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# Genetic improvement of West African tree species: past and present

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## ABSTRACT

Internal and external demand for indigenous tropical hardwoods is increasing in many West African countries, while natural forests have become depleted as a result of over-exploitation. Selective logging has probably eroded the gene pools of some traditionally well-known species. Owing to a lack of information and various biological problems, insufficient seed is available for the reforestation programmes which are required to reduce the deforestation pressures on the surviving areas of natural forest.

The identification of these biological problems, and the realisation of their imminent environmental and commercial consequences, resulted in enhanced research efforts in various West African countries in the late 1960s. Studies on seed management, provenance evaluation, vegetative propagation and genetic selection for improved yield and quality are some of the areas of research initiated for the domestication of a few important indigenous hardwood species. These developments by the individual countries of West and Central Africa have been supported by the UK Overseas Development Administration, the International Tropical Timber Organisation, the Danish International Development Agency and the World Bank.

Provenance trials and gene banks have been established in Ghana, Cameroon, Nigeria and in Côte d'Ivoire, representing much of the geographical range of certain species, with clonal testing also initiated in Nigeria, Côte d'Ivoire, and currently Cameroon. Clonal evaluations have resulted in better understanding of genetic variability, and for *Triplochiton scleroxylon* (obeche) an overall gain in stem volume of over 30% has been achieved. Studies on the early growth of obeche clones have included the relationship between branching frequency and apical dominance, as well as measurements of photosynthesis, as aids to early selection of desirable genotypes. Developments from these research efforts have enhanced reforestation, particularly in Côte d'Ivoire and Nigeria.

At least in the short term, substantial benefits could be achieved in West Africa by the establishment of clonal plantations of indigenous trees, exploiting variation present in wild populations. Renewed efforts in this area could help to ensure a continuing timber supply in the future.

## INTRODUCTION

In most West African countries, the demand for indigenous tropical hardwoods for export and domestic consumption is increasing, while the natural forest is being depleted as a result of over-exploitation (Table 1). Population pressure on the forests and demand for land for other uses are major issues affecting the forest industry (Table 2). In addition to these problems, selective exploitation of the remaining forest resources has

*Table 1.* Balance of supply and demand for major wood products in Nigeria (millions of $m^3$ roundwood equivalent) (source: Agricultural Development in Nigeria, 1983–2000, Forestry Sector Review)

| | 1975 | | | 1985 | | | 1995 | | |
|---|---|---|---|---|---|---|---|---|---|
| Product | Demand | Supply | Deficit | Demand | Supply | Deficit | Demand | Supply | Deficit |
| Sawnwood | 2.0 | 2.0 | – | 4.8 | 2.2 | 2.6 | 11.6 | 2.4 | 9.2 |
| Plywood | 0.1 | 0.1 | – | 0.4 | 0.1 | 0.3 | 1.4 | 0.1 | 1.0 |
| Paper products | 0.6 | – | 0.6 | 1.9 | 0.5 | 1.4 | 5.2 | 1.0 | 4.2 |
| Poles | 1.6 | 0.8 | 0.8 | 2.0 | 0.8 | 1.2 | 2.3 | 1.0 | 1.3 |
| Firewood | 42.0 | 42.0 | – | 48.0 | 49.0 | (+1.0) | 54.0 | 54.0 | – |
| Total | 46.3 | 44.9 | 1.4 | 57.1 | 52.6 | 4.5 | 74.5 | 58.5 | 16.0 |

*Table 2.* Area of tropical moist forests in some West African countries (source: FAO/UNEP 1981)

| | Area ($km^2$) | | Estimate of population | |
|---|---|---|---|---|
| | Total | Tropical moist forest | Total ($10^6$) | Persons $km^{-2}$ |
| Cameroon | 475 442 | 179 200 | 7.1 | 15 |
| Côte d'Ivoire | 322 463 | 44 580 | 8.0 | 25 |
| Gabon | 267 670 | 205 000 | 0.5 | 2 |
| Ghana | 238 538 | 17 180 | 11.4 | 48 |
| Liberia | 96 320 | 20 000 | 2.0 | 21 |
| Nigeria | 923 768 | 59 500 | 85.0 | 92 |
| Sierra Leone | 73 326 | 7 400 | 3.4 | 46 |

probably reduced the diversity of the available gene pool of most of the important timber species, such as *Milicia* (syn. *Chlorophora*) *excelsa*, *Entandrophragma angolense*, *Terminalia* species and *Triplochiton scleroxylon*, among others. However, the information on this aspect is scant.

