10 Improving Rural Livelihoods through Domestication of Indigenous Fruit Trees in the Parklands of the Sahel

A. KALINGANIRE,[1] J.C. WEBER,[1] A. UWAMARIYA[2] AND B. KONE1

[1]*World Agroforestry Centre, West and Central Africa Region, Bamako, Mali*; [2]*Bamako, Mali*

10.1 Introduction

The West African Sahel, a semiarid landscape stretching from Niger to Senegal, is characterized by high temperatures throughout the year, with a low and highly unpredictable rainfall pattern (400–1000 mm/year), occurring during a 3-month period, and a 9-month dry season. The population growth rate is high, life expectancy is low, particularly for infants and children, and illiteracy is endemic, especially among women. Burkina Faso and Niger rank lowest on the United Nations Development Programme (UNDP) human development index. Improving peoples' livelihoods is, therefore a challenge for Sahelian countries (UNDP, 2003). Rural people have developed strategies to adapt to this harsh environment and reduce their vulnerability to risks. Nevertheless, the rate of growth in food crop production – about 2% – is not commensurate with the population growth rate of about 2.5% per year (World Bank, 2004). More than 70% of the 44 million people in Niger, Burkina Faso, Mali and Senegal live in rural areas. How the rural population will continue to survive given the current food crop production is a daunting question. Part of the answer lies in the diversity of native trees and shrubs that people have used for generations in the parkland agroforestry system.

Parklands are mixtures of trees and shrubs that farmers select for certain functions and cultivate together with staple food crops, such as millet and sorghum. It is the principal agricultural system used by subsistence farmers in the Sahel (Bonkoungou *et al.*, 1997; Boffa, 1999). In Mali, for example, parklands occupy approximately 90% of the agricultural land. Parklands are managed to fit environmental conditions and to fulfil specific functions, so they vary in species composition and density within and among countries in the region.

Parkland trees and shrubs provide many functions for the rural poor (Appendix 10.1). They are sources of food, including fruits, fats, oils, leafy vegetables, nuts and condiments, which complement staple food crops in the local diet. Some of these foods are particularly important during the months when grains are in short supply and during years of intense drought. In addition, parkland trees and shrubs provide numerous traditional medicines that are essential for rural health-care (Fortin *et al*., 2000). Severe micronutrient deficiencies can be alleviated by consuming indigenous fruits and vegetables (Ruel *et al*., 2005).

They also supply fuelwood, construction materials, cordage, dyes and materials for household implements, handicrafts and clothing. Moreover, since the parkland is an essential source of forage, fodder and medicines for livestock, maintaining healthy parklands is essential for maintaining healthy animal herds. In addition to providing products, parkland trees and shrubs provide environmental services such as moderating the soil temperature, reducing soil erosion and improving soil fertility through nitrogen fixation and nutrient cycling of their leaf biomass. Since most annual food-crop plants are grown in the parkland, these service functions play a key role in maintaining annual food-crop productivity. The fact that the rural poor maintain diverse sets of species and functions in their parklands underscores the importance of this diversity in their livelihood strategies.

Unfortunately, the richness and abundance of indigenous trees and shrubs is being eroded in the parklands and other forested landscapes in the region (Eyog Matig and Ouedraogo, 1999; FAO, 2000). Less species richness means fewer distinct sources of products and services. Lower abundance means less genetic variation within species, which reduces both the capacity of trees and shrubs to adapt to environmental change and the potential gain that farmers can realize from selection. Decreases in both the richness and the abundance of these useful trees and shrubs leave the rural poor with fewer options to improve their health, nutrition and income. In addition, it reduces the available habitat for the other native plants and animals that figure importantly in local diets, medicines, etc. Since traditional knowledge is often transmitted from generation to generation by using plants, this knowledge is also being eroded as species richness and abundance decline. The loss of this knowledge will make it more difficult for future generations to establish and manage the useful species of native trees and shrubs in the region.

In 1995, the World Agroforestry Centre (ICRAF) worked with farming communities and other partners to identify the priority species for domestication programmes in the Sahel. These included baobab (*Adansonia digitata* L.), detar (*Detarium microcarpum*), néré (*Parkia biglobosa*), tamarind (*Tamarindus indica*), shea tree or karité (*Vitellaria paradoxa*) and ber (*Ziziphus mauritiana*). These species were preferred by farmers because of their nutritional, medicinal and income-generating values. In this chapter, we discuss the principal uses of these species and their potential value, and the current and future plans for their domestication.

10.2 Principal Uses of Major Species

10.2.1 Baobab (*Adansonia digitata* L.)

In the Sahel, the natural range of baobab extends from Chad to Senegal. Baobab is associated with other species in the savannas, especially in the drier parts of West Africa (Sidibé and Williams, 2002). It is one of the most characteristic species in the region because of its massive size and its importance in people's lives. Baobab trees are one of the main sources of income, food and nutritional security during the dry season in the Sahel. All parts of the tree are exploited. The bark is used for making ropes. The leaves, bark, fruit pulp, seed and roots are used for medicines. Juice, rich in vitamin C, is prepared from the fruit pulp. The sun-dried fruit pulp can also be eaten either raw or added to sauces (A. Niang, unpublished results). The leaves are the staple vegetable used in sauces consumed with cereal-based meals. Seeds are also used in soups or roasted and consumed as snacks. Sidibé and Williams (2002) present a thorough review of the importance of the baobab in the Sahel.

Baobab fruits mature during the dry season, providing the products mentioned above, whereas the leaves are typically harvested during the rainy season, then dried and stored for further use during the long dry season. Most rural people consume the leaves in sauces. Leaves can also be produced and harvested all year round in irrigated baobab gardens, a technology developed by ICRAF and its partners in West Africa. It is widely recognized that baobab leaves are an extremely valuable source of protein, vitamin A and essential minerals. However, the traditional method of sun-drying can reduce the vitamin A content (Sidibé *et al*., 1996).

The fruits and leaves of baobab are important sources of income in the Sahel. Surveys carried out in Bamako and Ségou, Mali, show that prices range between 250 and 500 F CFA/kg for various dried leaf and fruit products (C.O. Traoré, unpublished results).

