Expl Agric. (2001), volume 37, pp. 279–296
Printed in Great Britain

REVIEW PAPER

DIVERSIFICATION OF TREE CROPS: DOMESTICATION OF COMPANION CROPS FOR POVERTY REDUCTION AND ENVIRONMENTAL SERVICES

By R. R. B. LEAKEY† *and* Z. TCHOUNDJEU‡

†*Centre for Ecology and Hydrology, Bush Estate, Penicuik, Midlothian,*
EH26 0QB, Scotland, UK and ‡*International Centre for Research in Agroforestry,*
PO Box 2067, Yaoundé, Cameroon

(*Accepted 19 January 2001*)

SUMMARY

New initiatives in agroforestry are seeking to integrate indigenous trees, whose products have traditionally been gathered from natural forests, into tropical farming systems such as cacao farms. This is being done to provide from farms, marketable timber and non-timber forest products that will enhance rural livelihoods by generating cash for resource-poor rural and peri-urban households. There are many potential candidate species for domestication that have commercial potential in local, regional or even international markets. Little or no formal research has been carried out on many of these hitherto wild species to assess potential for genetic improvement, reproductive biology or suitability for cultivation. With the participation of subsistence farmers a number of projects to bring candidate species into cultivation are in progress, however. This paper describes some tree domestication activities being carried out in southern Cameroon, especially with *Irvingia gabonensis* (bush mango; dika nut) and *Dacryodes edulis* (African plum; safoutier). As part of this, fruits and kernels from 300 *D. edulis* and 150 *I. gabonensis* trees in six villages of Cameroon and Nigeria have been quantitatively characterized for 11 traits to determine combinations defining multi-trait ideotypes for a genetic selection programme. *I. gabonensis* fruits are rich in vitamin A (67 mg 100 ml^{-1}), while the kernels are rich in fat (51.3%) and contain a polysaccharide that is a food thickener. The fruits of *D. edulis* are also rich in oil (31.9%) and protein (25.9%).

This poverty-reducing agroforestry strategy is at the same time linked to one in which perennial, biologically diverse and complex mature-stage agroecosystems are developed as sustainable alternatives to slash-and-burn agriculture. To meet the objective of poverty reduction, however, it is crucial that market expansion and creation are possible. Hence, for example, it is important to determine which marketable traits are amenable to genetic improvement. While some traits (such as fruit and kernel mass) that benefit the farmer are relatively easy to identify, there are undoubtedly others that are important to the food, pharmaceutical or other industries which require more sophisticated chemical evaluation. There is a need, therefore, for better linkages between agroforesters and the private sector. The domestication activities described are relevant to the enrichment of smallholder cacao farms and agroforests. This diversification is seen as being important for the support of the cacao industry.

---

†The Centre for Ecology and Hydrology (CEH) is a component of the Edinburgh Centre for Tropical Forests.
Corresponding author: E-mail: rrbl@ceh.ac.uk

INTRODUCTION

According to the World Commission on Forests and Sustainable Development (WCFSD) about 14×10^6 ha of tropical forests have been lost each year since 1980 as a result of changes in land use from forest to agriculture (WCFSD, 1999). One of the five 'radical and urgent actions' recommended by the WCFSD to address this problem was to provide 'more extensive support to community-based agroforestry in order to reduce the pressure on primary forests for supplying subsistence products'. Community-based agroforestry also has the potential to provide on-farm sources of cultivated timber and non-timber forest products for domestic use and for marketing, in ways that also provide some important environmental services such as biological diversity and carbon sequestration (Leakey, 2001a;b). Increasingly this is being achieved. However, there can be complex tradeoffs between global environmental concerns and the objectives of poverty reduction and national development which, if not acted upon, could lead to further deforestation (Tomich *et al.*, 1998). This is an area of active research by the International Centre for Research in Agroforestry (ICRAF) and its partners in the CGIAR's Alternatives to Slash-and-Burn Programme in Indonesia, Cameroon and Brazil.

Agroforestry practices come in many forms (Nair, 1993) but it has recently been suggested that they should be seen more as stages in the development of an agroecosystem (Leakey, 1996). This concept sees the increasing integration of trees or agroforestry practices into land-use systems, over time, as a parallel to natural succession. In this way, diversifying an agroecosystem, whether a maize field or a cacao farm, moves it towards a mature agroforest of increasing ecological integrity (Leakey, 1996). De Clerck and Negreros-Castillo (2000) have described four stages in the development of a mature agroforest. These developmental stages differ in structure and species composition. Increasing scales of integrating various agroforestry practices into the landscape also enhance biological diversity and ecological stability by creating a complex land use mosaic (Leakey, 1999a). In the tropics, this could lead to the development of viable alternatives to slash-and-burn agriculture. The large-scale adoption of such an approach should be beneficial, especially since the ecological and economic benefits of diversity on a landscape-scale are considerably greater than the sum of the individual farm-scale benefits.

This more ecological concept of agroforestry has been accepted by the International Centre for Research in Agroforestry (ICRAF, 1997) which now defines agroforestry as 'a dynamic, ecologically based, natural resources management system that, through the integration of trees in farms and in the landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels'. Filling some of these niches with indigenous species that provide economically valuable timber and non-timber products traditionally obtained from natural forest, and important environmental services, should result in land use that is both sustainable and productive. The domestication of these trees to increase the quality, number and diversity of these products should enhance agroforestry's capacity to fulfil its ultimate potential as a way to reduce poverty and to mitigate deforestation and land depletion.

This paper reviews current activities towards the domestication of indigenous trees producing non-timber forest products, especially *Irvingia gabonensis* (bush mango; dika nut) and *Dacryodes edulis* (African plum; safoutier). It then examines the current and potential markets for these products and reviews the scope for enhancing farmer livelihoods by (i) establishing these indigenous trees within cacao agroforests, and (ii) developing improved cultivars.

DOMESTICATION IN PROGRESS

Domestication of the so-called 'Cinderella trees' (Leakey and Newton, 1994), indigenous trees traditionally important throughout the tropics that have been overlooked by science, recently has become a major programme in international agroforestry research (Simons, 1996a; Sanchez and Leakey, 1997; Leakey and Simons, 1998). In genetic terms, domestication is accelerated and human-induced evolution. Domestication, however, is not only about selection and breeding. It also integrates the four key processes of identification, production, management and adoption of agroforestry tree genetic resources.