Hardwood timber supplies have traditionally depended on natural forest management techniques for regeneration (Kio 1983), until this method was found to be insufficiently productive (Food and Agriculture Organisation 1989). The dependence on natural regeneration, coupled with poor control of logging in the Forest Reserves, has led to over-exploitation of the forest in humid W Africa, except where the terrain does not allow easy access, or where the areas are traditionally protected (fetish groves). Such areas are a valuable resource of germplasm, but they are being threatened by deforestation, which is continuing to have serious environmental and economic consequences. Reviewing the forest situation in Côte d'Ivoire, Caulfield (1982) reported that this country had lost more than 70% of its rainforests since the turn of the century. A continuing annual rate of deforestation of around 10% was expected to make Côte d'Ivoire a net importer of timber in the 1990s (Bourke 1987). Similarly, Nigeria and Ghana are expected to be unable to meet the internal demand for timber in a very short time. Because of this, Nigeria and Ghana banned further exports of certain timbers in 1976 and 1978, respectively, in order to help meet domestic wood requirements (Kio 1983). Partly as a result of its lower population and poor access to the eastern part of the country, Cameroon still has a significant timber resource, but at the International Tropical Timber Organization (ITTO) meeting at Yaoundé in May 1992, it was revealed that Cameroon loses 200 000 hectares of its moist forests annually.

With the high rates of deforestation, it became clear in the late 1960s that action was needed to restock the moist forests and to initiate intensive plantation forestry. At this time, most re-afforestation schemes in West African countries depended on exotic fast-growing hardwoods such as *Tectona grandis* and *Gmelina arborea* to meet the future hardwood needs of the population. *Eucalyptus* and *Pinus* species were grown for pulp. Seeds of these exotic species were available from trials located at various sites in these countries, so allowing the implementation of large-scale reforestation programmes for the production of lumber, industrial cellulose and poles. Attempts to plant indigenous species were also made, whenever seeds were available. However, the tendency was to plant exotics rather than indigenous species, as the silviculture of the former was better known. In the case of *Triplochiton scleroxylon*, the lack of planting was due to the poor and irregular seeding habit and the susceptibility of the seeds to insect attack (Britwum 1973b; Jones 1974; Howland & Bowen 1977). In others (iroko and mahogany), there were severe pest problems. In general, however, exotics were preferred because of their faster growth and the expectation of greater economic returns.

Despite early interest in indigenous hardwoods going back to colonial times (eg 1930–50s), it was not until the late 1960s and 1970s that it was realised that research on regeneration methods was needed, and that tree improvement could generate improved economic returns. Tree improvement programmes were, therefore, initiated at this time in Ghana, Côte d'Ivoire and Nigeria. The present paper presents what has been accomplished over the past 25 years under these and other more recent programmes with indigenous species.

## COLLABORATIVE SCHEMES FOR RESEARCH AND DEVELOPMENT

The history of tree improvement in West Africa cannot be complete without mention of various overseas governments, institutes and agencies. The example of *T. scleroxylon* will be emphasised as this was recognised as the species for which there were major problems and great commercial interest. The first action was in Ghana, at the Forest Products Research Institute at Kumasi, where clonal seed orchards of *T. scleroxylon* and *Terminalia ivorensis* were established in 1972 and 1973 and techniques of rooting juvenile cuttings were pioneered (Britwum 1970b), with external funding by the UK Overseas Development Administration (ODA). Subsequently, in 1971, the West African hardwoods improvement project (WAHIP) was initiated for the most promising indigenous hardwood tree species of West Africa at the Federal Department of Forest Research (later the Forest Research Institute of Nigeria [FRIN]) at Ibadan. WAHIP continues to the present day, but overseas funding ceased in 1977. This project was based on the use of vegetative propagation and clonal selection, again with external funding from ODA (Howland & Bowen 1977). In 1974, WAHIP was supplemented by a project to study the physiology of rooting in *T. scleroxylon* at the UK Institute of Tree Biology (later the Institute of Terrestrial Ecology [ITE]) in Edinburgh. Research on this and other West African hardwoods at ITE has continued up to the present. Together, these projects have developed techniques in *T. scleroxylon* to store seeds, root stem cuttings, select superior clones, induce flowering and establish breeding programmes, as part of an overall package to domesticate this commercially important timber tree (Longman & Leakey 1993).