10.2.2. Detar (*Detarium microcarpum* G. et Perr.)

Detar occurs naturally in the Sudano-Sahelian zone of Senegal, Mali and Burkina Faso, as well as in Cameroon, Chad, Nigeria and Sudan. In Mali it is threatened because of extensive fruit collection, uncontrolled tree cutting, overgrazing and bushfires (Kouyaté, 2005).

Fruits of the detar are consumed raw or cooked, or processed into cakes, which sell at 5–25 F CFA per cake (Kouyaté, 2005). Fruits are sold to Senegalese merchants for 100 F CFA/kg at Kita (Mali) along the Mali–Senegal railway (M.M. Sidibé, unpublished data). The net revenue from the sale of 100 kg of fruit in western Mali can reach 200 F CFA in periods of abundance and 3000 F CFA during the off-season. The pulp is used to make an alcoholic beverage and in the preparation of couscous. The fruit has the following nutritional values: 3.2 mg vitamin C, 4.9 g protein and 64.5 g of sugar per 100 g (Kouyaté, 2005).

Detar has several other uses for rural communities. The leaves are used to thatch roofs and the wood is used for fuel, construction poles and tool handles (Kouyaté, 2005). Seeds are dried, ground and used as a fragrance. In addition, necklaces are made from the dried seeds, which are considered to have an aphrodisiac effect because of their pleasant fragrance (Kouyaté, 2005). Mosquito repellent is prepared from the roots while medicines are prepared from the seeds, fruits, leaves, roots and bark. In Burkina Faso, for example, fruits are used in the treatment of meningitis (Bationo *et al*., 2001). Leaves and roots are also used to treat diseases of farm animals.

10.2.3 Néré (*Parkia biglobosa* (Jacq.) Benth.)

Néré is common in natural savannas and is widely cultivated in the parklands (Teklehaimanot, 2004). Néré occurs naturally from Senegal to Uganda (Hall *et al*., 1997). Farmers manage néré in the parkland because of its valuable non-wood products and its capacity to improve soil fertility. In the parklands, néré is associated with a range of crops, especially large leafy vegetables, but also with groundnuts and cereals such as maize and millet.

Néré seeds are valuable and are ground into a spice or condiment locally called 'soumbala', which is an important source of protein that is added to soups and stews throughout the Sahel. Hall *et al*. (1997) discuss néré as a commodity of local and regional trade in sub-Saharan Africa, especially in Benin, Burkina Faso, Cote d'Ivoire, Mali and Nigeria. Fresh soumbala is sold as balls of brown paste in the local markets. Seeds are also sold for commercial processing, which significantly increases their value. Surveys indicate that dried seed sells for about 600 F CFA/kg in Bamako and 500 F CFA/kg in Ouagadougou, Burkina Faso. Fruit pulp sells for about 200 F CFA/kg in Bamako (M.M. Sidibé, unpublished data). In 1997, the annual revenue earned from the sale of néré products was approximately 27,300 F CFA per household in Burkina Faso (Teklehaimanot, 2004).

Ouedraogo (1995) reported that the seeds are rich in protein, lipids, carbohydrates and phosphorous while the fruit pulp is high in carbohydrates and vitamin C. Fresh fruit pulp has a high sugar content and is fermented into a beverage (Kater *et al*., 1992). The flowers are also consumed.

Néré, which is a leguminous tree, is a valuable source of fodder (Sabiiti and Cobbina, 1992). Its branches are usually lopped by farmers and fed to livestock, especially in the dry season, when good-quality feed is scarce. Moreover, fruit exocarp, seeds and leaves are applied as an organic fertilizer.

Medicines for human diseases are one of the principal uses of néré in the Sahel. All parts of the plant are used to cure many diseases, including malaria and stomach disorders. Moreover, different parts are used to treat diseases of farm animals, such as poultry lice, trypanosomes and mouth ulcers of ruminants. It is also used in traditional ceremonies (Teklehaimanot, 2004).

10.2.4 Tamarind (*Tamarindus indica* L.)

Tamarind originated in Asia, but it is widely cultivated in much of tropical Africa. According to Gunasena and Hughes (2000), it is now naturalized in Burkina Faso, Cameroon, Central Africa Republic, Chad, Ethiopia, Gambia, Guinea, Guinea-Bissau, Kenya, Madagascar, Mali, Niger, Nigeria, Senegal, Sudan, Tanzania and Uganda. Farmers commonly cultivate it in parklands in the arid and semiarid zones of West Africa.

Although there are many uses for tamarind (Gunasena and Hughes, 2000), few are known or practised in the Sahel. In the Sahel, the fruit pulp is used primarily for sauces, porridge and juice. In Kenya, the fruit pulp is also used to tenderize meat (L. Betser, unpublished results; P. Nyadoi, personal communication), but this practice is unknown in the Sahel. Tamarind can be used as snacks, in sauces, confectionery, drinks, jam, ice cream, wine, and as a coffee substitute, a pectin, food stabilizer, dye, animal fodder, glue, edible oil and medicine (Maundu *et al*., 1999).

Tamarind fruit pulp is nutritious, rich in tartaric acid, and used as a natural preservative in the pickle industry (Nagarajan *et al*., 1998). The fruit pulp has low water content and high levels of protein, carbohydrate and minerals (potassium, phosphorus, calcium and iron), but it is not a significant source of vitamins A and C (Gunasena and Hughes, 2000). In eastern and western Africa, the fruit pulp is eaten raw, but local varieties generally have a strong acidic taste compared with sweet-tasting cultivars introduced from Thailand. The seeds are a rich source of protein, and have a favourable amino acid composition.

Tamarind is also a valuable timber species, used in making furniture, tool handles and charcoal and as fuelwood. In addition, the leaves, flowers, root, bark, fruit pulp and seeds are an important source of herbal medicines. The fruit pulp sells for about 400 F CFA per kilogra in Bamako, Mali (M.M. Sidibé 2006, unpublished results).

10.2.5 Karité (*Vitellaria paradoxa* C.F. Gaertn.)

Karité is a key economic fruit tree species that is very abundant across a 5000-km-wide belt of savanna between the equatorial rain forest and the Sahel (Hall *et al*., 1996; Maranz *et al*., 2004). Its natural range extends from eastern Senegal to the high plateau of Uganda. The best growth occurs on farmed land, where trees benefit from protection against bush fires and livestock (Kater *et al*., 1992). Its economic importance has been analysed by Hall *et al*. (1996) and Teklehaimanot (2004), and its nutritional value by Maranz *et al*. (2004).

