Tree germplasm management systems and their potential for sustaining plantation forestry in West and Central Africa

Marie Louise Tchamdjou Avana-Tientcheu
Université de Dschang

Fongnzossie Fedoung Evariste
University of Douala

Kemeuze Victor

Ngueguim Jules Romain
Institute of Agricultural Research for Development

African Journal of Rural Development, Vol. 4 (1): January-March 2019: pp. 33-63. ISSN 2415-2838

Tree germplasm management systems and their potential for sustaining plantation forestry in West and Central Africa

M. L. AVANA-TIENTCHEU[1]*, C. MARUNDA,[2] E. F. FONGNZOSSIE,[3] V. A. KEMEUZE,[4] J. R. NGUEGUIM and D. MUTTA[5]

[1]University of Dschang, Faculty of Agronomy and Agricultural Sciences, Department of Forestry, P.O. Box 96, Dschang, Cameroon

[2]Forestry Tasmania, Plantation Productivity Branch, 79 Melville Street, Hobart, Tasmania, 7000, Tasmania, Australia

[3]University of Douala, Higher Teacher's Training School for Technical Education, P.O. Box 1872, Douala, Cameroon

[4]University of Ngaoundéré, Faculty of Science, P.O. Box 454, Ngaoundéré, Cameroon

[5]Ministry of Scientific Research and Inovation, Agricultural Research Institute, Limbé, P.O. Box 77, Limbé, Cameroon

[6]African Forest Forum, P.O. Box 30677-00100, Nairobi, Kenya

Corresponding author: avanatie@yahoo.fr

ABSTRACT

In West and Central Africa (WCA), despite the significant increase in plantation forest establishment, quality and quantity tree germplasm supply is still challenging. This study explored institutional and operational frameworks for tree seed management and analysed the extent of forestry and agroforestry plantation within the WCA countries. The study approach was based on literature review, field visits, interview of staff of tree seed centres and other institutions in charge of reforestation/afforestation in four countries. The findings show a net increase of forest plantation by 122% from 1990 to 2015, driven by an enabling political and institutional framework and the domestication of various indigenous fruit and timber tree species. Trees and germplasm improvement in the region are still in their early stage. Tree seeds supply is adequate for exotics, but grossly inadequate for indigenous species. Overall, seed policies are either inadequate or lacking. The contribution of the informal sector to seed supply chain remain high, therefore offsetting the quality, quantity and diversity of germplasm deployed. The study urges for the development and harmonisation of sound seed policies, technology transfer among countries and the establishment/strengthening of national tree seed centres for sustainable production and supply of quality tree germplasm for plantation forestry in WCA.

Keywords: Germplasm sources and supply, informal sector, plantation drivers, priority species, seed policies and markets, West and Central Africa

RÉSUMÉ

En Afrique de l'Ouest et du Centre (AOC), malgré l'augmentation significative des plantations forestières, l'approvisionnement en semences d'arbres de qualité et en quantité reste contraignant. Cette étude a exploré les cadres institutionnels et opérationnels pour

Cite as: Avana-Tientcheu, M. L., Marunda, C., Fongnzossie, E. F., Kemeuze, V. A., Ngueguim, J. R. and Mutta, D. 2019. Tree germplasm management systems and their potential for sustaining plantation forestry in West and Central Africa. African Journal of Rural Development 4 (1): 33-63.