As a result of this research, commercial planting of clonal *T. scleroxylon* was initiated by 'Safa Splints' in the 1980s, using a mixture of selected clones provided by FRIN. A somewhat similar programme of vegetative propagation and clonal selection started in Côte d'Ivoire in the 1970s at Centre Technique Forestier Tropical (CTFT), with funds from the French Government (Verhaegen 1992). The practical application of these techniques, particularly with *Terminalia ivorensis*, was initiated as part of a World Bank/ Commonwealth Development Corporation project based in the Société de Dévéloppement des Forêts (SODEFOR), in collaboration with CTFT. Later in 1987 with funds from French Aid and Cooperation Fund, a similar industrial-scale project was initiated by SODEFOR at Téné (Verhaegen *et al.* 1992). Currently work continues at the Institut de Dévéloppement des Forêts (IDEFOR, previously CTFT) with clonal selection of *Triplochiton scleroxylon*.

In the early 1980s, an attempt was made to initiate a 'regional programme for improvement of tropical hardwoods for West and Central Africa'. Detailed proposals were prepared with funding from the European Commission (Leakey & Grison 1985) but the programme, which spanned Sierra Leone, Liberia, Côte d'Ivoire, Ghana, Nigeria, Cameroon and Congo, never materialised.

In the late 1960s and early 1970s, CTFT in the Congo was also developing a clonal approach to indigenous hardwoods (in parallel with their well-known programme on *Eucalyptus* species at Pointe Noire [Delwaulle, Laplace & Quillet 1983]), but with *Terminalia superba* instead of *Triplochiton scleroxylon* (Martin & Quillet 1974; Koyo 1983, 1985). Similarly, early studies in Gabon by CTFT concerned another hardwood, *Aucoumea klaineana* (Grison & Hamel 1978).

In addition to timber tree species, genetic improvement studies were in progress in Nigeria in the 1970s and 1980s with indigenous fruit trees (see Okafor & Lamb, pp34–41). Further work to domesticate fruit trees is currently in progress in:

- Cameroon with *Ricinodendron heudelottii* and *Irvingia gabonensis* at the Forest Research Station of Agronomic Research Institute at Kumba (P Shiembo, unpublished) and with *Dacryodes edulis* ( J Kengue, unpublished) at the Agronomic Research Institute at Nkolbisson; and
- Côte d'Ivoire with *Coula edulis* (L Bonnélin, unpublished) in Tai National Park, in collaboration with Wageningen University.

Currently, much of the research done with *T. scleroxylon* over the past 20 years is being applied in Cameroon by the Office National de Dévéloppement des Forêts (ONADEF, formerly the Office National de Regénération des Forêts (ONAREF)) in collaboration with ITE and with external funding from ODA (see Lawson, pp112–123). This project is part of the Cameroon and UK governments' response to the Tropical Forest Action Plan. This project has built on the earlier activities of the ONAREF Parc de Bouturage (Leakey 1985), which was part of the Cameroon/World Bank forestry project.

Current studies are also in progress in Ghana, with ITTO funds, to select and propagate vegetatively clones of *Milicia* (syn. *Chlorophora*) spp. resistant to the gall-forming psyllid *Phytolyma lata* (Cobbinah 1990). Further work on the vegetative propagation of *M. excelsa* is in progress at FORIG, Kumasi (D Ofori, unpublished).

Studies have also been made with clones of *Gmelina arborea* in Cameroon (Bibani 1983) and in Côte d'Ivoire (Kadio 1990), while other approaches to tree improvement are in progress with exotic hardwoods in Ghana, eg *Tectona grandis* provenance trials in collaboration with Danish International Development Agency; *Cordia alliodora* and *Cedrela odorata* provenance trials in collaboration with Oxford Forestry Institute; and *Gliricidia sepium* with the International Centre for Livestock in Africa.

## DEVELOPMENTS FROM RESEARCH ACTIVITIES, ESPECIALLY WITH *TRIPLOCHITON SCLEROXYLON*

Substantial information has been acquired over the past 20–25 years of research on various aspects of tree improvement in West Africa. To establish plantations, and to make better use of available land, there is a need to domesticate commercially important species. Genetic variation within a tree species offers the opportunity for selection of superior high-yielding populations and individuals. However, very few tropical trees have been improved genetically because of the difficulties of making improvements by breeding in tree species which have such a long life cycle, which do not flower regularly and do not become sexually mature for many years, and which are not self-fertile (Burley 1985).

## Seed storage

It is now known that seed of *T. scleroxylon* is available each year in small quantities and that mast years occur every four to seven years. Further, with adequate seed harvesting, processing and storage as developed by Howland and Bowen (1977), viability can be maintained for six years (Ladipo 1984). Regular power failures, however, result in considerable losses of stored germplasm. Seed of a number of other species (eg *Mansonia altissima* and *Entandrophragma angolense*) have also been stored successfully (Gyimah 1984; Damptey 1968).

## Provenance trials

Provenance trials provide information on geographical variation within species, which enables the best seed sources to be identified and selected. This was the first strategy employed in tree improvement in West Africa (Britwum 1973a, 1978).