The tree's main product is a fat (shea butter) extracted from the nuts. It is one of the rare local sources of vegetable fat in the region (Kater *et al*., 1992). Shea butter is sold at about 400 F CFA/kg in the Bamako market (M.M. Sidibé, unpublished results). Becker and Statz (2003) estimated that 650,000 t of karité nuts were collected throughout Africa in 2000. In addition to local uses, shea butter is exported for use in chocolate products and the pharmaceutical industry in European and other markets. Shea exports from Africa are more than 150,000 t of dry kernel per year (Becker and Statz, 2003), accounting for a market value of more than US$30 million. In 2004/2005 Mali exported about 10,000 t of dry kernel for about 800 million F CFA (AFE, 2006).

The fruits are important to the inhabitants of the Sahel because of their high nutritional value (Maranz *et al*., 2004). Although there is much emphasis on shea butter for the international market, the use of the fruit pulp in the local diet needs to be taken into consideration during the domestication of the species.

10.2.6 Ber (*Ziziphus mauritiana* Lam.)

The natural distribution of ber extends from central Asia to Africa (Diallo, 2002). In West Africa, it occurs in all countries in the Sahel. Farmers rank it as one of the most preferred fruit tree species, but the fruits are very small: farmers are interested in Indian and Thai varieties that produce large and tasty fruits (Kalinganire *et al*., 2007).

The main use for ber is for the fruit pulp, which is consumed fresh or dry, and also prepared into a juice. The highest potential for ber in the Sahel is for the sale of juice, fresh fruit pulp and dry fruit paste. In Bamako, the fruit pulp sells for about 350 F CFA/kg. In addition, the leaves are used for fodder and the leaves, roots and bark are used for medicinal purposes. The wood is used for handles, kitchen utensils, firewood and charcoal (Roussell, 1995; Diallo, 2001). In the Sahel ber is also used together with other tree and shrub species to make live fences that protect crops against browsing by animals in the dry season. It is recommended for planting along contour lines for erosion control.

10.3 Progress in Domestication and Improvement of Preferred Species

Deforestation, overgrazing and increasing population are resulting in the degradation of the Sahelian parklands and a decrease in the most important indigenous fruit trees, which in turn reduces the availability of wild fruits to local populations. Although many species with high potential for fruit production and a wide range of products have been identified, little work has been done in the Sahel to bring them under improved management and cultivation. In general, progress in the domestication and improvement of indigenous fruit tree species has been slow, mainly because of limited financial and skilled human resources.

The domestication programmes in the Sahel follow a farmer-driven and market-led process as discussed by Simons and Leakey (2004). The process matches the intraspecific diversity of locally important trees to the needs of subsistence farmers, product markets and agricultural environments. It also includes the exploration and manipulation of wild genetic resources to deliver uses and products for maximum social benefit. Farmers' expertise is a central part of the programme. For example, the programme includes vegetative propagation techniques to capture and multiply the characteristics that farmers prefer based on their expertise and market requirements.

The overall aim is to improve the productivity and sustainability of preferred fruit-tree species in the Sahel. The research aims at developing domestication strategies for identified species to enhance the conservation of biodiversity in the region and the use of improved fruit tree germplasm of high value for the general social benefit of producers. These participatory domestication strategies must consider not only the economic benefits and social consequences for rural communities (Faminow *et al*., 2001; FAO, 2004; Dampha and Camera, 2005), but also the potential effects on genetic diversity within the tree species (Ledig, 1992; O'Neill *et al*., 2001; Adin *et al*., 2004; Hollingsworth *et al*., 2005). For example, there is a clear trade-off between genetic improvement and genetic diversity, in that any strategy to produce genetic gain will reduce genetic diversity in the breeding population. This is particularly important for strategies based on the selection and multiplication of clones (Cornelius *et al*., 2006).

ICRAF and its partners have initiated research to increase the production of indigenous fruit trees and make the improved genetic materials available to producers. Such research activities include mainly studies on the genetic variation of some fruit tree species, provenance/progeny trials, 'plus-tree' selection and vegetative propagation methods. The research components in the Sahel include the following:

- Evaluation of genetic variation in existing progeny/provenance trials of preferred species.
- Research supporting the effective mass-production and use of genetically improved planting stock of preferred species.
- Experimental interventions to improve seed and seedling production in partner countries, and the preparation and distribution of guidelines for the production of improved germplasm.

The programme supports the ongoing national efforts in the provision of improved germplasm of proven and promising Sahelian species. Decentralized systems for enhanced access to germplasm by rural farmers are also being promoted. These are supported by the provision of training courses for the sharing of knowledge and technology among farmers, researchers and development agents. The programme is building strong partnerships with the key research and development institutions as well as private industry to support specific interventions, which are likely to increase returns to the producers of primary agroforestry products while ensuring the preservation of the agroforestry resources.

Until relatively recently, people have collected indigenous fruits from the wild. Such fruits are mostly of very poor quality. However, for the last 2 years there has been progress in fruit tree domestication for the preferred fruit tree species in the region.

10.3.1 Studies on intraspecific variation

There are very few studies of genetic variation within the preferred fruit tree species in the Sahel. Some provenance/progeny trials have been established during the last decade, but results are not available, especially for fruit production. Such studies will provide information on geographical and genetic variation within species. A list of existing provenance and species trials for the indigenous fruit trees in the Sahel is given in Table 10.1 (trials have been established for all of the preferred species). Information about genetic variation within selected species is given briefly below.

Baobab (Adansonia digitata)

The pattern of genetic variation in the baobab has not been adequately studied. However different types, based on bark characteristics, have been classified in Mali (H. Sanou, personal communication) but not genetically confirmed. These may be considered to be ecotypes, but it is necessary to characterize the variation adequately.

Preliminary results from a 5-year-old species/provenance trial revealed better growth of *A. digitata* compared with other *Adansonia* species, namely *A. za*, *A. fony*, *A. perrieri* and *A. gregorii* (Sidibé, 2005). The study showed no significant differences in growth between two Malian provenances. Sidibé and Williams (2002) reported that leaf production is a major challenge due to its seasonality. Irrigation extends leaf production in Sahel, and Sidibé and Williams (2002) reported that the local black bark type responds well to this. The same may also apply to fruit production, but this has not been investigated. In Mali, some ecotypes were reported to have fruits with an exceptionally high vitamin C content.

