Domesticating and Commercializing Indigenous Fruit and Nut Tree Crops for Food Security and Income Generation in Sub-Saharan Africa

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Abstracts

Research on indigenous fruit and nuts has accumulated considerably in Sub-Saharan Africa, and their role is being recognized in the domain of poverty reduction. An *ex ante* impact analysis in southern Africa indicate that indigenous fruit can reduce vulnerability of rural households to income poverty. Hence, research has been on-going on development of long-term domestication strategies, selection of priority species, germplasm collection and tree genetic improvement, propagation systems and field management, harvesting and post-harvest technology, economic analysis and market research. There are similarities in the approaches and lessons learnt in different regions, especially in West and southern Africa. The selection, management and cultivation of IFTs are generally characterized by integration of silvicultural and horticultural approaches. Time to fruiting of wild fruit trees have been reduced from more than 12 years in the wild to less than four years in all the three regions. This paper provides synthesizes available studies on the domestication of indigenous fruit trees as tree crops, and commercializing their products, highlights the lessons learnt and provided the way forward to tap into the opportunities presented by IFTs to enhance food security and income generation in sub-Saharan Africa

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**Paper presented at the New Crops International Symposium, 3-4 September, 2007, Southampton, United Kingdom.*

1. INTRODUCTION

The harvesting, utilization and marketing of indigenous fruit and nuts have been central to the livelihoods of majority of rural communities throughout Africa (Akinnifesi *et al.,* 2007; Leakey *et al.,* 2005) and can make a difference during period of famine and food scarcity (Mithofer and Waibel, 2003, Akinnifesi *et al.,* 2006). Wild harvesting of fruits from forests and semi-domesticated trees growing on-farm and homesteads can substantially boost rural income and employment opportunities in Africa (Leakey *et al.*, 2005; Ruiz-Perez *et al.*, 2004). Market and financial analyses in southern Africa show that indigenous fruits contribute to household income, and women and children are the major beneficiaries (Ramadhani, 2002).through value addition and fruit processing (Saka *et al.*, 2004, 2006). Indigenous fruit trees provide higher value-to-weight ratio and are easier to transport than timber or wood products (Teklehaimanot, 2004). Several indigenous fruit tree crops are excellent sources of vitamin C that can reduce malnutrition that is widespread many SSA countries. For example, baobab (*Adansonia digitata*) pulp produces 5.13g vitamin C (Sidibe *et al*., 1998) which more than 10 times as much as same weight of oranges.

Focusing on wild collection and management of semi-domesticated trees on farm and homestead has been indicated as an effective way of reducing the sunk costs, providing households with improved species diversity in terms of desired fruit and tree traits (Kruse, 2006). However, wild harvesting (extractivism) and over-extraction have led to market expansion and supply shortages in many cases (Simons and Leakey, 2004). As forests recede due to deforestation, wild fruit trees become severely prone to overexploitation and extinction. Relatively little research and development attention has been given to the development of indigenous trees as tree crops for wider cultivation. Domestication of indigenous fruit trees emerged as a farmer-driven, marked-led process and has become an important agroforestry initiative in the tropics (Akinnifesi *et al.,* 2006, Tchoundjeu *et al.,* 2006; Leakey *et al.,* 2005). In the last decade, the World Agroforestry Centre (ICRAF) has advanced research on domestication and commercialization of indigenous fruit trees in order to improve rural livelihoods—nutritional status, household income, entrepreneurial opportunities and economic empowerment--and promote biodiversity conservation and the sustainable use of natural resources in the tropics.

There is increasing enthusiasm among researchers and development practitioners to explore the opportunities to meet the food needs of humanity through indigenous fruit trees (IFTs). Much of this work has been undertaken in Africa, and it builds on the efforts of smallholder farmers who had initiated the first step towards domestication through retaining, selection and cultivation of semi-domesticated fruit trees (Leakey *et al.,* 2005; Tchoundjeu *et al.*, 2006; Akinnifesi *et al.*, 2006, 2007). As a result, there is an increasing emphasis to promote IFTs with economic potential as new cash crops, product development, commercialization and marketing of agroforestry tree products (AFTPs). This paper provides a synthesis of the lessons learnt and the way forward for domesticating indigenous fruit trees as tree crops, and commercializing their products in West, East and Southern regions of Africa.

2. PARTICIPATORY DOMESTICATION APPROACHES

Domestication involves a long-term iterative and integrated strategy for tree selection and improvement, for the promotion, use and marketing of selected products and their integration into agroforestry practices (Akinnifesi *et al.,* 2006). The indigenous fruit tree domestication is based on the concept of 'ideotypes' derived from an understanding of the tree-to-tree variation in commercially important traits (Leakey *et al.* 2005; Leakey and Akinnifesi, 2007), and participatory selection of superior clones and cultivars with users following objective criteria, vegetatively-propagating and integrating them into the farming systems.

The participatory domestication research and development in the humid lowlands of West and Central Africa began in 1998 with initial a focus on *I. gabonensis* in Cameroon and Nigeria but has expanded progressively to Equatorial Guinea, Gabon, Democratic Republic of Congo and Ghana in the last four (Leakey *et al*., 1998; Tchoundjeu *et al*., 2005), *D. edulis* (Leakey *et al*., 2002; Anegbeh *et al*., 2005). In southern Africa, it started in 1996 in Malawi, Zambia, Zimbabwe and Tanzania with focus on *Uapaca kirkiana* and *Sclerocarya birrea* in (Kwesiga *et* *al.,* 2000; Akinnifesi *et al.,* 2004, 2006, 2007). In both regions, participatory tree domestication approaches involves the following steps:

i. Selection of priority indigenous fruit tree species based on farmers' preferences and market orientation;
ii. Identification of superior or elite trees based on established criteria by users, marketers and market preference (tagging and naming trees for purpose of ownership and property right recognition);
iii. Development and applying efficient vegetative propagation and nursery management techniques for producing quality propagules of on-farm dissemination;
iv. Integration of improved germplasms into farming systems; and,
v. Post-harvest handling, processing and marketing research of fresh and processed products from domesticated species.

2.1 Taking Advantage of Genetic Diversity

The first step in IFTs domestication is to identify the most valuable trees for smallholder farmers and for market. The key steps include i) verifying the importance and potential of indigenous fruits in the rural economy, ii) initiating a tree selection and improvement of germplasm, iii) develop and promote the wider cultivation of superior cultivars of indigenous fruit, and iv) commercialise new IFTs products through a functional supply chain (fruit storage and processing, product quality assurance, value-adding, marketing research, rural revenue generation and enterprise development). The early results obtained by ICRAF indicated that indigenous fruit trees could be propagated and cultivated. Some of the trees had fruited within three years and increased the enthusiasm of researchers. In southern Africa, a region-wide germplasm collection and multi-locational provenance and family trials was initiated with partners during 1996-98 (Akinnifesi *et al.,* 2004).

