently, index-based pre-selection [11] was carried out, in order to index-based pre-selection (planting dates in brackets).

A diagrammatic representation of the programme for VTT improvement by mass selection with open pollination

Table 2. Simplified description of the trials and collections observed.

<table>
<thead>
<tr>
<th>Generation (Accession)</th>
<th>Type</th>
<th>Field number</th>
<th>Origin</th>
<th>Planting date</th>
<th>Experimental design</th>
<th>Sol</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1 (VTT1)</td>
<td>Collection</td>
<td>P02</td>
<td>Surunda Plant.</td>
<td>1964</td>
<td>–</td>
<td>Coral</td>
</tr>
<tr>
<td>G1 (VTT1)</td>
<td>Collection</td>
<td>P00</td>
<td>Leroux Plant.</td>
<td>1967</td>
<td>–</td>
<td>Coral</td>
</tr>
<tr>
<td>G1 (VTT2)</td>
<td>Collection</td>
<td>P50</td>
<td>Leroux Plant.</td>
<td>1969</td>
<td>Rows</td>
<td>Plateau</td>
</tr>
<tr>
<td>G2 (VTT2)</td>
<td>Trial GC1</td>
<td>P43</td>
<td>Leroux Plant.</td>
<td>1969</td>
<td>2 blocks</td>
<td>Plateau</td>
</tr>
<tr>
<td>G2 (VTT2)</td>
<td>Trial GC2</td>
<td>P51</td>
<td>VTT1 (P02)</td>
<td>1969</td>
<td>Lattice 5x5, 4 replications</td>
<td>Plateau</td>
</tr>
<tr>
<td>G3 (VTT2)</td>
<td>Trial GC9</td>
<td>P44(54)</td>
<td>VTT1 (P02) x VTT2 (P00)</td>
<td>1982</td>
<td>5 blocks</td>
<td>Plateau</td>
</tr>
<tr>
<td>G4 (VTT2)</td>
<td>Trial GC14</td>
<td>P63</td>
<td>Trial GC2</td>
<td>1997</td>
<td>–</td>
<td>Plateau</td>
</tr>
<tr>
<td>G1 (Elite B seed garden)</td>
<td>P06(11)</td>
<td>Trial GC9</td>
<td>1987</td>
<td>–</td>
<td>Plateau</td>
<td></td>
</tr>
<tr>
<td>G3 (Elite B seed garden)</td>
<td>P06</td>
<td>Trial GC9</td>
<td>1997</td>
<td>–</td>
<td>Plateau</td>
<td></td>
</tr>
<tr>
<td>G4 (Elite B seed garden)</td>
<td>P06</td>
<td>Trial GC9</td>
<td>1998</td>
<td>5 blocks</td>
<td>Plateau</td>
<td></td>
</tr>
</tbody>
</table>
watering, the first germinations were obtained between 30 or 50 days obtained (The germination curves were plotted for a few of the generations beating the Rennell Tall for this trait, which is itself reputed to be rapid. The Vanuatu Tall is a Tall ecotype displaying very rapid germination [16], Germination rate

Results

in 9 meters equilateral triangles. on the basis of 143 palms per hectare corresponding to a planting design

P00) had 50% of flowering palms after 54 months as opposed to only

44 months for the same type of material planted on plateau soil (P43). For generations G2, G3 and G4, which were all planted on plateau soil, the first flowers appeared after 29 to 33 months, which is remarkable for a Tall. For generation G2, 50% of the palms had flowered after 50 months, as opposed to 44 months for generation G3 and 36 months for G4. The performance of generation G4 (Elite VTT) was quite exceptional, with a much less staggered start to the flowering period than for the earlier generations, which may have been due to a less variable planting material from a genetic viewpoint, but also to planting with material displaying more uniform development on leaving the nursery. The seedlings of this generation also benefited from favourable climatic conditions in 1999 and 2000, which were warmer and wetter years than average.

Precocity therefore seems to depend on the environment, as already reported by de Nucé [16], who indicated that the VTT1 flowered 12 to 18 months earlier in Vanuatu than at the Marc Delorme station in Ivory Coast, where the soil and climate are less suitable for its development. This trait is also improved through culling in the nursery. The Vanuatu Tall has confirmed its very precocious Tall trait. The Elite VTT, seeds currently distributed give an improved population which, under good nursery and field growth conditions, starts to flower after

Figure 4. VTT germination in the nursery for different generations. Rennell Tall as control

Figure 5. Vanuatu Tall flowering for different generations.

– adverse conditions: the effect of cyclones is considerable and can seriously reduce the performance of a palm [14]. A prolonged period of drought (rare event on Santo) can also disrupt growth and yields. Lastly, insect attacks or diseases may also play a role.

