DOMESTICATION AND IMPROVEMENT OF TROPICAL CROPS FOR MULTI-FUNCTIONAL FARMING SYSTEMS

R.R.B. LEAKEY[1], T. NEVENIMO[2], J. MOXON[2], R. PAUKU[3], H. TATE[4], T. PAGE[1] and J. CORNELIUS[1]

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SUMMARY

The increasing loss of forest resources in tropical countries leaves farmers without the food and other products that used to be gathered locally. This coupled with land degradation creates a poverty trap from which it is difficult for smallholder farmers to escape. To address these problems, the domestication of new perennial crops from traditionally important indigenous trees is seen as a way to diversify farming systems making them more sustainable through the provision of a range of products and environmental services. This enriches existing mixed tree/crop farming systems and creates new ones that are more productive and enhance the livelihoods of poor households. A participatory approach to tree domestication is used to ensure that farmers' needs are met. Elite trees are selected on the basis of 'ideotypes' derived from quantitative data of the tree-to-tree variation in many commercially important traits. Genetically superior cultivars are then developed using simple techniques of vegetative propagation. In parallel with domestication, markets are being developed for the products from these new crops so that integrated mixtures of food crops and agroforestry trees can generate income, as well as social and environmental benefits. This approach is thus in accord with the findings of the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD), which has recently identified the need for agriculture to be more multi-functional and to simultaneously achieve economic, social and environmentally sustainability by restoring:- biological resources and natural capital (soil fertility, water, forests, etc); livelihoods (nutrition, health, culture, equity, income) and agroecological processes (nutrient and water cycles, pest and disease control, etc.).

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[1]Agroforestry and Novel Crops Unit, School of Marine and Tropical Biology, James Cook University, Cairns, Australia QLD 4780
[2] Lowlands Agricultural Experiment Station, National Agricultural Research Institute, PO Box 204, Kokopo, Keravat, East New Britain, Papua New Guinea
[3] Maraghoto Consultancy Services, PO Box 1322, Honiara, Solomon Islands
[4] Vanuatu Department of Forests, PMB 9064, Port Vila, Vanuatu.

The International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD) has recently reviewed the state of global agriculture *vis à vis* sustainable rural development (McIntyre et al., 2009). It concluded that to achieve economic, social and environmental sustainability it was necessary to redirect agriculture towards multi-functionality in recognition of the 'inescapable interconnectedness of agriculture's different roles and functions'. Thus in future agriculture should be as much about enhancing the livelihoods, health and nutrition of rural households and restoring natural capital, as about increasing food production and economic growth.

Land degradation is one of the most serious problems facing agriculture as it affects 2000 million hectares (38% of world's cropland) and is intimately interconnected with increasing population densities, declining livelihoods, malnutrition, hunger and poverty (Leakey *et al*., 2009). To rehabilitate degraded land and restore sustainability requires soil fertility replenishment, diversification at the plot and landscape level and perennial vegetation to provide environmental services and increase the number of niches in the agroecosystem. The 'Green Revolution' promoted intensive production of high-yielding staple food crops on land cleared of much of its natural vegetation. In many tropical countries poor farmers are unable to have access to agricultural inputs such as fertilizers and pesticides. Consequently, other ways have to be found to maintain and restore soil fertility and maintain sustainable production, such as low-input resource-conserving technologies based on integrated management systems and an understanding of agroecology and soil science (*e.g.* agroforestry, conservation agriculture, ecoagriculture, organic agriculture and permaculture) which minimise the need for high inputs. These low-input systems are pro-poor, approaches to agriculture that can also build social capital at community and landscape levels and are especially relevant to smallholder agriculture in the tropics – *i.e.* multi-functional agriculture.

With the exception of agroforestry, there has been very little plant breeding or crop domestication aimed specifically at these forms of low-input agriculture, yet domestication has an important role to play by promoting the diversification of farming systems with new crops. The domestication of agroforestry trees was initiated in the mid 1990's, by the World Agroforestry Centre (ICRAF) and its partners aimed at improving the quality and yield of products from traditionally important species that used to be gathered from forests and woodlands. As well as meeting the everyday needs of local people, these products are widely traded in local and regional markets and so have the potential to become new cash crops for income generation and to counter malnutrition and disease by diversifying dietary uptake of micro-nutrients that boost the immune system. These indigenous tree species also play an important role in enhancing agroecological function and, through carbon sequestration, help to counter climate change.

In the Melanesian context, indigenous tree species are common in many farming systems representing a strategy that suits the needs, lifestyle and social commitments of many households. A typical village farm in Melanesia uses family labour and comprises cocoa, coconut, and a wide range of fruit and nut tree species such as triploid banana, papaya, breadfruit, betel nut, and other indigenous nuts such as *Canarium indicum*, *Barringtonia* spp. and *Terminalia kaernbachii*. Within this mix are exotic species like avocado, rambutan, durian, mangosteen and a number of shade or semi-shade loving species. All these species are grown for domestic use as food, bartering within the village and sale in local and urban markets. Income is used to pay for schooling, weddings, funerals and other customary commitments.

Multi-functional agriculture and the role of agroforestry

There are many examples from around the world of low-input, pro-poor, approaches to rural development that enhance production, livelihoods, and ecosystem service functions. Some of these approaches are based on integrated management systems such as reduced- or no-tillage, conservation agriculture, ecoagriculture, agroforestry, permaculture and organic agriculture. Of these, agroforestry seems to be particularly relevant to the delivery of multi-functional agriculture. Like the other systems, it addresses the issues of soil fertility management; the rehabilitation of degraded farming systems; loss of biodiversity above and below ground; carbon sequestration; and soil and watershed protection. However, in addition, agroforestry also provides three crucial outputs that are not provided by the other systems, namely: (i) useful and marketable indigenous tree products for income generation, fuel, food and nutritional security/health and the enhancement of local livelihoods; (ii) complex mature and functioning agroecosystems akin to natural woodlands and forests; (iii) linkages with culture through the food and other products of traditional importance to local people. Thus, the aims of agroforestry are to simultaneously restore: biological resources and natural capital (soil fertility, water, forests, etc); livelihoods (nutrition, health, culture, equity, income) and agroecological processes (nutrient and water cycles, pest and disease control, etc.).