ICRAF has started domestication programmes with a number of tree species in each of the six eco-regions in which it operates (Leakey and Simons, 1998). One of these programmes, in partnership with Institut de la Recherche Agricole pour le Développement (IRAD) and with the collaboration of the UK Centre for Ecology and Hydrology (CEH), is based in Yaoundé, Cameroon. This West and central African programme is targeted at the area in which cacao is an important export crop and thus is the focus of this paper.

The first step in the domestication process (Simons, 1996a) has been the identification of priority species for domestication. This first step of priority setting has already been widely reported (Leakey and Jaenicke 1995; Jaenicke *et al.*, 1995; Franzel *et al.*, 1996; Simons, 1996b). It involves household interviews to determine farmer preferences, the assessment of market potential and the inputs of researchers on technical points such as genetic variability. From this process, a shortlist of priority species for a region can be assembled (Table 1). Farmers in humid West and central Africa identified indigenous fruit tree species as their top priorities. In addition and as a result of wider consultation, two commercially important medicinal species, *Prunus africana* (Pygeum) and *Pausinystalia johimbe* (Yohimbe), have been added to the priority list. This arose from industrial fears about the future of these resources, as well as the need perceived by researchers for conservation of the species and their habitats. This illustrates the principle that while the domestication process should be driven by a farmer-led approach, consideration has to be given also to market needs and thus must not overlook a market-led approach (Leakey and Simons, 1998).

After priority setting, the second step in the domestication process is the assemblage of rangewide germplasm collections of the chosen species. These

Table 1. Priority tree species selected for domestication by implementation of farmer preference surveys and priority-setting guidelines (Franzel *et al.*, 1996) by ICRAF and partners in the humid lowlands of West and central Africa

Priority order	Scientific name	Common name
1	*Irvingia gabonenis; I. wombolu*	Bush mango; Dika nut
2	*Dacryodes edulis; D. klaineana*	African plum; Safoutier
3	*Ricinodendron heudelottii*	Njangsang
4	*Chrysophyllum albidum*	Star apple
5	*Garcinia kola; G. afzelii*	Bitter kola

activities tend to be species-specific, either because of past history or because of constraints imposed by funding. To date, the majority of work in humid West Africa has been restricted to the two top priority species, *Irvingia gabonensis* and *Dacroydes edulis*. Some work not reported here is also in progress on *Ricinodendron heudelotii*, *Garcinia kola* and *Cola nitida*.

Irvingia gabonensis: *bush mango or dika nut*

This species, which occurs in the moist forests of West and central Africa, produces edible fruits that, while unrelated, resemble the cultivated mango. The fruit contains a nut that is widely traded and consumed regionally as a food-thickening agent for traditional soups and stews. ICRAF and partners have made germplasm collections of *I. gabonensis* from a wide range of sites in Ghana, Nigeria, Cameroon and Gabon, with some additional material of *I. wombolu*, and *I. robur*. The collection strategy used for *Irvingia* species was to involve farmers in targeting superior trees. In each village visited, farmers identified 20 to 30 trees with desirable fruit and kernel traits. Based on visible attributes, the collection team (NARS, NGOs and ICRAF) then selected two of these trees from each of 59 villages. During this period of exploration and collection, studies were made of the phenotypic variation in tree form, phenology and fruit characteristics such as shape, colour and sweetness (Ladipo *et al.*, 1996). Seedlings were then established in living genebanks at Onne and Ibadan in Nigeria, and at Mbalmayo in Cameroon, but this last collection has not thrived. Each genebank contained approximately 60 accessions (single-tree progenies).

The living genebanks serve several functions including genetic conservation and the provision of a source of variability for research and future breeding and selection. In this respect they are very important although they impose a long-term cost in maintenance and management. So far, one study done on this material has characterized genetic variation captured by the germplasm collection exercise using polymerase chain reaction-based molecular techniques (Lowe *et al.*, 2000). Aspects of genetic structure, amount of variation, ecogeographic partitioning and hybridization have been examined in *I. gabonensis* and *I. wombolu*. No significant genetic integrity, or evidence of interspecific hybridization, was found in these two morphologically similar species. Significant genetic differentiation was also found between geographically separated samples, with genetic similarity decreasing with geographic distance. 'Hot spots' of genetic diversity were clustered in southern Nigeria and southern Cameroon for *I. wombolu*, and in southern Nigeria, southern Cameroon and central Gabon for *I. gabonensis*. This level of understanding about within-species genetic diversity is important for the development of wise species conservation and domestication strategies. At present, little is known about the potential pests and diseases of this species but it is assumed that the risks can be minimized by ensuring genetic diversity in the cultivated population and integrating cultivars in species-rich agroforests.

The third phase of work is to identify superior trees within the wild population and to multiply them vegetatively as potential cultivars by using the standard horticultural techniques of grafting, air-layering and rooted cuttings. This allows the capture of the additive and non-additive genetic variation between individual plants (Leakey and Jaenicke, 1995). There are several components to this phase. Firstly, vegetative propagation methods are required that are simple, inexpensive and robust enough for use in rural communities. Secondly, methods based on a wide range of superior attributes affecting such characteristics as flavour, size, yield and quality, are required for the identification of the superior trees. Thirdly, farmers willing to cooperate with researchers use these methods in their own farms and communities to identify large numbers of trees with desirable attributes. This is done in accordance with the requirements of the Convention on Biological Diversity regarding the rights of sovereign states and of the farmers to both their indigenous knowledge and the germplasm itself. Fourthly, the cooperating farmers have to be helped to establish village nurseries wherein to propagate their own trees and so form putative cultivars. Finally, the trees are established on the farms of participating farmers to test and confirm the genetic quality of the material. This last step is crucial to the long-term success of the concept and to provide the incentive to continue the domestication process. Within all of this there is a need to ensure that the nurserymen or women understand the need for genetic diversity among cultivars and that a strategy to ensure this is built into the overall operation (Leakey, 1991). If all of this is successful, then it can be hoped that not only will the farmers benefit from having higher quality and more-productive companion tree crops, but also that the nurseries will develop a spirit of entrepreneurialism so that some members of the community can benefit from selling cultivars to neighbouring villages. It is hoped also that the skills learnt on one tree species can be transferred to the domestication of other local species.

Progress down this path to implementation has been made. Simple low-technology techniques for propagating seedling and coppice shoots of *I. gabonensis* have been developed (Leakey *et al.*, 1990; Shiembo *et al.*, 1996). They are practised within the project and are now being transferred to the village nurseries (Tchoundjeu *et al.*, 1998). As with all trees, propagation of mature material capable of flowering and fruiting at an early age is more difficult, but methods of air layering (marcotting) are being used successfully, albeit with only low rates of success. Grafting trials are also in progress.