### *Triplochiton scleroxylon*

A major provenance trial established in Nigeria under WAHIP included investigation based on seed collected from the following six countries: Sierra Leone, Liberia, Côte d'Ivoire, Ghana, Nigeria and Cameroon, forming the West African moist forest region and spanning most of the natural range of this species. Results revealed substantial variation in growth, with the Nigerian and Côte d'Ivoire provenances showing the greatest promise (Howland & Bowen 1977).

Working on some Nigerian provenances, Adedire (1986) also reported substantial early variation between the seedlots evaluated. The Oturkpo provenance performed better in height and diameter than the Obubra and Ubiaja provenances.

### *Terminalia superba*

In 1969, CTFT, Côte d'Ivoire, started provenance trials of *T. superba* using 16 provenances from Sierra Leone (1), Côte d'Ivoire (3), Ghana (3), Cameroon (3), Gabon (3), Congo (1) and Central African Republic (2). Results of assessment three years after establishment showed significant differences between provenances in height growth and stem form (Delaunay 1978a). The best provenance was from Ghana (Abofour) with a mean height of 9.4 m, almost double that of Dahomey (Quedo) provenance with a height of 5.3 m. The Ghana-Abofour provenance was followed by two provenances from Côte d'Ivoire and two from Cameroon. The provenances from Congo and Gabon were poor and that of Dahomey was the worst. Studies using electrophoresis have examined the polymorphism of enzymatic systems differentiating 'fraké' in Côte d'Ivoire from 'limba' in Congo (Vigneron 1984). The former were more polymorphous.

### *Terminalia ivorensis*

This species has been planted extensively in many countries in West Africa, especially under the taungya system in high forest areas. Provenance trials exist in Ghana, Côte d'Ivoire and Cameroon.

In 1973, Ghana and Côte d'Ivoire exchanged *T. ivorensis* seeds for provenance studies. The provenances tested in Ghana included five from Ghana, three from Côte d'Ivoire and one from Cameroon. Results of assessment for height growth in Ghana showed a highly significant difference between the Cameroon provenance and the provenances from Ghana and Côte d'Ivoire (Britwum 1978; Delaunay 1978b). The Cameroon seed source was the poorest on all the three sites tested. There were no significant differences between the Ghana and the Côte d'Ivoire provenances. Some of the trees in this study started to flower in 1976. There was no observed provenance variation in flowering.

## Tree breeding

### *Plus-tree selection and seed orchards*

To aid genetic improvement, it is important that superior genotypes are identified and centralised. In Nigeria (FRIN), budwood from 105 plus-trees of *Triplochiton scleroxylon* were collected and propagated by grafting before 1976 (Howland & Bowen 1977). These were preserved in field plantings at three sites and in the nursery. Many of the identified and labelled plus-trees in farmland were subsequently felled. Thus, the grafted material provides an important germplasm resource, although relatively few of these grafts have subsequently provided seeds. These nursery plants at least are not subjected to the risks of fire or logging.

A similar programme of selecting provisional plus-trees of T. scleroxylon and T. ivorensis in Ghana, in the natural high forest, was started in 1968 (Jones 1968, 1970; Britwum 1970a). The phenotypic characteristics on which selection was based, as in Nigeria, included height growth and tree form. Most of these plus-trees, other than those in clonal seed orchards, have subsequently been lost through logging.

### *Clonal seed orchards*

Apart from the nursery stock described above, all other propagules derived from 30 mature plus-trees were in established experiments and have now been converted into clonal seed orchards (Howland & Bowen 1977) at field sites in southern Nigeria.

Clonal seed orchards of *T. scleroxylon* and *Terminalia ivorensis* were established in Ghana in 1972 and 1973, using scion material collected from provisional plus-trees and budded on to seedling root stock. Twenty clones of each species were used to establish the two orchards in South Formangsu Forest Reserve (Britwum 1973a).

Flowering and fruiting in both the Ghanaian and Nigerian *Triplochiton scleroxylon* seed orchards have generally been poor. Some of the clones have never fruited, but clone 4 in Ghana has flowered almost every year since 1974. In Nigeria, two trees of S93 in Sapoba have flowered consistently and much more frequently than the other clones.

**Vegetative propagation**

Cuttings of *T. scleroxylon* were rooted originally to circumvent seed problems. Subsequently, the extent of clonal variation indicated the potential of selecting clones for their superiority in growth and form. Research on the rooting of single-node leafy cuttings has reflected these changes in the reason for clonal propagation.

