Improving livelihoods and nutrition in sub-Saharan Africa through the promotion of indigenous and exotic fruit production in smallholders' agroforestry systems: a review

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SUMMARY

The cultivation of indigenous and exotic fruits for sub-Saharan Africa's domestic markets can bring increased revenues for smallholders and improve the diets of local consumers. There are, however, many bottlenecks which need to be addressed so that wider benefits from such activities are realised. Here, we describe key interventions being taken to address current constraints. For indigenous fruit trees, it is necessary to set priorities for which species to promote and to engage in participatory domestication for the improvement of yield, quality and germplasm delivery to farmers. For exotic fruits, 'south-south' transfer of advanced cultivars and the development of small-scale commercial suppliers of planting material are required to reinvigorate production. For both indigenous and exotic species, a focus on improving market value chains to bring greater benefits to producers is needed. We describe where further work is required to increase efficiency in the sector and to favour smallholder involvement.

Keywords: indigenous and exotic fruits, African smallholders, market value chains, participatory domestication, 'south-south' transfer

Améliorer le niveau de vie et la nutrition dans l'Afrique sub-saharienne à l'aide de la promotion de la production des fruits locaux et exotiques dans les systèmes d'agroforesterie de petite taille: une étude

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La culture de fruits exotiques et locaux pour les marchés domestiques de l'Afrique sub-saharienne peut être une source de revenus pour les petis producteurs et améliorer la nutrition des consommateurs locaux. Plusieurs empêchenments existent cependant et doivent être pris en compte pour permettre à des bénéfices plus larges de se réaliser. Nous décrivons ici les interventions les plus importantes en place actuellement pour faire face à ces contraintes. Pour les arbres fruitiers indigènes, il est nécessaire de donner priorité aux espèces à promouvoir et à engager dans une domestication participationnelle pour l'amélioration de la production, de la qualité et du germplasm fournis aux cultivateurs. Pour les fruits exotiques, le transfert "sud-sud" des cultivars avancés, et le développement des petits producteurs commerciaux de matériel de plantation sont nécessaires pour renvigorer la production. Pour les espèces indigènes et exotiques, une concentration sur l'amélioration des chaînes de valeurs de marché est nécessaire pour offrir de plus grands bénéfices aux producteurs. Nous décrivons les zones où un travail plus poussé est nécessaire pour accroître l'éfficacité du secteur et favoriser la participation des petits producteurs.

Mejora en los medios de subsistencia y la nutrición en el África subsahariana mediante la promoción de la producción de frutas nativas y exóticas en sistemas agroforestales de pequeños productores: una revisión

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El cultivo de frutas nativas y exóticas para los mercados domésticos subsaharianos puede aportar ingresos a los pequeños productores y mejorar la dieta de los consumidores locales. Sin embargo, existen muchos problemas que hace falta superar para poder alcanzar estos beneficios.

Aquí describimos las acciones clave que se están implementando para superar las restricciones actuales. Para árboles frutales nativos, es necesario establecer prioridades sobre qué especies promocionar, así como llevar a la práctica una domesticación participativa para el aumento de la producción y la mejora de la calidad y el suministro de germoplasma a los productores. Para frutales exóticos, son necesarias la transferencia de 'sur-a-sur' de cultivares avanzados y la aparición de proveedores comerciales de pequeña escala de material de plantación para dar vigor a la producción. Tanto para especies nativas como exóticas es necesario un enfoque centrado en mejorar las cadenas de valor del mercado para atraer así mayores beneficios para los productores. Describimos dónde se requieren mayores esfuerzos para aumentar la eficiencia del sector y dar prioridad a la participación de los pequeños productores.

INTRODUCTION

Sub-Saharan Africa's efforts to mitigate malnutrition are lagging behind the rest of the world, with 30% of the population under-nourished (FAO 2005a). Indeed, eight of the 20 nations with the highest burden of under-nutrition worldwide are in the region (Bryce *et al*. 2008). A lack of micronutrients, or 'hidden hunger', leads to poor health consequences for millions of Africans (Saka and Msonthi 1994, Saka *et al*. 2007, www.nap.edu, www.purdue.hort.edu). For example, around 50 million African children are at risk of vitamin A deficiency, the continent's third greatest public health problem after HIV/AIDS and malaria (Black *et al*. 2008, www.worldmapper.org). Nutritionists agree that solving malnutrition requires a range of interconnected approaches (Bhutta *et al*. 2008). These include the bio-fortification through conventional breeding or genetic modification (GM) of staple crops (the first option has generally been preferred because of societal resistance to the second, although GM approaches have become more acceptable in developing countries in the last few years, Dawson *et al*. 2009a), further spending on food supplementation programmes, and greater use of a wide range of edible plants for more diverse diets (Leakey 1999, World Bank 2006, UNICEF 2007, Negin *et al*. 2009). The further promotion of indigenous fruits and vegetables is an attractive option, as it allows consumers to take responsibility over their diets in culturally relevant, and therefore potentially more sustainable, ways (Keatinge *et al*. 2010). Furthermore, the nutritional profiles of these indigenous species in supplying micronutrients, fat, fibre and protein are often better than staple foods (Leakey 1999).

Current nutritional deficiencies in sub-Saharan Africa are exacerbated by a number of factors, including declining soil fertility and lack of water that limit the yields of staple crops, and anthropogenic climate change that restricts the range of crops that can be grown (Costello *et al*. 2009, Keatinge *et al*. 2010, Müller *et al*. 2011). In addition, continued deforestation, currently estimated at 3.4 million hectares annually for Africa as a whole (FAO 2010), means that many communities can no longer gain easy access to natural stands of fruits, nuts and other edible non-timber forest products (NTFPs) that they once collected to supplement their diets. In these circumstances, agroforestry, the practice of integrating a range of trees with annual crop cultivation and other farm activities, is an approach adopted by farmers to meet their needs for essential resources and improved livelihoods (Garrity 2004). At the same time, farmland tree planting provides valuable environmental services (Scherr and McNeely 2008, Nair *et al*. 2009, Leakey 2010). Indeed, worldwide, it is estimated that more than 1.2 billion people practise agroforestry in some form, and that approximately 560 million people live in farm landscapes that have more than 10% tree cover, many of which are found in the sub-Sahara region (Zomer *et al*. 2009).