Agroforestry practices are especially numerous in the tropics and used by more than 1.2 billion people. They produce the products that are important for the livelihoods of millions of other people in developing countries. The area under agroforestry worldwide has not been determined, but probably exceeds 100 million hectares. Like organic farming, conservation agriculture and ecoagriculture, agroforestry addresses soil fertility management issues for the rehabilitation of degraded farming systems; loss of biodiversity above and below ground; carbon sequestration; and soil and watershed protection. On the ‘down-side’, trees are competitive with crops (Cooper *et al*., 1996) and the net benefits of agroforestry can be slow to materialize due to the longevity of trees. However, techniques such as the vegetative propagation of ontogenetically mature tissues speeds-up the benefit flows by creating cultivars from parts of the tree which already have the capacity to flower and fruit without going through a long juvenile phase.

Crop domestication

Harlan (1975) said that crop domestication is human-induced change in the genetics of a plant to conform to human desires and agroecosystems. Crop domestication has been limited to less than 0.05% of all plant species and about 0.5% of edible species (Leakey and Tomich, 1999) and the process goes back thousands of years, for example, the domestication of oranges and apples go back about 3000 years in China and central Asia respectively (Simmonds, 1976). According to Diamond (1997), species have been domesticated as the precursor to the development of settled, politically centralized, socially stratified, economically complex, and technologically innovative societies.

Against this background the domestication of tropical tree crops, such as mango, lychee and timber trees emerged very recently (Okafor, 1980, 1983; Leakey *et al*., 1982; Leakey, 1991). In 1992, a conference in Edinburgh recognized the need to domesticate the trees that have in the past provided poor people with their everyday needs for food, medicinal and other forest products (Leakey and Newton, 1994a/b). At this conference, these species were described as "Cinderella species" because they have been overlooked by science (Leakey and Newton, 1994c). The recent history of agroforestry tree domestication has been reviewed by Leakey *et al*. (2005a; 2007), and the products of these cultivated trees have been named Agroforestry Tree Products (AFTPs) to distinguish them from the extractive resource of Non-timber Forest Products (NTFPs) (Simons and Leakey, 2004).

Domestication is also said to be stimulated when demand exceeds supply. The latter would explain this recent interest in domesticating tree crops from wild forest species in the tropics, as deforestation has increased in proportion to population growth. Interestingly, some poor smallholder farmers have reacted to deforestation by starting to select useful trees for growth within their farms (Leakey *et al*., 2004; Leakey, 2005). These farmers can probably be said to be practising 'commensal' domestication as they have retained natural seedlings in their fields and home gardens and cut down those that do not have desirable characteristics when they clear land for other crops. Secondly, they also sow and disperse the seeds of the tastier fruits that they eat, close to the homestead. Based on unusually large size of fruits and nuts of *Canarium indicum* on the small islands of Nissan and Manchungan in the Autonomous Region of Bougainville, it seems that there maybe some evidence of commensal domestication of indigenous fruits and nuts by local communities in Melanesia over many human generations. This commensal approach to domestication provides a good foundation for the 'direct' pathway to domestication that is now being taken by agroforesters working to empower local communities through participatory approaches (described below).

Tree domestication

The definition of domestication used for agroforestry trees (Leakey and Newton, 2004 a/b) encompasses the socio-economic and biophysical processes involved in the identification and characterisation of germplasm resources; the capture, selection and management of genetic resources; and the regeneration and sustainable cultivation of the species in managed ecosystems. This definition therefore stresses that domesticates will be compatible with sustainable land use systems and have beneficial socio-economic and environmental impacts. Consequently, the domestication of agroforestry trees is an incentive to promote sustainable agriculture through diversification with species which generate income, improve diets and health, meet domestic needs, and restore functional agroecosystems; as well as empowering local communities.

Strategies of domestication for agroforestry trees

Firstly, for the purpose of efficiency and speed, the domestication strategy adopted by agroforestry has been a clonal one, based on horticultural techniques of vegetative propagation (Leakey, 2004), applied in a very robust and low-tech manner (Leakey *et al*., 1990) so as to be appropriate for implementation in remote areas of tropical countries which lack reliable supplies of running water or electricity. Vegetative propagation is a uniquely powerful means of capturing existing genetic traits and fixing them so that they can be used as the basis of a genetic 'variety' or 'cultivar'. The advantage of using clonal propagules outweighs those of seedlings when the products are valuable; when the tree has a long generation time and when the seeds are scarce or difficult to keep in storage (Leakey and Akinnifesi, 2008). The consequent uniformity in the crop is advantageous in terms of maximising quality, meeting market specifications and increasing productivity, but it also increases the risks of pest and disease problems, consequently, risk aversion through the diversification of the clonal production population is a crucial component of the strategies used.

Secondly, to benefit the target population of poor smallholder farmers, the strategy is based on participatory approaches to both decision making and implementation (Tchoundjeu *et al*., 1998; Leakey *et al*., 2003). This foundation in participatory processes ensures that domestication is a *farmer-driven* process that also has an eye on the local market to ensure that farmers will be able to sell their products (Simons, 1996; Leakey and Simons, 1998; Simons and Leakey, 2004). The first participatory step involved an exercise in priority setting, in which farmers listed their preferred species for domestication (Franzel *et al*., 1996). This was to ensure that the outputs of the programme were relevant to farmers' needs and so to encourage their active interest and involvement. Interestingly, almost everywhere in the world where this priority setting has been done, farmers have selected familiar and locally-marketed indigenous fruits and nuts as their top priority. This is because these traditionally important products are no longer readily available in the wild and are important domestically to rural people because of their cultural and nutritional value. The second step is a participatory approach to project implementation aimed at empowering local communities, promoting food self-sufficiency, generating income and employment and enhancing nutritional benefits. By providing knowledge and training, the programme assists farmers to develop the skills to set up village nurseries and apply simple and adoptable approaches to nursery management; the horticultural techniques of vegetative propagation and tree selection; agroforestry and community development. The participatory approach has been adopted in order to provide the incentive for farmers to raise themselves out of poverty, malnutrition and hunger through enhanced livelihoods, and food and nutritional security. Together these two steps to participatory domestication probably also explain the rapid adoption by rural communities (Tchoundjeu *et al*., 2006). After about 12 years the number of engaged communities had grown from 2 pilot villages in Cameroon to 485 villages centred on five Rural Resource Centres and involving about 7100 farmers (Leakey and Tentchou, 2009). The concept has also spread to neighbouring countries (Tchoundjeu *et al*., 2006): 11 villages in Nigeria (about 2000 farmers), 3 villages in Gabon (about 800 farmers) and 2 villages in Equatorial Guinea (about 500 farmers).