In the early 1970s, the objective was to achieve a practical and reliable method of bulking up planting stock (Britwum 1970b; Okoro 1974; Howland 1975) using mist and non-mist propagators. Ladipo (1985) further demonstrated that rooted cuttings could be as good as seedlings for commercial field use and that no problems of plagiotropism occurred. From 1974, greater emphasis was placed on understanding the sources of variation in rooting ability and the achievement of physiological understanding, such that stockplant management could ensure cost-effective and sustainable methods of rooting to retain juvenility during mass propagation (Leakey 1983; Leakey, Dick & Newton 1992). This work to acquire physiological understanding of the rooting process continues and is presented in greater detail by Leakey, Newton and Dick (pp72–83).

More recently, since 1986, progress has been towards scaling up the operation and applying the existing knowledge in a forest regeneration project in Cameroon (Lawson, pp112–123) and Côte d'Ivoire (Verhaegen *et al.* 1992). Currently, in Cameroon, propagation in the ONADEF/ODA forest management and regeneration project's Parc de Bouturage is producing about 20 000 rooted cuttings for planting about 30 ha each year (Leakey, Njoya & Bockett 1992; Lawson, pp112–123). This project is utilising low-technology non-mist propagators (Figure 1), which have been adapted from an earlier design used in Nigeria. These propagators are cheap and simple and so are suitable for rural development projects in the tropics (Leakey *et al.* 1990).

In Côte d'Ivoire, cuttings are rooted under mist propagators with a capacity of 250 000 cuttings per year. For research purposes, these propagators are enclosed with shade cloth (40% shade) and misted twice a day (Verhaegen *et al.* 1992). On average, the rooting success is 68%. In the period December 1990 to March 1991, 40 000 cuttings had been set in these propagators, and mean rooting success had increased to 80%.

The developments with *T. scleroxylon* have now been transferred to other species (Table 3), with intensive projects on *Khaya ivorensis* and *Lovoa trichilioides* (Tchoundjeu 1989; see also Newton *et al.*, pp256–266). In addition, detailed studies on *in vitro* micropropagation have been completed with *Khaya ivorensis* and *Nauclea diderrichii* (Mathias 1988).

**Clonal selection**

Selection for improvement is one element of the domestication process currently employed for *Triplochiton scleroxylon* and some other native hardwood species in West Africa. It has been used at FRIN and by ITE in Nigeria (Howland & Bowen 1977; Leakey & Ladipo 1986), at CTFT/IDEFOR in Côte d'Ivoire (Verhaegen *et al.* 1992), and has recently started at ONADEF in Cameroon (Leakey, Njoya & Bockett 1992). Many species have problems of seed availability, and vegetative propagation is capable of

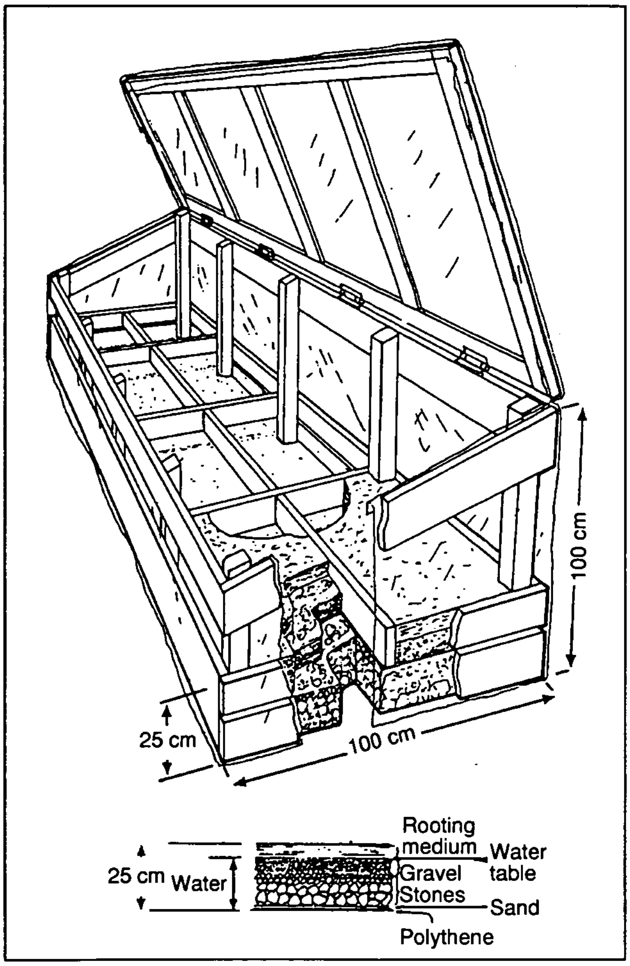


*Figure 1.* Diagram of the construction of an ITE non-mist propagator (source: Leakey *et al.* 1990)

