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Developing more productive African agroforestry systems and improving food and nutritional security through tree domestication

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The domestication of new tree crops is one means for improving food and nutritional security. In the last decade, a participatory domestication approach involving scientists and farmers in close collaboration has been developed in sub-Saharan Africa, based on satisfying household needs for tree foods and then growing to meet wider demands. The approach, when practiced in mixed agroforestry regimes that promote yields and resilience, has resulted in significant improvements in incomes, diets and in rural business development. In the next decade, successful agroforestry tree domestication approaches require scaling-up and better engagement is needed with markets. The domestication of the edible oil-producing tree allanblackia provides a model for the involvement of private–public partnerships in sustainable business development.

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Introduction

Solving the problem of food and nutritional security in sub-Saharan Africa, where nine of the 20 nations with the highest burden of child under-nutrition worldwide are found [1], and where fruit and vegetable consumption are well below global averages [2], requires a range of interconnected approaches, including improvements in crop yields, the bio-fortification of food staples and the cultivation of a wider range of edible plants [3]. As well as the greater use of a wider range of exotic crops, potential for agricultural diversification lies in the great range of lesser-used indigenous foods found naturally and traditionally managed in African forests and wooded lands, foods which are often richer in micronutrients, fibre and protein than staple crops [4] [Box 1]. In addition to providing human foods' directly, tree domestication provides animal fodder (important to support dairy and meat production) [5], improves soils (thereby supporting staple crop yields) [6], provides energy needs (important for the proper processing and cooking of food) [7] and supports incomes (for the purchase of foods) [8•,9].

The process of domestication — bringing plants into cultivation and adapting them to meet human needs — began over 10 000 years ago for annual crops [10], and for a few selected food trees has already occurred over several millennia, most obviously in Latin America [11–14]. The great majority of the world's >80 000 tree species are, however, still essentially wild or exist only as early stage, incipient domesticates [15], and in particular the domestication of African food trees has been limited, with few documented examples [16,17••] and limited characterisation work undertaken [18]. Access to wild food trees in Africa is however declining due to deforestation, and attention to bring species into wider cultivation provides opportunities to improve livelihoods, increase productivity, combat malnutrition and adapt to anthropogenic climate change [19,20]. This paper outlines our opinion and describes recent tree domestication progress in the region.

Tree domestication methods

Two basic approaches to tree domestication have been described. The first is a centralised approach involving field trials, controlled crosses and, in some cases, biotechnological breeding methods to carry out genetic improvement [21,22], while the second makes use of more decentralised community-driven strategies [23]. The first approach is straightforward to coordinate, and has been applied to exotic fruits planted in sub-Saharan Africa [17••], but the results do not always filter down to small-scale farmers, who face high transaction costs in obtaining external farm inputs such as tree planting material and the information needed on the management of cultivars [24]. The first approach is also a narrow view of domestication in that it focuses on genetic improvement,

Box 1 Examples of indigenous food trees important for domestication in sub-Saharan Africa (for further information on these and other important tree species for smallholders, see www.worldagroforestry.org/resources/databases/agroforestree)

Baobab: The edible white, powdery pulp found in the fruit of *Adansonia digitata* is very rich in vitamins C and B2. Young leaves are rich in vitamin C and are in high demand in West Africa as a soup vegetable.

Ber: The fruit of *Ziziphus mauritiana* is eaten fresh or dried and can be made into a floury meal, butter, or a cheese-like paste, and is a good source of carotene, vitamins A and C, and oils. Also native to Asia, large-fruited cultivars are found there.

Bush mango: The fruit mesocarp of *Irvingia gabonensis*, sweet bush mango, is appreciated as a fresh fruit snack. Ground kernels of *I. gabonensis* and *I. wombolu* are used to thicken and flavour soups.

Desert date: The fleshy pulp of *Balanites aegyptiaca* fruit is eaten dried or fresh, and oil from the kernel is used for cooking and cosmetics. Young leaves and tender shoots are used as a vegetable.