The tree domestication strategy involves the maintenance and use of three inter-linked populations (Figure 1):-

- Gene Resource Population, for genetic conservation
- Selection Population, for the development of improved cultivars, and
- Production Population, for farmers to plant and grow.

The strategy is equally appropriate for the domestication of species producing fruits and nuts; medicinal products; leafy vegetable and animal fodder; timber and wood, and extractives like essential oils, resins, etc. (Table 1).

The above strategy is also important because it conforms to the Convention on Biological Diversity (Tchoundjeu *et al*., 1998; Leakey *et al*., 2003; Simons and Leakey, 2004), by recognising the rights of local people to their indigenous knowledge and traditional use of native plant species. Protection of the farmers' intellectual property is needed to ensure that participatory domestication by local farmers can be recognised as a good model of biodiscovery; an alternative to biopiracy by expatriate or local entrepreneurs. However, until global negotiations create an effective means of protecting the intellectual property of farmers they remain at risk of being exploited.

One constraint to tree domestication is that agroforestry trees are notoriously difficult to domesticate because they are predominantly out-breeding. This means that gains in selected traits are on average small because of the wide range of intra-specific variation in the progeny arising from controlled pollinations. Additionally the long generation time of many trees (10-20 years), means that an individual geneticist does not produce many generations within his/her career. These problems can be overcome by the horticultural approach to domestication, using vegetative propagation to mass produce individual trees with superior characteristics. Until recently, however, trees have had the reputation of being very difficult to propagate by stem cuttings, and the alternative approaches of budding and grafting have other technical difficulties (graft incompatibility, dominance by the rootstock, etc.), as well as requiring some special skills. Nevertheless, perhaps the overriding factor that constrained the 'direct' approach to tree domestication has been the disinterest in products that did not appeal to 'western' tastes. Consequently they were neither promoted by early European settlers, nor were they funded by the 'Green Revolution'.

Putting tree domestication into practice

Globally, the lead in agroforestry tree domestication has been taken by the World Agroforestry Centre in partnership with the national agricultural research institutes of many countries, but there are also a growing number of other research teams joining the global initiative, such as the Agroforestry and Novel Crops Unit of James Cook University (JCU). JCU has been actively involved in tree domestication for eight years with projects in Africa and the Oceania. For example, in Pacific countries, research and development work to domesticate indigenous trees producing fruits, nuts and essential oils is in progress in Papua New Guinea (Galip nut – *Canarium indicum*), the Solomon Islands (Cutnut – *Barringtonia procera*; Tahitian chestnut - *Inocarpus fagifer*), Vanuatu (Sandalwood – *Santalum austrocaledonicum*) and in Australia (*Santalum lanceolatum*).

A fundamental requirement of the clonal approach to domestication is a good understanding of the intraspecific variation in all traits of importance for selection and improvement. Consequently, quantitative studies have been made of the tree-to-tree variation in a range of fruit and nut traits to determine the potential for highly productive and qualitatively superior cultivars with a high Harvest Index (*e.g.* Atangana *et al*., 2001, 2002; Anegbeh *et al*., 2003, 2005; Leakey *et al*., 2002; Waruhui *et al*., 2004; Ngo Mpeck *et al*., 2003b; Leakey *et al*., 2005b/c). This information is needed in order to identify the elite trees with the desirable combinations of different traits that would be appreciated by different markets (*e.g.* edible fruits, edible nuts, nuts for food oil, nuts for cosmetic oils, or fruits and nuts for medicinal products). The practical approach is to seek trees, which have particular, market-oriented, trait combinations – such as big, sweet fruits (even seedlessness) for the fresh fruit market (a fruit ideotype); big, easily extracted kernels for the kernel market (kernel ideotype), etc. The latter can then be sub-divided into those meeting the demands of different markets (Leakey and Page, 2006), such as food thickening agents confering drawability and viscosity (Leakey *et al*., 2005d), or other products, such as pectins or oils for food or cosmetic industries (Kapseu *et al*., 2002; Kalenda *et al*., 2002; Leakey *et al*., 2005c). One of the key findings of these characterisation studies is that each trait shows very considerable and continuous variation from low to high values. Interestingly, this is greatest at the village level, while the variation between villages is only modest. Importantly, it is also found that high values of one trait are not necessarily associated with high values of another trait: thus large fruits are not necessarily sweet fruits, and do not necessarily contain large nuts or kernels. Consequently the more trees that are examined the greater are the opportunities for creating exciting new cultivars.

In Papua New Guinea, a preliminary investigation of tree-to-tree variation in Galip Nut (*Canarium indicum*) has shown that patterns of intraspecific variation in fruit, nut and kernel mass (Figure 2a) are very similar to those described for African species (Leakey et al., 2008b) Similarly, on Kolombangara Island in the Solomon Islands the fruits, nuts and kernels of Cutnut (*Barringtonia procera*) also showed continuous variation (Pauku, 2005). Thus it seems clear that these patterns of intraspecific variation are common in indigenous fruit and nut trees, and will probably be found in the many other traditionally-important trees of the Pacific producing similar products (Elevich, 2006).