Tamarind (Tamarindus indica)

Gunasena and Hughes (2000) reported high phenotypic variation in fruit traits (length of pod, pod weight, seed number, pod colour and sweetness of pulp). Nagarajan *et al*. (1998) reported extensive variation in foliage and flower production, flower colour, fruit size, fruit pulp yield and wood quality. There

Table 10.1. Provenance trials for indigenous fruit tree species in the Sahel

Species	Establishment date	No. of provenances	No. of sites	Site name and country
Adansonia spp.	2001	6	2	Samanko and Cinzana, Mali
Adansonia spp.	2001	6	1	Baguineda, Mali
Tamarindus indica	2001	8	1	Samanko, Mali
Tamarindus indica	1990	13	1	Dinderesso, Burkina Faso
Tamarindus indica	1990	13	1	Gonse, Burkina Faso
Tamarindus indica	2000	10	1	Bandia, Senegal
Vitellaria paradoxa	1997	5	1	Gonse, Burkina Faso
Ziziphus mauritiana	2000	8	1	Bandia, Senegal
Ziziphus mauritiana	2001	10	2	Samanko and Cinzana, Mali
Ziziphus mauritiana	2001	4	1	Baguineda, Mali
Ziziphus mauritiana	2001	7	1	Gonse, Burkina Faso
Ziziphus mauritiana	2002	3	1	Ouagadougou, Burkina

appears to be more diversity in native African populations of tamarind than in those introduced from the South and Southeast Asian regions. Diallo (2001) confirmed the high degree of diversity and phenotypic difference among the African populations, and attributed this to geographical isolation and gene mutation.

Preliminary results from tamarind provenance trials revealed considerable variation in growth and biomass production among Sahelian provenances (B.O. Diallo, unpublished results). Considerable variation in pod production within and among provenances was also reported from a 15-year-old provenance trial in Dinderesso, Burkina Faso.

Néré (Parkia biglobosa)

Results of an isozyme analysis based on samples collected from 11 countries in West Africa has shown very high genetic diversity in *Parkia biglobosa* at the inter- and intrapopulation levels (Teklehaimanot, 2004). This diversity should be considered during the planning of any genetic conservation or improvement programme.

Karité (Vitellaria paradoxa)

Bouvet *et al.* (2004) reported an analysis of molecular diversity from 80 populations covering most of the natural range from Senegal to Uganda. Using random amplified polymorphic DNA (RAPD) analysis, results from 118 individual trees indicated variation among individuals within populations. Studies carried out in 2002 across the species range indicated that human activities have affected genetic variation in this species (Teklehaimanot, 2004). Kelly *et al.* (2004) reported that populations in crop fields have the highest mean number of alleles and the highest expected heterozygosity when compared with populations in fallows and forests. On the basis of fruit characteristics and on ecological local knowledge in Mali, *Vitellaria paradoxa* can be divided into five classes (H. Sanou, unpublished results), but the differences may be due to environmental rather than genetic differences. However, H. Sanou (unpublished results) reports that selection of quality germplasm must consider the variation within populations in the improvement of karité.

Two subspecies have been proposed, *V. paradoxa* subsp. *paradoxa* and *V. paradoxa* subsp. *nilotica* (Hall *et al.*, 1996), but there is no clear distinction between them based on leaves, inflorescences and flowers, fruits or morphology. Hall *et al.* (1996) concluded that the difference is based on the origin of the populations, which originated in the eastern (subsp. *nilotica*) and western (subsp. *paradoxa*) parts of the natural range of the species. Using isozymes, Lovett and Haq (2000) found high genetic diversity within populations of *V. paradoxa* in Ghana. Fontaine *et al.* (2004), using molecular markers, recommended a separation between western and eastern populations. Moreover, chemical analysis by Maranz *et al.* (2004) indicates different fatty acid profiles across Africa and following an east–west trend among the natural populations.

It is clear that the genetic characterization of the shea tree needs further work, and genetic and environmental effects on the expression of different traits need to be understood. Regarding growth, preliminary results from an 8-year-old provenance trial established in Gonsé, Burkina Faso, revealed significant differences among provenances for tree height, collar diameter and transpiration rates (J. Bayala, unpublished results). Further observations are expected on fruit production.

Ber (Ziziphus mauritiana)

Pareek (2001) has reported high genetic variability in the growth and morphological characteristics of ber in India, and Diallo (2002) confirmed this in Africa. Early results from provenance trials in Mali and Senegal indicated significant differences in growth and biomass production among provenances. Fruit production was just beginning, but early results suggested that it also varies among provenances.

Improved cultivars are being produced from China, India and Thailand. Cultivars such as Gola, Kaithli, Umran and Seb (from India) and Sotubata (from Thailand) and various sweet Thais (from Thailand) are being tested in the Sahel, along with the best accessions collected in Brazil, Burkina Faso, Kenya, Mali, Niger and Senegal. In Burkina Faso, Ouedraogo *et al*. (2006) investigated the effects of irrigation, rock phosphate and cultivars (Gola, Seb, Umran and local as control) on growth and fruit production. At 18 months, the introduced cultivars performed better than the local cultivar.

10.3.2 Genetic improvement of preferred fruit trees

Genetic improvement using selected clones has been initiated in the Sahel. The selection of plus-trees and their clonal development may be faster means of improvement and have greater impact than conventional breeding. However, considering the trade-off between genetic gain and diversity, it is very important to ensure that genetic diversity is not severely reduced in the clonal breeding populations (Cornelius *et al*., 2006). This is particularly important for on-farm breeding populations, because farmers tend to select very few trees/clones to establish fruit tree populations on the farm (Brodie *et al*., 1997; Lengkeek, 2003).

Some plus-trees of *Tamarindus indica*, *Vitellaria paradoxa* and *Ziziphus mauritiana* were selected by farmers and researchers in 2004–2005, and clones were established in gene banks and regeneration plots. The initial collections (more than 150 plus-trees) were made in parts of Burkina Faso, Mali, Niger and Senegal for all three species, and also in the Tharaka district of Kenya for *T. indica*. More collections are planned in the future to ensure that the breeding population has a broad genetic base. The selected materials will be used for further improvement programmes and for the production of vegetative plant materials for large-scale propagation with collaborating farming communities.