*Table 3.* Indigenous timber tree species of moist forests of W Africa vegetatively propagated using intermittent mist and simple low-technology propagators

| Species | Family | Other uses | Country where propagated |
|---|---|---|---|
| *Entandrophragma angolense* | Meliaceae | | UK |
| *Entandrophragma cylindricum* | Meliaceae | Carving | Nigeria, Cameroon, Ghana |
| *Entandrophragma utilis* | Meliaceae | Medicine | Ghana, Nigeria |
| *Khaya ivorensis* | Meliaceae | Carving | Cameroon, Nigeria, UK |
| *Lovoa trichilioides* | Meliaceae | Carving | Cameroon, Côte d'Ivoire, UK |
| *Mansonia altissima* | Sterculiaceae | Fuelwood/food | Ghana, Nigeria |
| *Mitragyna stipulosa* | Rubiaceae | Carving | Ghana, Nigeria, Cameroon, UK |
| *Milicia excelsa* | Moraceae | Medicine | Ghana, Cameroon |
| *Nauclea diderrichii* | Rubiaceae | Carving | Nigeria, Ghana, Cameroon, UK |
| *Pericopsis elata* | Leguminosae | Carving | Ghana |
| *Terminalia ivorensis* | Combretaceae | Fuelwood | Nigeria, Côte d'Ivoire, Cameroon, UK |
| *Terminalia superba* | Combretaceae | Fuelwood | Nigeria, Cameroon, Côte d'Ivoire, UK |
| *Triplochiton scleroxylon* | Sterculiaceae | Canoe building | Ghana, Nigeria, Cameroon, Côte d'Ivoire, UK |

circumventing them. With propagation methods already well developed, it is then possible to increase the productivity of the plantations or agroforestry systems by selecting elite clones and propagating them vegetatively to provide large quantities of genetically superior planting stock.

In Nigeria, clonal trials representing the full geographical range of *T. scleroxylon* have been established at five sites. The first phase of the study examined the variation in a wide range of growth characteristics among large numbers of clones of different seed origins in an attempt to identify criteria for clonal selection (Ladipo *et al.* 1983). Selection of the ten tallest clones at 18 months old from this randomly chosen clonal population of 98 clones originating from 15 seedlots showed a potential height gain of 16.5% over the mean of all plants. At nearly five years, a selection of 33% of the clones with both above-average mean stem volume and mean stem scores resulted in potential overall gains in volume of 30.5%. These gains could be substantially improved, however, by the selection of the best ten clones, resulting in about 80% improvement in yield (Leakey & Ladipo 1986). For a large-scale clonal reforestation programme, it is necessary to have a strategy of clonal selection and deployment that will maximise productivity while minimising the risk of utilising a narrow genetic base and also minimising the risks of ecological problems. Consequently, an approach has been developed for *T. scleroxylon* to introduce a large number of unrelated clones (Leakey 1991; see also Foster & Bertolucci, pp103–111), and to ensure the conservation and wise use of germplasm.

To achieve this objective by testing large numbers of clones in field trials is not practicable, so efforts have been made to identify desirable characteristics at an early age. This approach is geared towards screening for 'superior' seedlings in the nursery, as a preliminary procedure to reduce the numbers of clones to be tested in the field. Having examined the possibilities of identifying selection criteria, it became apparent that branching frequency was important to both yield and form, with low branching frequency being preferred. Consequently, after standardising environmental and morphological variables, Ladipo (1981) examined clonal variation in apical dominance (the process of determining branching frequency). He identified conditions under which a nursery study of sprouting following decapitation could be used as a 'predictive test' to select potentially superior clones (Ladipo, Leakey & Grace 1991a, b). Using this test, a strong relationship ($r$=0.76; P=0.001) was found between the bud activity at weeks 3–4 in young decapitated plants of *T. scleroxylon* and the branchiness of four-year-old trees of the same clones in plantations (Ladipo *et al.* 1991c). It, therefore, seems that, at least for trees conforming to Rauh's model of branching architecture (Hallé, Oldeman & Tomlinson 1978), there is potential for screening seedlings in the nursery for those worthy of inclusion in clonal field trials.

The predictive test described above is currently being utilised in the Parc de Bouturage of the ONADEF/ODA forest management and regeneration project at Mbalmayo in Cameroon. Recently, 14 000 seedlings of *T. scleroxylon* of ten seed origins have been subjected to the test to identify those for subsequent cloning and field plantings (see Lawson, pp112–123).