A start has been made to look at the genetic variability in nutritive value or sensory analysis in a few AFTP producing crops. Kengni *et al*., (2001) have made a preliminary examination of the variability in flavour, taste and aroma in samples of *Dacryodes edulis*, while a similar preliminary analysis of *Sclerocarya birrea* fruits has identified considerable tree-to-tree variation in protein and vitamin C (Thiong'o *et al*., 2002). Similarly, preliminary studies have been done in *Canarium indicum* from Papua New Guinea to evaluate tree-to-tree variation in fatty acid profiles, protein and vitamin E, anti-oxidant activity and phenolic content (Leakey *et al*., 2008b). Interestingly, the latter study also identified very considerable tree-to-tree variation in the anti-inflammatory property of kernel oil between just ten trees (Figure 2b), illustrating the very real opportunity to develop cultivars for medicinal properties. Other evidence of tree-to-tree variation in medicinal value has been recorded in the major sterol component, B-sitosterol, from the bark of *Prunus africana*, which is of importance for the treatment of Benign Prostatic Hyperplasia (Simons and Leakey, 2004). This variability in nutritional quality and medicinal properties is likely to affect the potential for different markets, so there is an urgent need for agroforesters to work closely with the food, nutraceutical and pharmaceutical industries to optimise the domestication / commercialisation partnerships (Leakey, 1999). One aspect of the potential health benefits of agroforestry is the fortification of the immune systems of HIV/AIDS sufferers through the selection of especially nutritious cultivars of indigenous fruits and nuts (Barany *et al*., 2001; 2003); something that requires further investigation as an output from agroforestry (Villarreal *et al*., 2006).

Until recently it was not known whether this pattern of continuous variation would also be found in quality attributes in wood, but a study of the essential oils in two sandalwood species (*Santalum austrocaledonicum* and *S. lanceolatum*) has shown this to be the case (Figure 3: Page *et al*., 2007a/b), thus it seems that this pattern of variation is typical for most traits.

In addition to these qualitative traits there is also the opportunity for cultivars to capture variation in quantitative traits and in phenology, such as yield, seasonality and regularity of production, reproductive biology and reduction of susceptibility to pests and diseases which can reduce productivity or quality (Kengue *et al*., 2002). High yield is obviously a desirable trait, but in the early stages of domestication it may be even more important economically, nutritionally, etc., to expand the fruiting season from 2-4 to 6-8, or even 12 months. Emerging evidence suggest that in many species there are rare individuals that flower and fruit outside the main season, so this offers important opportunities to increase the period of production and so reduce the periodicity of income generation for the farmer as well as to make it easier to provide commercial markets with year-round supply.

Having identified which are the elite trees worthy of becoming cultivars they are propagated vegetatively to capture the specific combination of genetic traits as a clone (Leakey *et al*., 1990; Leakey, 1991). To ensure that optimal use of the genetic resource is achieved the clonal approach is integrated with others to ensure that a wise genetic improvement strategy is adopted (Leakey and Akinnifesi, 2008). The use of vegetative propagation techniques to capture the tree-to-tree variation is now relatively simple and well understood (Leakey, 1985, 2004; Leakey *et al*., 1990, 1996; Mudge and Brennan, 1999), with high multiplication rates, for almost all tree species, although the numbers of people with the appropriate skills may be a constraint to its widespread application in the future (Simons and Leakey, 2004). Typically, the techniques of grafting, budding and air-layering (marcotting) are used to capture superior fruit trees and to multiply them as cultivars. This is because mature tissues with the capacity to flower and fruit can only be propagated by cuttings with great difficulty (low multiplication rates) (Leakey, 2004). Propagation by cuttings is, however, the preferred option for participatory domestication in village nurseries (Mialoundama *et al*., 2002; Tchoundjeu *et al*., 2002a), and ways have to be found to get around the difficulty of propagating mature shoots with the capacity to flower and fruit. Circumventing this problem is most easily achieved by capturing the genotype as a graft or rooted marcot, and then by good nursery management, enhancing the rooting ability of the resulting stockplant once it is severed from the tree and on its own roots.

Pacific tree species seem to be as amenable as those of other parts of the tropics, with both *Barringtonia procera* and *Inocarpus fagifer* being very easy to propagate (Pauku, 2005). Initially efforts to propagate *Canarium indicum* by cuttings indicated some difficulty, but attention to detail and particularly to stockplant management have overcome these problems (Nevenimo, Moxon and Pauku, personal communication), although the propagation of mature material remains a challenge. Likewise sandalwood cuttings were recalcitrant at first, but rates of success are improving although the reasons for some trees being difficult-to-propagate remain unresolved (Tate and Page, personal communication).

As elsewhere in the world, experience in Melanesia suggests that the adoption of agroforestry initiatives is increased by the recognition of the need for change. For example, there is great current interest in the planting of Galip nut in East New Britain (Papua New Guinea) following the recent devastation of the cocoa crop by Cocoa Pod Borer. Already some 26,000 seedlings of Galip nut have been readily accepted by farmers who recognize its value as a traditional food, a source of oil and an 'A' grade timber. This acceptance is no doubt heightened by the fact that due to the cocoa pod borer, around 30,000 cocoa-producing families are expected to lose their main source of income over the next three to four years. The domestication of Galip nut is aimed at strengthening this initiative by the development of a new cash crop with export potential.

Retention and protection of genetic diversity

Typically only the best plants are brought into domestication programmes, so domestication is generally considered to reduce the genetic diversity of the species being domesticated; creating the so-called 'domestication bottleneck'. This is probably true in situations where the domesticated plant replaces or dominates the wild origin, but is probably not the case at the current level of domestication of agroforestry trees. So, for example, in most of the trees currently being domesticated there is still a robust wild population. Evidence from molecular studies of *Barringtonia procera* in the Solomon Islands (Pauku, 2005) found that the trees with the largest kernels were found in many different populations and so were not closely related (Figure 4). Thus selected cultivars produced by different communities will all have large kernels but they will be genetically diverse in all the unselected traits, such as pest and disease resistance, etc. This population variation is another advantage of implementing a participatory domestication strategy implemented independently in different villages (Leakey *et al*., 2003). Modern molecular techniques are useful in the development of a wise strategy for the maintenance of genetic diversity, as within the geographic range of a particular species they can be used to identify the 'hot-spots' of intraspecific diversity (*e.g.* Lowe *et al*., 1998, 2000), places which should if possible be protected for *in situ* genetic conservation, or be the source of germplasm collections if *ex situ* conservation is required.