Received: 10 September 2018
Accepted: 12 March 2019
Published: 31 March 2019

la gestion des semences forestières et analysé l'étendue des plantations forestières et agroforestières dans les pays de l'AOC. L'approche méthodologique était basée sur une analyse documentaire, des visites de terrain, des entretiens avec le personnel des centres nationaux de semences forestières et d'autres institutions en charge du reboisement et du boisement dans quatre pays de la sous-region. Les résultats montrent une augmentation nette de 122% des plantations forestières entre 1990 et 2015, grâce à un cadre politique et institutionnel favorable et à la domestication de diverses espèces locales d'arbres fruitiers et forestiers. L'amélioration des arbres et du matériel génétique dans la région en est encore à ses débuts. L'approvisionnement en semences d'arbres est adéquat pour les espèces exotiques, mais reste largement inadéquat pour les espèces locales. Dans l'ensemble des pays, les politiques semencières sont soit inappropriées, soit inexistantes. La contribution du secteur informel à la chaîne d'approvisionnement en semences reste élevée, ce qui remet en question la qualité, la quantité et la diversité du matériel génétique utilisé. L'étude préconise le développement et l'harmonisation de politiques semencières saines, le transfert de technologie entre les pays et la création/le renforcement de centres nationaux de semences d'arbres pour la production durable et la distribution de matériel génétique de qualité pour la plantation forestière en AOC.

Mots-clés : Sources des semences, secteur informel, moteurs des plantations, espèces prioritaires, politiques et marchés des semences, Afrique de l'Ouest et du Centre

INTRODUCTION

West and Central Africa (WCA) region is known to host the second most important forest landscape in the world (Malhi *et al.,* 2018). This region is home to a variety of ecosystems ranging from lowland evergreen rainforests, semi-deciduous forests, to tropical savannahs and other woodlands. These ecosystems are known as the main source of industrial timber for the continent (Okali and Eyog, 2004). They also provide non-timber products to meet subsistence needs of local populations and contribute to national economy of producing countries (Eba'a *et al.,* 2015; Hetemaski and Hurmekoski, 2016). Many people in WCA countries depend on tree products and services for food, health, shelter, energy as well as many other livelihoods needs, and their demand is estimated to increase given the population growth and the development of new markets and products (Leakey and van Damme, 2014; Endamana *et al.,* 2015; Rasmussen *et al.,* 2017). However, these forests are under high pressure of deforestation and degradation, driven by unsustainable agricultural practices, infrastructure development and overexploitation of some high value species. In Côte d'Ivoire for example, the forest cover decreased from 16 million ha in early 1900 to 2.5 million ha in year 2000 (FOSA, 2000). In some countries like Cameroon, although the forest cover did not significantly change, their economic and ecological values have been reduced by selective logging and many other anthropogenic factors (Marien and Mallet, 2004; EDF, 2013; Shu, 2013). Recent estimates indicate an overall decrease of 10% of the forested land in WCA (FAO, 2014). For the Congo Basin Forest, reduction in forest area include 20% for humid forest and 40% of dry forests. Meanwhile, more than 70% of the forest cover has already been lost in many Sahelian countries (Ariori and Ozer, 2005; EDF, 2013; FAO, 2014). Therefore, to meet increased demand for forest and tree products, many plantations have been established in different countries in the region since early 1900s (FAO, 2000; Chamshama *et al.,* 2009). Of the 8 million ha of forest plantations estimated in year 2000 in Africa, 42% were found in West and Central Africa (FAO, 2003a; FAO, 203b; Chamshama, 2011; Koskela *et al.,* 2014). It is estimated that the increasing demand for ecological services (trees for soil fertility improvement, conservation of water catchment), forest products (fruit, fuelwood, fiber, fodder and timber), climate change adaptation and mitigation will only be met from expanding cover of planted forests rather than from natural forest (FRA, 2015; Sloan and Sayer, 2015). Therefore, an efficient tree germplasm supply system is of critical importance for establishing sustainable forest plantations and agroforestry programs (Nyoka *et al.,* 2011; Thomas *et al.,* 2015).