Different ideotypes and selection criteria for the species were identified in a participatory manner with farmers and researchers. The following selection criteria were retained for the different fruit tree species:

- *A. digitata*: leaf production during dry season, fruit pulp with higher vitamin C content, high fibre production (Sidibé and Williams, 2002).

- *T. indica*: vigour, early fruit set, sweetness of the fruits, resistance to pests and disease, long, straight pods (pod size), a large, round canopy with many branches for greater fruit production, a large number of seeds, high pod production, exocarp and fibres easily removable from the fruit pulp.
- *V. paradoxa*: vigour, early and annual fruit set, sweet fruits, high oil content, resistance to pests and disease, freedom from *Tapinanthus* (a parasitic plant) attacks, young tree, uniform crown.
- *Z. mauritiana*: vigour, early fruit set, sweet fruits, resistance to pests and disease, small seeds, large round fruits, good fruit conservation, fewer thorns, high fruit production, large canopy with many branches for greater fruit production.

10.3.3 Vegetative propagation

The principal reason for using vegetative propagation is to capture and fix desirable traits, or combinations of traits, of individual trees (Leakey and Newton, 1994). Because higher yields and better products are desired, vegetative propagation is a useful tool for the domestication of indigenous fruit trees. The adapted varieties and cultivars are propagated vegetatively to maintain their desired characteristics, which would, if sexually propagated, be diluted over time (Nyambo *et al*., 2005). For example, preliminary results from ICRAF and its research partners have shown that grafting can accelerate fruit precocity (shortening the period to first fruiting) compared with plants produced by seed. The fruiting period can be reduced from 20 to 6 years for *Vitellaria paradoxa*, from 6 to 3 years for *Parkia biglobosa*, from more than 10 years to 4 years for *Adansonia digitata*, and from 2 years to 6 months for *Ziziphus mauritiana*.

In the Sahel, vegetative propagation of fruit trees is mostly done by grafting or budding or using stem cuttings. A summary of successful methods for key fruit tree species is given below.

Preliminary results from research in Senegal and Mali indicate that *A. digitata* can be successfully grafted (with a survival rate of 85%) and multiplied by cuttings. Top- and side-grafting give the best results, but top-grafting is preferred as it is easier to do. A top-grafted plant in Mali started flowering 4 years after grafting.

According to Teklehaimanot (2004), cuttings of *P. biglobosa* are relatively easy to root if they are obtained from terminal nodes and auxins are applied.

Tamarindus indica can be vegetatively propagated by stem cuttings, shield and patch budding, grafting, air-layering or marcotting, and tissue culture (Gunasena and Hughes, 2000). The easiest and cheapest method is by using stem cuttings. The use of the growth regulator 3-indolebutyric acid (IBA) significantly increased rooting. For patch budding, rootstocks from 6- to 9-month-old seedlings should be grown in raised beds for large-scale multiplication. For grafting, although top-cleft grafting is successful under Sahelian conditions, approach grafting may be more successful (up to 85% success rate) (B. Kone, unpublished results).

Hall *et al*. (1996) reported that *V. paradoxa* can be propagated by root suckers, grafting, budding, cuttings and tissue culture. The top-cleft grafting technique gives a survival rate of about 70% on the farm (B. Kone, unpublished results). However, Sanou *et al*. (2004) reported side-cleft grafting to be an easy way of propagating this species. The recommended grafting period is in May in the Sahel, which is the end of the dry season/onset of the rainy season. Grafting on mature saplings in the field has produced successful results in Mali and is recommended as a way of enriching the parklands. Propagation by stem cuttings from hardwood, softwood and coppice shoots of mature trees can be used with 80% success. In addition, apical shoots from seedlings can be established and multiplied *in vitro* (Lovett and Haq, 2000).

Ziziphus mauritiana can be vegetatively propagated by budding and grafting techniques, but attempts to propagate it by cuttings have not yet been successful. Top-grafting is the most popular technique for propagating this species in the Sahel because it is quick and easy (the success rate is up to 95%; M. Doumbia, personal communication). For budding (Pareek, 2001), bud sticks with well swollen and recently matured (but not open) buds should be collected from juvenile shoots. In the Sahel, budding is carried out by the T (shield) method. The best time for successful budding is during the active growth period from June to September (the success rate is up to 85%; B. Kone, unpublished results). Budding should be done as close as possible to the ground to minimize the area for emergence of sprouts from the rootstock. Micrografting can also be used (Danthu *et al*., 2001); this allows the rapid multiplication of clones but is very expensive and not readily available.

10.3.4. Fruit tree management

The management of indigenous fruits needs more investigation in the Sahel. Information about nutrition and water management, pest and disease management, tree training and pruning, and harvesting and postharvesting techniques is limited.

10.4 Conclusion

Indigenous fruit-tee species are undoubtedly important for the rural poor in the Sahel, but considerable work is needed to ensure that they contribute significantly and in a sustainable manner to the livelihoods of the rural poor. This effort requires working in a participatory manner with rural communities, research and development institutes, non-governmental organizations and private enterprise.

Acknowledgements

We wish to thank Dr Harold Roy-Macauley and an anonymous reviewer for their valuable comments on the manuscript. Mr Mamadou M. Sidibé and Doumbia Modibo of the World Agroforestry Centre, Bamako made their unpublished results available.

References

Adin, A., Weber, J.C., Sotelo Montes, C., Vidaurre, H., Vosman, B. and Smulders, M.J.M. (2004) Genetic differentiation and trade among populations of peach palm (*Bactris gasipaes* Kunth) in the Peruvian Amazon – implications for genetic resource management. *Theoretical and Applied Genetics* 108, 1564–1573.

AFE (2006) *Filière Amande de Karité au Mali: Importance, Compétitivité, Défis et Solutions Potentielles*. Action for Enterprise (AFE), Arlington, VA.

Bationo, A.B., Ouedraogo, S.J. and Guindo, S. (2001) Stratégies de régénération naturelle de *Detarium microcarpum* Guill. et Perr. dans la foret classée de Nazinon (Burkina Faso). *Fruits* 56, 271–285.