2.2 Choosing the 'Big Five' priority indigenous fruits species

Given that participatory domestication involves selection and management of the most highly valued trees and cultivars, prioritisation is the first logical step to obtaining premium species. Guidelines for systematic priority setting in different regions involving the participation of local communities and partners have been developed (Franzel *et al.* 1996, 2007) and applied in West Africa (Adeola *et al.* 1999), and with modifications in southern Africa (Maghembe *et al.* 1998) and East Africa (Teklehaimanot, 2007; Jama *et al.* 2007). The guidelines involves (i) Team building among stakeholders to agree on approaches and refine method to local conditions, (ii) Identifying clients and assessment of users' needs (farmers, marketers, etc); (iii) Inventory of all species used by clients, including potentially useful ones; (iv) Identify the most important products from IFTs in the target region. Consider only those with the greatest importance; (v) Selection of smallest number of species with highest benefits: (vi) Estimating the production value of key species to set priorities and; (vii) Synthesize previous results, review the process and select the final choice of species (Franzel *et al.,* 1996). Results from the priority setting exercises in four eco-regions of Africa are illustrated in Table 1.

2.2.1 Miombo eco-region of southern Africa

In the miombo eco-region of southern Africa, multi-site ethnobotanical surveys were conducted in Malawi, Tanzania, Zambia, and Zimbabwe in 1990-1991 to understand species diversity and role of trees on farm, with respect to their establishment and management, location and arrangement, market opportunities, uses and functions in farmer fields (Kwesiga and Chisumpa, 1992; Maghembe and Seyani, 1991). The surveys identified over 75 indigenous fruit tree species that are an important resource to rural communities as important sources of food and income.

Subsequently, a priority setting workshop identified two species for the region, namely *Uapaca kirkiana* and *Sclerocarya birrea,* and range-wide germplasm collection of both species were undertaken during 1996 in Malawi, Zambia, Tanzania and Zimbabwe (Kadzere *et al.*, 1998). Further surveys were held in four countries leading to the identification of *Uapaca kirkiana, Parinari curatellifolia, Strychnos cocculoides, Ziziphus mauritiana and Adansonia digitata* as the five most preferred species for domestication by farmers in the region. Recently, the different methods used in the region were triangulated to obtain a more reliable consensus (Akinnifesi *et al.* 2007; Franzel *et al.* 2007). This approach recognized the effects of location, sample size, time dynamics, socio-economic and ecological niches. Based on these results, the three top regional spearhead priority species (species which drive the domestication programme) were *Uapaca kirkiana, Strychnos cocculoides* and *Sclerocarya birrea* (Akinnifesi *et al.*, 2006). Adapted species such as *Ziziphus mauritiana* and *Casmiroa edulis* and *Tamarindus indica* were also widely preferred by farmers and users (Akinnifesi *et al.,* 2007). Further, analysis clearly showed that farmers and users highly prefer exotic and conventional horticultural tree crops such as mangoes, citrus, avocado, bannana among the top ten fruits in Malawi and Zimbabwe where exotics were included in farmer and market surveys (Akinnifesi *et al.,* 2007; Franzel *et al.,* 2007; Ramadhani, 2002). The approach was also applied to IFTs products in southern Africa (Table 2).

2.2.2 Humid lowlands of West Africa

Several priority setting surveys conducted in the humid lowlands of West Africa including Cameroon, Nigeria, and Ghana showed considerable variability among farmers' priority species within and between the countries surveyed (Franzel *et al.,* 2007). The number of species mentioned in each of the three countries ranged from 60 in Cameroon to 172 in Nigeria (Franzel *et al.,* 2007). No single species ranked among the top ten in all three countries. In general, *Irvingia gabonensis, Dacryodes edulis* and *Chrysophyllum albidum were ranked* among the top four in at least two of the countries (Table 1). All three were important as both food and cash earners (Adeola *et al.,* 1998). Unlike in southern and East Africa, the priority setting results in West Africa showed less concordance among neighbouring countries. This is probably due to the heterogeneity o ecological conditions between and within countries. Details of the ranking have been documented elsewhere (Franzel *et al.,* 2007).

2.2.3 Sudano-Sahelian Zone of West Africa

In a survey conducted across Senegal, Mali, Burkina Faso, and Niger at the southern margins of the Sahara desert, a total of 59 indicated as important, of which 15 were common among countries (Franzel *et al.,* 2007). The study showed the following order of preference: 1. baobab (*Adansonia digitata*), 2. karate or shea butter tree (*Vitellaria paradoxa*), 3. tamarind (*Tamarindus indica*), 4. ber *(Ziziphus mauritiana)* and 5. nere (*Parkia biglobosa*) (Table 2). There were also country specific species, such as *Balanites aegyptiaca, Diospiros mespiliformis* and *Vitex doniana* in Niger. As in the humid lowlands of West Africa, trees providing food dominated farmers' choices among species. Baobab also provided leaves as food (Sidibé *et al*., 1996).

2.2.4 Dry Regions of Eastern Africa

Priority setting workshops in dry region of Eastern Africa were carried out by the Association of Forest Research Institutions in Eastern Africa (AFREA) in collaboration with IPGRI-SSA and national partners in 2004 (Chikamai *et al.* 2005; Jama et al, 2007). The workshops involved participants from Ethiopia, Kenya, Sudan, Tanzania and Uganda and carried out the following: i) national priority setting through brainstorming meetings and discussions senior extension and researchers ii) field surveys involving local community leaders, farmers, pastoralist, traders and other community dwellers in 26 villages in the five countries. The combined results of the two approaches indicated the five top regional priority species as follows: *Adansonia digitata*, *Balannites aegyptiaca* Del.,) *Cordeaux edulis*, *Sclerocarya birrea* and *Tamarindus indica* in a decreasing order of importance. In addition, *Vitellaria paradoxa, Parinari curatellifolia* Planch and *Ziziphus mauritiana* Lam were among the top eight species. Details of the results are documented in Chikamani *et al.* (2005) and Teklehaimanot *et al.* (2005).

2.2.5 Overview of the BIG FIVE in Sub-Saharan Africa

The discussion above shows that there has been no systematic continental level research to identify the top priority indigenous fruit trees in sub-Saharan Africa. It seems logical that due to the diverse ecology, farming systems and vast geographical area such research will have little application to cultivation. Therefore, regional priority setting is more relevant. However, for the purpose of comparing with other tropical regions, it is possible to identify the BIG five top priority species in Africa, based on the long-term investment into priority setting in the last ten years, led by ICRAF and partners across Africa.

For such prioritization to be relevant, it is important to identify these as humid tropics, semi-arid and dry regions. For the humid region (West Africa), *D. edules, I. gabonensis* and *C. albidum* are important (Table 1). Of these three, *I. gabonensis* and *D. edules* are most widely traded. There are also regionally cross-cutting species such as *S. birrea* and *T. indica* in southern and East Africa. *Z. mauritiana* in the Sahel, southern Africa and East Africa. *V. paradoxa* is common to dry region of East Africa and the Sahel of West Africa. Therefore, the Big five species based on market extent and preference could be (1) *V. paradoxa,* (2) *S. birrea,* (3) *I. gabonensis*, (4) *Z. mauritiana* and (5) *D. edules.* This ranking is based on subjective criteria, mainly personal knowledge of the market and priority setting results from each region. A systematic study identifying continental species is further warranted.