By providing on-farm resources, the cultivation of trees for NTFPs, now known as agroforestry tree products (AFTPs) to distinguish them from common property resources (Simons and Leakey 2004), has the potential to reduce pressure on extraction from natural forest (Simons *et al*. 2000, Jamnadass *et al*. 2010). Furthermore, planting AFTPs with other crops improves the resilience of smallholders' agricultural systems (Steffan-Dewenter *et al*. 2007) and can bring significant revenues (Weinberger and Lumpkin 2007, Akinnifesi *et al*. 2010, Asaah *et al*. 2011). Rural women in particular can benefit, as markets for fruits, vegetables and other AFTPs have a lower capital threshold for involvement than other sectors of the economy (Awono *et al*. 2002, Akinnifesi *et al*. 2006, Kadzere *et al*. 2006). In Africa, special potential for cultivation lies in the great biological diversity of indigenous fruits, nuts and other edible products found in the forests of the continent (IPGRI *et al*. 2005, Akinnifesi *et al*. 2008). There are hundreds of indigenous fruit tree species (IFTs) that, although relatively unknown in global markets, are important locally. These are now the focus of domestication initiatives which could contribute significantly more to the livelihoods and nutrition of local people (Leakey 1999, Leakey *et al*. 2005, Degrande *et al*. 2006b, Schreckenberg *et al*. 2006, Pye-Smith 2009, Ræbild *et al*. 2011, Box 1). At the same time, the cultivation of IFTs allows valuable genetic resources to be conserved outside threatened forests (Dawson *et al*. 2009b). Planting also provides opportunities for carbon credit sales as non-destructive harvesting of fruits should not materially reduce sequestration (Nair *et al*. 2009), although current payment mechanisms are generally inefficient and further attention to approaches is required if farmers are to benefit significantly (Jack *et al*. 2008).

In this review, we consider the promotion of fruit tree cultivation on smallholdings, of both indigenous species and exotics that have traditionally been grown in the region, often for centuries, as one means of improving nutritional security in sub-Saharan Africa. We describe key areas where measures are being taken to address current constraints (Box 2) for the involvement of small-scale growers in production and markets, and indicate where further action is required to make

Box 1 Indigenous fruit and nut trees identified through priority-setting exercises as targets for promotion in Cameroon, Kenya and/or Malawi (see Table 1 for particular countries where a priority; the same species may also be important in other nations)

Allanblackia A genus of nine species found in the humid forests of Central, East and West Africa, the tree grows to 40 m tall and produces a large fruit that contains between 14 and 90 seeds. The seed produces an edible oil of interest to the global food industry as well as for local use in cooking and soap production (www.allanblackia.info). Oil from two species, *A. parviflora* and *A. stuhlmannii*, has received the approval of the European Union Novel Food Regulations that certify safe usage as a foodstuff in European markets.

Baobab *Adansonia digitata*, a tree with a large swollen trunk that can have a diameter of up to 10 m, is a very long-lived species (specimens found up to 2 000 years old) located in arid and semi-arid savannah in sub-Saharan Africa. The edible white, powdery pulp found in the fruit is very rich in vitamin C and vitamin B2 and is used to make a refreshing drink. Young leaves are also rich in vitamin C and are in high demand in West Africa as a soup vegetable.

Ber *Ziziphus mauritiana*, a spiny evergreen shrub or small tree up to 15 m high, is native to drylands in Africa and Asia. Fruit is eaten fresh or dried and can be made into a floury meal, butter, or a cheese-like paste, used as a condiment. The fruit is a good source of carotene, vitamins A and C, and oils. A refreshing drink is prepared by macerating the fruit in water. The use of ber in India can be traced back as early as 1 000 BC.

Bitter cola *Garcinia kola*, native to the moist lowland tropical forests of Central and West Africa, is a medium-sized evergreen tree. The bitter kernels are highly valued in Central Africa and are chewed as a stimulant. The kernels are also used for the treatment of coughs, bronchitis and liver disorders. Split stems and twigs are used as chewing sticks. A recent inventory revealed that the species, which is currently harvested mainly from the wild, is close to commercial extinction in Ghana.

Bush mango *Irvingia gabonensis* and *I. wombolu*, collectively known as bush mango or dika nut, are economically important long-lived fruit trees native to moist lowland tropical forest in Central and West Africa. The fruit mesocarp of *I. gabonensis*, sweet bush mango, is appreciated as a fresh fruit snack. Ground kernels of both species are used to thicken and flavour soups, although those of *I. wombolu*, bitter bush mango, are most valued and fetch high prices in cross-border trade, contributing significantly to local economies.

Desert date *Balanites aegyptiaca*, a spiny shrub or tree up to 10 m high, is a species with a wide ecological distribution across Africa. The fleshy pulp of both unripe and ripe fruit is eaten dried or fresh. The fruit is processed into drinks in West Africa and is used as a soup ingredient in East Africa. Young leaves and tender shoots are used as a vegetable, which are boiled, pounded and fried.

Kola nut *Cola nitida*, an under-storey evergreen tree that generally grows to 9 to 12 m tall, is native to lowland tropical forests in Central and West Africa. Nuts, which contain caffeine, kolatine and theobromine, are chewed as a stimulant. The nuts taste bitter when chewed at first but they leave a sweet taste in the mouth later. Chewing cola nuts before drinking water thus helps to render the water sweeter. The nut is widely used for social ceremonies.

Marula The long-lived tree *Sclerocarya birrea* has an extensive distribution across dryland savannah habitats in the sub-Sahara. The fruit pulp of *S. birrea* subsp. *caffra*, widely distributed in southern Africa, is used to produce jam, juice, beer and, in South Africa, the internationally available liqueur Amarula Cream, while the oily kernels are consumed raw, roasted and in sauces. In addition to current use, archaeological evidence indicates human harvesting of fruit extending back 10 000 years.

Njansang *Ricinodendron heudelotii*, a fast-growing tree reaching up to 50 m in height, is found primarily in Central and West Africa, often in secondary forest. A spicy sauce made from the kernels is widely used in stews, and the high oil content of the seeds makes them suitable for use in the soap industry. In Cameroon, it is also valued for its medicinal properties and is used to treat constipation, dysentery, eye infections and female sterility, and also as an antidote to poison.

Safou *Dacryodes edulis* is a medium-sized evergreen tree found in the humid tropical zone of Central and West Africa. It has been cultivated by farmers in southern Nigeria and Cameroon for many years, and is considered 'semi-domesticated' in some areas, based on planters' selective seed sampling. Widely sold in local markets, the highly nutritious fruits have an oily texture similar to avocado and are eaten boiled or roasted. The fruit pulp is rich in vitamins and amino acids.

Star apple *Chrysophyllum albidum*, a long-lived tree which grows to 35 m tall, is a canopy species of lowland mixed rainforest that is distributed from West Africa to western Kenya. The fleshy and juicy fruits are popularly eaten, and can be fermented and distilled for the production of wine and spirits.