The second component is well underway. Farmers are willingly collaborating with researchers in the identification of superior trees for propagation and an active programme of air layering is in progress in many villages in southern Cameroon. Over 2000 trees had been identified and marcotted by 1998 (Tchoundjeu *et al.*, 1998). Village nurseries are emerging and farmers are gaining experience in what for them is a very new activity. In parallel with the farmer identification of superior trees, a study to determine the range of variability in fruit traits within the species is also in progress. Fruits have been collected from up to 100 trees in two villages in Cameroon and one in Nigeria. These are being assessed for 11 traits that influence fruit and kernel size and quality to obtain a good understanding of the biological opportunity for genetic improvement that can be obtained (Atangana, 1999; Atangana *et al.*, 2001). The consequence of this quantified characterization is the definition of fruit and kernel ideotypes that optimize the traits that determine combinations defining superior multi-trait ideotypes for a genetic selection programme and for commercial production. The results will then be compared with farmer and market perceptions of the opportunities and options open for a domestication strategy. Also, the results will help the researchers to explain to farmers what traits, or combinations of traits (ideotypes), are available for selection (Leakey *et al*, 2000). This work will indicate what level of improvement is possible, without recourse to tree breeding and biotechnology.

Another important form of variation relates to the ease of kernel extraction. This tends to be a very labour-demanding process that potentially reduces market appeal. Hope here arises from the discovery that in *I. wombolu* in Gabon there is a variety with a self-cracking nut. Recent evidence suggests that easily cracked nuts also occur at low frequency in *I. gabonensis* and that this trait may be the result of the formation of a thin-shelled nut (Leakey *et al*, 2000). Assuming that this is genetically determined variation, these trees are strong candidates for selection to become cultivars through cloning (Leakey and Jaenicke, 1995).

It is recognized generally that many non-timber forest products, traditionally used by local people in Cameroon, are nutritionally important as sources of vitamins, minerals, proteins, oils and carbohydrates. There is published information about the chemical composition of the fruits and kernels of *Irvingia* species. For example, the extraction rate of juice from *I. gabonensis* fruit pulp was 75% and the sugar concentration of this juice is comparable with pineapples and oranges (Akubor, 1996), but the ascorbic acid (vitamin A) content (67 mg 100 ml^{-1}) is higher. The most important product from these species (especially *I. wombolu*), however, is the nut kernel. This is extracted, dried and can be stored for long periods. The composition of *I. wombolu* kernels at 88.1% dry matter was reported by Ejiofor *et al.* (1987) to be 51.3% fat, 26.0% total carbohydrate, 2.5% ash, 7.4% crude protein, 0.9% crude fibre, 9.2 mg 100 g^{-1} vitamin C and 0.6 mg 100 g^{-1} vitamin A. Other reports (e.g. Oke and Umoh, 1978) have quoted values of 54–67%, and even 72%, for fat content and 38.8% for carbohydrate (Ejiofor, 2001). Okolo (2001) reports that the fat has an absence of volatile oils, a melting point of 37–42° C, a saponification value of 233–250 and an iodine value of 2–9. He also quotes reports from 1929–39 that state that the myristic acid and lauric acid contents of *Irvingia* kernels vary depending on the source of the fruits (Nigeria: 50.6 and 38.8%; Sierra Leone: 33.5 and 58.6% respectively). Hellyer (unpublished data) has given myristic acid and lauric acid values of 39.2 and 51.1% from *I. wombolu* kernels from Cameroon. Amubode and Fetuga (1984) have reported the amino acid composition of kernels.

A comparison of kernel composition between *I. gabonensis* and *I. wombolu* has shown that the latter has less fat, more crude protein, less crude fibre and less vitamin C than the former (Ejiofor *et al.*, 1987). The fat from *I. wombolu* has lower iodine and saponification values (Joseph, 1995). Kernels are ground into meal, and this is then pressed to separate the residue from the fat. The residue is used as a food additive to thicken soups and stews. It produces a viscous consistency when added a few minutes before serving. A rheological study of the polysaccharides in dika nut found that the variation of 'zero-shear' specific viscosity was broadly similar to the general form of disordered polysaccharides, although some specific attributes were consistent with it having a compact molecular geometry rather than a 'random coil' conformation (Ndjouenkeu *et al.*, 1996). Joseph (1995) reported that the viscosity of mucilaginous solutions is lower at high temperatures and at high shear rates, making it appropriate as a thickening agent. Calculated on a crude protein basis, dika nut meal showed comparatively better water and fat absorption properties than did raw soy meal and, hence, it may have useful applications in processed foods such as bakery products and minced meat formations (Giami *et al.*, 1994). It is possible that in the future the nutritional value of bush mango fruits and dika nuts could be increased through genetic selection within the domestication programme.

Dacryodes edulis: *African plum or safou*

This species probably originates from southern Nigeria, but is now widely distributed in central Africa where it is commonly found growing with cacao. Currently, pests and disease problems do not appear to be a major problem. In the case of *D. edulis*, provenance collections have been made by IRAD and these have been assessed for over 12 years for their phenology, growth and yield (Kengue and Singa, 2001). They have also served as a stock of material for propagation. This has led to the establishment of the first series of clonal variety trials, on station and on farms (Kengue *et al.*, 2001). As in *I. gabonensis*, vegetative propagation techniques have been developed for *D. edulis*, both for juvenile cuttings (Avana and Tchoundjeu, personal communication) and for mature marcots (Kengue *et al.*, 2001). These propagation techniques are starting to be implemented in village nurseries. Again, as in *I. gabonensis*, the genetic variability of fruit characteristics is under investigation (Waruhiu, 1999) to provide a knowledge base for domestication opportunities and identification of ideotypes. This builds on an earlier, and much less extensive study, which found that there was at least five-fold variation in fruit weight (Leakey and Ladipo, 1996).

Regarding the chemical composition of *D. edulis* fruits, the flesh has good nutritional value and has been reported by Umoro Umoti and Okiy (1987) to contain 31.9% oil, 25.9% protein, 17.9% fibre, as a percentage of dry matter. The main fatty acids in the lipid fraction are palmitic acid (36.5%), oleic acid (33.9%) and linoleic acid (24%), giving a profile similar to palm oil (*Elaeis guineensis*). The main essential amino acids are leucine (9.57%) and lysine (6.3%), while others are glutamic (17.0%) and aspartic (15.1%) acids and alanine (7.7%). The ascorbic acid content of the flesh is 24.5%, but this is lost by some forms of cooking (Achinewhu, 1983). Many of the nutrients, however, are in the skin of the fruit, which is usually discarded. Youmbi *et al.* (1989) reported that different fruit types vary in their chemical composition, with the large fruits characterized by a higher lipid content in the mesocarp than in the seed, and the converse in small fruits. Fatty acid content, however, was not significantly different in two contrasting fruit types (Kapseu and Tchiegang, 1996). Non-structural carbohydrates are higher in the seed than in the mesocarp of both types. There is also much variation in taste, and some variation in protein content (Kapseu and Tchiegang, 1996). The further characterization of these differences is important in the domestication of the species and their orientation to different markets.