3. CLONAL SELECTION AND PROPAGATION

Tree domestication refers to how humans select, manage and propagate trees where the humans involved may be scientists, civil authorities, commercial companies, forest dwellers or farmers (Simons and Leakey, 2004). Tree domestication is a paradigm shift from focus on tree improvement based on breeding and conventional forest tree selection to horticultural approaches focused on quality germplasm production for wider cultivation to serve the needs of smallholder farmers.

3.1 Clonal selection in southern Africa

An extensive PRA selection was used to capture superior individuals in southern Africa (Akinnifesi *et al.,* 2006). Tree-to-tree variation was measured in wild populations of *U. kirkiana* and *Strychnos cocculoides* with communities, and selection of superior trees was based on market-oriented ideotype products (Akinnifesi *et al.,* 2006). The local knowledge of the rural communities was captured by brainstorming at village workshops about objectives of selection with 20-30 people in each group. Together with villagers, the superior trees were identified on the basis of superior traits, and were systematically named and tagged in situ according to year of collection, location and ownership. Site descriptors were documented and fruits sampled for detailed assessment of the qualitative and quantitative characteristics, including chemical and organoleptic analysis. Seeds and scions were also collected for growth and multiplication in the nursery. In some cases, duplicate materials were collected by farmers and raised in individual or group nurseries in their own communities. The superior germplasm is subsequently evaluated in clonal orchards on-station and on-farm and fruits are characterized and analyzed for their chemical characteristics. This evaluation identifies the trees for subsequent vegetative propagation and clonal testing, so that high quality planting materials can be available to farmers as soon as possible. Through the selection and propagation of elite genotypes from the wild, new cultivars with superior or better marketable products: fruit size, sweetness and fruit load with improved uniformity have been obtained. Trees with superior phenotypes of *U. kirkiana, S. cocculoides, S. birrea* and *V. mombassae* were selected in the region from the wild, based on jointly determined criteria with rural community dwellers (farmers, marketers, traditional chiefs, school children) in Malawi, Zambia, Zimbabwe and Tanzania.

3.2. Clonal Selection in West and Central Africa

The selection of superior indigenous fruit trees involved quantitative descriptors of variation in indigenous fruit and nut traits (Leakey *et al*., 2000), and phenotypic selection indicate significant tree-to-tree variation in measured traits (Atangana *et al*., 2001; *Anegbeh et al., 2005*; Leakey *et al*., 2005). Phenotypic variation in fruit and nut traits of *I. gabonensis* and *D. edulis* have been widely reported (Atagana *et al.*, 2002; Anegbeh *et al*., 2005; Leakey *et al*., 2005). This allowed selection of 'superior trees' for vegetative propagation using the 'ideotype' concept for *I. gabonensis* and *D. edulis* (Leakey *et al.,* 2005, 2006). The ideotype included traits of economic importance like size of different components of the fruit and/or kernel, visual traits like colour of the skin, or flesh, organoleptic traits, nutritional traits (including protein, fatty acid and vitamin content and, food thickening properties (Leakey *et al*., 2005). Genetic selections were also aimed at the identification of market-oriented 'ideotype', as they were based on seasonality of fruiting, yield or any other relevant trait that may enhance the value or utility of a product.

3.2 Role of Propagation in Domestication

Participatory domestication, in which farmers are trained to use vegetative propagation techniques, would enable farmers in different locations to select cultivars for different set of characteristics thus ensuring in the short to medium term that farm-level inter- and intra specific diversity is maintained (Akinnifesi *et al.*, 2006; Tchoundjeu *et al.*, 2006; Schreckenberg *et al.*, 2006; Leakey and Akinnifesi, 2007).

Grafting and air-layering of indigenous fruit tree have addressed precocity problems, and enabled selection of superior fruit traits (Akinnifesi *et al.*, 2006). Vegetative propagation is needed to rapidly multiply, test, select from and use the large genetic diversity in wild tree species on-station and on-farm. Mature tissues have capacity to flower and fruit, and can be multiplied or captured through grafting, budding and air-layering (Leakey *et al.*, 2005; Tchoundjeu *et al.*, 2004, 2006), and micropropagation (Mng'omba *et al.*, 2007 a, b). Because of ease of propagating juvenile tissues by cuttings, it has been a preferred option for participatory domestication of short gestation fruit trees such as *D. edulis* in West Africa in village nurseries (Leakey *et al.*, 2005). Also the tissue culture of juvenile tissues has proved more successful than matured for miombo fruit trees, e.g. *U. kirkiana* (Mng'omba, 2007; Mng'omba *et al.*, 2007a).

Some of the miombo fruit trees are not amenable to propagation by juvenile stem cuttings, e.g. *U. kirkiana, P. curatellifolia* and *S. birrea*. Stem cutting was unsuccessful for most miombo fruit trees (Mhango and Akinnifesi, 2001; Akinnifesi *et al.*, 2004a, 2006). Grafting is the most efficient way to rapidly effect improvements in these fruit trees. Airlayers were promising for *U. kirkiana*, but it not successful for *Parinari* and *Strychnos* species (Mhango and Akinnifesi, 2001). The results showed that the factors determining grafting success are: the skill of the person, the time of the year scion is collected and the interval between scion collection and grafting (Akinnifesi *et al.*, 2004a, 2006, 2007).

In addition, graft take in tissue cultures of *U. kirkiana* was limited by phenolic accumulation at the graft union line, leading to possibility of early or late rejection (Mn'gomba, 2007; Mn'gomba *et al.*, 2007a). Trees have three types of ages that may affect the ease of propagation and also the juvenility or precocity (period of waiting before the first fruiting). There are chronological age (age since planting), physiological age (cell differentiation stage and structural maturity, including level of lignification) and ontogenetic age (state of reproductive maturity). The implication is that if vegetative propagation is used, the appropriate location of the propagule becomes important for trees aimed at fruit production. A tree of seedless bread fruit (*Artocarpus altilis*) established in southern Nigeria from root cutting did not fruit until about 20 years (personal observation), whereas trees grafted from scions collected from matured tree had fruited in less than four years (D.O. Ladipo, 1998, unpublished data). Farmers in southwest Nigeria use the rooting method of propagation for *Artocarpus altilis or A. communis*, but the lengthy juvenile period before fruiting can only ensure generational security, i.e. growing trees for future generation. Awareness creation was the major reason for failure of farmers to adopt efficient methods such as air-layering and grafting.