Tamarind *Tamarindus indica*, a tree growing to 30 m tall, has an extensive distribution through much of the tropics, but is believed to have originated in Africa, where it is found across dryland savannah regions. The species was cultivated in Egypt as early as 400 BC. The fruit pulp is used to prepare juice and jam, and is an ingredient in curries, chutneys and sauces. The ripe fruits of 'sweet' types are eaten fresh as a snack.

Box 1 *Continued*

Wild loquat *Uapaca kirkiana*, a small- to medium-sized evergreen or semi-deciduous tree, is found in the miombo woodlands of southern Africa. The fruit of *U. kirkiana* is highly regarded and is eaten fresh as well as being used to prepare jams and beverages. Harvesting of fruit from wild stands is an important coping strategy during times of extreme hunger.

For further information on species see ICRAF's Agroforestree Database (AFTD), from which the majority of the above was taken (www.worldagroforestry.org/Sites/TreeDBS/aft.asp). The AFTD contains data on the use, ecology and management of more than 600 tree species planted by smallholders in the tropics.

Box 2 Current constraints to smallholder involvement in fruit production in sub-Saharan Africa

The lack of cultivars bred specifically for African smallholders There has been a lack of investment in the development of new fruit tree varieties – of high quality, with wider production seasons and highly marketable products – of both indigenous and exotic species that are specifically suited to African farmers' circumstances. In particular, the great potential for improvement of a wide range of IFTs, the 'Cinderella' species, has until the last 20 years been under-recognised, with most species being little researched to help guide cultivation and domestication.

The inability of farmers to access superior cultivars developed outside the region Many sub-Saharan African smallholders grow old varieties of exotic fruit trees that were introduced into the region over the last thousand years from Asia and elsewhere. Since introduction, breeding work in other continents has produced cultivars with higher yields and better quality characteristics, but planting material of these varieties has not reached small-scale African producers.

Use of poor farm management practices Smallholders in sub-Saharan Africa are frequently unaware of, or cannot afford to practice, the management methods that are needed to make fruit production more efficient and profitable. Better practices applied by small-scale farmers in other continents, for propagation, pest control, irrigation and harvesting, etc., have not yet reached them. In common with small-scale farming in the sub-continent generally, the possible role of the private sector in supplying products and services that could improve current practices has been under-valued.

Inadequate post harvest practices Smallholders and other small- and medium-scale enterprises often do not have access to the information and equipment they need for the proper storing, grading, packing, processing, preserving and transporting of fruit, which often has a short shelf life. As a result, wastage is high, the quality of product in the market is often low and sales are therefore limited.

Weak marketing systems Existing markets to deliver fruit to urban consumers are poorly structured and coordinated, resulting in high prices of fruit for consumers and low and unstable returns to farmers. From the producers' perspective, problems frequently cited include an absence of collective bargaining, lack of transparency, poor transport infrastructure, and the involvement of multiple value-robbing brokerage layers that reduce farm-gate prices. It is as a result of prevailing low produce prices that farmers struggle to afford inputs to improve their current sub-optimal management practices. Traders face many problems as well, including poor roads, corrupt officials and the costs of collecting produce from geographically scattered producers.

For discussion of the constraints listed here, see Leakey and Newton (1994), Poulton and Poole (2001), FAO (2004), Weinberger and Lumpkin (2007), Graudal and Lillesø (2007), Akinnifesi *et al*. (2008), Ham *et al*. (2008), Jordaan *et al*. (2008), Jamnadass *et al*. (2009), Tschirley *et al*. (2010).

greater progress towards their inclusion. By outlining appropriate interventions, our objective is that African smallholder producers and domestic consumers will benefit from greater and better directed government and commercial investment in the sector. Indigenous and exotic fruits both have a role to play and no 'ideological' attribution of value based on whether a fruit is of local or introduced origin should be made. Origin is however of importance when considering the different types of intervention that are needed for promotion. Below, we draw illustrations from relevant research carried out by the World Agroforestry Centre (ICRAF, www.worldagroforestry.org), its partners and other organisations over the last decades.

PROMOTING THE CULTIVATION OF INDIGENOUS FRUITS

Priority-setting for promotion

Since there is a very large range of IFTs that could potentially be cultivated, the first intervention is to decide on which species to focus attention. Guidelines for species priority-setting have been developed by ICRAF and partners that take into account the interests of local farmers, markets and consumers, as well as the knowledge of scientists (Franzel *et al*. 1996, Maghembe *et al*. 1998). Important factors for scientists to consider include the potential for rapid yield and/or nutritional quality improvements and whether a species is easy to grow by smallholders (Franzel *et al*. 2008, Mng'omba *et al*. 2008). Priority-setting must also take into account the different interests of male and female producers and consumers, since gender is a key factor in determining which species, cultivars and products are deemed valuable (ICUC 2003). Using these guidelines, priority-setting exercises led by ICRAF have been undertaken at different times in over a dozen countries in sub-Saharan Africa; the same guidelines could, in principle, be applied in other nations in the region.

Typical results, for Cameroon, Kenya and Malawi, are given in Table 1, while more information on the priority IFTs identified is given in Box 1. Results for these three countries illustrate that some species have been found to be important in several nations; for example, baobab (*Adansonia digitata*), ber (*Ziziphus mauritiana*) and tamarind (*Tamarindus indica*) were priorities in both Kenya and Malawi. In other instances, favoured species were specific to a nation or sub-region due to climatic restrictions or traditional use. In the case of marula (*Sclerocarya birrea*), which is found throughout dry sub-Saharan Africa, the species was important in Kenya but not in Malawi, as only in the latter nation has the fruit been traditionally used in beverage production (Hall *et al*. 2002, Wynberg *et al*. 2003). Priorities not only vary between countries but also within them; for example, in Kenya exotic fruits are preferred in high rainfall areas, while indigenous fruits are more popular in low rainfall districts (Muok *et al*. 2001, Simitu *et al*. 2009). Based on priority-setting it is possible to determine if international trials are appropriate for identifying superior cultivars and/or management methods, or if local approaches, such as the participatory domestication method described below, are the best for cultivar development and delivery. Since producer and consumer preferences change with time, priority-setting needs to be repeated at regular intervals. It should seek out species that are likely to be priorities for long enough for promotion activities to deliver genuine impact in terms of improved livelihoods, etc., within an appropriate time frame (Franzel *et al*. 2008).