In Côte d'Ivoire, a different approach has been taken to clonal selection in *T. scleroxylon*. In this instance, a four-year-old plantation of 191 ha on good soil at Mopri was used to select plus-trees (Verhaegen *et al.* 1992). The seeds for this plantation were of local origin. It was felt that at four years of age these trees, which had a mean height of 11 m and basal area of 10 $m^2$ $ha^{-1}$, had expressed their potential and yet were young enough to be multiplied vegetatively. As the first stage, the best 35 trees $ha^{-1}$ were selected (5% selection intensity) on the basis of visual appearance. In the second stage, these 35 trees were assessed for their form and vigour relative to their neighbours (Boutin 1983, 1991). Relative vigour ($E$) was assessed as stem circumference at 1.5 m of the selected tree ($C_s$) and the mean circumference of its eight nearest neighbours ($MC_v$):

$$E = \frac{(C_s^2 - MC_v^2)}{\delta \; cv}$$

where $cv$ is the coefficient of variation. On the basis of this analysis, 308 trees were selected, of which 154 were selected by a second visual inspection as plus-trees. This represents an 0.3% selection intensity.

The plus-trees were then coppiced at 0.4–0.5 m in 1984 and cuttings collected one month later; 116 clones were established. Stockplants of these clones have subsequently been planted at Téné, and clonal trials covering 23.8 ha established in 1987–90 at Mopri, Téné and Sangoué. These clones have performed better at Mopri than at Téné (Kadio, Legaré & Bohousson 1991). After two to five years, the mean performance of the clones was 14% better than a control plot of unselected seedlings (Verhaegen *et al.* 1992).

Ladipo *et al.* (1984) reported considerable clonal variation between clones of *T. scleroxylon* in net photosynthesis, stomatal resistance and mesophyll resistance. A good relationship was found ($r$=0.81; P=0.05) between gas exchange parameters and yield. To date, this relationship has not been used in selection programmes, and further work is needed to take advantage of such physiological selection criteria.

## RESEARCH ON WILD FRUIT OR FOOD TREES

The basic principles of vegetative propagation and clonal selection of indigenous hardwoods are equally applicable to the domestication of wild fruit tree species (see Okafor & Lamb, pp34–41) (see Table 4).

In addition to Okafor's (1975, 1981) extensive studies with *Irvingia gabonensis*, *Treculia africana*, and other species, there are currently other studies in Nigeria by the International Centre for Research in Agroforestry (ICRAF) (multipurpose tree species project), in Cameroon by the Agronomic Research Institute, and in Côte d'Ivoire by Wageningen University. Further objectives of these projects are to determine the ecological, biological and physiological factors influencing the domestication process, to select superior trees for mass production and to test these cultivars under agroforestry situations. Techniques of marcotting have been developed in Nigeria (ICRAF/International Institute of Tropical Agriculture/Oregon State University) for *Treculia africana*, *Irvingia gabonensis* and *Dacryodes edulis*, while the rooting of stem cuttings has been used in Cameroon for *Ricinodendron heudelotii* and *Irvingia gabonensis*. This approach is particularly aimed at improving the compound farm system of agroforestry.

Currently, there are proposals to add studies on the vegetative propagation and clonal selection of fruit trees to the ODA/ONADEF project in Cameroon, perhaps including the domestication of *Cola nitida*, *Cola lepidota*, *Xylopia* spp., *Cola pachycarpa*, *Tetrapleura tetraptera*, etc, and their genetic improvement by selection at ICRAF (Nigeria/Cameroon). This aspect of the project is important as the demand for some local fruit products in the urban areas of West Africa is expanding, while some products like the cola nut have considerable importance in regional trade.

## GENETIC RESISTANCE TO PESTS

Not surprisingly, there are pest and disease problems associated with cultivating indigenous tree species. Recently, however, attempts have been made to search for pest-resistant genotypes (Ladipo 1986; Cobbinah 1990). In Nigeria, work on *Terminalia ivorensis* leaf gall commenced in 1986, while at the Forestry Research Institute of Ghana (FORIG) work is in progress with ITTO funds to screen Iroko half-sib progenies of *Milicia*

*Table 4.* Some indigenous fruit tree species vegetatively propagated using simple horticultural methods in West Africa

| Species | Family | Method of propagation | Country |
|---|---|---|---|
| *Garcinia kola* | Guttiferae | Marcotting and stem cuttings | Nigeria, Cameroon, Côte d'Ivoire |
| *Irvingia gabonensis* | Irvingiaceae | Grafting/marcotting and stem cuttings | Nigeria, Cameroon, Côte d'Ivoire |
| *Pentaclethra macrophylla* | Leguminosae | Marcotting | Nigeria, Côte d'Ivoire |
| *Dialium guineensis* | Leguminosae | Stem cutting | Nigeria |
| *Dacryodes edulis* | Burseraceae | Marcotting | Nigeria, Cameroon, Côte d'Ivoire |
| *Maesobotrya barterii* | Rubiaceae | Marcotting | Nigeria |
| *Treculia africana* | Moraceae | Grafting | Nigeria, Côte d'Ivoire |
| *Masularia acuminata* | Rubiaceae | Stem cuttings and marcotting | Nigeria |