Becker, M. and Statz, J. (2003) Marketing of parkland products. In: Teklehaimanot, Z. (ed.) *Improvement and Management of Agroforestry Parkland Systems in Sub-Saharan Africa*. EU/INCO Project Contact IC18-CT98-0261, Final Report, University of Wales, Bangor, UK, pp. 142–151.

Boffa, J.-M. (1999) *Agroforestry Parklands in sub-Saharan Africa*. FAO Conservation Guide No. 34. Food and Agriculture Organization of the United Nations, Rome.

Bonkoungou, E.G., Ayuk, E.T. and Zoungrana, I. (eds) (1997) *Les Parcs Agroforestiers des Zones Semi-Arides d'Afrique de l'Ouest.* Centre International pour la Recherche en Agroforesterie, Nairobi, Kenya.

Bouvet, J.-M., Fontaine, C., Sanou, H. and Cardi, C. (2004) An analysis of the pattern of genetic variation in *Vitellaria paradoxa* using RAPD markers. *Agroforestry Systems* 60, 61–69.

Brodie, A.W., Labarta Chávarri, R.A. and Weber, J.C. (1997) Tree germplasm management and use on-farm in the Peruvian Amazon: a case study from the Ucayali region, Peru. Research Report, Overseas Development Institute, London and International Centre for Research in Agroforestry, Nairobi, Kenya.

Cornelius, J., Clement, C.R., Weber, J.C., Sotelo-Montes, C., van Leeuwen, J., Ugarte-Guerra, L.J. and Arévalo-López, L. (2006) The trade-off between genetic gain and conservation in a participatory improvement programme: the case of peach palm (*Bactris gasipaes* Kunth). *Forests, Trees and Livelihoods* 16, 17–34.

Dampha, A. and Camera, K. (2005) Empowering Communities through Forestry: the MA&D Approach in the Gambia. Food and Agriculture Organization of the United Nations, Rome, Italy.

Danthu, P., Hane, B., Touré, M., Sagna, P., Ba, S., De Troye, M.A. and Soloviev, P. (2001) Microgreffage de quatre espèces ligneuses sahéliennes (*Acacia senegal*, *Faidherbia albida*, *Tamarindus indica* et *Ziziphus mauritiana*) en vue de leur rajeunissement. *Tropicultura* 19, 43–47.

Diallo, O.B. (2001) Biologie de la reproduction et évaluation de la diversité génétique chez une légumineuse: *Tamarindus indica* L. (Caesalpinioideae). Thèse de doctorat. Université de Montpellier II: Sciences et Techniques du Languedoc, Montpellier, France.

Diallo, I. (2002) Etude de la biologie de la reproduction et de la variabilité génétique chez le jujubier (*Ziziphus mauritiana* Lam.). Thèse de doctorat de troisième cycle. Université Cheik Anta Diop, Dakar, Sénégal.

Eyog Matig, O. and Ouedraogo, A.S. (1999) State of forest genetic resources in the Sahelian and north Sudanian zone of Africa. Food and Agriculture Organization of the United Nations, Rome.

Faminow, M.D., Weber, J.C., Lariviere S. and Martin, F. (2001) Linking poverty and the environment through commodity chain analysis: strategic management of tree genetic resources for sustainable livelihood options in the Amazon. Working Paper. International Centre for Research in Agroforestry, Nairobi, Kenya.

FAO (2000) Global forest resource assessment – 2000. Food and Agriculture Organization of the United Nations, Rome.

FAO (2004) Simpler forest management plans for participatory forestry. Forest Policy and Institutions Service, Working Paper No. 4. Food and Agriculture Organization of the United Nations, Rome.

Fontaine, C., Lovett, P.N., Sanou, H., Maley, J. and Bouvet, J.-M. (2004) Genetic diversity of the shea tree (*Vitellaria paradoxa* C.F. Gaertn.), detected by RAPD and chloroplast microsatellite markers. *Heredity* 93, 639–648.

Fortin, D., Lô, M. and Maynart, G. (2000) Plantes médicinales du Sahel. Série Etudes et Recherches No. 187–188–189. Edition révisée. Enda-Editions. Dakar, Sénégal.

Gunasena, H.P.M. and Hughes, A. (2000). *Fruits for the Future – Tamarind*. International Centre for Underutilised Crops, Southampton, UK.

Hall, J.B., Aebischer, D.P., Tomlinson, H.F., Osei-Amaning, E. and Hindle, J.R. (1996) *Vitellaria paradoxa: A Monograph*. School of Agricultural and Forest Sciences Publication No. 8. University of Wales, Bangor, UK.

Hall, J.B., Tomlinson, H.F, Oni, P.I. Buchy, M. and Aebischer, D.P. (1997) *Parkia biglobosa: A Monograph*. School of Agricultural and Forest Sciences, University of Wales, Bangor, UK.

Hollingsworth, P., Dawson, I., Goodall-Copestake, W., Richardson, J., Weber, J.C., Sotelo Montes, C. and Pennington, T. (2005) Do farmers reduce genetic diversity when they domesticate tropical trees? A case study from Amazonia. *Molecular Ecology* 14, 497–501.

Kalinganire, A., Dakouo, J.M. and Bayala, J. (2007). Rapport technique final du projet biodiversité -'Enrichissement de la biodiversité dans les parcs agroforestiers et amélioration du bien-être des populations rurales démunies au Sahel. World Agroforestry Centre, Région de l'Afrique de l'Ouest et du Centre, Bamako, Mali.

Kater, L.J.M., Kante, S. and Budelman, A. (1992) Karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*). *Agroforestry Systems* 18, 89–105.

Kelly, B.A., Hardy, O.J. and Bouvet, J.-B. (2004) Temporal and spatial genetic structure in *Vitellaria paradoxa* (shea tree) in an agroforestry system in southern Mali. *Molecular Ecology* 13, 1231–1240.

Kouyaté, A.M. (2005) Enquête ethnobotanique sur *Detarium microcarpum* Guill. et Perr. au sud du Mali. In: Kalinganire, A., Niang, A. and Kone, B. (eds) Domestication des espèces agroforestières au Sahel: Situation actuelle et perspectives. ICRAF Working Paper No. 5. World Agroforestry Centre, Nairobi, Kenya.