Across the regions covered, different propagation techniques were employed. This includes asexual methods, vegetative propagation (cuttings, grafting, air layering, budding, etc) techniques (Akinnifesi *et al.*, 2006; Tchoundjeu *et al.,* 2006). Other approaches used include rooting of leafy stem cuttings to air layering and grafting. Air layering (or marcotting) is often used to produce the first set of clonal plants from sexually mature trees with desirable traits, and when established as a stock plants, are a valuable source of cuttings or scions for multiplication by rooting or grafting. Farmers enthusiastically adopt these techniques, and made further refinements to the design of the non-mist poly-propagator (Mbile *et al*., 2004). Techniques for marcotting were also improved. This led to an increase in the post-severance survival of *I. gabonensis* (from 10% to 50%) and *D. edulis* (up to 70%) (Tchoundjeu *et al.*, 2006, 2007). However, *G. kola* has proved difficult to marcot, but it is being successively multiplied (50-60%) using grafting techniques (Tchoundjeu *et al.*, 2007). The rates of tree survival in the clonal orchards are generally high for grafted *A. digitata* (100%) in Zambia, for *U. kirkiana* (80%) in Malawi, and *S. birrea* (90%) in Tanzania, but low (40%) for *S. cocculoides* in Zambia (Akinnifesi *et al.*, 2006). However, the survival of established marcots was low in Malawi, and declined with period due to poor root development. Rejection in grafts is also attributed to stock/scion incompatibility (Mng'omba *et al.*, 2007). Tree orchards established in Makoka from grafted trees started to fruit after two years, but fruit load only became stable after four years.

3.3 Micro propagation for mass multiplication

As the awareness on the potential of indigenous fruit trees has increased in the last decade, the demands will inevitably increase, and tree planting initiatives due to efforts in mitigation of global warming will further trigger massive demands for high-value indigenous fruits trees. In the short run, none of the conventional vegetative propagation method can meet the demand of farmers in Sub-Saharan for high quality propagules. Production of IFTs in sufficient quantities for wider-adoption will of necessity depend on biotechnology (Akinnifesi *et al.,* 2007). Tissue culture has recently been introduced in ICRAF southern Africa programme through partnership with advanced laboratories in South Africa, and Tissue Culture laboratory at the Bunda College of Agriculture in Malawi. Progress has been made on some priority indigenous fruit trees including *U. kirkiana*, *U. nitida,* and *Pappea capensis* (plum), with the objective of developing reproducible clonal protocol for rapid regeneration and multiplication, and to determine early graft compatibility using in vitro techniques (Mng'omba, 2007). Based on a series of results, micro-propagation protocols have been developed for rapid multiplication of mature *U. kirkiana* and *P. capensis* (Mng'omba, 2007; Mng'omba, *et al.*, 2007 a, b).

The research recognized that incompatibility between stock and scions in fruit orchard could constitute a major bottleneck to production. Phenolic compounds and ρ-cumaric acids were implicated for early graft incompatibility in *U. kirkiana*. Graft compatibility increased with homografts than hererografts—between *U. kirkiana* clone, species and provenances. *U. kirkiana* and *U. nitida* had weak compatibility, and may exhibit delayed incompatibility. Although Jatropha and *U. kirkiana* belong to same family, there is outright incompatibility or early rejection. The technique seems promising for detection of early incompatibility between close and distant related propagule sources.

4. TOWARDS SUSTAINABLE MANAGEMENT

Sustainable on-farm management of indigenous fruit trees requires proper understanding of their ecological and production requirements. It is not fully known whether the management of indigenous fruit trees is different from exotic horticultural tree crops, and there is urgent need for adaptive research on tree management. Cultivation and good tree management improve fruit traits of planted indigenous fruit trees, even for semi-domesticated trees (Maghembe, 1995; Leakey et al., 2005). It is important to understand the extent of improvement in fruit traits due to management from those due to genetic selection. To date, research on tree management of indigenous fruit trees is limited (Akinnifesi *et al.,* 2007; Tchoundjeu *et al.*, 2006). The effect of thinning through re-spacing of natural stand of *U. kirkiana* fruit yield parameters has been reported by Mwamba (1995). The result showed that thinning increased fruit load significantly in the first few years following treatment, and increased pulp content per fruit. However, fruit colour and other hereditary traits were unaffected.

4.1. Soil fertility and water management

Knowledge of specific soil fertility and water requirement of fruit tree species is important when introducing IFTs in a new location. In Peru, the application of NPK fertilizer, weeding and timely elimination of excessive shoots were reported to have improved performance of peach palm (*Bactris gasipaes*) (Cornelius *et al.,* 2006). Experience from Malawi showed that management of miombo indigenous fruit trees differ from exotics. For instance, the nutrient and water requirements of mango (*Mangifera indica*) were different from that of *U. kirkiana, S. birrea* and *V. infausta* under same experiment (Akinnifesi et *al.*, in press). Fertilizer application, manure and irrigation did not increase growth and survival in *U. kirkiana* and *S. birrea* contrary to widely held assumptions that indigenous fruit trees could be managed as cultivated tree crops. Single factors rather than their combination may be more important at strategic periods, e.g. a light irrigation during a period of prolonged droughts or dry season. Timeliness in the application of irrigation and fertilizer application can help synchronize nutrients supply necessary for phonological development. Liming has also been shown to be important for tree crops in acidic soils. In Botswana, Mateke (2003) also showed that application of fertigation had varied effects on *V. infausta, S. birrea* and *S. cocculoides*. This suggests that research is needed to understand and develop management package for different IFTs.

4.2. Pest management

Pests may affect fruit productivity, either directly through fruit infestation or indirectly by attacking the roots, shoots and foliage, thereby interfering with the normal physiological processes of the plant. Pests of fruit trees include weedy plants and parasitic higher plants that compete with fruit trees for water, light and nutrients, and herbivorous mites, insects, birds and mammals that physically feed on the plant, and pathogenic organisms (e.g. viruses, bacteria, mycoplasma) that cause diseases. Fruit trees are known to be easily infested with pests and diseases in the wild, and the level of infestation can easily escalate even further when introduced to a new environment in the cultivated field. For example susceptibility to pest may become a problem as cultivation of peach palm is intensified (*Clement et al., 2007*). Insect pests such as *Palmelampius heinrichi* have reduced fruit yield significantly along the Pacific coasts of Colombia to 100%. (Penn, 2006). A parasitic climbing plant known as 'sueda sueda' (*Moradendron* spp.) was reported on 15% of fields, *Fumago* spp. on 34% of fields, although flood water was thought by farmers as helping to reduce the impact of pests. In the Brazilian Amazon, mistletoe is a menace to the introduction of cupuaçu (*Theobroma grandifolia*). EMBRAPA is currently deploying clonal improvement strategies to develop pest-resistant cultivars.

Few pest management studies have been conducted in domestication studies in Africa. Sileshi et al (2007) synthesises approaches for pest and diseases management. The pest complexes of most wild miombo fruit tree species are not known and also little, if any, published information on pest biology and population dynamics exists. For example, in Botswana domestication of *V. infausta* is seriously hampered by a mite that causes galls on the leaves. The mite spreads easily and quickly if the trees are grown at high density, and severe infection will probably affect production adversely.

Accordingly, pests of miombo fruit trees were conveniently divided into three major guilds as root-damaging, stem and leaf-damaging, and flower, fruit and seed damaging. A tentative number of insect pests damaging various parts of the major miombo fruit trees are presented in Table 4. These records were generated from the Agroforestry pest database (Sileshi, unpublished).