Marula: The fruit pulp of *Sclerocarya birrea* is used to produce jam, juice, beer and, in South Africa, the liqueur Amarula Cream, while the oily kernels are consumed raw, roasted and in sauces.

Njansang: A spicy sauce made from the kernels of *Ricinodendron heudelotii* is widely used in stews, and the high oil content of the seeds makes them suitable for use in the soap industry.

Safou: Extensively sold in local markets in Central and West Africa, *Dacryodes edulis* fruit are rich in vitamins and amino acids, and are eaten boiled or roasted.

Star apple: The fleshy and juicy fruits of *Chrysophyllum albidum* are popularly eaten, and can be fermented and distilled for the production of wine and spirits.

Tamarind: The fruit pulp of *Tamarindus indica* 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.

Wild loquat: The fruit of *Uapaca kirkiana* is highly regarded and is eaten fresh as well as to prepare jams and beverages. Harvesting of fruit from the wild is an important coping strategy during famine.

which — although very important — does not address the many other elements required for a successful tree cultivation programme, including decisions by communities on which species to prioritise for cultivation [25], developing efficient farm management methods in a smallholder context, and addressing the many other bottlenecks small-scale farmers face in planting a new crop, including social and political constraints [23].

In the last decade, greater attention has been given to more decentralised and holistic strategies in Africa. One decentralised method, referred to in the literature as the participatory domestication approach, has been developed through close collaboration between scientists and farmers and involves combining scientific advances in germplasm selection, propagation, processing, etc., with local communities' experiences in management to bring indigenous fruits and nuts into wider cultivation [26••]. The initial focus in participatory domestication is on satisfying immediate household needs for tree foods and then growth occurs through producing planting material for sale to other farmers and by the commercialisation of tree products [27••,28]. By supporting the domestication of a range of different trees, chosen by farmers who are guided in their choices by markets and other considerations, the approach is able to buffer production and market risks that may result from a focus on an individual species [29•]. The approach is being extended through the development of rural resource centres managed by local communities that: train farmers in how to propagate and manage trees; hold stockplants for vegetative propagation; link with smaller nurseries to provide germplasm more widely; provide fruit processing facilities and business training; and act as venues for farmers to meet and form associations that allow them to market their products and obtain services more effectively [30•].

The benefits of tree domestication

Increasing yield and value when bringing indigenous food trees into cultivation is essential, as if indigenous trees are not productive they have little chance of becoming properly established in farming systems, which will otherwise be dominated by a few staple crops, reducing agrobiodiversity and limiting resilience [31]. Genetic variation within wild and semi-wild populations of African food tree species is often high [17••], with >2- [32], >4- [33] and >5-fold variation common in nutrient content, yield and economic value, respectively, and lower but still important variation in other important traits [34]. Using simple cloning methods adopted by farmers, gains in multiple food traits (seed size, fruit thickness, shape, etc.) can be captured simultaneously, addressing markets' particular preferences [35], and the time between planting and maturity can be reduced compared to planting from seed, decreasing the time gap between investment and return for farmers [36].

Adoption of the participatory domestication method, particularly in the humid forest margins of Central Africa, where indigenous fruits and nuts are highly valued in the local economy [37–39], has resulted in significant improvements in incomes, diets and in rural business development, supporting diversified, more resilient and more productive farms and improving the social well-being of the communities involved [29•,30•]. A multifaceted approach by which agroforestry supports food and nutritional security, and provides other tree products and environmental services, involves the following steps: first, support for soil fertility replenishment technologies to improve overall farm productivity and increase staple crop self-reliance; second, participatory tree domestication of more nutritious fruit and nut trees (as described above); and, third, entrepreneurship and value-addition

to increase returns from tree product sales [40]. The allanblackia tree (a range of species in the *Allanblackia* genus), found wild in the humid forests of Central, East and West Africa, provides a model for the involvement of private-public partnerships in sustainable business development (www.allanblackia.info) [41,42•]. The seed of allanblackia yield edible oil with significant potential in the global food market of >100 000 tonnes annually. Wild harvesting, cultivation, market-development and conservation activities are being promoted in parallel, and the integration of allanblackia into small-scale cocoa farms is being promoted to support more biodiverse and resilient agricultural landscapes that spread farm production and farmers' incomes across the year. The involvement of Unilever and other commercial partners helps drive investment [41].