PROGRESS TOWARDS COMMERCIALIZATION

There is growing international interest in the commercial use of genetic resources worldwide, especially those from the tropics. Consequently there are important issues (reviewed by ten Kate and Laird, 1999) regarding access to these resources and the means of ensuring the sharing of benefits. Discussion of the role of tree domestication, however, cannot be divorced from that of product commercialization since, without expanded or new markets, the incentives to domesticate are insufficient. Conversely, if the market explodes, the incentive for large-scale producers to establish monocultural plantations may sweep away the benefits that agroforestry could deliver to small-scale, resource-poor farmers in the tropics (Leakey and Izac, 1996). As has been pointed out by Dewees and Scherr (1996), policies that promote the linkages between the domestication and commercialization of non-timber forest products (NTFPs) are one of the important areas for policy development. In this respect, there is also a need for better integration of the needs (regarding the process of tree domestication for smallholder agroforestry) of the food and other industries from non-timber forest products with those of the subsistence farmer.

It is clear from the above descriptions of work and knowledge about the two priority species for West and central Africa, that considerable progress towards their domestication has been made in a short time. It is evident also that most of the methods needed to domesticate indigenous fruits are known and that they are being disseminated to subsistence farmers. For substantial impact on poverty alleviation, however, this work needs to be widely implemented. Two crucial factors in this process are (i) the development of markets and processing and marketing infrastructure and (ii) the adoption of agroforestry practices that utilize these tree species. These important steps towards enhancing the livelihoods of small-scale farmers and developing sustainable approaches to agriculture based on tree crops, are discussed below.

In West Africa, as in other parts of the tropics, the products of indigenous trees are marketed locally on a small scale. They are a means of generating cash to supplement a subsistence lifestyle (Falconer, 1990; Arnold, 1996). Frequently these products are collected in natural forest or from wild trees retained on farmland. Some of these products also enter regional trade (Ndoye, 1995). *Irvingia gabonensis* kernels are traded on both a local and a regional scale in West Africa at prices between US$ 0.7–4.0 kg^{-1}, depending on the season.

Uzo (1980) considered that the fruits from a single tree could generate income of US$ 300 per annum. An extrapolation from market surveys in Cameroon suggests that the trade of four indigenous fruits (*Ricinodendron heudelottii, Irvingia gabonensis, Dacryodes edulis* and *Cola acuminata*) from the humid forest zone over the six-month period January-July 1995 was valued at US$ 1.3×10^6 (Table 2). A proportion of this trade was to the neighbouring countries of Gabon, Nigeria, Equatorial Guinea and the Central African Republic (Ndoye, 1995); 30% of this trade goes to Gabon and Equatorial Guinea. In this case, the reason given by individual farmers for selling non-timber forest products was to acquire cash for the basic needs of their household (74%), to pay for school fees (9%), and for other needs (17%).

Increasingly, a small quantity of these products is being marketed in the USA and Europe. To encourage the expansion of regional and perhaps international trade, local-level processing is needed. For *I. gabonensis* kernels, for example, oil can be extracted and the residue can be made into cubes or pellets with enhanced storage life (Ejiofor *et al.*, 1987). Okolo (in press) has calculated that a pilot plant with a capacity of 100 kg h^{-1} would require 256 t of kernels per year. It has been recognized that expanded markets for these products would increase the value of natural forests and benefit forest dwellers (Peters *et al.*, 1989). Similarly, markets for non-timber forest products (NTFP) produced on areas already deforested could improve the income of subsistence farmers and provide an alternative to slash-and-burn agriculture, one of the major causes of deforestation. The

Table 2. Market details of four non-timber forest products in Cameroon over a period of six months (after: Ndoye, 1995)

Species	Price (US $ kg^{-1})	Weight traded (t)	Value of trade (US $)
R. heudelotii	2.7	172	460200
I. gabonensis	2.2	140	301590
D. edulis	0.4	587	244480
C. acuminata	1.0	212	211970
Others	–	401	122580
Total for non-timber forest products	–	1512	1 340 820

relatively small-scale market of these NTFPs is both a problem and an asset. It is a problem in that the wild, unimproved product may not have enough market appeal to encourage greater commercial interest. This raises the question of which comes first, the demand or the supply? This is a ‘chicken and egg’ problem, one made more complex by the price fluctuation caused by varying supply and demand. By contrast, in the current early stage of the development of domestication activities, the relatively small market for these products can be seen as an asset. If demand for the products of improved cultivars was too big, large-scale company interests might swamp the production before small-scale farmers practising agroforestry had developed marketing infrastructures. Ideally, for the purpose of poverty reduction and incidental environmental benefits through agroforestry, small-scale operations are preferable. It is clear that such developments require two things: an appropriate policy environment (Leakey and Izac, 1996) and commercial interests sympathetic to small-scale production, like those associated with organic farming. The question of what characteristics of fruits and other products need to be improved to make a better food-thickening agent illustrates the need for dialogue between the food industry and the field scientists – a dialogue that doesn’t exist at present. Similar problems relate to the pharmaceutical and cosmetic industries where, again, appropriate domestication could lead to higher quality natural products if the desired pharmaceutical traits were known to agroforestry scientists. Furthermore, there are regulations affecting the food, pharmaceutical and cosmetic industries that determine the toxicological acceptability of products. Scientists involved in the domestication of species producing potential new products need to be aware of the limits and opportunities imposed by these regulations and by the needs of industry (Leakey, 1999b).

A commercial problem arises from the seasonality of production of many NTFPs, especially for perishable products such as fresh fruits. Domestication can almost certainly have considerable impact in this regard. For example, in the fruit tree *I. gabonensis*, there is considerable within-species variation in phenology with some trees flowering and fruiting outside the main season or fruiting several times per year instead of the normal once per year. An alternative is to have a year-round supply of products from a number of different species coming in and out of production sequentially. Seasonality is not a problem in the case of dika nuts as kernel storage allows a year-round market.