4.3 Pre-harvest and post-harvest handling of IFTs

The pre-harvest and post-harvest handling is an aspect of indigenous fruit tree research and development that has been neglected for too long in Sub-Saharan Africa (Akinnifesi *et al.,* 2007). The direct and indirect post-harvest losses are estimated at 25 to 50% in developing countries (Kadzere *et al.,* 2001, 2006). Post-harvest deterioration often results from cracks during harvesting, mechanical damages during transportation and storage, and insect pest damage (Kadzere *at al.*, 2001, 2006). Majority of marketers (78-84%) had indicated post-harvest losses as major constraint for *U. kirkiana*. Similarly, Ramadhani (2002) found that 50-75% of marketers associated market constraints to perishability of fruits. At the market, there is no agreed number of fruit a consumer could freely taste before buying.

A study was undertaken in Zimbabwe by Kadzere *et al*. (2004) involving interviewing 180 producers (collectors), 120 processors and 210 marketers. The results indicate that the time of the year, colour changes, skin softness and abscission, were the indicators used by respondents to determine ripening depending on species. For *Adansonia digitata*, 85% of users or harvesters climb the tree to harvest because it did not readily abscise when ripe (Kadzere *et al.,* 2001). Most of the harvesters collect fruits that dropped naturally. Other means of harvesting included shaking the trees or throwing objects at the tree crown, hitting the stem, etc to dislodge the fruits thereby leaving damaging tree stem and branches. In many cases, fruits were harvested at unripe, just ripe and well-ripened stages, and were harvested several times during season (Kadzere *et al.*, 2004). However, allowing fruits to drop often result in contamination and pest and diseases attacks.

Fruit ripening overlapped for many species opening an avenue for having fresh fruits throughout the year (Akinnifesi *et al.,* 2004a). Harvesting time has been shown to affect the ripening and darkening in *U. kirkiana* (Kadzere *et al.,* 2006). Fruits that were harvested in December lost less weight (14%) in storage than those that were harvested two weeks earlier (34%). The soluble sugar content measured six days after harvest was also lower for fruits harvested in December (18%) compared to those in November (9%). This indicates that there are benefits in delayed harvesting to improve fruit skin colour at harvest and during storage, reduced weight loss and maintain higher soluble sugar content.

More than half of the fruits harvested were often retained for home consumption for *A. digitata, Azanza gackeana, Strychnos cocculoides*, but less for *U. kirkiana* and *Z. mautritiana*, indicating that these were most frequently sold fruits. Before marketing several methods were used to add value: cleaning, grading, packaging, protecting from sun, but these vary with species.

In terms of fruit processing, there have been reports of small cottage industries in different countries in the regions. Amarula liquor is commercialised in South Africa and sold in more than 63 countries world-wide (Ham, 2005). Wine production from *Syzigium owariense*, *U. kirkiana*, *Tamarindus,* mangoes, and others fruits, e.g. commercialised at one time by the Mulunguzi wine in Malawi (Ngwira, 1996). *Z. mauritiana* and *S. birrea* are produced at export quality in Lusaka, Zambia. In Tanzania, about 198 rural women were trained in 1998 in making wine, jam and juice from indigenous fruits, and two years later they had trained other 2045 processors (Saka *et al.*, 2004; Akinnifesi *et al.*, 2006).

4.3.1 Decisions of when to harvest indigenous fruits

In commercial fruit production, decisions on when to harvest are based on objective maturity indices that have been developed for specific commodities using physical, chronological, physiological and chemical characteristics (Reid, 1992; Kader, 2002). For example fruit color changes; shape, size, surface characteristics, abscission, and texture are all physical indicators while numbers of days from flowering, accumulated heat units during the growing period of the fruits are chronological indicators. In citrus the sugar: acid ratio is used to predict fruit harvest while in apples, the distribution of starch in the flesh is also used to predict harvest. These indices, including the accumulation of carotenoids and increased total soluble solids and decreased titratable acidity in *Ziziphus mauritiana* are all chemical indicators. The physiological indicators such as accumulation of ethylene and increased respiration rates can be used to time harvest in climacteric fruits (Kadzere *et al*., 2006a, b). For long distance transportation, fruits harvested at the fully ripened stage may suffer greater transit losses compared to those harvested when partially ripe or unripe but mature. The use of objective indices allows fruits to be harvested at an optimum stage that enables them to be transported to varying distances to markets as well as ensuring that the fruits contain the desirable aesthetic values to consumers.

In southern Africa decisions of when to harvest indigenous fruits still depends largely on experiences and observations by communities. Depending on the species, indicators used include time of the year (season), color changes, fruit softening and abscission as presented in Table 6 for Zimbabwe. Kadzere *et al.* (2006b) investigated fruit variability and relationships between color at harvest and quality during storage of *U. kirkiana* fruit from natural woodlands and found that large variations existed in fruit size, color at harvest, color during storage and the soluble solids concentrations after ripening, within and among trees for fruit harvested on the same day at the same location. Later (early December) harvested *U. kirkiana* fruits had a brighter color, higher soluble solids concentrations and were less susceptible to weight loss during storage compared with those harvested at an earlier stage (early November) (Kadzere *et al.,* 2007).

There is the need to develop appropriate techniques for fruit handling, preservation and processing to maximize returns from fresh and processed fruit products. The development of such post-harvest systems requires understanding of current practices and how they influence post-harvest losses.

5. CONTRIBUTION OF INDIGENOUS FRUIT TREES

Indigenous fruits form a staple food during the hunger periods in the agricultural cycle. A study Malawi, Mozambique and Zambia revealed that 26-50% of rural households relied on indigenous fruits as a coping strategy during critical seasonal hunger period which usually lasts for three to four months per year (Akinnifesi *et al.,* 2004a). The fruit trees ripen at different times of the year and can be targeted to meet the food needs of rural household (Akinnifesi *et al.* 2004, 2006).

Without an expanded or new market, the incentives to domesticate and commoditize indigenous fruit trees are not sufficient (Simons and Leakey, 1998; Akinnifesi *et al.* 2006; Jama *et al.* 2007). As rural household becomes more integrated into formal market, the proportion of the contribution of non-timber tree products (NTFP) to household income increases (Ruiz-Perez *et al.* 2004). In addition, households that engage in cultivation had higher returns to labour, used more intensive technology for production, and had higher productivity per hectare, associated with stable tenure and enjoyed a stable resource-base. On the contrary, wild harvesting on the other hand, is associated with declining resource base.

A few indigenous fruits trees products have large market potential in Sub-Saharan Africa. There are evidences of potential market opportunities for indigenous fruit trees in Africa. There is extra growth potential for boosting rural incomes, which in turn will stimulate demand for non-tradable goods and services in rural economies. The marula tree (*Sclerocarya birrea*) in the miombo ecosystem of southern Africa is the source of a popular product known as 'Amarula cream.' It is traded in 63 countries world-wide. The share of market margins for selling *U. kirkiana* fruits was estimated in Zimbabwe at 32-45% for collectors, 53% for retailers, and 2% for wholesalers (Ramadhani, 2002)..