Leakey, R.R.B. and Newton, A.C. (eds) (1994) Domestication of tropical trees for timber and non-timber products. MAB Digest 17. UNESCO, Paris.

Ledig, F.T. (1992) Human impacts on genetic diversity in forest ecosystems. *Oikos* 63, 87–108.

Lengkeek, A.G. (2003) 'Diversity makes a difference'. Farmers managing inter- and intra-specific tree species diversity in Meru Kenya. PhD Thesis, Wageningen University, Wageningen, The Netherlands.

Lovett, P.N. and Haq, N. (2000) Diversity of the sheanut tree (*Vitellaria paradoxa* C.F. Gaertn. F.) in Ghana. *Genetics and Crop Evolution* 47, 293–304.

Maranz, S., Kpikpi, W., Wiesman, Z., De Saint Sauveur, A. and Chapagain, B. (2004) Nutritional values and indigenous preferences for shea fruits (*Vitellaria paradoxa* C.F. Gaertn. F.) in African agroforestry parklands. *Economic Botany* 58, 588–600.

Maundu, P.M., Ngugi, G.W. and Kabuye, C.H.S. (1999) *Traditional Food Plants of Kenya*. National Museums of Kenya, Nairobi, Kenya.

Nagarajan, B., Nicodemus, A., Mandal, A.K, Verma, R.K., Gireesan, K. and Mahadevan, N.P. (1998) Phenology and controlled pollination studies in Tamarind. *Silvae Genetica* 47, 237–241.

Nyambo, A., Nyomora, A., Ruffo, C.K. and Tengnas, B. (2005). *Fruits and Nuts: Species with Potential for Tanzania. Technical Handbook No. 34*. Regional Land Management Unit (RELMA in ICRAF)/World Agroforestry Centre, Nairobi, Kenya.

O'Neill, G.A., Dawson, I.K., Sotelo Montes, C., Guarino, L., Current, D., Guariguata, M. and Weber, J.C. (2001) Strategies for genetic conservation of trees in the Peruvian Amazon basin. *Biodiversity and Conservation* 10, 837–850.

Ouedraogo, A.S. (1995) *Parkia biglobosa* (Leguminosae) en Afrique de l'Ouest. Biosystematique et amelioration. PhD thesis, Institute of Forestry and Natural Resources, Wageningen, The Netherlands.

Ouedraogo, S.J., Bayala, J., Dembele, C., Kabore, A., Kaya, B., Niang, A. and Some, A.N. (2006) Establishing jujube trees in sub-Saharan Africa: response of introduced and local cultivars to rock phosphate and water supply in a peri-urban garden in Burkina Faso, West Africa. *Agroforestry Systems* 68, 69–80.

Pareek, O.P. (ed.) (2001) *Fruits for the Future 2 – Ber (*Ziziphus mauritiana*)*. International Centre for Underutilised Crops, Southampton, UK, 290 pp.

Roussel, J. (1995) Pépinières et plantations forestières en Afrique tropicale sèche. Manuel a l'usage des ingénieurs et techniciens du reboisement. Institut Sénégalais de Recherches Agricoles, Dakar, Sénégal, 35 pp.

Ruel, M.T., Minot, N. and Smith, L. (2005) Patterns and determinants of fruit and vegetable consumption in sub-Saharan Africa: a multi-country comparison. Background paper for the joint FAO/WHO Workshop on Fruit and Vegetables for Health, 1–3 September 2004, Kobe, Japan. World Health Organization, Geneva.

Sanou, H., Kambou, S., Teklehaimanot, Z., Dembele, M., Yossi, H., Sina, S., Djingdia, L. and Bovet, J.-M. (2004) Vegetative propagation of *Vitellaria paradoxa* by grafting. *Agroforestry Systems* 60, 93–99.

Sabiiti, E.N. and Cobbina, J. (1992) *Parkia biglobosa*: a potential multipurpose fodder tree legume in West Africa. *International Tree Crops Journal* 7, 113–139.

Sidibé, M.M. (2005) Evaluation des performances de cinq espèces et provenances de baobab dans les conditions soudano-sahéliennes du Mali. Mémoire de DEA en Sciences Biologiques Appliquées. Faculté des Sciences et Techniques, Université de Bamako, Bamako, Mali.

Sidibé, M. and Williams, J.T. (2002) *Fruits for the Future – Baobab (*Adansonia digitata *L.)*. International Centre for Underutilised Crops, Southampton, UK, 96 pp.

Sidibé, M, Scheuring, J.F., Tembely, D., Sidibé, M.M., Hofman, P. and Frigg, M. (1996) Baobab – home grown vitamin C for Africa. *Agroforestry Today* 8, 13–15.

Simons, A.J. and Leakey, R.R.B. (2004) Tree domestication in tropical agroforestry. *Agroforestry Systems* 61, 167–181.

Teklehaimanot, Z. (2004) Exploiting the potential of indigenous agroforestry trees: *Parkia biglobosa* and *Vitellaria paradoxa* in sub-Saharan Africa. *Agroforestry Systems* 61, 207–220.

UNDP (2003) *Human Development Report 2003. Millennium Development Goals: A Compact among Nations to End Human Poverty*. Oxford University Press, London [available at http://hdr.undp.org/reports/global/2003/].

World Bank (2004) *World Development Indicators Database*. World Bank, New York.

Appendix

Appendix 10.1. Common indigenous trees that farmers cultivate for food and other uses in parklands of the West African Sahel.