The dangers of domestication

Domestication processes always result in shifts and/or losses in underlying genetic diversity in manipulated populations that have implications for the sustainability of cultivation, but impacts on diversity depend on the domestication method adopted, with some approaches providing a better balance between productivity gains and conserving sufficient genetic variation to support longer term use [40,43]. Cloning may for example result in significant diversity bottlenecks, potentially mimicking commercial monoculture tree plantations which may be more vulnerable to pests and diseases [44] and other environmental catastrophes [31]. Risks are however reduced in participatory domestication when different villages each clone their local superior genotypes for planting, as a range of genotypes are maintained in the wider landscape. To be avoided, however, are production systems where a new tree crop takes over the farming landscape to the detriment of other crops, as has for example been observed in palm oil production systems elsewhere in the tropics [45,46] and in west Africa in cocoa production [47]. Mixed agroforestry regimes such as shade coffee and shade cocoa production systems (www.cocoasustainability.com/) that combine commodity crops, food trees (such as allanblackia, see above [41,42•]), staple crops and vegetables, etc., which maintain commodity yields and profitability and at the same time promote resilience [48] and maximise synergy [49], are required. Multi-functional, multi-species agroforestry systems are often favoured by small-scale farmers [30•], reducing overall production risks associated with losses of genetic diversity in any one species planted for a particular use.

Future directions

The domestication of high-value trees species in agricultural landscapes is increasingly being recognised for its important contribution to rural livelihoods, especially as natural forests that have otherwise provided tree products and services recede in the face of demand for agricultural land [19]. As human populations continue to grow and the demand for resources increases, tree domestication to provide food, fodder, medicines and other products is an important approach to meet demand. These tree products need to be grown in the right niches (hedgerows, gardens, contour strips, etc.) to complement other agricultural production options [30•,40]. For the future, a better understanding is required of the consequences of cultivation and market development for various livelihood indicators (poverty-, malnutrition-, hunger-alleviation, etc.) and for the status of and interactions between resources in forest and farmland [40,41]. A recent review of >400 papers on the topic [50••] assessed the progress that had been made in agroforestry tree domestication over the last ten years in comparison to the decade before. Between 1992 and 2001, there was a focus on assessing tree species potential and the development of propagation techniques. Between 2002 and 2011, more emphasis was placed on new techniques for assessing variation, on product commercialisation, and on adoption and impact issues. For the decade 2012 to 2021, it has been suggested [50••] that one of the major challenges in Africa and worldwide is to scale up successful agroforestry tree domestication approaches. To do this, an understanding of what approaches to tree domestication to date have been most effective in benefiting smallholders in improving incomes, food and nutritional security, health, etc., based on a more extensive quantification of impacts of past and present initiatives, is required. Particular attention should be given to evaluating the utility of the participatory domestication approach [26••] outside Central Africa, where to date it has been practiced most widely.

A second major challenge is better engagement with markets [50••]. Value chain analysis [51,52], used to map the actors participating in the production, distribution, marketing and sale of a particular product and to bring about positive change for smallholders and small-scale enterprises, is an important approach. For example, by organising smallholder banana growers into producer business groups linked buyers, TechnoServe (www.technoserve.org) improved farmers' incomes >80% in East Africa [53]. 'Nutrient-sensitive' value chains are required that improve nutritional knowledge and awareness among value-chain actors and consumers, that focus on promoting the involvement of women, and that consider markets for a wide range of tree foods [17••]. Lessons can be learnt from existing tree commodity crops such as cocoa, rubber and coffee that have an important role in supporting rural livelihoods. A better understanding of the complicating factors in the conversion of land to monoculture production of these commodities, and the effects of single-source incomes on food and nutritional security, are also required [9]. Commodity varieties that are highly productive and combine more effectively with other components in mixed farming systems, such as

better shade-adapted cocoa and coffee (and also other shade-tolerant crops such as yams, cocoyam, beans and sweet potatoes), are needed [22].