Tree Seed System is composed of actors (organisations, individuals) involved in different roles/functions (breeding, multiplication, testing, processing, storage, marketing) toward tree seeds production and distribution to meet different tree planting objectives (Figure 1). Lillesø *et al.* (2011) described eigth tree seed supply systems based on the three main components of the input supply chain (seed sources, seed procurement, seeds and seedlings distribution) and the dichotomic (centralised or decentralised) control approach involved in the management at each component level. These were further grouped into three major models namely the Government Model, the Non Govenmental Organisation Model (NGO Model) and the decentralised Model. The application of this approach of seed systems classification is important in all countries to rightly understand the type of tree germplasm sources being used as well as the logistical and institutional processes involved in their deployment (Lillesø *et al.,* 2018).

One key element for improving tree performance and production is to ensure the availability of high-quality germplasm to meet plantation needs (Koskela *et al.,* 2014; Thomas *et al.,* 2015). National tree seed centers are therefore expected to play an important role in the procurement, collection, processing, storage and distribution of high-quality forest tree seeds. In addition, they serve as *ex situ* seed gene banks use for the conservation of forest genetic resources, to undertake research and to formulate policies that guide tree seed procurement and deployment (Phartyal *et al.,* 2002; Koskela *et al.*, 2014; Thomas *et al.,* 2015). However, an earlier evaluation indicated that most of the 50 National Tree Seeds Centers established from 1960 to 2005 in tropical

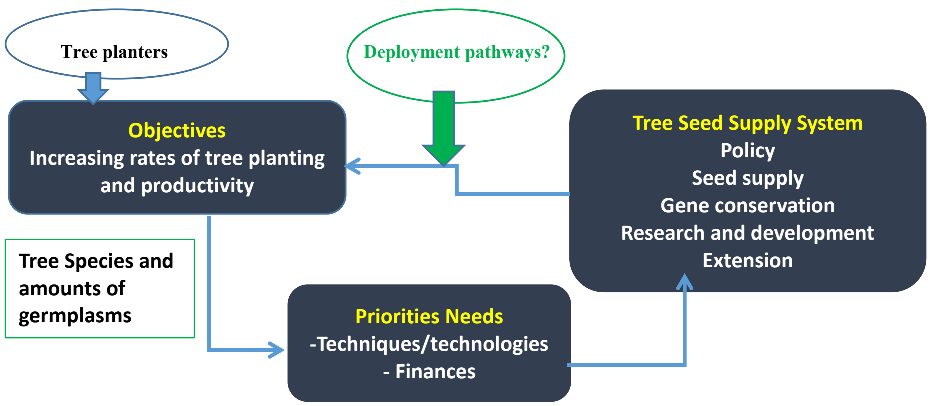

Figure 1. Principles of tree germplasm Deployment/flow (Adapted from Nyoka *et al.,* 2015)

countries were either not fully operationals or unable to satisfy the increasing need for quality tree seeds for afforestation/reforestation projects (Nyoka *et al.,* 2015). There is therefore a need to document alternative approaches of tree seed systems being developed in different contexts (Dedefo *et al.,* 2017).

Climate change will exacerbate the current constraint related to poor access to quality tree germplasm by affecting distribution, productivity, pests and diseases risks, grow and development performance for many tree species. A recent evaluation of 38 Project Design Documents (PDD) for 38 Afforestation/Reforestation Clean Development Mechanism (CDM) projects had raised a concern about how to ensure germplasm access to meet the tree planting objectives (Roshetko *et al.,* 2017). To address these shortfalls, tree seeds management systems should build on specific germplasm-based climate change opportunities as suggested by Dawson *et al*. (2011).

In this paper, tree seed production and supply system in WCA is reviewed with a focus on the extent of forest plantations and associated tree germplasm needs, current state of tree improvement activities, techniques to produce improved germplasm and planting stocks, status of existing seedbanks and gene-bank in the region as well as seed supply, processing and distribution networks in WCA countries.

RESEARCH APPROACH

This study was carried out in two parts, as a desktop literature review and field visits in four west and central African countries namely the Republic of Congo, Cameroon, Senegal and Burkina Faso. The study countries were chosen based on the extent of their forestry plantations and tree planting activities (Cameroon and Congo) as well as the existence of an operational Tree seed centre or programme (Burkina Faso and Senegal).