Social, economic and environmental benefits of domestication

Crop domestication has been credited with being one of the major stimulants of agricultural development and hence the diversification of civil society and economic development, and even the evolution of civilization (Diamond, 1997). This illustrates the close linkage between domestication and the commercialization of the products. Recognizing this linkage and deliberately promoting the parallel development of domestication and commercialization is a very important part of the domestication strategy for agroforestry trees (Leakey, 1999; Leakey and Akinnifesi, 2008; Bunt and Leakey, 2008). In west and central Africa, a number of indigenous fruits and nuts, mostly gathered from farm trees, contribute to regional trade (Ndoye *et al*., 1997). In Cameroon, the annual trade of the products of five key species has been valued at US$ 7.5 million, of which exports generate US$ 2.5 million (Awono *et al*., 2002). Perhaps because of this trade, evidence is accumulating that AFTPs do contribute significantly to household income (Gockowski *et al*., 1997) and to household welfare (Schreckenberg *et al*., 2002; Degrande *et al*., 2006).

In terms of social benefits, women, who are the main retailers of NTFPs (Awono *et al*., 2002), are often the beneficiaries of this trade and they have especially indicated their interest in marketing *D. edulis* fruits because the fruiting season coincides with the time to pay school fees and to buy school uniforms (Schreckenberg *et al*., 2002). The role of women in trade and marketing of AFTPs is being enhanced by domestication, and hopefully children will also benefit, not only from improved nutrition, but by greater access to education. Similar trends are emerging in southern Africa, where indigenous fruits have relatively new local and international markets (Brigham *et al*., 1996; Shackleton *et al*., 2000; 2002; 2003b). Because the production and trading of AFTPs are based on traditional lifestyles, it is relatively easy for new producers to enter into production and trade with minimal skills, low capital requirement, and with little need for external inputs. Together these things make this approach to intensifying production and enhancing household livelihoods very easy and adoptable by poor people.

Integrating domesticates into the cropping system.

Domesticated trees for the production of AFTPs can be integrated into farming systems in many ways, either in home gardens, or as shade in cash cropping systems such as cocoa or coffee (Leakey and Tchoundjeu 2001; Leakey in press a), as scattered trees in food crop fields, or as boundary trees, to generate income, provide products for domestic use as well as to provide environmental services. Trees also used to maintain tenure of customary land which would otherwise have to be forfeited if not seen to be in use.

Agroforestry often creates opportunities for shade-adapted species to fill shady niches and increase the benefits derived from mixed-cropping systems. In this connection, most existing food crops have been selected and bred for cultivation in full sun, so there are opportunities for plant breeders and domesticators to develop new crops or crop varieties that are better adapted to partial shade. When new agroforestry crops are integrated with other agroforestry practices, such as improved fallows for soil fertility management, the combined impacts can reduce the crop Yield Gap, (the difference between potential yield of a food crop and the actual yield achieved by farmers) and result in many economic, social and environmental benefits (Leakey and Tentchou, 2009) that go a long way towards meeting the goals of multi-functional agriculture (Figure 5).

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Figure 1. Domestication strategy for agroforestry trees (after Leakey and Akinnifesi, 2008 and White, 1987).