Observation methods

The main characteristics of the populations were recorded using methods developed by IRHO and standardized by IPGRI [15]. Harvesting was carried out by hand with hooked knives, taking bunches with partially dry nuts. The nuts were placed in the shade in a dry place for between 10 and 15 days to ensure a uniform degree of ripeness. After sorting to eliminate abnormal nuts, they were roasted and placed in a seedbed with supplementary watering. New germinations were recorded each week. After cumulation, a germination-versus-time curve was plotted.

Once the first flower appeared in a plot, an inspection round was organized to record newly flowered palms every two months. A cumulated flowering curve gave the percentage of palms bearing flowers in relation to time.

At Sarautou, the yields of the Tall populations were estimated by recording the number of bunches and the number of ripe nuts, palm by palm, at a rate of 6 harvesting rounds per year. Meat weight was then determined either by individual weighing in the case of collections, or by sampling the elementary plots in the case of trials, in order to make up a sample of 20 to 30 nuts per treatment. Nut copra content was calculated from the fresh meat weight and the moisture content of the meat obtained after drying in an oven at 105°C. By definition, copra weight was equivalent to that of meat with 6% moisture. The copra yield per palm was thus equal to the number of nuts multiplied by the weight of copra per nut. Lastly, the theoretical yield of a plantation was determined on the basis of 143 palms per hectare corresponding to a planting design in 9 meters equilateral triangles.

Results

Germination rate

The Vanuatu Tall is a Tall ecotype displaying very rapid germination [16], beating the Rennell Tall for this trait, which is itself reputed to be rapid. The germination curves were plotted for a few of the generations obtained (figure 4). Under good nursery conditions, with supplementary watering, the first germinations were obtained between 30 or 50 days

1 The origin of the VTT population at the Marc Delorme station is not formally known but, in view of the introduction date (1969), it can be imagined that it involves a selection from the Leroux estate (VTT1, generation G1). All the VTT populations worldwide (Tanzania, Ghana, Jamaica, Philippines, Brazil) are derived from this African collection.
30 to 36 months, with 50% of flowering palms between 40 and 45 months after planting. The first harvest can therefore take place 4 years after planting out.

**Description of the palm**

The VTT has a long and thin stem, and a rather large bole (figure 6). The fruits are of medium size with various shapes but most of them are oblong and green, greenish brown, or reddish brown in colour (figure 7).

**Yield characteristics**

**Improvement of copra content**

The Vanuatu Tall populations on which the breeding programme is based had an average copra/nut weight (C/N) of under 150 g. At each stage of selection, an attempt was made to eliminate parents with a C/N of less than 160 g.

In addition, to obtain the palms in trial GC9, use was made of VTT1 parents from plot P02 whose individual C/N was equal to or greater than 189 g on average over 5 seasons (overall mean of the C/N for all these palms = 210 g), and VTT2 parents from plot P00 with an individual C/N equal to or greater than 183 g over 3 seasons (overall mean of the C/N for all these palms = 201 g).

The results obtained (figure 8) shows this selection to be efficient, as reflected in a 46% increase in C/N between G0 and G4, and even reaching 50% in the case of GC9 palms with almost 210 g of copra per nut (minimum 200g – maximum 226 g).

The environmental effect seems to be not decisive. No notable difference was found between palms of the same origin depending on soil type (coral or plateau). Moreover, de Nucé [16] did not report any significant difference for this character between the VTT population at Saraoutou and the one at Marc Delorme in Ivory Coast.

**Number of nuts per palm and copra per palm**

In the long term, these two parameters were closely dependent upon the environment (soil, growing conditions), but were also highly sensitive

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*Figure 6. Young 5-year-old VTT in the trial GC29 (Generation G4). Photo J.P. Labouisse.*

*Figure 7. Bunch of VTT. Photo J.P. Labouisse*

*Figure 8. Copra content of the nuts (C/N) for different Vanuatu Tall generations.*

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358 OCL VOL. 11 N° 4/5 JUILLET-OCTOBRE 2004
Table 3

<table>
<thead>
<tr>
<th>Field number</th>
<th>Soil</th>
<th>Coral (g)</th>
<th>Plateau (b)</th>
<th>Plateau (c)</th>
<th>Plateau (d)</th>
<th>Plateau</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of nuts/palm/year</td>
<td>71.6</td>
<td>81.4</td>
<td>74.5</td>
<td>73.1</td>
<td>81.1</td>
<td></td>
</tr>
<tr>
<td>Copra/nut (g)</td>
<td>172.7</td>
<td>173.9</td>
<td>194.7</td>
<td>209.8</td>
<td>197.0</td>
<td></td>
</tr>
<tr>
<td>Production copra/palm/year (kg)</td>
<td>12.4</td>
<td>14.1</td>
<td>14.5</td>
<td>15.8</td>
<td>16.4</td>
<td></td>
</tr>
<tr>
<td>Production copra/ha/year (tonnes)</td>
<td>1.77</td>
<td>2.02</td>
<td>2.07</td>
<td>2.25</td>
<td>2.34</td>
<td></td>
</tr>
<tr>
<td>Cumulated number of nuts/9 years after planting</td>
<td>342</td>
<td>414</td>
<td>372</td>
<td>352</td>
<td>448</td>
<td></td>
</tr>
</tbody>
</table>