The participatory domestication approach

One way to undertake fruit tree breeding is to use a 'formal', centralised approach involving on-station field trials, controlled crosses and, in some cases, biotechnological breeding methods (Ray 2002). These techniques have been successfully applied to temperate fruits and a smaller number of popular, widely-grown tropical fruits such as avocado (*Persea americana*), orange (*Citrus sinensis*) and mango (*Mangifera indica*) (Samson 2003). A 'formal' strategy for breeding is relatively easy to coordinate and allows advanced methods to be applied to combine multiple important traits into single cultivars, but can be expensive, may not be able to reach farmers with improved germplasm and can become disconnected from growers' key requirements (Clement *et al*. 2008).

TABLE 1 *Ten fruit and nut trees identified through priority-setting exercises as targets for promotion in each of three African countries (Cameroon, Kenya and Malawi chosen as representative nations from Central, East and southern Africa, respectively). The same species may also be important in other nations*

	Fruits and nuts ranked highly for promotion (alphabetical order)		
Country	**Indigenous**	**Exotic**	**Methods used to set priorities**
Cameroon	• *Allanblackia* species • Bitter cola (*Garcinia kola*) • Bush mango (*Irvingia gabonensis*/ *I. wombolu*) • Kolanut (*Cola nitida*) • Njansang (*Ricinodendron heudelotii*) • Safou (*Dacryodes edulis*) • Star apple (*Chrysophyllum albidum*)	• Avocado (*Persea americana*) • *Citrus* species (e.g., orange, *C. sinensis*) • Mango (*Mangifera indica*)	Participatory priority-setting exercises, household surveys, market value data, future market predictions
Kenya	• Baobab (*Adansonia digitata*) • Ber (*Ziziphus mauritiana*) • Desert date (*Balanites aegyptiaca*) • Tamarind (*Tamarindus indica*)	• Avocado (*Persea americana*) • *Citrus* species (e.g., orange, *C. sinensis*) • Macadamia nut (*Macadamia tetraphylla*) • Mango (*Mangifera indica*) • Papaya (*Carica papaya*) • Passion fruit (*Passiflora edulis*)	Horticultural Crops Development Authority market value data, indigenous species survey in drylands
Malawi	• Baobab (*Adansonia digitata*) • Ber (*Ziziphus mauritiana*) • Marula (*Sclerocarya birrea*) • Tamarind (*Tamarindus indica*) • Wild loquat (*Uapaca kirkiana*)	• Avocado (*Persea americana*) • *Citrus* species (e.g., orange, *C. sinensis*) • Macadamia nut (*Macadamia tetraphylla*) • Mango (*Mangifera indica*) • Papaya (*Carica papaya*)	Participatory priority-setting exercises of smallholders and markets, household surveys, future market predictions

For further information on priority-setting exercises, see Maghembe *et al*. (1998), Muok *et al*. (2001), Franzel *et al*. (2008) and Faulkner *et al*. (2009). Information on the IFTs listed here is given in Box 1.

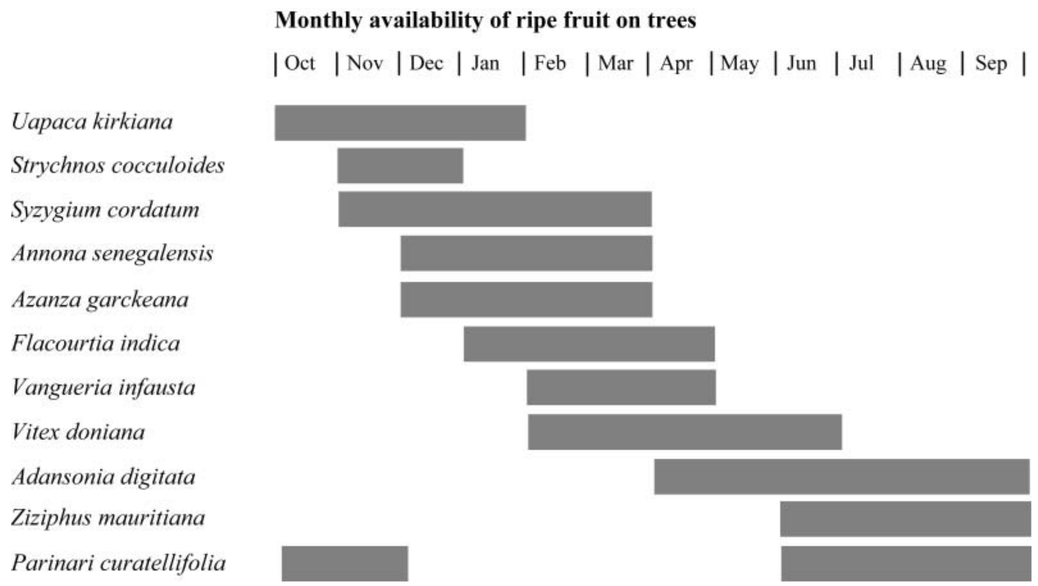
Alternatively, a decentralised, participatory strategy can be employed that involves local people and builds on their existing knowledge on fruit tree use and cultivation (Tchoundjeu *et al*. 2006, Miller and Nair 2006, Asaah *et al*. 2011). The participatory domestication approach, as developed by ICRAF and partners, involves combining communities' traditional knowledge with scientific advances in germplasm collection, selection and vegetative propagation. Farmers are trained in appropriate techniques for handling germplasm and are then encouraged to apply newly-acquired skills to the fruit trees that they find growing naturally in the landscapes they inhabit (Leakey *et al*. 2005). At some locations, then, farmers are being updated in methods of management that they have already been practising sub-optimally; at other sites, the concept of participating in domestication activities may be completely novel (Leakey *et al*. 2003).

Key advantages of the participatory approach are that it empowers communities to manage local resources themselves and promotes greater and more rapid adoption (Degrande *et al*. 2006a, Lombard and Leakey 2010, Tchoundjeu *et al*. 2010). Furthermore, it provides farmers with the strategic skills they need to domesticate a range of different species and therefore supports diversification that buffers production and market risks (Tchoundjeu *et al*. 2010). If the diverse species (or cultivars within a species) being domesticated have different ripening times – see Fig. 1 for an example of a fruit tree 'portfolio' containing species that fruit in different months – this helps to provide nutrients across the year, including during times when hidden hunger is most prevalent (Dawson *et al*. 2007). Spreading the time period of production also allows for the more efficient use of labour during harvesting and of equipment for processing (Axtell and Fellows 2008).