Literature review was based on the following thematic areas:

a) sustainable forest management issues as they relate to commercial and community tree planting activities in WCA;
b) species introductions, provenance testing, and conservation of key species;
c) policies that are affecting afforestation and reforestation programmes.

The country visits were designed to meet with key forest plantation industry players, policy makers, foresters and development practitioners. Discussions with these actors yielded information on reforestation and afforestation rates, the range of species planted, seed deployment strategies and constraints, seed demand and supply, mains species being used in forestry and agroforestry plantations and on-going forestry and agroforestry projects. A standard questionnaire was designed and administered during field visits to managers of tree seed centres/programmes and other institutions involved in afforestation and reforestation activities. These informations were analysed to understand their seed sources, procurement and distribution strategies as well as their national and international collaborating partners. Information was also collected on activities for tree planting for both commercial, non-commercial, indigenous and exotic trees species, afforestation and reforestation rates, gaps in planting activities, seed and seedling production capacities, opportunities and constraints, institutions and policies impacting on germplasm production, research and development.

For countries not visited, information was searched in the literature. Telephone conversations were also conducted with key actors when possible on some important points of the questionnaire. The questionnaires were also sent via emails to those who agreed to fill them out.

Information from filled questionnaire were analysed together with those from literature review to document the extent of forestry plantation and tree seed systems in WCA countries.

FINDINGS AND DISCUSSION

State of forest plantations in WCA. According to FAO (2015), the planted forests in WCA covered 16 million ha representing 2.56 % of the African total forest cover, and accounting for 5.8 % of the global forest planted area. There has been a significant increase in tree planting during the past decades in many countries within the region. The total area of forest cover in the region changed from 346.6 to 313.0 million ha from 1990 to 2015 of which only 3.3 million ha is planted (Payn *et al.,* 2015). The area of forest plantation increased from 1, 204, 000 ha in 1990 to 2, 089, 000 ha in 2010 and 3, 300, 000 ha in 2015, representing roughly 20 % of the forest plantation cover on the African continent (Table 1). The annualised change in planted forest area from 1990 to 2015 was estimated to be 3.2 % (Payn *et al.,* 2015). The increasing rate of planted forest cover in some WCA countries was estimated using the benchmark forest areas in 1990's for Ghana (220 %), Côte d'Ivoire (118 %), Rwanda (85 %), Nigeria (80 %), and Senegal (75 %) (FAO, 2010). Since 1990, the change in planted forest in WCA FAO-sub region has been estimated to be 122 %, indicating very high rates of tree planting (Payn *et al.,* 2015).

The planting approach adopted by many countries is consistent with the concept of "Forest Landscape Restoration". In this approach, many actors such as farmers plant trees as part of their land-use, while governments, NGOs and private sectors are involved in agroforestry promotion and forestry plantations management, respectively (Harris, 1993; Eyog Matig *et al.,* 2002; Marien and Gourlet-Fleury, 2013; Laestadius *et al.,* 2015).

Most forest plantations within the region are established and managed by public forestry agencies, except for the Republic of Congo. These publicly owned forest plantations are generally reported to be in poor state due to inadequate governance frameworks, weak capacity of forestry departments, inappropriate silvicultural management, financial constraints, and lack of purposeful research (MacDicken *et al.,* 2015). Côte d'Ivoire is reported as the only WCA country with well managed publicly owned forest plantations (Payn *et al.,* 2014).

In Central African countries, the new silvicultural approach for sustainable natural forest management combined with the development of forest plantations in degraded forest and savanna areas constituted the main strategy to maintain or even extend forest cover within the region (Marien and Gourlet-Fleury, 2013). In the dryland part of the region, many plantations have been established to try to stop, or even to reverse, the desertification process, which is the main ecological problem of numerous countries with arid climates like Niger, Chad, Mali, Nigeria, Burkina Faso, Mauritania, Senegal (FAO, 2000a; Sacandé *et al.,* 2015). Among these tree plantation programmes, is the Great Green Wall initiative, launched since 2011 in the Sahel and Sahara involving 12 countries of which more than 90% are from West Africa (Sacandé *et al.,* 2015).