There has been an under-investment in the development of new tree lines, cultivars, etc., that have high yields and provide quality products under smallholder production conditions, with insufficient scientists working on bringing indigenous food trees into cultivation [17••] and in developing methods to deliver new cultivars to farmers [24]. Research should support existing and newly developing technologies [54] for tree domestication that are appropriate for meeting smallholders' needs, and assess complementarity and resilience in agroforestry systems under climate change, in the context of other global challenges to food and nutritional security [55].

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References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

1. Bryce J, Coitinho D, Darnton-Hill I, Pelletier D, Pinstrup-Andersen P: **Maternal and child under-nutrition: effective action at national level**. *Lancet* 2008, **371**:510-526.
2. Ruel MT, Minot N, Smith L: *Patterns and Determinants of Fruit and Vegetable Consumption in sub-Saharan Africa: A Multi-country Comparison*. Washington, DC, USA: International Food Policy Research Institute; 2005.
3. Frison EA, Cherfas J, Hodgkin T: **Agricultural biodiversity is essential for a sustainable improvement in food and nutrition security**. *Sustainability* 2011, **3**:238-253.
4. Leakey RRB: **Potential for novel food products from agroforestry trees**. *Food Chem* 1999, **64**:1-14.
5. Place F, Roothaert R, Maina L, Franzel S, Sinja J, Wanjiku J: *The impact of fodder trees on milk production and income among smallholder dairy farmers in East Africa and the role of research, ICRAF Occasional Paper No. 12*. Nairobi, Kenya: The World Agroforestry Centre; 2009.
6. Sileshi G, Akinnifesi FK, Ajayi OC, Place F: **Meta-analysis of maize yield response to planted fallow and green manure legumes in sub-Saharan Africa**. *Plant Soil* 2008, **307**:1-19.
7. World Bank: *Wood-based Biomass Energy Development for Sub-Saharan Africa: Issues and Approaches*. Washington, DC, USA: The World Bank; 2011.
8. • Gyau A, Chiatoh M, Franzel S, Asaah E, Donovan J: **Determinants of farmers' tree planting behaviour in the north west region of Cameroon: the case of *Prunus africana***. *Int Forest Rev* 2012, **14**:265-274.

This research paper discusses the main factors which influence farmers' attitudes towards tree planting using Cameron as a case study. Implications for policy and agroforestry practices are discussed.

9. Jamnadass R, Place F, Torquebiau E, Malézieux E, Iiyama M, Sileshi GW, Kehlenbeck K, Masters E, McMullin S, Weber JC, Dawson IK: *Agroforestry, food and nutritional security, ICRAF Working Paper No. 170*. Nairobi, Kenya: The World Agroforestry Centre; 2013.
10. Harlan JR: *Crops and Man*. Madison, WI, USA: The American Society of Agronomy and the Crop Science Society of America; 1975.
11. Clement CR: **A center of crop genetic diversity in western Amazonia**. *BioScience* 1989, **39**:624-631.
12. Clement CR: **Domesticated palms**. *Principles* 1992, **36**:70-78.
13. Clement CR: **1492 and the loss of Amazonian crop genetic resources, I. The relation between domestication and human population decline**. *Econ Bot* 1999, **53**:188-202.
14. Peters CM: **Precolombian silviculture and indigenous management of neotropical forests**. In *Imperfect Balance: Landscape Transformations in the Pre-Columbian Americas, Historical Ecology Series.* Edited by Lentz DL. New York, USA: Columbia University Press; 2000:203-223.
15. Miller AJ, Gross BL: **From forest to field: perennial fruit crop domestication**. *Am J Bot* 2011, **98**:1389-1414.
16. Maranz S, Wiesman Z: **Evidence for indigenous selection and distribution of the shea tree, *Vitellaria paradoxa*, and its potential significance to prevailing parkland savanna tree patterns in sub-Saharan Africa north of the equator**. *J Biogeogr* 2003, **30**:1505-1516.
17. •• Jamnadass RH, Dawson IK, Franzel S, Leakey RRB, Mithöfer D, Akinnifesi FK, Tchoundjeu Z: **Improving livelihoods and nutrition in sub-Saharan Africa through the promotion of indigenous and exotic fruit production in smallholders' agroforestry systems: a review**. *Int Forest Rev* 2011, **13**:338-354.