A literature review of the chemical constituents of the priority agroforestry trees for humid West and central Africa (Leakey, 1999b) demonstrated that, in general, there is information at the species level regarding proximate analysis of fruits and kernels. It is clear, however, that there is inadequate information about the levels of within species variation in chemical composition of fruits and other plant parts especially at the genotypic level relevant for tree domestication by the means described above. This gap in knowledge enhances the need for the food industry to collaborate in tree domestication programmes aimed at providing products for wider-scale markets.

CACAO AGROFORESTS

By using the combined approach of diversification and domestication, agroforestry becomes an integrated land use system that, through the capture of intra-specific diversity and the diversification of species on farm, combines increases in productivity and income generation with environmental rehabilitation and the creation of biodiverse agroecosystems (Leakey, 1999a). Progress, however, will be dependent on the formulation and application of appropriate development strategies, and the demonstration of environmental advantages of this more ecological approach to land husbandry.

Cacao, previously a plantation-grown export crop, is now predominantly a smallholder crop, especially in Africa. It was introduced into Cameroon in the 1880s and by 1913 there were 58 different plantations in the area around what is now Limbe (Gockowski and Dury, 1999). By the mid-1920s, however, cacao production had shifted to smallholder systems. The cacao growing area has also changed and covers most of the Southwest, South, Centre and East Provinces. In South and Centre Provinces, approximately 75% of rural households produce cacao and the area per household ranges from 0.1 to 10 ha, with a mean of 1.4 ha. In the southern area, where population pressure is not great (1–20 people km^{-2}) but is concentrated along roadsides, cacao is grown on small plots that were established early in the shifting cultivation cycle. Many of these plots are now relatively old and have an upper canopy of indigenous timber and fruit trees forming an agroforest with a well-diversified ground flora. These agroforests resemble secondary forest. In this area, staple food crops are established mostly in newly cleared areas of secondary forest or forest fallow within the farmers' control. Further north, however, in the forest-savannah transition zone north of Yaoundé, population pressure is higher (over 50 people km^{-2}) and forest is much more scarce or absent. Farmers here have developed mixed cropping systems, or agroforests, that are based on cacao. These cacao agroforests, which are not as tall as those in the south, are more obviously man-made and contain a greater number of exotic species. For example, a recent characterization of agroforests around Obala (Gockowski and Dury, 1999) found that the average tree composition per hectare was 495 cacao, 35 timber trees, 22 mango, 22 avocado, 22 *D. edulis*, 21 Clementine mandarine, 18 other Citrus species, 15 oil palm, 56 banana or plantain plants, 18 pineapple, 5 *Cola* spp., 3 papaya, 3 guava, 1 soursop and one *I. gabonensis*. In the area around Makenene, which is further north and west, the agroforests have a greater preponderance of *D. edulis*. In both the Obala and Makenene areas, staple food crops such as maize and cassava are integrated with the tree cropping wherever there is a gap.

It is clear from the above information, that cacao agroforests are already a socially and economically important land use system in Cameroon. An economic analysis by the Alternatives to Slash-and-Burn Programme in Cameroon (ASB, 1998), showed that the social profitability (that is, returns per hectare adjusted for economic distortions using the Net Present Value approach in which profitability was evaluated over a 30-year period with a discount rate of 10%) was greatest from intensive cacao with fruits (US$ 1755). Lower values were obtained from intensive cacao without fruit (US$ 1236), extensive cacao with fruit (US$ 1136) and extensive cacao without fruit (US$ 616) with lowest values from forest crop field (US$ 283). Also, returns to labour were high from intensive cacao with and without fruits and extensive cacao with fruits.

Globally, there is increasing evidence of the effects that cacao cultivation has on biodiversity (Rice and Greenberg, 2000). Firstly, forest clearance for cacao threatens biodiversity by degrading both the physical structure and species diversity of the canopy, and increasing the fragmentation of the landscape. Once forests are cleared, however, cacao farms have positive benefits especially when grown under the shade of secondary forest or other species-rich tree canopies because they provide a wider array of ecological niches for wildlife than do many other cultivated land uses. Rice and Greenberg (2000) therefore advocate two approaches to enhancing the impacts of cacao on biodiversity, (i) the continuation in existing cacao farms of the practice of using a diversity of shade trees rather than the change to monocultures or low-diversity shade systems, and (ii) in deforested areas, the promotion of cacao establishment under a wide range of shade species. Both of these recommendations concur with the thesis of this paper.

PROSPECTS FOR DOMESTICATION TO ENHANCE THE INCENTIVES TO DIVERSIFY

The domestication of trees for NTFPs has not progressed far enough yet to be able to determine the economic benefits. However, a small market survey of *D. edulis* fruits, currently the main species planted by farmers in Cameroon to diversify cacao farms and provide alternative income, indicates that there is five-fold variation in fruit weight (Leakey and Ladipo, 1996). In addition, there was a five-fold variation in price per kilogram of fruit pulp, which was independent of fruit size and probably due to flavour and other quality attributes. In this study, three fruits of one type sold for 250 FCFA (US$ 0.40), while at the other extreme 22 fruits sold for 50 FCFA (US$ 0.08). In other words, the price per fruit for the best fruit was 37-fold greater than that for fruit from the poor tree. This does not suggest, however, that domestication would result in a 37-fold increase in income, because a tree producing 1000 small fruits could not necessarily be replaced by a tree producing 1000 large fruits. This is because the dry matter allocated to fruit production by fruit trees is usually a proportion of overall dry matter produced per year. A harvest index of 0.3 – 0.6 would be typical (Cannell, 1989). Experience from the herbaceous and other tree crops indicates that harvest index usually can be increased by only about 100% by domestication (for example, 0.4 to 0.75 for coffee). As a hypothetical example, however, the crop of a tree producing 1500 fruits, selling for US$ 0.08 each, would sell for a total of US$ 120. If this tree was replaced by a tree producing 600 larger and better tasting fruits, selling for US$ 0.40 each, the total income would rise to US$ 240, a doubling of the farmer's income.

Another way of looking at what could be possible with domestication is illustrated by a farmer (Mr Womeni) near Makenene. He had 3400 cacao trees, with 117 *D. edulis* trees in the upper canopy. In 1998, he sold the fruits from his nine best D. edulis trees for about US$ 150 per tree. The fruits from the other trees were inferior (the worst sold for US$ 20 per tree) but, if he had vegetatively propagated his best trees thereby creating cultivars, he could have replaced the inferior ones with the cultivars. His *D. edulis* trees would then have made a lot more money (US$ 10 000 – 15 000) providing that the market demand was not saturated. In this way, therefore, the enhancement of smallholder income, and thus livelihood, depends on the availability of the techniques and the development of the market. The livelihoods of these cacao-producing farmers are very important for the cacao and chocolate industry that, in turn, is dependent on their continued production.