*excelsa* for resistance to *Phytolyma lata* galls. Evidence has been obtained that some *M. excelsa* trees are probably resistant to attack by this psyllid (Cobbinah 1990). This ITTO project aims to quantify possible sources of resistance and to test them using two bioassay techniques (insect bioassay and the standard choice bioassay). For these tests, both susceptible and resistant trees will be cloned using stem cuttings. Initial results have shown that some individuals are less frequently attacked and that insects in the galls formed do not develop to maturity. Similar studies on genetic resistance to *Hypsipyla* shoot-borers in Central American mahogany (Newton *et al.*, pp256–266) could be applied to the W African members of the Meliaceae, such as *Khaya* spp.

## REPRODUCTIVE BIOLOGY AND BREEDING

There have been limited studies on the breeding systems of tropical hardwoods of West Africa. Howland and Bowen (1977) reported that *Triplochiton scleroxylon* is self-sterile and is pollinated by many insect species from several families. Pollen management and storage of *T. scleroxylon* have been investigated (Leakey, Ferguson & Longman 1981; Oni, Fasehun & Ladipo 1988) and deep-frozen pollen has been successfully used for cross-pollination. Attempts to induce precocious flowering in *T. scleroxylon*, while not successful in all clones, did demonstrate that flowering can be initiated in young plants (18 months old) by inducing root dormancy in plants with active shoots (Leakey *et al.* 1981). Subsequently, cross-pollinations resulted in the development of normal seedlings and, in one instance, a second-generation progeny was also created as a result of precocious flower induction. It thus appears that there is potential to add early breeding techniques to the domestication procedures of this species and so obtain full-sib progeny on a short generation cycle (1.5–2 years). Studies by Grison (1978) on *Aucoumea klaineana* described the flowers and their pollination mechanisms, and reported some successful controlled pollinations.

Recent studies on *Terminalia ivorensis* have shown that the species is andromonoecious. The flowers are either male or bisexual, with both hermaphrodite and male flowers occurring on the same spike. The distribution of male and hermaphrodite spikes on flowering twigs of *T. ivorensis* differed significantly between sites at 1% probability. The ratio of male/hermaphrodite spikes (MF:HF) is 1.9:1 (Oni 1989). The flowers are mostly insect-pollinated. Results of controlled pollination carried out on the species indicated self-compatibility. The reproductive efficiency of the species is 21%. Pollen grains of *T. ivorensis* are amenable to storage at –17°C or –30°C and can be grown successfully on a medium containing 0.1% boric acid + 20% sucrose (Oni 1989). In Ghana, seeds have been obtained from a clonal seed orchard. The size of the fruits varied among the different clones.

Flowering and flower morphology of *T. superba* have also been studied in Ghana (see *FORIG Technical Note*, no. 29). Flowering occurs at not earlier than ten years of age, and takes place between mid-October and early January. The flowers appear in a whorl of spikes, and last for one month. The whorl contains 19 flower spikes, of which nine are entirely composed of hermaphroditic flowers, two of only male flowers, and the remaining eight contain hermaphroditic flowers at the base with staminate flowers arranged above them in an average ratio of 29:47. The ovary is inferior and unilocular. The hermaphroditic flowers are self-compatible, and pollination by the staminate flowers is restricted if not inhibited.

## GERMPLASM CONSERVATION

Deforestation poses a major threat to the genetic resources of indigenous tree species in West Africa. In Nigeria, 12 strict Natural Reserves have been established in various ecological zones to provide *in situ* conservation of these and many other species. Similar action has been or is being taken in several other countries in the region. With more efficient control and management, Forest Reserves can play a major role in germplasm conservation. However, as already mentioned, *ex situ* conservation by seed, pollen and live plants also has an important contribution to play, especially when linked to tree improvement programmes.

## CONCLUSIONS

In conclusion, much progress has been made in West Africa by local research organisations with and without international collaboration. What is needed is greater regional collaboration, particularly in germplasm collection and exchange, and the widespread application of this research, together with ongoing studies to deepen understanding and broaden the spectrum of species domesticated for the production of timber and non-timber products. This development would have significant implications for the timber and wood supply, economy and environment of West Africa.

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