Until tree domesticators economic returns on IFTs investment is high enough, adoption by farmers, development programs and policy makers will remain low. Several studies revealed that the cultivation of IFTs or their collection from the wild is a profitable enterprise. Wild collection for fruits is an efficient labour allocation strategy and its returns to labour are considerably higher than that of crop production enterprises (Mithofer and Waibel, 2003). For example, the collection of *U. kirkiana* generated USD 50 in Zimbabwe, and $US 78 for S. *birrea* in South Africa (Schackleton, 2002). The real term risk-adjusted rate of return for planting IFTs is 16% (Mithofer and Waibel 2007). Financial analysis showed that each *Dacryodes edulis* tree is worth US$50-150 per year and on average, an unimproved *Dacryodes edulis* tree produces US$20 compared to 150 US$ when improved (Leakey *et al.* 2005). Studies in Malawi, Tanzania, and Zimbabwe (Joordan et al (2007) found that the percentage of net profit of IFT products reached 28% with higher profits being obtained in locations that are close to the markets (, Table 1). In South Africa communities collectively harvest about 2000 tons of *S birrea*, collectively earn USD180,000 annually, representing more than 10% of average household income in the communities (Ham, 2005). A popular southern African Natural Products Trade Association (Phytotrade, 2005) reported gross revenue of $629,500 from sale of natural tree products by members. The key fruit tree products among them fetched US$126,420 for *S. birrea*, $44,120 for *Ximenia caffra*, $22,250 for *Adansonia digitata* (baobab) and $20,000 for *Kigelia* spp. (Phytotrade M&E report, 2005, 36 pp.). A recent market projection has put the potential market of baobab to 960 million USD (PhytoTrade, pers. comm.). Studies in Zimbabwe revealed that improvements in tree yield and earlier fruiting of IFTs create incentives for farmers to cultivate indigenous fruits and, that household vulnerability to hunger and poverty can be reduced by 33% during the critical period that occurs between August through March (Mithofer and Waibel 2003;

Mithofer 2005, Mithofer *et al.*, 2006). In addition, households that had access to IFTs were able to live above the poverty line throughout the year. The studies revealed further that households used indigenous fruits to diversify their income and that benefits from selling indigenous fruits come at a critical time when income is generally low, and provides nutrition and food when agricultural labour demands are high (Mithofer, 2005).

Feasibility analysis showed that small enterprises of indigenous fruit trees are profitable in Malawi, Zambia, Tanzania and Zimbabwe ranging from 14 to 29% (Table 5).

6. CULTIVATION, ADOPTION AND SCALING UP OF IFTS

6.1. On-farm cultivation of indigenous fruits

Farmers have consistently cited the lack of quality germplasm as a major constraint to diversifying and expanding their agroforestry practices (Simons, 1996; Weber *et al.*, 2001; Akinnifesi *et al.* 2006; Carandang *et al.,* 2006). Making quality planting material available to farmers in timely manner is an important step for effective scaling up. Supporting farmer nurseries was hypothesized to be one pathway in promoting decentralized tree seedling production in an efficient way, while at the same time providing opportunities for building natural resource, human and social capital, all three being considered equally crucial in developing more sustainable land use systems. The process is however time-consuming and expensive to undertake for each species, especially when large number of farmers widely dispersed over distant locations are involved. One of the most effective ways of achieving scaling up of IFTs cultivation is to involve farmers in the entire process of participatory selection, propagation, nursery and tree establishment and management of superior planting materials. This will dramatically shorten the time required to produce and disseminate planting materials from centralized nurseries to farmers. Farmers can be organized to produce high quality seed, seedlings and vegetative propagule as evidenced in small-scale nursery enterprise managed by farmer groups in West Africa (Tchoundjeu *et al.*, 2006; Akinnifesi *et al.* 2006). This approach seems to be uniform in southern Africa (Akinnifesi *et al.,* 2006a) and West Africa (Tchoundjeu *et al.*, 2006). In southern Africa, farmers were supported to raise their own nurseries, graft and establish trees on-farm. The main scaling up approaches used by ICRAF to disseminate agroforestry technologies including IFTs in rural farming communities in southern Africa include direct training of farmer trainers and local change agents; direct training of partner institutions' staff; farmer-to-farmer exchange visits and, support to existing national agroforestry extension initiatives.

Indigenous fruit tree seedlings have been disseminated to farmers in Malawi, Zambia, Zimbabwe and Tanzania since the late 1990's. Farmer-to-farmer exchange and farmer training have been important methods of training large number of farmers in nursery establishment and tree management. About 13,000 farmers have been trained in tree propagation, nursery establishment and management, and farm management. Special emphasis has been given in each community to train a few people in grafting techniques, as this is central to the domestication programme. These trainees can then offer services to other farmers and farmer groups, as well as manage their own commercial nurseries. In Malawi the majority of nurseries were of the group-type (86%). That makes it easy to train farmers in groups, and farmer training in nursery management has been on-going in the last ten years.

Roshetko and Verbist (2000) recognized three pathways in which improved germplasm can be made available to farmers: 1) distribution of seed originating from national research centres, community-based NGOs and the private sector, 2) dissemination of selected seeds originating from farmers and farmer groups, and 3) direct diffusion through informal farmer-to-farmer exchange. In IFT tree domestication, the extent to which the establishment of nursery by smallholder farmers can be strengthened through training will determine the success and sustainability of new tree crop development. This include training smallholder farmers to collect quality germplasm from superior trees in a way that ensures genetic quality, efficient establishment and management of nurseries, tree establishment and management on-farm, harvest and post-harvest handling activities, and marketing of germplasm and tree products.

6.2. Implications for landscape management

Many local communities have been actively engaged in domesticating tree species and production systems as well as gradually adapting these to their household needs (Wiersum, 2007; Leakey *et al.,* 2005). In the cocoa-agroforests of humid zones of West Africa, the ecosystem becomes gradually altered. Cash crops are planted in intensive nearly monoculture system, with scattered upper-storey shade trees. Arable crops are managed in the under-storeys. These landscapes modified from primary or secondary forests gradually become mixed agroforests, and homegarden systems with varying tree/crop intensification. Eventually it may gradually shift in diversity and composition from polyculture mixed-species, multi-storeyed towards more cropland and monoculture systems. However, studies showed that such trajectory of change is not always uniform, as some smallholder cultivators gradually change their 'intermediate' fruit tree production systems towards more specialized arboricultural practices, others smallholders may maintain these systems although they modify the species composition and/or specific management practices (Wiersum, 2007).

Vegetative propagation and tree density can be used to alter the crown architecture of domesticated trees. In terms of managing the trees at landscape level, it is important to realise that the stature of domesticated indigenous fruit trees will change. For example, grafted and marcotted *U. kirkiana* in Makoka, Malawi are dwarf in stature such that their fruits can now be harvested while sitting down on a chair. These were trees that usually require climbing in the wild, and it is a positive improvement. It is expected that trees that are in the emergent or dominant canopy will likely become co-dominant or lower canopy tree when vegetatively propagated.. These have implications on the type of insects needed for pollinization, shade versus light tolerance or requirement, etc. The above and below ground tree architectures need to match the predominant land use as well. For instance, a fruit tree with aggressive rooting system may become competitive to associated crops, and fruit trees that are dominant or emergent may require more light and tolerate less shade.