At the same time, individually owned woodlots are now widespread in some WCA countries like Cameroon, Ghana and Nigeria. Though information on their extent is still unreliable, these privately-owned woodlots are known to significantly contribute as major source of fuelwood, poles and common non-timber forest products and continue to play an important role in the livelihoods of rural communities and national economies (Buongiomo and Zhu, 2014; Whiteman *et al.,* 2015).

Constraints and opportunities for forest plantation development in WCA countries. Despite several forest plantation initiatives, Ariori and Ozer (2005) demonstrated a continuous decline, at a rate of -2% of forest cover per year in some Sahelian countries (Burkina Faso, Chad, Guinea Bissau, Mauritanie, Mali, Niger, Sénégal) during the second half of the 20th century. From their study, it was shown that 15 out of 44 sites covered by forests in 1955 had disappeared, while many other forested lands were reduced by more than 70% of their initial surface area. The main cause of planted forest loss identified were increased demand for fuel and other wood products (93% of respondents) and forest land conversion into agriculture (89% of respondents). A similar trend was reported in other WCA countries (Payn *et al.,* 2015).

In Cameroon, the planted forest cover estimated at 35800 ha in 1990 was reduced to 6631 ha in 2007, driven mainly by human activities such as agriculture expansion, firewood exploitation and settlements (MINEF, – FAO, 2007; Ngueguim, 2014). In 2006, the Government launched a national program of reforestation with the aim of sustaining its forest capital and support decentraliszed organisations (city councils, community based organiszations, NGOs, schools, and universities) for the creation and management of forest plantations for social, economic and environmental benefits (MINFOF, 2006). As a result of this initiative, recent estimates indicated that up to 4665 ha of forest have been planted from 2010 to 2015 (MINFOF, 2016). However, new data on Cameroon forest cover missed these reforestation initiatives.

In the Republic of Congo, among the 70,000 ha of forest plantations estimated in 2007, 42 000 ha were made of clonal Eucalyptus established in the coastal plains of Kouilou and owned by a private industrial company called Eucalyptus-Fibre du Congo (EFC). Moreover, the National Society of Reforestation (SNR) in collaboration with some forestry industries had undertaken a programme of enrichment planting of exploited forests as well as establishment of forest plantation using species such as *Aucoumea klaineana* (Okoumé), *Entandrophragma cyndricum* (Sapelli), *E. util*e (Sipo), *T. superba* (Limba) (Marien and Gourlet-Fleury, 2013). Agroforestry plantations involving community-based organisations are being promoted through the production and distribution of seedlings of nitrogen fixing shrubs such as *Albizzia lebbeck, Flemingia congesta, Gliricidia sepium*, *Leucaena leucocephala* and *Piliostgma malarborium* (Matondo, 2013).

In Benin, forest plantations have been estimated to cover 19000 ha mainly dominated by *Tectona grandis* planted both by state institutions and farmers for pole production (Aoudji *et al.,* 2014). A recent assessment in 2013 of land use and land cover change for a 33 years period in the country indicated that although tree plantations are expected to double by 2025, they will not compensate for the loss of natural woody vegetation (Toyi *et al.,* 2013). The situation is different in Senegal, where the area planted during the period from 1933 to 1998 was estimated at 65 000 ha, located mainly in the central northern zone of the groundnut basin. Since 1990s, State-controlled plantations were being replaced by village-based and private planting programmes showing the beginnings of enthusiasm among local people to participate in natural resource management programmes (Diouf *et al.,* 2001).