This review describes the value of smallholder cultivation of fruit trees in sub-Saharan Africa and the bottlenecks that need to be addressed to bring wider benefits. Many of the key interventions identified by the authors to address current constraints to production apply to the domestication of trees generally in the region.

18. Jamnadass R, Lowe A, Dawson IK: **Molecular markers and the management of tropical trees: the case of indigenous fruit**. *Trop Plant Biol* 2009, **2**:1-12.
19. FAO: *Global forest resources assessment 2010, FAO Forestry Paper No. 163*. Rome, Italy: Food and Agriculture Organization of the United Nations; 2010.
20. Dawson IK, Vinceti B, Weber JC, Neufeldt H, Russell J, Lengkeek AG, Kalinganire A, Kindt R, Lillesø JB, Roshetko J *et al.*: **Climate change and tree genetic resource management: maintaining and enhancing the productivity and value of smallholder tropical agroforestry landscapes. A review**. *Agroforest Syst* 2011, **81**:67-78.
21. Ray PK: *Breeding Tropical and Subtropical Fruits*. Berlin, Germany: Springer-Verlag; 2002.
22. Mohan Jain S, Priyadarshan PM (Eds): *Breeding Plantation Tree Crops. Tropical Species*. New York, USA: Springer Science + Business Media; 2009.
23. Leakey RRB, Akinnifesi FK: **Towards a domestication strategy for indigenous fruit trees in the tropics**. In *Indigenous Fruit Trees in the Tropics: Domestication, Utilization and Commercialization.* Edited by Akinnifesi FK, Leakey RRB, Ajayi OC, Sileshi G, Tchoundjeu Z, Matakala P. *et al.*: Wallingford, UK/ Nairobi, Kenya: CAB International in association with The World Agroforestry Centre; 2008:28-49.
24. Lillesø J-PB, Graudal L, Moestrup S, Kjær ED, Kindt R, Mbora A, Dawson I, Muriuki J, Raebild A, Jamnadass R: **Innovation in input supply systems in smallholder agroforestry: seed sources, supply chains and support systems**. *Agroforest Syst* 2011, **83**:347-359.
25. Franzel S, Jaenicke H, Janssen W: *Choosing the right trees: setting priorities for multipurpose tree improvement. ISNAR Research Report No. 8*. The Hague, The Netherlands: International Service for National Agricultural Research; 1996.
26. •• Tchoundjeu Z, Asaah EK, Anegbeh P, Degrande A, Mbile P, Facheux C, Tsobeng A, Atangana AR, Ngo-Mpeck ML, Simons AJ: **Putting participatory domestication into practice in West and Central Africa**. *Forests Trees Livelihoods* 2006, **16**:53-69.

The authors describe key features of the participatory tree domestication approach that has been successfully applied in Central Africa.

27. •• Leakey RRB, Tchoundjeu Z, Schreckenberg K, Simons AJ, Shackleton S, Mander M, Wynberg R, Shackleton C, Sullivan C: **Trees and markets for agroforestry tree products: targeting poverty reduction and enhanced livelihoods**. In *World Agroforestry into the Future*. Edited by Garrity D, Okono A, Parrott M, Parrott S. Nairobi, Kenya: The World Agroforestry Centre; 2007: 11-22.

This review describes the importance of commercialisation in linking tree production with markets for successful tree domestication initiatives.

28. Tchoundjeu Z, Atangana A, Asaah E, Tsobeng A, Facheux C: **Domestication, utilisation, and marketing of indigenous fruit trees in West and Central Africa**. In *Indigenous Fruit Trees in the Tropics: Domestication, Utilization and Commercialization.* Edited by Akinnifesi FK, Leakey RRB, Ajayi OC, Sileshi G, Tchoundjeu Z, Matakala P. *et al.*: Wallingford, UK/Nairobi, Kenya: CAB International in association with The World Agroforestry Centre; 2008:137-170.