Evidence of similar opportunities is emerging for *I. gabonensis* fruits and kernels (Atangana *et al*, 2001). This suggests that through the selection of trees that combine fruit size and quality attributes such as sweet flavour and low fibrosity, it should be possible to develop cultivars that are very attractive to farmers. Together, variations in size and quality of products from companion trees add up to great opportunities to improve the products from these trees. Improvements from tree domestication could greatly increase the incomes of smallholder cacao farmers producing cacao in enriched and diversified cacao agroforests.

A clear conclusion from the Alternatives to Slash-and-Burn economic study (ASB, 1998) was that the most profitable system was an agroforest that combined intensive cacao production with the production of a range of fruits and other non-timber forest products. Based on this scenario and the information on NTFP markets, it would appear that improving the quality and yield of products from companion crops through their domestication and commercialization would increase income and provide a buffer against falling cacao prices and the risks of lower returns due to pests or disease. Perhaps also, greater improvements to economic returns could be made by further enriching these agroforests with a number of other high-value species (Table 3). Studies are needed, however, to test these hypotheses.

As Leakey (2001b) has indicated, there are also environmental benefits from these complex agroforests. This suggests that they are win-win uses of land that combine economic benefits with environmental benefits. Are there trade-offs, however, between the objectives of raising farmers' incomes and the global environmental benefits (biodiversity and carbon sequestration)? Again the Alternatives to Slash-and-Burn team in Cameroon have examined this (ASB 1998). They concluded that the intensive cacao systems were both profitable and good carbon sinks (time averaged carbon stocks increase from 4.5 to 61 t ha^{-1} a^{-1}), with greater biodiversity than crop fallows. By contrast with intensive cacao, extensive cacao had lower global environmental benefits in terms of carbon storage. The team, however, raised concerns about soil structure (bulk density) and the high incidences of pest attack and pesticide use in intensive systems. They

Table 3. A sample of the West African tree, shrub and liane species appropriate for inclusion in multi-strata agroforests and for domestication (after Leakey, 1998)

Species	Common name(s)	Mature height (m)
Anthocleista schweinfurthii	Ayinda	15–20
Antrocaryon micraster	Aprokuma; onzabili	40–50
Baillonella toxisperma	Moabi	45–55
Calamus spp	Rattan	35–45
Canarium schweinfurthii	Aiele; African canarium; incense tree	45–55
Chrsophyllum albidum	Star apple	30–40
Cola acuminata	Kola nut	15–25
Cola lepidota	Monkey Kola	10–20
Cola nitida	Kola nut	15–25
Coula edulis	Coula nut; African walnut	25–35
Dacryodes edulis	African plum; safoutier	15–25
Entandrophragma spp	Sapele; Tiama; Utile; Sipo	50–60
Garcinia kola	Bitter Kola	20–30
Gnetum africanum	Eru	0–10
Irvingia gabonensis	Bush mango; Andok	20–30
Khaya spp	African mahogany	50–60
Lovoa trichloides	Bibolo; African walnut	40–50
Milicia excelsa	Iroko; Mvule; Odum	45–55
Nauclea diderichii	Opepe; Kusia; Bilinga	35–45
Pausinystalia johimbe	Yohimbe	35–40
Pentaclethra macrophylla	Oil bean tree; Mubala; Ebe	20–30
Prunus africana	Pygeum	20–25
Raphia hookeri and other spp	Raphia palm	5–15
Ricinodendron heudelotii	Groundnut tree; Nyangsang; Essessang	40–50
Terminalia ivorensis	Framiré; Idigbo	45–55
Terminalia superba	Fraké; Afra; Limba	45–55
Tetrapleura tetraptera	Prekese; Akpa	20–30
Treculia africana	African breadfruit; Etoup	20–30
Trichoscypha arborea	Anaku	15–25
Triplochiton scleroxylon	Ayous; Obeche; Wawa	55–65
Vernonia amygdalina	Bitter leaf	0–10
Xylopia aethiopica	Spice tree	15–25

indicated that the fruit component of cacao agroforests adds greatly to the profitability of the system but that this is negatively impacted by transportation costs due to poor road infrastructure in rural areas. Furthermore, there is a lack of data on the biodiversity or ecosystem function benefits of diversifying cacao farms with fruit trees, for example in terms of susceptibility to pests and diseases.

In the light of the Kyoto Protocol and international concerns about global climate change, there is discussion about trading in carbon storage. Calculations by ASB in Cameroon suggest that permanent conversion of short fallow to cacao agroforest would remove about 70 t carbon from the atmosphere (Gockowski and Dury, 1999). At current prices of US\$ 10 t^{-1}, farmers potentially could receive a lump sum payment of US\$ 700 ha^{-1} as a planting subsidy for conversion of degraded forest and fallows to cacao agroforests. This could be even greater if other larger trees were integrated into cacao agroforests as a result of the diversification of tree crops. Somehow, the cacao industry should help its farmers to take advantage of this opportunity.

CONCLUSION

The concepts, strategies and policies associated with agroforestry are rapidly evolving towards the creation of sustainable land uses that enhance farmers' livelihoods, provide commodities for global markets and mitigate global concerns about environmental degradation. In parallel, the techniques for the domestication of indigenous trees for the agroforestry production of NTFPs also are evolving rapidly and should produce further benefits in terms of income generation for agricultural inputs and household welfare. The diversification of tree crops with trees to produce other traditional NTFPs appears to have a number of benefits both to the farmer and to the environment. This diversification may increase as farmers develop and apply domestication strategies to a wider range of species. The economic and social values of diversification are illustrated by evidence from cacao agroforests in Cameroon, but to date there is only limited data to indicate whether or not there are ecological benefits that might confer greater sustainability (Rice and Greenberg, 2000).

The potential financial and environmental benefits from the domestication of companion crops and diversification of cacao farms are important for the livelihoods of smallholder cacao producers and, thus, for a thriving industry. Finding ways for farmers to achieve these benefits will be a challenge for the cacao industry.

Acknowledgements. We wish to acknowledge the influence of many colleagues on our thinking, especially the farmers in Cameroon who have been so interested in our work. This paper was prepared for and presented at the USDA-CABI-ACRI Collaborative Cacao Research Review Meeting, London, 7–8 December 1999.