In Niger, the most important forest ecosystem of the country is represented by agroforestry parks dominated by *Faidherbia albida, Borassus aethiopum, Hyphene thebaica, Vitellaria paradoxa, Prosopis africana* and *Neocarya macrophylla*, covering an estimated surface area of 5 000 000 ha for Zinder and Maradi (CNEDD, 2014). This agroforestry effort is supplemented by urban and peri-urban forestry plantations under the umbrella of the Great Green Wall Initiative, with 2500 ha of plantation for the town of Niamey (CNEDD, 2014). In Togo, forest plantations have been established since the colonial period, using exotic species such as *T. grandis, Eucalyptus* spp., *Cassia* spp., *Acacia* spp., *Leucaena* and *Anacardium occidentale.*

Other success stories on indigenous and exotic forest/agroforestry tree plantations in some Central African countries have been reported to include *A. klaneana* in Gabon, *Terminalia superba*, *Eucalyptus* spp. and *Pinus* spp. (Republic of Congo), cocoa agroforests under the shade of timber species (Cameroon), *Acacia auriculiformis* based agroforestry plantation (Democratic Republic of Congo) (Marien and Mallet, 2004; Biseaux *et al.,* 2009).

The statistics on planted forests are not reliable in several countries (e.g. Guinea, Ghana, Liberia, and Chad) because of lack of inventories, frequent fires, poor maintenance and/or uncontrolled clearing (Payn *et al.*, 2014). Although some countries (e.g. Republic of Cameroon, Congo, Côte d'Ivoire, Benin, and Nigeria), have significant areas of industrial forest plantations using mainly exotic species, plantations for timber production, which are expensive and difficult to manage, have been insufficient to compensate for the extensive exploitation of natural forests. In addition, the

Table 1. Forest statistics changes for countries in the West and Central Africa region from 2010 to 2015

Country	Forest cover (ha)	% cover	2010 Deforestation (ha yr^{-1})	2010 Afforestation (ha yr^{-1})	2010 Reforestation (ha y^{r-1})	2015 Plantations (ha)	%Net change (2015)
Central Africa							
Central Africa Republic	22 170 000	35.6		400		2 000	-1.0
Cameroon	18 816 000	39.8				260 000	-1.0
Congo	22 334 00	65.4			100	71 000	-1.0
Democratic Republic of Congo	152 578 000	67.3		300		60 000	-0.2
Equatorial Guinea	1 560 000	55.9				58 500	-0.7
Gabon	23 000 000	89.3				30 000	0.2
Tchad	4 875 000	3.9					
West Africa							
Benin	4 311 000	39.0			14 600	23 000	-1.2
Burkina Faso	5 350 000	19.6		15 000	14 000	239 000	-1.0
Côte d'Ivoire	1 040 000	32.7				427 000	0.1
Gambie	488 000	78.8				1 000	0.4
Ghana	9 337 000	41.0		0	20 000	325 000	0.3
Guinee	6 364 000	25.9		2 100	0	104 000	-0.5
Guinee Bissau	1 972 000	70.1				1 000	-0.5
Liberia	4 179 000	43.4	200	0.0	300	8 000	-0.7
Mali	4 715 000	3.9	146 000	0.0	67 000	135 000	-1.4
Niger	1 143 000	0.9				150 000	-2.1
Nigeria	6 993 000	7.7			214 000	420 000	-3.5
Senegal	8 273 000	43.0			19000	561 000	-0.5
Sierra Lone	3 044 000	42.5		700	300	16 000	-0.1
Togo	188 000	3.5		0.0	1000	46 000	-5.0

Blank denotes very small number rounded off to zero

Source : FAO, 2015; Rodney *et al.,* 2015) area planted with high-grade hardwood timber like that which is extracted from the natural humid forests is insufficient to have any impact on the supply of such timber in the foreseeable future (Toyi *et al.,* 2013). Many plantations in Cameroon, Gabon and Democratic Republic of Congo have failed owing to lack of maintenance and poor management (Chamshama *et al.,* 2009; Whiteman *et al.,* 2015).