29. • Tchoundjeu Z, Degrande A, Leakey RRB, Nimino G, Kemajou E, Asaah E, Faceux C, Mbile P, Mbosso C, Sado T, Tsobeng A: **Impacts of participatory tree domestication on farmer livelihoods in West and Central Africa**. *Forests Trees Livelihoods* 2010, **19**:217-234.

The authors describe how impact can be measured in a participatory tree domestication programme, and improvements in income, diet and other livelihood measures achieved through adoption.

30. • Asaah EK, Tchoundjeu Z, Leakey RRB, Takousting B, Njong J, Edang I: **Trees, agroforestry and multifunctional agriculture in Cameroon**. *Int J Agric Sust* 2011, **9**:110-119.

This review describes the utility of a multifunctional agricultural approach, involving participatory tree domestication as an important component, to improve the lives of smallholders in Cameroon.

31. Sunderland TCH: **Food security: why is biodiversity important?** *Int Forest Rev* 2011, **13**:265-274.

32. Thiongo MK, Jaenicke H: **Preliminary nutritional analysis of marula (*Sclerocarya birrea*) fruits from two Kenyan provenances**. *Acta Hort* 2000, **531**:245-249.

33. Peprah T, Ofori DA, Siaw DEKA, Addo-Danso SD, Cobbinah JR, Simons AJ, Jamnadass R: **Reproductive biology and characterization of *Allanblackia parviflora* A, Chev. in Ghana**. *Genet Resour Crop Evol* 2009, **56**:1037-1044.

34. Atangana AR, Van der Vlis E, Khasa DP, Van Houten D, Beaulieu J, Hendrickx H: **Tree-to-tree variation in stearic and oleic acid content in seed fat from *Allanblackia floribunda* from wild stands: potential for tree breeding**. *Food Chem* 2011, **126**:1579-1585.

35. Leakey RRB, Page T: **The 'ideotype concept' and its application to the selection of 'AFTP' cultivars**. *Forests Trees Livelihoods* 2006, **16**:5-16.

36. Leakey RRB: **Physiology of vegetative reproduction**. In *Encyclopaedia of Forest Sciences.* Edited by Burley J, Evans J, Youngquist JA. London, UK: Academic Press; 2004:1655-1668.

37. Awono A, Ndoye O, Schreckenberg K, Tabuna H, Isseri F, Temple L: **Production and marketing of safou (*Dacryodes edulis*) in Cameroon and internationally: market development issues**. *Forests Trees Livelihoods* 2002, **12**:125-147.

38. Degrande A, Schreckenberg K, Mbosso C, Anegbeh P, Okafor V, Kanmegne J: **Farmers' fruit tree-growing strategies in the humid forest zone of Cameroon and Nigeria**. *Agroforest Syst* 2006, **67**:159-175.

39. Schreckenberg K, Awono A, Degrande A, Mbosso C, Ndoye O, Tchoundjeu Z: **Domesticating indigenous fruit trees as a contribution to poverty reduction**. *Forests Trees Livelihoods* 2006, **16**:35-51.

40. Leakey RRB: **Agroforestry: a delivery mechanism for multi-functional agriculture**. In *Handbook on Agroforestry: Management Practices and Environmental Impact. Environmental Science, Engineering and Technology Series.* Edited by Kellimore LR. Hauppauge, USA: Nova Science Publishers; 2010: 461-471.

41. Jamnadass R, Dawson IK, Anegbeh P, Asaah E, Atangana A, Cordeiro N, Hendrickx H, Henneh S, Kadu CAC, Kattah C *et al.*: **Allanblackia, a new tree crop in Africa for the global food industry: market development, smallholder cultivation and biodiversity management**. *Forests Trees Livelihoods* 2010, **19**:251-268.