REFERENCES

Achinewhu, S. C. (1983). Ascorbic acid content of some Nigerian local fruits and vegetables. *Qual. Plant. – Plant Foods for Human Nutrition* 33:261–266.

Akubor, P. I. (1996). The suitability of African bush mango juice for wine production. *Plant Foods for Human Nutrition* 49:213–219.

Amubode, F. O. & Fetuga, B. L. (1984). Amino acid composition of some lesser known tree crops. *Food Chemistry* 13:299–307.

Arnold, J. E. M. (1996). Economic factors in farmer adoption of forest product activities. In *Domestication and Commercialization of Non-timber Forest Products in Agroforestry Systems*, 131–146 (Eds R. R. B. Leakey, A. B. Temu, M. Melnyk & P. Vantomme). *Non-wood Forest Products No.9*, Rome: FAO.

ASB (1998). Alternatives to Slash and Burn Program. *Phase II Report: Forest Margins Benchmark, Cameroon, International Institute of Tropical Agriculture, Yaoundé*, 47p.

Atangana, A. (1999*). Characterisation biophysique de Irvingia gabonensis de la zone de forêt dense humide de basse altitude du Cameroun*, M. Sc. thesis, University of Yaoundé, Cameroon.

Atangana, A. R., Tchoundjeu, Z., Fondoun, J-M., Asaah, E., Ndoumbe, M. and Leakey, R. R. B. (2001).

Domestication of *Irvingia gabonensis*: I. Phenotypic variation in fruit and kernel traits in two populations from the humid lowlands of Cameroon. *Agroforestry Systems*.

Avana, M-L and Tchoundjeu, Z. (Personal communication). International Centre for Research in Agroforestry, Yaoundé, Cameroon.

Cannell, M. G. R. 1989. Food crop potential of tropical trees. *Experimental Agriculture* 25:313–326.

de Clerck, F. A. J. and Negreros-Castillo, P. (2000). Plant species of traditional Mayan homegardens of Mexico as analogs for multistrata agroforests. *Agroforestry Systems* 48:303–317.

Dewees. P. A. & Scherr, S. J. (1996). Policies and markets for non-timber tree products. *EPTD Discussion Paper, No.16*, Washington D.C: IFPRI, 78 p.

Ejiofor, M. A. N. (2001). Nutritional values of Ogbono (*Irvingia gabonensis* var. excelsa). In *Irvingia: Uses, Potential and Domestication*. (Eds D. Boland & D. O. Ladipo). Nairobi: ICRAF.

Ejiofor, M. A. N., Onwubuke, S. N. & Okafor, J. C. (1987). Developing improved methods of processing and utilization of kernels of *Irvingia gabonensis* (var. gabonensis and var. excelsa). *International Tree Crops Journal* 4:283–290.

Falconer, J. (1990). The major significance of 'minor' forest products. The local use and value of forests in the West African humid forest zone. *Forests, Trees and People, Community Forestry Note, No.6*, Rome: FAO, 232 p.

Franzel, S., Jaenicke, H. & Janssen, W. (1996). Choosing the right trees: setting priorities for multipurpose tree improvement. *ISNAR Research Report 8*, 87 p.

Giami, S. Y., Okonkwo, V. I. & Akusu, M. O. (1994). Chemical composition and functional properties of raw, heat-treated and partially proteolysed wild mango (I*rvingia gabonensis*) seed flour. *Food Chemistry* 49:237–243.

Gockowski, J. J. & Dury, S. (1999). The economics of cacao-fruit agroforests in southern Cameroon. In *Multi-strata Agroforestry Systems with Perennial Crops*, 239–241 (Eds F. Jiménez & J. Beer). Turrialba: CATIE, Costa Rica.

ICRAF (1997*). ICRAF Medium Term Plan 1998–2000*, Nairobi: ICRAF, 340p.

Jaenicke, H., Franzel, S. & Boland, D. J. (1995). Towards a method to set priorities among species for tree improvement research: a case study from West Africa. *Journal of Tropical Forest Science* 7:490–506.

Joseph, J. K. (1995). Physico-chemical attributes of wild mango (*Irvingia gabonensis*) seeds. *Bioresource Technology* 53:179–181.

Kapseu, C & Tchiegang, C. (1996). Composition de l'huile des fruits de deux cultivars de safou au Cameroun. *Fruits* 51:185–191.

Kengue, J. & Singa, E. M. (2001). Preliminary characterization of some African Plum accessions in Barombi-Kang germplasm collection. In *Deuxièmè Séminaire International sur la Valorisation du Safoutier et autres Olégineux non Conventionnels*. (Eds C. Kapseu & G. J. Kayem). Ngaoundéré, Cameroon, 3–5 December 1997.

Kengue, J. Tchio, F. & Ducelier, D. (2001). Le marcottage aérien: une technique pour la multiplication végétative du Safoutier, In *Deuxièmè Séminaire International sur la Valorisation du Safoutier et autres Olégineux non Conventionnels*. (Eds C. Kapseu & G. J. Kayem). Ngaoundéré, Cameroon, 3–5 December 1997.

Ladipo, D. O., Foundoun, J. M. & Ganga, N. (1996). Domestication of the Bush Mango (*Irvingia* spp.): some exploitable intraspecific variations in West and Central Africa. In *Domestication and Commercialization of Non-timber Forest Products for Agroforestry*, 193–205 (Eds R. R. B. Leakey, A. B. Temu, M. Melnyk & P. Vantomme). *Non-Wood Forest Products No. 9*, Rome: FAO.

Leakey, R. R. B. (1991). Towards a strategy for clonal forestry: some guidelines based on experience with tropical trees. In *Tree Breeding and Improvement*. (Ed J. E. Jackson). Royal Forestry Society of England, Wales and Northern Ireland, Tring, UK.

Leakey, R. R. B. (1996). Definition of agroforestry revisited. *Agroforestry Today* 8 (1):5–7

Leakey, R. R. B. (1999a). Agroforestry for biodiversity in farming systems. In *Biodiversity in Agroecosystems*, 127–145 (Eds W. W. Collins & C. O. Qualset). New York: CRC Press.

Leakey, R. R. B. (1999b). Potential for novel food products from agroforestry trees: a review. *Food Chemistry* 66:1–14.

Leakey, R. R. B. (2001a). Win:Win landuse strategies for Africa: I. Building on experience with agroforests in Asia and Latin America. *International Forestry Review*, in press.

Leakey, R. R. B. (2001b). Win:Win landuse strategies for Africa: II. Capturing economic and environmental benefits with multistrata agroforests. *International Forestry Review*, in press.