The relevance of the participatory domestication approach has been researched in southern (Akinnifesi *et al*. 2006, 2008) and dry zone West Africa (Kalinganire *et al*. 2008, Jensen *et al*. 2011) over the last decade, but the method has been most intensively applied in the humid forest margins of Central Africa where IFTs are highly valued in the local economy, as described in more detail elsewhere (Leakey *et al*. 2005, 2007, Tchoundjeu *et al*. 2006, 2008, Box 1 lists some of the species involved). The participatory approach has been used in Central Africa where farmers can still gain relatively easy access to populations of high value tree species that interest them; where such stands are harder to access, for example, due to extensive deforestation and agricultural intensification, the method is clearly less appropriate. In this second situation, a more formal approach based on the introduction of germplasm from outside is obviously required.

Significant success of the participatory domestication approach has been achieved through the 'Food for Progress' project in Cameroon. A recent survey there (Tchoundjeu *et al*. 2010) demonstrated that smallholders achieved increased incomes from the sale of fruits from locally selected, clonally propagated cultivars and from selling nursery stock of selected trees to other growers. Around 50% of local adopters included more indigenous fruit in their own diets, having a direct impact on their own nutrition, whilst participatory domestication also contributed to a reduction in human migration from rural to urban areas. Again indicating success, Tadjo (2008) found that tree nurseries in Cameroon that had received support from the participatory tree domestication initiative supplied a wider range of fruit trees, propagated in more appropriate ways, and with higher purchaser satisfaction, than those nurseries that had not received assistance. Asaah *et al*. (2011) determined that Cameroonian tree nurseries applying participatory domestication methods were transforming farmers' lives and generating thousands of US Dollars annually (income depending on nursery size). The

FIGURE 1 *A fruit tree 'portfolio' consisting of species fruiting at different times of the year. The example given here is based on underutilised fruits found in southern Africa (FA, personal observations)*



propagation methods being taught as part of the participatory domestication approach for IFTs were also being applied to exotic fruits.

In order to further promote the participatory domestication approach in Central Africa, rural resource centres (RRCs) managed by local communities are now being established (Tchoundjeu *et al*. 2010). These centres train farmers in how to collect and propagate germplasm, host small field trials to demonstrate effective horticultural methods, hold stockplants of selected trees for vegetative multiplication, and link with satellite nurseries to provide germplasm and knowledge at a wider range of locations. Centres also provide processing facilities, business training, and act as venues for farmers, wholesalers and service providers (e.g., of fertiliser, credit) to meet, so that they can share market information and undertake transactions (Asaah *et al*. 2011). Trials established at RRCs will in future allow communities to gather the data they need to gain Plant Breeders Rights over their best cultivars, an important issue if these types are to be more widely disseminated or adopted in 'formal' improvement programmes (Lombard and Leakey 2010). The RRC approach, integrating participatory tree domestication with a broader set of services, is recognised as an important example of multifunctional agricultural development in the tropics (Leakey 2010), and as such was awarded an Equator Prize for livelihood improvement and biodiversity conservation in 2010 (www.equatorinitiative.org/).

Yield and quality improvements through vegetative propagation and selection

The time taken between planting and fruiting is a key factor determining the profitability of fruit tree planting and farmers' interest in it (Waibel *et al*. 2005). To realise early yields, the participatory domestication approach has applied vegetative techniques for propagation (Leakey 2004) that result in accelerated fruit production compared to tree establishment from seed. In this way, for example, the period between planting and first fruiting of baobab can be reduced from more than 10 years to around 4 years, in safou (*Dacryodes edulis*) from 5 to 2 years, in sheanut (*Vitellaria paradoxa*) from 20 to 5 years or less, and in wild loquat (*Uapaca kirkiana*) from 12 to 4 years (Sidibe and Williams 2002, Sanou *et al*. 2004, Leakey and Akinnifesi 2008). Another advantage of vegetative propagation is that the material collected is a clone of the mother tree and it is therefore easier to capture genetic gain through selection when compared to sampling by seed, where the paternal parent of the progeny is unknown when a species is outbreeding, as are most trees (Petit and Hampe 2006, Leakey and Akinnifesi 2008). Vegetative propagation also allows female, fruit-bearing trees to be cloned specifically for species such as *Allanblackia* and safou that are dioecious and thus have separate male and female plants (Jamnadass *et al*. 2010).

The most common approaches promoted for vegetative propagation have been the rooting of leafy stem cuttings, grafting and air layering. Rooting of leafy stem cuttings is practiced in non-mist propagators that communities can build for themselves based on a simple design (Leakey *et al*. 1990). In addition, micropropagation protocols for rapid multiplication have been devised for a few IFTs, though it is not yet clear how such micro-propagules can be delivered to growers for planting, as the technology required to generate clones goes beyond what can be handled directly by farmers (Mng'omba *et al*. 2007a, b). Although vegetative propagation has many attractive features, the collection of too few clones and/or too narrow a genetic base could result in losses in performance through inbreeding depression that leads to low fruit set (Leakey and Akinnifesi 2008). In the worst case situation, multiplication of only a single clone may lead to no fruit being produced if the tree is an obligate outbreeder and can therefore reproduce only through mating with a genetically different individual. The possibility for inbreeding amongst clonally propagated individuals can be minimised by maintaining wide sampling of source plants and supporting pollinator presence (Dawson *et al*. 2009b). Another issue is that the level of acceleration in fruiting of vegetative propagules depends on the level of ontogenetic maturity. This is determined by the origin of the scion, marcot or cutting within the tree crown/stockplant, which also affects the level of success of propagation (Leakey, 2004). This determines the approach to multiplication that should be employed; research to optimise methodology may be needed on a species-by-species basis.

An essential part of the participatory domestication approach is to deliver quality and yield improvements through the selection of superior germplasm with the right combinations of traits. Developing effective selection strategies requires understanding how genetic variation is structured within and between fruit tree populations through phenotypic observations and other methods for characterisation such as molecular genotyping (Jamnadass *et al*. 2009). Ideally, species should have high genetic diversity at a local geographic scale, providing farmers with the opportunity to select superior 'ideotypes' (Leakey and Page 2006, Jamnadass *et al*. 2009). Determining the proportion of genetic variation within an IFT that occurs within local stands is therefore an important topic for research: if high for important characteristics, a participatory strategy is appropriate; if low, a more centralised breeding approach, in which varieties are developed outside the local area and some method is then found to bring them to farmers, may be better.