Scientific, English and French names	Uses
Adansonia digitata Baobab Baobab	Food (milk substitute and cream from fruit pulp; condiment for sauces from leaves), medicine (fruit pulp and seed to treat anorexia), cordage (from bark), glue (from gum), pottery preparation (wood for firing pots), soil fertility (branches for mulch)
Balanites aegyptiaca Desert date Dattier du désert	Firewood, fodder (from leaves), food (cooked seeds, fruit pulp), oil (from seed), soap (from oil in seed and bark), medicine (oil from seed to treat ear inflammation and dermatitis, fruit pulp to treat constipation and joint pain), live fence/fodder bank, dead fence
Bombax costatum Red flowered silk cotton Kapokier rouge	Food (flower sepals for sauce, high-quality honey from flowers), household items (wood for floors, stools, chairs, window trim, basins for feeding animals, masks), fibre (from fruit for mattresses, cushions and cotton replacement for clothing), fodder (from leaves at end of dry season)
Borassus aethiopum Fan palm Rônier	Food (immature seeds, immature shoot, fruit juice, wine from sap), fibre (bath sponge from petiole; fans, house mats, baskets, hats, furniture from leave), medicine (juice from fruit to kill intestinal parasites), construction (poles and boards from stem), dune fixation and soil conservation (fibre mats from leaves)
Boscia senegalensis – Boscia du Sénégal	Food (fresh fruit, seeds), medicine (several medicines, including treatment of bilharzias, syphilis and intestinal parasites, and as purgative, tranquilliser)
Ceiba pentandra Silk cotton Fromager	Condiments (flower sepals for sauce, seeds), fibre (from fruit for cushions and mattresses), household items (wood for floors, stools, chairs, window trim, basins for feeding animals, masks), canoes (wood from stem), medicine (host for parasitic plant (Tapinanthus pentagonia) that is used for several medicines)
Cordyla pinnata – Poire du Cayor	Food (pulp from mature fruit), household items (wood for mortars and pestles, handles for tools)
Detarium microcarpum – Detar	Food (pulp eaten raw or cooked, processed into cakes, couscous preparation), drinks (juice, alcoholic beverage), firewood and charcoal (good quality wood, fuel wood), household items (leaves to thatch roofs, tool handles, seed used as necklaces), medicine (medicines extracted from seeds, fruits, leaves, roots, bark used to treat more than 20 different diseases)
Diospyros mespiliformis Ebony Ébenier	High-value wood (for furniture, masks, etc.), food (fresh fruit), medicine (broth from leaves to relieve fever, powder from fruit to treat gastric ulcers and haemorrhoids), pottery preparation (extract from fruit for metallic finish)

Continued

Appendix 10.1. *Continued*

Scientific, English and French names	Uses
Elaeis guineensis Oil palm Palmier à huile	Oil (from fruit), wine (from sap), medicine (unfermented sap to treat anorexia), fibre (from petiole for baskets)
Hyphaene thebaica Dum palm Palmier doum	Fibre (from leaves for mats, fans), food (fruit), wine (from sap), medicine (powder from fruit pulp to treat gastric ulcers), incense (from roots), construction wood, windbreaks
Lannea microcarpa – Raisinier	Food (fruit pulp, young leaves, roots), drinks (aromatic flavour from young leaves and dried fruit, beer from fermented fruit), oil (from seed), fodder (older leaves), feed for small animals (from residue after extracting oil from seed), medicine (from leaves to control vomiting and diarrhoea, from seed oil to treat dermatitis), insecticide (from seed oil), dye (from bark for cloth and skin decoration), house construction (impermeable solution to cover banco walls obtained from residue after extracting oil from seed)
Landolphia heudellotii – –	Food (fruit pulp)
Parkia biglobosa African locust bean Néré	Food (fresh fruit pulp, dried fruit pulp, protein-rich paste and cakes from seeds), medicine (from fruit pulp to treat protein deficiency in children, from bark to treat inflamed tonsils), animal food (dried fruit pulp), medicine (paste from seeds to relieve hypertension), house construction (fruit coats used as organic structural matrix for banco walls; impermeable solution from fermented fruit coats used to cover banco walls and fill cracks in banco), soil fertility improvement (nitrogen fixation)
Prosopis africana – –	Firewood and charcoal (especially for blacksmiths), food during drought (flour from seed), fodder (from fruit, young branches and leaves), medicine (from bark to treat plaque on teeth, from leaves to relieve joint pain), household items (wood for mortars and pestles, yokes for cattle, planks for house, doors, window trim, handles for tools), soil fertility improvement (leaf mulch)
Sclerocarya birrea Marula Prunier africain	Food (fresh seeds, biscuits and cakes from seed, condiment for couscous, honey from flowers), drinks (fresh fruit juice and fermented fruit juice), medicine (from bark to treat diabetes), household items (wood for chairs, handles for implements, masks, statues)
Strychnos spinosa – –	Food (mature fruit pulp, juice), medicine (note: roots, leaves, unripe fruits and seeds are poisonous), firewood, shade
Tamarindus indica Tamarind Tamarinier	Food (dried fruit pulp added to millet porridge, honey from flowers), drinks (fresh fruit juice), medicine (from fruit pulp to treat constipation, counteract fatty foods and facilitate digestion; juice from fruit pulp for antibiotic skin cream and beauty cream; from bark to treat gingivitis and other oral inflammations), household items (wood for tool handles)

Appendix 10.1. *Continued*

Scientific, English and French names	Uses
Vitellaria paradoxa Shea nut tree Karité, arbre à beurre	Food (butter from seeds), medicine (butter to treat gastric ulcer and dry skin, butter as base for bactericidal skin creams and beauty creams), soap (from low-quality butter), forage (host of parasitic plant (Tapinanthus pentagonia) which is used as forage)
Vitex doniana Black plum Prunier noir	Food (fresh fruit), firewood, wood products (softwood for planks, tables, paper)
Ximenia americana Wild plum Citron de mer	Food (fresh ripe fruit pulp), firewood, medicine (several medicines: seed oil, roots to treat syphilis and intestinal parasites, leaf for stomach-ache and diarrhoea, leprosy, tranquilliser), firewood (firewood and charcoal), fodder (from leaves), dye (extract from leaves to dye clothes), house construction (timber of good quality and very hard: poles and rafters)
Ziziphus mauritiana Jujube Jujubie*r*	Food (fruit pulp to make cakes, porridge, high in vitamin C), drinks (from fruit pulp), medicine (low dose extract from roots to treat gastric ulcers, vomiting and syphilis; fruit pulp and other ingredients to treat anorexia; pulp and green beans for infant food), household items (wood for tool handles), firewood, live fence, fodder (from leaves), fishing (high-dose extract of roots to kill fish), soil fertility improvement (leaf mulch) Source: B. Kone (ICRAF), based on farmer surveys in Mali (unpublished data) and Fortin *et al*

Source: B. Kone (ICRAF), based on farmer surveys in Mali (unpublished data) and Fortin *et al.* (2000).