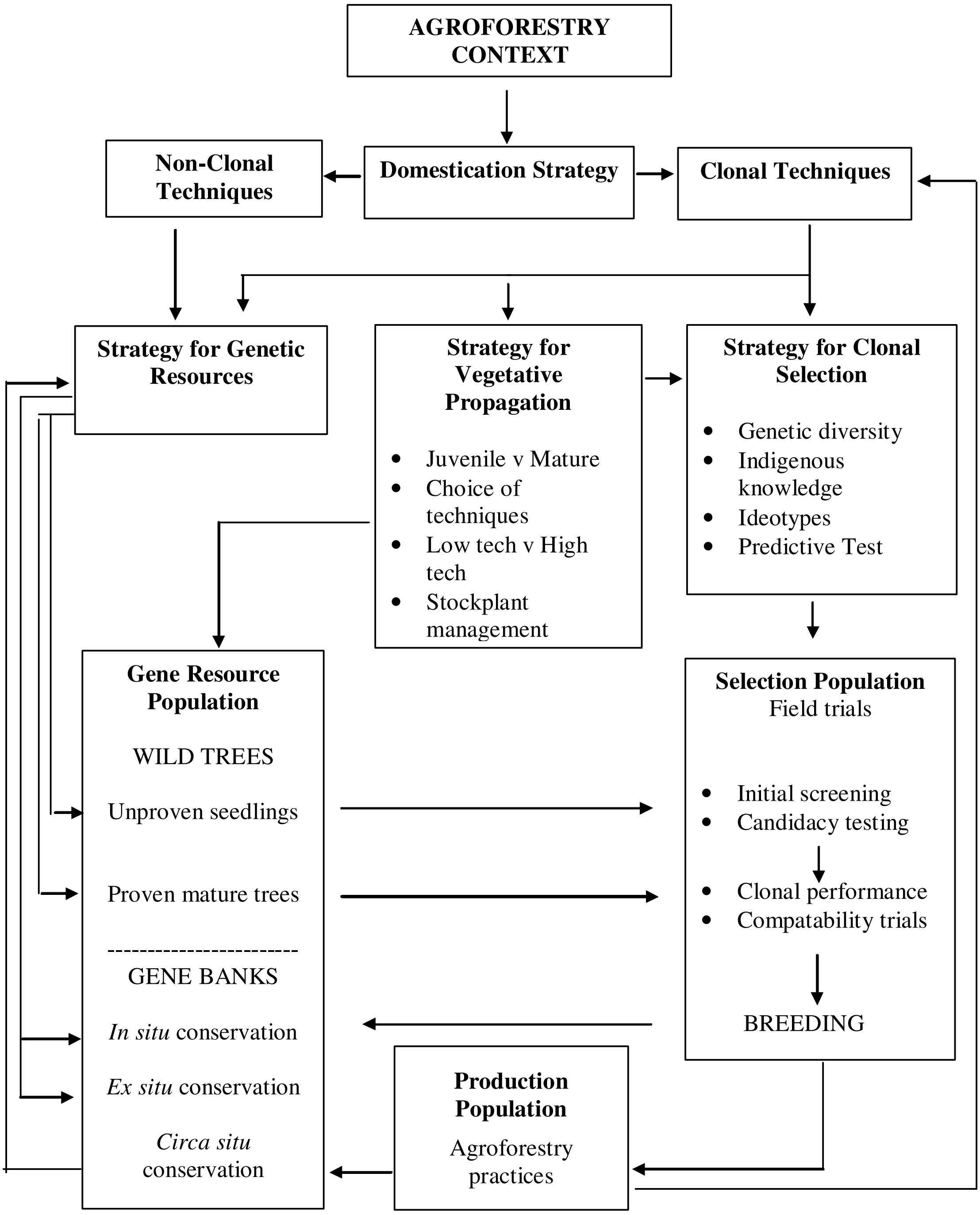

Figure 2a. Continuous tree-to-tree variation in kernel mass from individual trees of *Canarium indicum* in East New Britain, Papua New Guinea (after Leakey *et al*., 2008b)

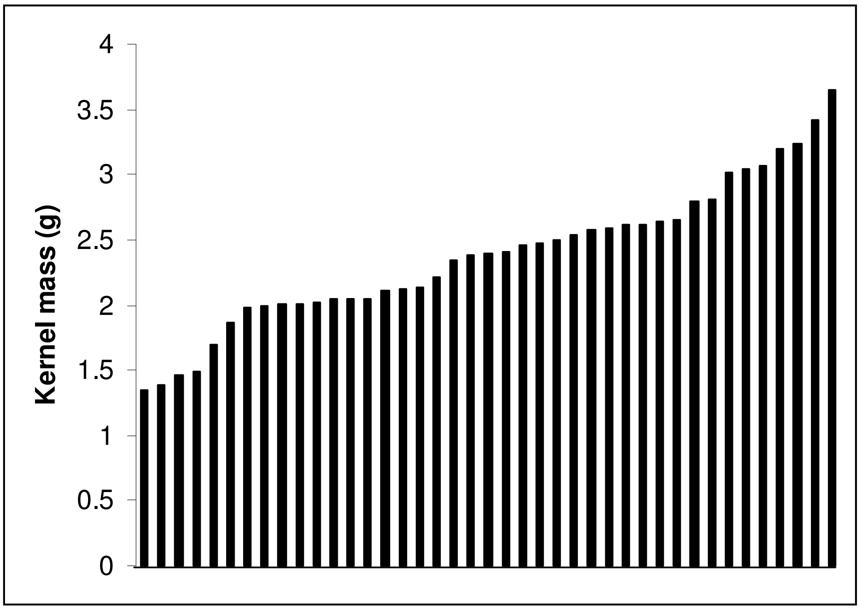

Figure 2 b. Tree-to-tree variation in anti-inflamatory properties of *Canarium indicum* kernel oil (inhibition of prostaglandin E2 [PGE2]) (after Leakey *et al*., 2008b).

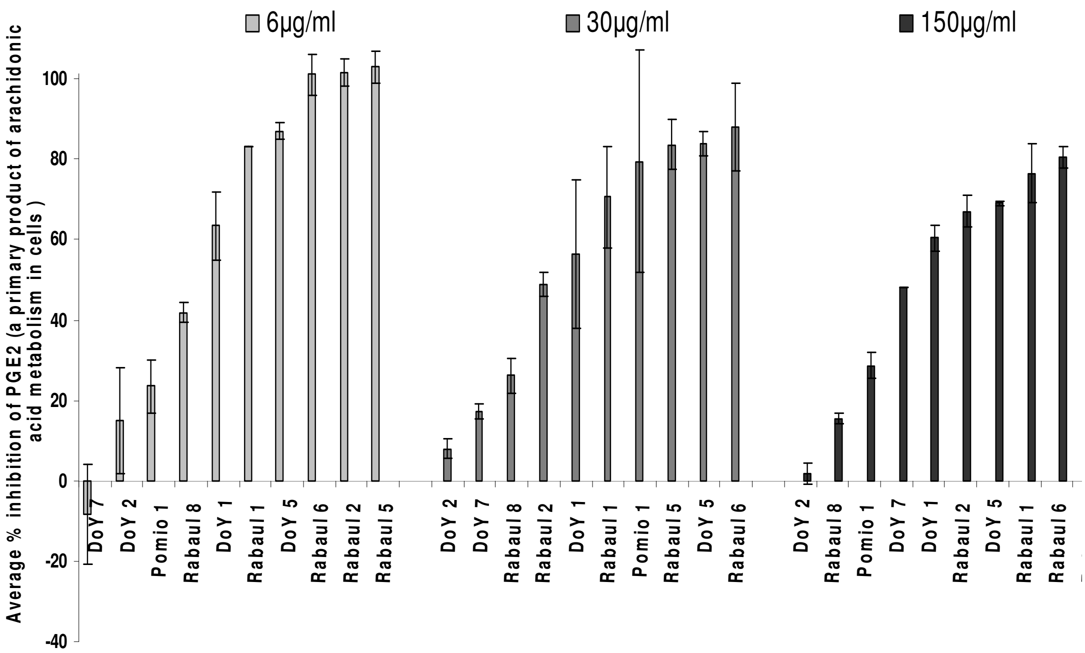

Figure 3. Continuous tree-to-tree variation in α–santalol in *Sandalum austrocaledonicum* in Vanuatu