6.3. LESSONS LEARNED AND ISSUES FOR SCALING UP TREE DOMESTICATION

Although most of the fruits from IFTs are still being harvested from the wild, there is a general move away from sole dependence on wild harvesting towards on-farm management. Domestication research and development has also progressed significantly, especially in Africa and Latin America for indigenous fruit trees. Listed below is a summary of the lessons learnt, challenges remaining and way forward to the scaling up of IFTs:

- Research and development on the domestication of IFTs has advanced only in a few species such as, *Uapaca kirkiana, Sclerocarya birrea, Parinari curatellifolia* in southern Africa, *Dacryodes edules*, *Irvingia gabonensis* in West Africa, *Vitellaria paradoxa and Adansonia digitata in Sahelian region* of Africa. There is need to expand the range of IFTs currently being researched in different regions.
- The investment needs for wider cultivation and scaling up of tree domestication of indigenous fruit trees include, i) quality planting material in sufficient quantity, ii) adequate skills and resources for village-level nurseries in decentralized systems, and iv) facilities for micropropagation and tissue culture centers for rapid multiplication of specialized propagules (Akinnifesi *et al.* 2006).

- Measures to speed up the multiplication of improved planting materials are necessary. These include the application of biotechnology and tissue culture techniques in germplasm multiplication and delivery deserves greater attention.
- Droughts and climate change may affect fruiting potentials of IFTs; cycles and seasonal variability and cause major reduction in fruit production and quality. It is important to investigate how tree planting affects climate change on one hand and, how trees are (can be) affected by and or adapted to climate change on the other. This will ensure that sufficient resilience is built in tree domestication efforts.
- Farmers and researchers have complimentary knowledge and knowledge-deficiencies, so that integrating this knowledge from both parties through participatory processes has been shown to speed up technology adoption and performance.
- There are comparatively few studies that provide conclusive evidence on the profitability and payback periods of IFTs cultivation or wild collection. Smallholder farmers may need initial incentives or credit lines for tree establishment, management and value addition.
- Adoption of tree-based practices such as IFTs is more complex than those of conventional crops because of the multi-year cycles required for testing, modification and eventual "adoption" by farmers. There is need to understand the key factors that drive adoption of improved IFTs and their impacts at multi-scales, i.e. household and landscape levels. Such studies will provide insights into the level of technology change that would stimulate adoption and impact of IFTs. Such studies are important to guide investment, adoption and policy decisions regarding IFTs.
- As the technology development processes become complex, the uptake of the technologies by farmers will remain low. The development and dissemination of IFT systems must continue to emphasize practices that require little capital and simple methods of scaling up, improved processes and techniques to wider communities. Such low-cost techniques include small-scale nursery operations, vegetative propagation, use of organic manures and tree management.
- For market-led IFT initiatives, the market attribute of IFTs products must be unique or substantial enough and should be comparable or superior to conventional product sources to make a dent in the market. For instance, *Adansonia digitata* has very high vitamin C

content in its dry pulp (more than 5 g of ascorbic acid per 100g)--this is ten times as high as equivalent weight of orange.

- Second generation issues such as the potential occurrence of new pests following the introduction of new trees must be carefully investigated as IFTs are domesticated and improved germplasm are selected.
- There is need for improved systematic data gathering to update knowledge on the contributions of IFTs to household, community and national income and livelihood strategies in Africa. This will this enhance the opportunities by policy makers and development organizations in using IFTs as a potential intervention strategy for reducing poverty.
- There is need for innovative research and development efforts on IFTs to help bring about improvements in cultivation, scaling up, markets and small-scale enterprises in Africa. The improved performance of market of AFTPs would stimulate growth in the rural economy.
- Adoption of agroforestry is not a simple direct relationship of technological characteristics only, but is a matrix of several groups of factors including household, community level factors, institutions, the socioeconomic constraints and incentives that farmers face. As a result, rather than technology change alone, it is recommend that the development of IFTs should put balanced emphasis on the economics, the people and the institutional and policy context under which farmers operate.
- Enacting policies to ensure that intellectual property rights of farmers (farmer breeders), community custodians and breeders right of researchers are well protected. This will ensure that benefits from IFTs domestication are not exploited by large-scale commercial growers.
- There is need to engage in a pro-active increase in awareness creation and raising the profile of the contributions of IFTs in policy debates and development intervention programmes. This will also require a long-term investment and an appraisal of policies governing land and tree tenure in many countries in the tropics to reduce institutional constraints to tree planting and enact policies that facilitate cross-border trades and harmonization of exploitation, transportation and germplasm exchange.
- There is need to involve reinforcing, not only, parental participation in knowledge-intensive fruit trees domestication and marketing process, and capacity building, but also in preparing the next

generation of indigenous trees cultivators through involvement of school children involvement in the process of 'bringing out trees from the wild'.

9. CONCLUSIONS

The high local demand for exotic fruit trees indicate clearly the urgency and need to provide fruits throughout the year to supplement food requirements. There is prospect for transforming farming systems and rural livelihoods of smallholder farmers through domestication and commercialization of indigenous fruit trees remains challenging in sub-Saharan Africa. The lack of improved germplasm, high post-harvest losses and poor markets access emerged as dominant constraints. The policy and commercialization components will ensure realization of social benefits through nutritional and food security, poverty reduction and employment as well as environmental benefits. The various priority setting exercises and domestication activities indicate that, across the regions of Africa, there is considerable experience and knowledge on indigenous fruit trees domestication. However, constant updating of species prioritization to cater for emerging peoples' needs and preferences are needed. Through good science, the regions have developed robust domestication approaches to obtain improved superior tree clones or cultivars, with superior fruit and tree traits. Two clear opportunities for institutional involvement were foreseen. The first is to re-orient national research institutions and agricultural extension systems to support participatory domestication of indigenous fruit trees through awareness creation, sensitization and dissemination of agroforestry technologies, involving fruit trees, in the region. Secondly, the science of IFTs domestication can be brought to scale, if farmers and group of farmers can become engaged, on their own volition, in the testing and adapting of fruit trees domestication options. Effective extension and dissemination systems will help stimulate production, utilization and marketing. This will require the development of simple domestication guidelines for extension workers and farmers. Research has shown that improving markets and quality of indigenous fruit and products would be a major driver for increased investment by the private sector in the production and commercialization of indigenous fruit trees.

6. Acknowledgements

We would like to thank the BMZ and GTZ for providing the funds for implementing the project on 'Domestication and Marketing of Indigenous Fruit Trees for Improved Nutrition and

Income in Southern Africa' (Project No. 2001.7860.8-001.00), and the CIDA Canada for funding the Zambezi Bazin Agroforestry Project (Project no. 050/21576). We would like to thank our partners, National Agricultural and Forestry Research and Extension Systems, private entrepreneurs and Non-governmental organizations (NGO's) collaboration in the project in the four countries.