Evidence collected from a range of African fruit trees shows that large variation in yield, fruit size, shape and composition, among other important characteristics, is found within natural stands and farmers' existing populations, which is very encouraging for the participatory approach. For example, in *Allanblackia*, a more than four-fold difference in average seed yield per fruit has been observed between trees within natural stands (Peprah *et al*. 2009), a difference mirrored by high molecular genetic variation (Atangana *et al*. 2009, Russell *et al*. 2009) and the different fatty acid profiles found within populations (Atangana *et al*. 2011). Similarly, in safou, it is estimated that local selection from within natural and/or farmers' stands could result in a five-fold increase in the economic value of material (Waruhiu *et al*. 2004). Again, greater than two-fold variation between trees in the vitamin C content of fruit pulp has been observed in natural populations of marula (Thiongo and Jaenicke 2000), which accords with the high molecular genetic variation also noted in populations (Kadu *et al*. 2006).

The targeted sampling of superior phenotypes during participatory domestication will, however, only be effective for characters of medium to high heritability, because of the environmental heterogeneity of collection sites (White *et al*. 2007). Research suggests that heritability in characters such as fruit yield and quality may be reasonably high compared to other tree traits (Ræbild *et al*. 2011 and references therein, although see Atangana *et al*. 2011). That this is the case for particular species can however only be confirmed through controlled field trials in which different selections are brought together into a uniform environment. Even using the participatory domestication approach, therefore, a degree of centralised activity to compare genotypes, as one might do when undertaking 'formal' breeding, is necessary to understand the potential genetic gains that are achievable through farmer selection (Cornelius *et al*. 2006, Weber *et al*. 2009). Such studies are required on a wide range of IFTs (Ræbild *et al*. 2011), possibly based at RRCs. More research is also needed on within-population genetic variation in the chemical composition of different fruits (Leakey 1999).

EXOTIC FRUITS TO COMPLEMENT THE CULTIVATION OF INDIGENOUS SPECIES

The 'south-south' transfer of cultivars

During exercises to determine which IFTs are the farmers' priorities, exotics such as avocado, mango and orange are often also mentioned (Table 1). Often, these exotics were introduced into Africa many centuries ago. For example, mango and banana from Asia were already present in the sub-Sahara in the 14th Century according to the Arabian traveller Ibn Battuta (Vinceti *et al*. 2009). Farmers often now think of these species as indigenous. Many of the cultivars now grown by African smallholders are derived from these ancient introductions, but they do not perform well when compared to more modern cultivars developed elsewhere. For example, various local mango varieties in Kenya are considered stringy in texture and are not well matched to current consumer preferences (FAO 2004, Kehlenbeck *et al*. 2010).

To revitalise sub-Saharan smallholder production of these long-present species, two approaches are possible. The first is to breed new cultivars within the sub-Sahara based on the existing 'landrace' gene pool, while the second is to renew 'south-south' linkages to bring in superior cultivars developed outside the region. Taking advantage of new cultivars developed elsewhere is likely to be the more cost effective approach because local landraces in Africa may be based on a very narrow genetic base with limited potential for gain, and there seems little benefit in duplicating breeding efforts already undertaken in other locations (Ray 2002, Samson 2003). However, the 'transfer' approach requires that introduced material be compared with existing local cultivars under African conditions, so that the level of potential gain in yield and/or quality is quantified. A recent example of the success of south-south transfer has been the introduction of new varieties of ber from Asia into Sahelian countries (Danthu *et al*. 2004). In this case, the species is in fact indigenous to both the sub-Sahara and Asia, but varieties developed in Asia perform significantly better when introduced and tested against local types in West Africa (Kalinganire *et al*. 2008, Ræbild *et al*. 2011). There is also great potential for renewed transfers of fruits such as guava (*Psidium guajava*), tamarind, pomegranate (*Punica granatum*), papaya (*Carica papaya*), custard apple (*Annona squamosa*) and jackfruit (*Artocarpus heterophyllus*) (www.fao.org/hortivar/index.jsp).

Undertaking the international exchange of planting material is however complicated by a lack of effective coordination amongst relevant legislations, such as the Convention on Biological Diversity (CBD), Plant Breeders Rights and phytosanitary import requirements. Although current rules that control transfers were devised with the best of intentions (e.g., to protect the rights of those that have domesticated the species), their net effect has in recent decades been to significantly restrict exchange that could benefit farmers and consumers more widely. At the same time, a situation in which unregulated germplasm exchange out of Africa resulted in the cultivation of African indigenous fruits in other continents and the out-competition of African smallholders is clearly not desirable, such as happened in the past with oil palm, *Elaeis guineensis* (Simons and Leakey 2004). The harmonisation of regulations to remove unintended hindrances while providing the right level of protection is therefore crucial (Gepts 2004, Koskela *et al*. 2009). Members of the Consultative Group on International Agricultural Research, of which ICRAF is one, may have an important role to play in facilitating harmonisation and transfer.

Supporting small-scale commercial suppliers of planting material

Once superior exotic fruit cultivars have been introduced into Africa, they need to be delivered to smallholders to plant them, along with the new management methods needed to assure maximum performance. These apparently simple steps require greatly improved national-level tree germplasm delivery systems (Dawson *et al*. 2009b). The problem is that national-level suppliers, such as tree seed centres and horticultural research institutes, are unable to reach smallholders because of the high costs involved in dealing with widely dispersed clients that each requires only a small number of individuals of a particular tree species (Graudal and Lillesø 2007). This difficulty in access is one reason (amongst others described above) why the participatory domestication approach has been favoured when promoting indigenous fruit cultivation, as germplasm delivery to farmers is assured by their being directly involved in genetic improvement; in the case of exotic cultivars developed internationally, an alternative approach to farmer delivery is clearly required (Koskela *et al*. 2009).

Graudal and Lillesø (2007) have suggested that small-scale, decentralised, private nursery operators with low investment overheads provide the best basis for ensuring reach and sustainability in delivering healthy plants of new exotic fruit tree cultivars to farmers (see also Muriuki 2005). These entrepreneurs are currently being supported through training in successful propagation methods and business management, and through the provision of 'starter' germplasm for stockplant blocks. Greater support is however required to introduce new policies to discourage the common NGO practice of providing subsidised tree planting material to farmers, since this discourages the involvement of small-scale entrepreneurial suppliers (Brandi *et al*. 2007).

Lessons on what type of support to these entrepreneurs is likely to work best can be gleaned from the crop sector, which is generally more advanced (Graudal and Lillesø 2007, Lillesø *et al*. 2011). Innovations there are being tested in the Programme for Africa's Seed Systems (PASS, www.agra-alliance.org/section/work/seeds), the Vegetable Breeding and Seed Systems programme (vBSS, www.avrdc.org) and in other initiatives. PASS is concerned with broadening smallholder access to a range of agricultural inputs including improved staple crop seed, while vBSS involves supporting small African seed companies to supply new indigenous and exotic vegetable cultivars. Possibly, the delivery of tree germplasm can be made to 'piggyback' on crop seed delivery (Nathan *et al*. 2005). At some level, linkages also need to be established between the RRCs designed to promote the participatory domestication of IFTs (see above) and the delivery systems for exotic fruit trees, in a manner that supports the livelihoods of the people involved in both; this remains an important topic for research.