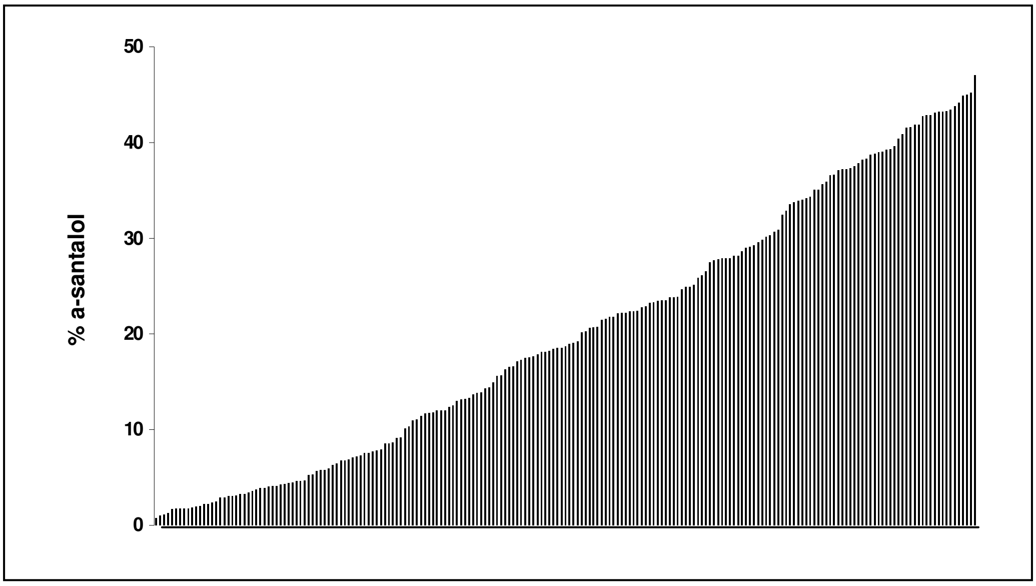

Figure 4. Relationship between kernel morphotypes and genetic relatedness in *Barringtonia procera* (after Pauku, 2005).

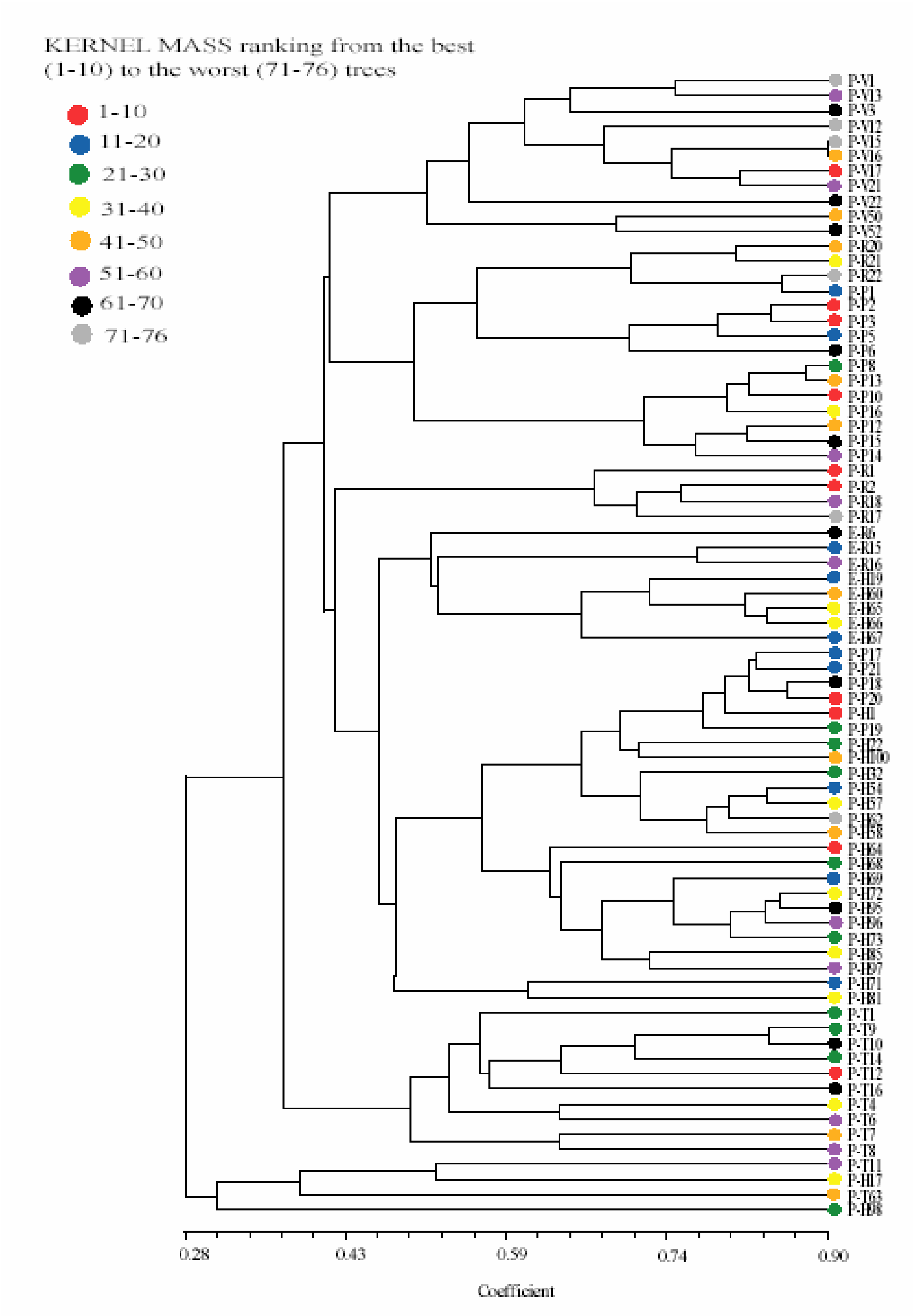

Figure 5. Agroforestry approach to closing the Yield Gap (after Leakey, in press b). Three steps (1 = ; 2 = ; 3=) to reducing the Yield Gap.