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Table 1. List of the five most preferred priority indigenous fruit tree species in selected regions

Region	**Rank 1**	**Rank 2**	**Rank 3**	**Rank 4**	**Rank 5**	**Method**	**Source**[†]
East Africa (Ethiopia, Kenya, Sudan, Uganda, Tanzania)	*Adansonia digitata* (Baobab)	*Tamarindus indica* (Tamarind)	*Ziziphus mauritiana* (Ber)	*Sclerocarya birrea* (Marula)	*Balannites aegyptiaca Del.*	Field surveys (n=167)	1, 2,3
Southern Africa (Malawi, Zambia, Zimbabwe, Tanzania, Mozambique)	*Uapaca kirkiana* (Wild loquat)	*Strychnos cocculoides* (Wild orange)	*Parinari curatellifolia* (Maula)	*Ziziphus mauritiana* (Ber)	*Adansonia digitata*	Field surveys (n=451)	4,5
West Africa (Ghana, Nigeria, Cameroon)	*Irvingia gabonensis* (Wild mango)	*Dacryodes edulis* (African plum)	*Chrysophyllum albidum* (Star apple)	*Garcinia cola* (Bitter cola)	*Cola nitida*	Workshops, field surveys (n=94)	6
Sahelian zone	*Adansonia*	*Tamarindus*	*Vitellaria*	*Ziziphus*	*Parkia*	Field	6,7

(Seneghal, Mali, Niger, Burkina Faso)	*digitata* (Baobab)	*indica* (Tamarind)	*paradoxa* (Shea)	*mauritiana* (Ber)	*biglabosa*	surveys (n=470)	

[†]*Jama et al (2007); 2. Teklehaimanot (2007); 3. Chikamai et al (2005); 4. Maghembe et al (1998); 5. Akinnifesi et al (2007), 6. Franzel et al (2007). 7. Bounkoungou et al (1998).*

Table 2. Participants' priority products in workshops held in Magomero, Malawi, Tabora, Tanzania, and Harare, Zimbabwe.

Magomero	**Tabora**	**Harare**
Mango juice	Baobab juice	Parinari oil
Mango dried	Groundnut butter	Strychnos jelly
Mango jam	Strychnos juice	Marula oil
Tomato jam	Parinari wine	Marula jelly
Baobab wine	Vitex jam	Ziziphus fruit leather
Baobab juice	Syzygium juice	Uapaca jam
Uapaca wine	Marula wine	
Uapaca juice	Flacourtia jam	
Marula wine	Mango juice	
Marula juice	Guava jam	

Source: Ham and Akinnifesi (2006).

Table 3. Relative tree growth and indicative fruiting of *Uapaca kirkiana* trees at Makoka orchard from grafted, marcotted and seedling stocks, at four years after establishment (Akinnifesi, unpublished data).

Parameter	**Marcots**	**Grafts**	**Seedling stock**
Tree height (m)	2.4±0.11	2.0±0.13	2.7±0.14
Bole height (m)	0.39±0.04	0.35±0.04	0.46±0.64
Root collar diameter (cm)	8.50±0.32	9.14±0.35	10.3±0.36
Crown depth (m)	2.0±0.13	0.35±0.04	2.4±0.76
Crown spread (m)	2.7±0.14	2.3±0.13	2.4±0.160
Number of primary branch	17.2±1.33	15.8±0.95	15.3±2.00
Number of secondary	25.0±2.60	19.9±2.60	15.3±2.00
Number of tertiary	15.0±2.97	10.3±2.91	5.6±1.32
Minimum number of fruits	2	3	0
Maximum number of fruits	414	127	0
Mean	78	52	0

Table 4. The number of insect pests recorded on the priority miombo fruit tree species of southern Africa.

Priority miombo fruit tre species	Root damaging	Leaf and stem-damaging			Fruit and seed-damaging		Total
		Defoliating	Sap-suckin	Stem bor	Fruit- feedi	Seed-feeding	

Uapaca kirkiana	1	17	11	4	7	1	41
Parinari curatellifolia	1	14	4	?	3	1	23
Adansonia digitata	1	3	8	1	1	-	16
Strychnos cocculoides	-	-	1	-	-	-	1
Anisophyllea boemii	-	1	-	-	-	-	1
Azanza garckeana	-	16	2	2	1	-	21
Flacourtia indica	-	5	4	-	-	-	9
Syzygium guineense	-	2	1	-	1	-	4
Syzygium cordatum	-	17	1	-	-	-	18
Uapaca nitida	-	2	-	-	-	-	2
Vanguaria infausta	-	6	-	-	3	-	9
Annona senegalensis	-	6	1	-	5	-	12
Sclerocarya birrea	-	25	5	16	5	-	51

Source: Sileshi *et al.* 2007); - = records are not available

Table 5. Feasibility analysis of small indigenous fruit enterprises in Malawi, Tanzania and Zimbabwe (Joordan *et al.* 2007).

	Malawi (Juice concentrat	Tanzania (Juice concentra	Zimbabwe (Baobab)	Zimbabwe (Jam)
Income statement				
Gross production value ($)	107,400	137,359	61,090	20,209
Total cost $)	61,700	108,187	33,080	11,336
Net income ($)	45,700	29,172	28,010	8,873
Tax ($)	16,000	10,210	9,803	3,105
Net profit after tax ($)	29,700	18,962	18,206	5,767
% Net profit*	27.7%	13.8%	29.8%	28.5%
Cash flow	Net positive for all months			
Net present value	Positive over selected period			
Breakeven price ($)	8.50 per 20kg ca	14.64 per 20kg can	0.34 per 50g bar	1.22 per 410g jar

*Profit as % of gross value of production

Table 6. Indicators of fruit "ripening", harvesting periods, stages and methods reported by survey respondents for selected indigenous fruits by communities in Zimbabwe

Name of fruit	Indications of fruit ripening	Period of ripening	Stages mainly harvested	Methods of harvest (% of survey respondents from six sites in the year 2000 in Zimbabwe)		
				Gather abscised fruits	Climb tree and pick	Others (e.g. shake tree by hand or objects)
Adansonia digitata	Color change from green to khaki, auditory indicators (ripe fruits make a rattling sounds when shaken whilst	April-October	Ripe	61	16	23

	unripe fruits do not), fruit abscission in some trees.					
Azanza garckeana	Cracks along the sutures on the fruits, Color change from green to brown	April-October	Ripe	5	85	10
Parinari curatelliflol-ia	Color change from green-khaki to orange , abscission, fruit softening and aroma	August-December	Ripe	99	1	0
Sclerocarya birrea	Color change from green to yellowish, abscission, aroma from fruits.	February-April	Ripe and Unripe	94	3	3
Strychnos cocculoides	Color change from deep green to yellowish, or orange, abscission, aroma fruits.	August-December	Ripe and Unripe	69	15	16
Uapaca kirkiana	Textural changes e.g. fruit softening, Color change from greenish to yellowish and usually to a brownish color (some fruits are formed with a yellow or brown color and ripen to a brown color), abscission, aroma.	October – January	Ripe and Unripe	78	5	17
Ziziphus mauritiana	Color change from greenish to yellowish and then brown, abscission, aroma	May-September	Ripe and Unripe	61	15	24

Adapted from Kadzere et al, 2004: Note: the harvest methods per species are not mutually exclusive.