EXPANDING AND IMPROVING MARKETS AND MARKETING SYSTEMS FOR INDIGENOUS AND EXOTIC FRUITS

Market supply and demand

The recommended daily consumption of fruit and vegetables is a minimum of 400 g per person (World Health Organization [WHO] guidelines) but in sub-Saharan Africa it is significantly lower (Ruel *et al*. 2005, FAOSTAT at www.fao.org). Figures for fruit consumption in a range of countries in the region illustrate this (Table 2): in East Africa, for example, mean consumption is only 35g per person per day, one of the lowest levels in the world. One reason why current consumption is so low is that households with limited incomes focus on purchasing staples that provide relatively cheap and 'concentrated' sources of carbohydrate to meet basic energy needs, leaving only a small fraction of the family budget to spend on other foods such as fruit and vegetables (Ruel *et al*. 2005).

Domestic markets for fruit are, however, predicted to grow rapidly in the next two decades in sub-Saharan Africa as economies grow and provide local consumers more income to spend on fruit, and as human populations increase and a trend to urbanisation continues (IMF 2008, Bill and Melinda Gates Foundation, personal communication). This raises the issue of how much extra fruit in total needs to be consumed within African nations to meet WHO guidelines. Calculations show that, for example, more than a million tonnes annually would be required in each of Ethiopia, Ghana, Kenya, Mozambique, Tanzania and Uganda (Table 2). This provides some indication of the potential incomes for farmers, in the order of hundreds of millions of US Dollars annually, in supplying domestic markets in the future, if fruit can be produced and delivered to consumers more effectively.

A particular opportunity to develop domestic markets and influence child nutrition involves consideration of 'home grown school feeding' (HGSF). Traditionally, school feeding programmes in food-insecure areas of the sub-Sahara have relied on foods of limited nutritional quality and variety that have often been sourced from outside the region (Bundy *et al*. 2009, WFP 2009). In contrast, HGSF initiatives seek to link schools with local agricultural producers to promote a more diverse, nutritionally-balanced range of foods (WFP 2008). These programmes are currently in the pilot stage, with the New Partnership for Africa's Development (NEPAD) and the World Food Programme inviting twelve countries[1] to test implementation, but political support for HGSF is expected to grow in future years (WFP 2009). Another notable opportunity is to supply the rapidly developing supermarket sector in sub-Saharan Africa, although these retailers may favour linkages with medium- or large-scale farmers rather than smallholders, in order to operate greater control over the supply chain (Neven and Reardon 2004).

Export markets for smallholders' produce should also not be neglected, though these are currently much smaller in volume and value than local sales (Table 2, www.worldmapper.org). For example, mango exports are around 4% of total production only for sub-Saharan African countries for which data are available[2] (FAO 2005b), the rest of the crop being consumed locally. South Africa, where the export value of exotic fruits exceeds domestic markets (~ 65% of revenues from export, South Africa Agricultural Research Council figures for 2005), is an exception. It is unlikely that other nations will be able to replicate South Africa's success that is based on good infrastructure and large commercial fruit production enterprises rather than smallholders. Niche markets have developed, however, for various indigenous fruits among expatriate African communities and these could be more widely promoted to benefit small producers (Awono *et al*. 2002). In addition, new markets for indigenous fruits may develop as consumers in high-income nations experiment with new tastes. Entering these markets, however, requires that non-tariff barriers to trade, such as the European Union (EU) Novel Foods Regulation (which requires costly safety checks on 'new' foods) and importing countries' stringent phytosanitary requirements for fresh fruits, be addressed (Hermann 2009, www.phytotradeafrica.com).

[1] Angola, Democratic Republic of Congo, Ethiopia, Ghana, Kenya, Malawi, Mali, Mozambique, Nigeria, Senegal, Uganda and Zambia.
[2] Average figures for Cote d'Ivoire, Kenya, Mali and Sudan, for the years 1996 to 2004 inclusive.

TABLE 2 *Characteristics of domestic consumption and international fruit markets for 10 countries in sub-Saharan Africa*

Country	Average domestic fruit consumption (g/person/day)*	Average % family food budget spent on fruit*	Human population (millions)$^{\varphi}$	Annual national deficit in fruit consumption (thousands of tonnes)$^{\$}$	Average annual value of the fruit export market (thousands of US Dollars)^	Average annual percentage of all exports^
Burundi	41	1.8	8.2	476	12	< 0.1
Ethiopia	4	0.4	81.0	5 795	2 049	0.3
Ghana	64	2.1	23.0	1 142	116 654	2.9
Guinea	103	3.7	9.2	326	3 012	0.3
Kenya	71	1.9	36.6	1 723	41 179	1.5
Malawi	30	1.9	13.6	844	7 697	1.6
Mozambique	23	1.2	21.0	1 357	24 998	1.7
Rwanda	41	4.2	9.5	551	73	< 0.1
Tanzania	55	2.5	39.5	2 091	53 411	4.2
Uganda	34	1.1	29.9	1 812	1 305	0.2

* Data taken from Ruel *et al*. (2005) and based on home production, local collection, purchase and barter. According to Food and Agriculture Organization figures (for 2004, FAOSTAT at www.fao.org), average consumption worldwide is ~ 130 g/person/day, 210 g/person/day in developed countries and 110 g/person/day in developing countries. Africa has the lowest consumption of any continent, with East Africans for example consuming on average only ~ 35 g/person/day.

$^{\varphi}$ United Nations Statistics Division's estimates for 2006 (http://unstats.un.org/unsd/).

$^{\$}$ Implied deficit based on average domestic fruit consumption/person and total population, and assuming that half of the World Health Organization's recommended intake of fruit and vegetables of 400g/person/day is met by eating fruit.

^ Information taken from the trade performance statistics of the International Trade Centre (www.intracen.org/). Shown is the average annual value of the export market for the years 2002 to 2006 inclusive for edible fruit, nuts, peel of citrus fruit and melons (for most countries the majority represents fresh fruit). Data are likely to be underestimates because informal flows within regions (markets between neighbouring countries) are difficult to account for; nevertheless, the total value of exports is low. Also given for the same period is the average annual value of the market as a percentage of all exports. Over the same period, the equivalent average annual export value for South Africa was approximately 1 billion US Dollars, which represented around 2.5% of all exports from that nation.