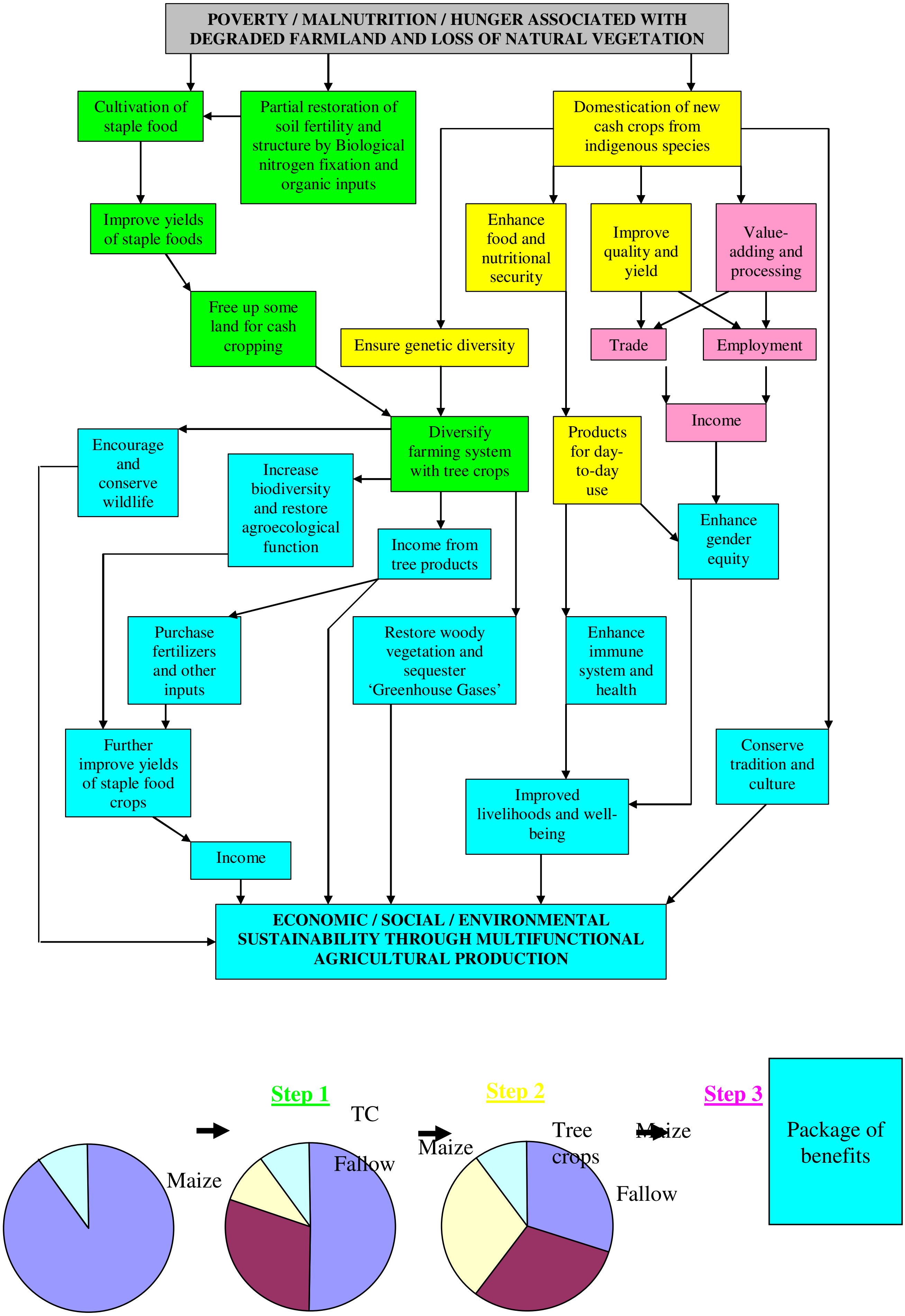

Table 1. Tree species being domesticated clonally that have potential as components of agroforestry systems

Species	**Use**	**Reference**
Irvingia gabonensis and *Irvingia wombulu*	Kernels and fruits	Okafor, 1980; Shiembo *et al.,* 1996a; Atangana *et al*., 2001; 2002; Anegbeh *et al*., 2003; Leakey *et al*., 2005
Dacryodes edulis	Fruits and oils	Okafor, 1983; Kengue *et al*;., 2002; Tchoundjeu *et al*., 2002a; Waruhiu *et al*., 2004; Anegbeh *et al*., 2005
Prunus africana	Bark for medicinal products	Simons *et al*., 2000; Leakey, 1997; Tchoundjeu *et al*., 2002b; Simons and Leakey, 2004.
Pausinystalia johimbe	Bark for medicinal products	Ngo Mpeck *et al*., 2003a; Tchoundjeu *et al*., 2004
Ricinodendron heudelottii	Kernels	Shiembo et al., 1997; Ngo Mpeck, *et al*., 2003b
Gnetum africanum	Leafy vegetable	Shiembo *et al*., 1996b; Mialoundama, 1993.
Barringtonia procera	Nuts	Pauku, 2005
Inocarpus fagifer	Nuts	Pauku, 2005
Santalum austrocaledonicum and *S. lanceolatum*	Essential oils	Page *et al*., 2006a/b
Canarium indicum	Nuts	Nevenimo *et al*., 2007; Leakey *et al*., 2008b
Sclerocarya birrea	Fruits and nuts	Leakey *et al*., 2005b/c; Leakey, 2005
Triplochiton scleroxylon	Timber	Longman and Leakey, 1995; Ladipo et al., 1991a/b; 1992
Chlorophora excelsa	Timber	Ofori *et al*., 1996a/b; 1997
Swietenia macrophylla and *S. mahogani*	Timber	Newton *et al*., 1993