Leakey, R. R. B. & Jaenicke, H. (1995). The domestication of indigenous fruit trees: opportunities and challenges for agroforestry. *Proceedings of the 4th International BIO-REFOR Workshop*. (Eds K. Suzuki, S. Sakurai, K. Ishii & M. Norisada). *BIO-REFOR, Tokyo*, 15–26.

Leakey, R. R. B. & Newton, A. C. (1994). Domestication of 'Cinderella' species as a start of a woody plant revolution. In *Tropical trees: Potential for domestication and the rebuilding of forest resources*, 3–6 (Eds R. R. B. Leakey & A. C. Newton). London: HMSO.

Leakey, R. R. B. & Izac A-M.N. (1996). Linkages between domestication and commercialization of non-timber forest products: implications for agroforestry. In *Domestication and Commercialization of Non-timber Forest Products for Agroforestry*. (Eds R. R. B. Leakey, A. B. Temu , M. Melnyk & P. Vantomme). 1–7, *Non-Wood Forest Products, No 9*, FAO, Rome, Italy.

Leakey, R. R. B. & Ladipo, D. O. (1996). Trading on genetic variation – fruits of *Dacryodes edulis*. *Agroforestry Today* 8 (2):16–17.

Leakey, R. R. B. & Simons, A. J. (1998). The domestication and commercialization of indigenous trees in agroforestry for the alleviation of poverty. *Agroforestry Systems* 38:165–176.

Leakey, R. R. B., Fondoun, J-M., Atangana, A., & Tchoundjeu, Z. (2000). Quantitative descriptors of variation in the fruits and seeds of *Irvingia gabonensis*. *Agroforestry Systems* 50:47–58.

Leakey, R. R. B., Mesén, J. F., Tchoundjeu, Z., Longman, K. A., Dick, J. McP., Newton, A. C., Matin, A., Grace, J., Munro, R. C. & Muthoka, P. N. (1990). Low-technology techniques for the vegetative propagation of tropical trees. *Commonwealth Forestry Review* 69:247–257.

Lowe A. J., Gillies, A. C. M., Wilson, J. & Dawson, I. K. (2000). Conservation genetics of bush mango from central/ west Africa, implications from random amplified polymorphic DNA analysis. *Molecular Ecology* 9:831–841.

Nair, P. K. R. (1993). *An Introduction to Agroforestry*. Dordrecht: Kluwer Academic Publishers.

Ndjouenkeu, R., Goycoolea, F. M., Morris, E. R. & Akingbala, J. O. (1996). Rheology of okra (*Hibiscus esculentus* L.) and dika nut (*Irvingia gabonensis*) polysaccharides, *Carbohydrate Polymers*. 29:263–269.

Ndoye, O. (1995). The markets for non-timber forest products in the humid forest zone of Cameroon and its borders: Structure, conduct, performance and policy implications. *Report to CIFOR, Bogor, Indonesia*, 86 p.

Oke, O. L. & Umoh, I. B. (1978). Lesser known oilseeds. I. Chemical composition, *Nutritional Reports International* 17:293–297.

Okolo, H. C. (2001). Industrial potential of various *Irvingia gabonensis* products such as oil, Ogbono and juice. In: *Irvingia: Uses, Potential and Domestication* (Eds D. Boland & D. O. Ladipo). Nairobi: ICRAF.

Peters, C. M., Gentry, A. H. & Mendelsohn, R. O. (1989). Valuation of an Amazonian rainforest. *Nature* 339:655–656.

Rice, R. A. and Greenberg, R. (2000). Cacao cultivation and the conservation of biological diversity. *Ambio* 29:167–173.

Sanchez, P. A. & Leakey, R. R. B. (1997). Land use transformation in Africa: Three determinants for balancing food security with natural resource utilization. *European Journal of Agronomy* 7:15–23.

Shiembo, P. N., Newton, A. C. & Leakey, R. R. B. (1996). Vegetative propagation of *Irvingia gabonensis*, a West African fruit tree. *Forest Ecology and Management* 87:185–192.

Simons, A. J. (1996a). Delivery of improvement for agroforestry trees. In *Tree Improvement for Sustainable Tropical Forestry*, 391–400 (Eds M. J. Dieters, A. C. Matheson, D. G. Nikles, C. E. Harwood & S. M. Walker). Vol 2, Queensland Forestry Research Institute, Gympie, Australia.

Simons, A. J. (1996b). ICRAF's strategy for domestication of non-wood tree products. In *Domestication and Commercialization of Non-timber Forest Products in Agroforestry Systems*. 8–22 (Eds R. R. B. Leakey, A. B. Temu, M. Melnyk & P. Vantomme). *Non-Wood Forest Products No. 9*, FAO, Rome.

Tchoundjeu, Z., Duguma, B., Fondoun, J-M. & Kengue, J. (1998). Strategy for the domestication of indigenous fruit trees of West Africa: case of *Irvingia gabonensis* in southern Cameroon. *Cameroon Journal of Biology and Biochemical Sciences* 4:21–28.

ten Kate, K. & Laird, S. A. (1999). *The Commercial Use of Biodiversity: Access to Genetic Resources and Benefit-sharing*. London: Earthscan Publications Ltd. 398 p.

Tomich, T. P., van Noordwijk, M., Vosti, S. and Witcover, J. (1998). Agricultural development with rainforest conservation: methods for seeking best bet alternatives to slash-and-burn, with applications to Brazil and Indonesia. *Journal of Agricultural Economics* 19:159–174.

Umoti, U. & Okiy, D. A. (1987). Characteristics and composition of the pulp oil and cake of the African pear, *Dacryodes edulis* (G. Don) H. J. Lam. *Journal of the Science of Food and Agriculture*. 38:67–72.

Uzo, J. O. (1980). Yield and harvest predictions of some indigenous perennial fruits, roots and leafy vegetables in tropical West Africa. *Proceedings of International Symposium on the Current Problems of Fruits and Vegetables (Tropical and sub-tropical), Laguna, 24–26 March 1980*, 22p.

Waruhiu, A. N. (1999). *Characterisation of fruit traits towards domestication of an indigenous fruit tree of West and Central Africa: A case study of* Dacryodes edulis *in Cameroon*. M Sc. thesis, University of Edinburgh, Scotland, 56p.

WCFSD (1999). Our forests – Our future. *Summary Report: World Commission on Forests and Sustainable Development, WCFSD, Winnipeg*, 38p.

Youmbi, E., Clair-Maczulajtys & Bory, G. 1989. Variations de la composition chimique des fruits de *Dacryodes edulis* (DON) LAM. *Fruits* 44:149–153.