42. • Ofori DA, Kehlenbeck K, Munjuga M, Jamnadass R, Asaah E, Kattah C, Rutatina F: ***Allanblackia* species: a model for the domestication of high potential tree crops in Africa**. *Acta Hort* 2013, **979**:311-318.

This case study on allanblackia highlights the importance of public-private partnerships in tree domestication.

43. Cornelius JP, Clement CR, Weber JC, Sotelo-Montes C, van Leeuwen J, Ugarte-Guerra LJ, Ricse-Tembladera A, Arevaro-Lopez L: **The trade-off between genetic gain and conservation in a participatory improvement programme: the case of peach palm (*Bactris gasipaes* Kunth)**. *Forests Trees Livelihoods* 2006, **16**:17-34.

44. Wagner MR, Agyemang VK, Cobbinah JR, Ofori DA, Nichols JD: **Agroforestry and mixed species plantations as pest management strategies for *Phytolyma lata* in West Africa**. In *Research Advances in Restoration of Iroko as a Commercial Species in West Africa.* Edited by Cobbinah JR, Wagner MR. Kumasi, Ghana: Forestry Research Institute of Ghana; 2000: 65-76.

45. Donald PF: **Biodiversity impacts of some agricultural commodity production systems**. *Conserv Biol* 2004, **18**:17-37.

46. Danielsen F, Beukema H, Burgess ND, Parish F, Brühl CA, Donald PF, Murdiyarso D, Phalan B, Reijnders L, Struebig M, Fitzherbert EB: **Biofuel plantations on forested lands: double jeopardy for biodiversity and climate**. *Conserv Biol* 2009, **23**:348-358.

47. Ruf FO: **The myth of complex cocoa agroforests: the case of Ghana**. *Hum Ecol* 2011, **39**:373-388.

48. Clough Y, Barkmann J, Juhrbandt J, Kessler M, Wanger TC, Anshary A, Buchori D, Cicuzza D, Darras K, Putra DD *et al.*: **Combining high biodiversity with high yields in tropical agroforests**. *PNAS* 2011, **108**:8311-8316.

49. Steffan-Dewenter I, Kessler M, Barkmann J, Bos MM, Buchori D, Erasmi S, Faust H, Gerold G, Glenk K, Gradstein RS *et al.*: **Trade-offs between income, biodiversity, and ecosystem functioning during tropical rainforest conversion and agroforestry intensification**. *PNAS* 2007, **104**:4973-4978.

50. •• Leakey RRB, Weber JC, Page T, Cornelius JP, Akinnifesi FK, Roshetko JM, Tchoundjeu Z, Jamnadass R: **Tree domestication in agroforestry: progress in the second decade**. In *Agroforestry: The Future of Global Land Use. Advances in Agroforestry.* Edited by Nair PKR, Garrity D. The Netherlands: Springer; 2012:145-173.

This review describes the evolution of tree domestication programmes over the last twenty years, and key areas for future work in the next decade, including impact assessment and scaling-up of appropriate options.

51. Leakey RRB, Tchoundjeu Z, Schreckenberg K, Shackleton SE, Shackleton CM: **Agroforestry tree products (AFTPs): targeting poverty reduction and enhanced livelihoods**. *Int J Agric Sust* 2005, **3**:1-23.

52. Kaplinsky R, Morris M: *A Handbook for Value Chain Research*. Ottawa, Canada: International Development Research Centre; 2002.

53. Milder B: **Closing the gap: reaching the missing middle and rural poor through value chain finance**. *Ent Dev Microfin* 2008, **19**:301-316.

54. Dawson IK, Hedley P, Guarino L, Jaenicke H: **Does biotechnology have a role in the promotion of underutilised crops?** *Food Policy* 2009, **34**:319-328.

55. Neufeldt H, Dawson IK, Luedeling E, Ajayi OC, Beedy T, Gebrekirstos A, Jamnadass RH, König K, Sileshi GW, Simelton E: *Climate change vulnerability of agroforestry, ICRAF Working Paper No. 143*. Nairobi, Kenya: The World Agroforestry Centre; 2012.