* Effect of cyclone Wendy in year 5 and year 6.
* Effect of cyclone Gordon in year 10 and year 11 during the KDP project, seednuts from the Elite A seed garden were used [18].
* Several demonstration plots were set up in Vanuatu [18, 19]. Some of them were observed during the KDP project, then from 1995 to 1997 in connection with a project of the International coconut genetic resources network (COGENT). By 3 1/2 years, 36% of the palms had flowered, and 93% by 4 1/2 years. The average copra weight recorded was 200.2 g, the number of nuts produced was 68.7 and annual production was estimated at 1.9 tonnes per hectare [20].

**Yield characteristics for 3 VTT generations.** Annual averages calculated from 5 to 10 years after planting.

- Copra per hectare = 2.1 to 2.4 tonnes (at a density of 143 palms per ha).
- Copra per palm = 15 to 17 kg; Copra per nut = 195 g to 205 g;
- Number of nuts = 75 to 85;
- Number of nuts per palm over the different generations, but rather a slight decrease. The progenies of GC9, whose parents were subject to severe selection for C/N, had a mediocre number of nuts. It should be noted that the control in GC9 was obtained by mass selection of VTT2 (plot P00) with open pollination (based on unknown selection criteria, though it was doubtless copra/nut). This control also produced very large nuts (C/N of 224 g) and came second out of 25 for this trait. For the number of nuts, it was within the trial mean. This shows that C/N is highly heritable and that the intensity of mass selection with open pollination is decisive. Consequently, in this precise case, controlled intercrossing was no more effective than mass selection with open pollination, since it was based too exclusively on the copra per nut criterion and involved two populations that are genetically very close.

- Selection is highly effective in increasing copra content, a trait which participates significantly, though in a limited way, in increasing the production potential of coconut palms.
- The gain, expressed as copra per ha, obtained between generation G1 (VTT2-P43) and G3 is modest (+15.8%), especially when bearing in mind that generation G1 was subjected to numerous climatic adversities (cyclone, drought).
- The performance of the latest generation G4 has yet to be completely assessed at the station. However, the production potential of the Elite seednuts (mean of years 5 to 10) can be estimated from that of generations G2 and G3 when established in good soil conditions:
  - Number of nuts = 75 to 85;
  - Copra per nut = 195 g to 205 g;
  - Copra per palm = 15 to 17 kg;
  - Copra per hectare = 2.1 to 2.4 tonnes (at a density of 143 palms per ha).

**Table 3**

Yield characteristics for 3 VTT generations. Annual averages calculated from 5 to 10 years after planting.
Achievements and limitations of VTT improvement by mass selection

The main purpose of the first genetic improvement work carried out on the Vanuatu Tall was to increase its production potential in a monoculture context, where it was often combined with cattle grazing, and exclusively geared towards copra production.

Mass selection with open pollination proved to be effective in improving nut copra content, right from the first generation. It led to populations that are more uniform, a trait that is also promoted by culling in the nursery. However, it revealed its limitations for increasing production potential. Flowering precocity, the number of nuts, and consequently copra production per plot remain highly dependent upon growing conditions and the care taken with seedlings in the nursery.

The breeding programme was based on using two Vanuatu Tall populations VTT1 and VTT2, which are probably very close in genetic terms, as they were surveyed in two estates next to the Saraoutou station. Mass selection with intercrossing thereby lost efficiency and the adaptation of progenies to ecological conditions different from those at Saraoutou – such as those found on soils developed on volcanic ash, or in a dryer or colder climate – could not be guaranteed. The demonstration plots set up during the KDP project were intended to assess such adaptation but, for lack of human and financial resources once the project ended, observations could not be satisfactorily completed. However, in order to widen the genetic base of the Vanuatu Tall, two surveys were carried out of local coconut populations between 1983 and 1986, then more recently between 1998 and 2000 on several islands in Vanuatu.[21] Samples of populations were collected and have been conserved ex situ at the Saraoutou station. These populations have been partially described and have yet to be used in a selection programme. Compared to other types of higher-yielding planting material, such as hybrids, the Vanuatu Tall offers two major assets: total tolerance of Coconut Foliar Decay (CFD), a viral disease endemic in Vanuatu, and the possibility of being reproduced very cheaply by growers from seednuts harvested from under their palms.

Conclusion and prospects

In order to compensate for low efficiency in mass selection of the Vanuatu Tall, hybridization of distinct cultivars was launched at the beginning of the 1970s, for which the main constraint was the search for CFD tolerance. However, such a programme meant setting up and maintaining exchange and conservation systems in village communities. It also relies on growers having good knowledge of the individual traits of the mother palms that will supply seednuts for setting up the seed garden. Such research on the site management of local genetic resources is under way.[23]

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RÉFÉRENCES