Improving value chains to bring greater benefits to producers

Smallholder fruit producers have traditionally been 'price takers' rather than 'price makers' in markets (Ham *et al*., 2008, Jordaan *et al*. 2008). Value chain analysis, which seeks to characterise the processes by which products are brought from production to consumption (*via* harvesting, processing, storage, transport, marketing, etc.) and understand how value is created, has been carried out to identify and overcome bottlenecks in delivery (KIT *et al*. 2006). In Cameroon, for example, value chain analysis indicated important areas for intervention in the njansang (*Ricinodendron heudelotii*) nut market (Tchoundjeu *et al*. 2008). Key issues were the need for better harvest and post-harvest techniques to improve product quality based on market requirements, the need for storage facilities to allow sales to be scheduled to avoid market gluts, the need to strengthen farmers' producer groups to allow direct negotiations with wholesalers, and the need to introduce market information and credit facilities (Facheux *et al*. 2007). Support in these areas resulted in farmers receiving a 31% increase in price for njansang kernels.

TechnoServe (www.technoserve.org) undertook a similar approach to that applied to njansang to analyse the banana market in Kenya and Uganda, where multiple brokerage levels were found to deprive farmers of significant revenues (Milder 2008). Based on this analysis, smallholders were organised into producer business groups (PBGs) linked directly to wholesale banana buyers, which resulted in farmers' incomes rising by over 80% during the project. By 2008, more than 7 000 farmers had been trained to participate in more than 145 PBGs that used text messaging to exchange market information. As a result of the project, participating farmers have become increasingly interested in producing fruit of other species that can also be sold to the same wholesalers (Milder 2008). TechnoServe is applying the lessons from this project to a new initiative to link smallholder producers of mango and passion fruit (*Passiflora edulis*) in Kenya and Uganda to Coca-Cola's supply chain for locally-processed and consumed juices (substituting for imported fruit juice concentrate). Greater application of these lessons is required in other countries and on other fruit value chains to bring smallholders more effectively into markets.

FINAL REMARKS

Significant gaps in knowledge on the productivity, market value, net returns and other features of smallholder fruit production and markets in sub-Saharan Africa need to be filled to properly guide future investments by private enterprise, governments and development donors (Leakey *et al*. 2005, Schreckenberg *et al*. 2006, Akinnifesi *et al*. 2008). According to the Agricultural Science and Technology Indicators website, public research capacity on fruit promotion (breeding, horticulture, nutrition, pomology, value chain development, processing, market monitoring, etc.) in sub-Saharan Africa is low compared to other regions in the tropics, with only a fifth as many scientists engaged in research per unit area of production as in Asia (www.asti.cgiar.org). This deficit in human capacity must be addressed to continue developing appropriate solutions to current constraints. There is, for example, a need to understand how best to educate consumers on the benefits of eating fruit, and how to respond to the opportunities and challenges presented by climate change. In the first case, it is well known that children can be effective agents of change in societies and teaching them about agriculture and nutrition is considered a wise investment (Sherman 2003). In Kenya, for example, the Education for Sustainable Development initiative includes a Healthy Learning programme aimed at school children that is resulting in attitudinal and behavioural changes in communities (Vandenbosch *et al*. 2009). The effectiveness of such initiatives for fruit promotion in Kenya and elsewhere needs to be explored.

In the case of anthropogenic global warming, tree growth can be more resilient to climate change than annual crop growth (Dawson *et al*. 2011). However, for many fruits, pollination is dependent on specific environmental conditions and on animal vectors that may be adversely affected by change (Bazzaz 1998, FAO 2008, Jamnadass *et al*. 2009). It is important to match both tree and pollinator to newly prevailing environments resulting from climate change at specific locations. To do so involves mathematical modelling based on current species distributions and the predictions of future temperature and rainfall profiles (Kindt *et al*. 2008, Dawson *et al*. 2011). The starting point – information on the ecogeographic range over which species currently grow – is, however, often lacking for indigenous fruits (www.lifemapper.org). This deficiency is currently being addressed through the creation of detailed vegetation maps for Africa; these will become available for Ethiopia, Kenya, Malawi, Rwanda, Tanzania, Uganda and Zambia later in 2011 (en.sl.life.ku.dk/upload/forestday3.pdf). Multilocational field trials that compare the performance of a range of populations/cultivars across different ecological zones are also required to determine the relative roles of germplasm transfer and local adaptation as strategies for agroforestry production to respond to climate change (Dawson *et al*. 2011).

In conclusion, we recommend that, in the future, particular attention be given to the following eight points:

- Fruit tree portfolios of indigenous and exotic species that spread farmers' production risks and can provide nutrients to consumers year-round should be devised and promoted across sub-Saharan Africa. To do so, more information is required on species distributions, the priorities of farmers and consumers, genetic variability, fruiting phenology and nutritional composition.
- The expansion of rural resource centres as training, communication and infrastructure hubs for implementing both production and market activities for indigenous fruit trees should be accelerated, scaling up the successful model of the 'Food for Progress' project in Cameroon. The boundaries (under what conditions and involving what partners?) for the successful operation of these centres need to be established.
- Methods are required for applying intellectual property protection to farmer-derived indigenous fruit tree cultivars, in order to ensure farmers benefit from the wider distribution of the varieties they develop. Ensuring tree domestication issues are included in the pan-African intellectual property agenda, for resolution within global plant variety rights negotiations, is an important requirement.
- An improvement in yield and quality of exotic fruit trees already grown in the sub-Sahara region is required. This involves the introduction of improved varieties, farm management methods and processing approaches from Asia in particular. Liaising with breeders and regulatory authorities in China, India and Sri Lanka will be essential for bringing in new cultivars and methods.
- Greater emphasis should be placed on developing commercial, decentralised methods for delivering exotic fruit tree planting material to African smallholders, rather than relying on existing 'formal' suppliers that do not have adequate reach. Lessons on what works best from ongoing research on crop germplasm delivery to farmers need to be adapted and applied to fruit trees.
- The opportunities presented by home grown school feeding programmes and initiatives to educate school children in the importance of nutrition should receive more attention. Education should include the role of fruit in improving diet, methods for preparation and consumption, and appropriate agroforestry practices for growing fruit and other products and services.
- Constraints to market development for both indigenous and exotic fruits should be identified and overcome by promoting wider adoption of the value chain approach to analysis.
- The likely impacts of climate change on indigenous and exotic fruit production should be explored in greater detail so that appropriate species, cultivars and farm management methods can be adopted to increase resilience and adapt to change.

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