The forest statistics indicate that there is a strong political commitment in WCA countries for tree plantation as a major contribution to environmental restoration and people's livelihoods. Expansion of plantations and the growing of trees by communities need to be further supported through capacity development in different domain related to sound forestry plantation management including tree germplasm production and improvement (Koskela *et al.,* 2014; Thomas *et al.,* 2015).

Overview of current state of tree improvement activities in WCA. In response to the depletion of forest resources, several activities have been carried out in recent decades within the region, on tree germplasm improvement and production to meet demand from public and private plantation owners. The aim of tree improvement is to (i) maximize adaptability of a species to potential planting sites (and thus its survival), (ii) maximise growth rate, (iii) increase resistance to diseases, and (iv) improve the quality of the end-use products such as timber, fuel-wood, fodder and soil stabilisation (Barner *et al.,* 1992). The adaptability to planting site is among the first-generation improvement programmes in which the environmental conditions of the potential planting sites are screened along with those of the natural distribution range of the species. This is mainly done using field provenance trials with the aim to identify which provenance of the species can perform well in each site (Koskela *et al.,* 2014). In the context of climate change, provenance trials are also useful to assess the plasticity of different provenance through their adaptability to a wider range of conditions using multilocation field trials and environmental data (Dawson *et al.,* 2011). Survival and growth performances are the main parameters used in evaluating the suitability of a species or provenance for a planting site. Meanwhile, different growth conditions are tested together with the provenance trials to determine the appropriate growing conditions for each tested provenance (Koskela *et al.,* 2014). Resistence to diseases and quality of end-products are improved either by selection of provenance or individual tree providing the preferred products or expressing better resistance. For timber species, this could be done by focusing on sustainable management of genetic variation to generate, identify and multiply well-adapted genotypes for operational planting based on characters such as wood characteristics, height, stem straightness, and fast growth (Haines, 1994).

The forest tree improvement activities commonly depend on the expected outcome of the tree plantation either for income generation, germplasm conservation, forest resource conservation or farm diversification (Simons, 1996). In forestry, seed-based tree breeding approaches are the most commonly used.

The main tree improvement activities widely undertaken within the region are:

a) provenance and progeny testing (almost all planted tree species);
b) multi-criteria and clonal selection and subsequent vegetative propagation of improved clones (*Eucalyptus* and *Pinus* spp. in the Republic of Congo; teak varieties in Côte D'Ivoire);
c) varietal creation (improved Eucalyptus hybrids for pulp production in the Republic of Congo), and
d) selection for marketable characters such as physical, mechanical and chemical properties of wood, pest and disease

resistance (e.g. Iroko in Ghana).

Tree improvement methodology adopted in the WCA region for exotic species included many phases among which elimination and selection phase are, followed by testing and selection of adapted provenances. "Plus trees" and "families" are selected to establish seed orchards for the most advanced programmes. Provenance and progeny testing are known as the most common and oldest research activity for more than 75% of the tree species involved in forestry plantation. Several provenance trials for exotic and indigenous species have been established in almost all WCA countries. The aims of these trials were to conserve gene pool, provide information on the nature and extent of genetic variation within and between provenances throughout the species native ranges and set a basis for selection of species for afforestation (Peprah, 1999; FAO, 2001). For some few species such as *F. albida* (Burkina Faso, Cameroun), *Parkia biglobosa* (Burkina Faso) and *Vichellia* spp., the provenance trials were based on systematic prospection, germplasm collection and comparative testing covering the distribution range of the species within the region (FAO, 2001).

According to FAO national reports from Cameroon, Cote d'Ivoire, Burkina Faso, Nigeria, Niger, Mauritania, Mali, Benin, Senegal, Togo, provenance and progeny trials were established for more than 30 tree species including *A. occidentale, Anogeissus leiocarpus, Atriplex* spp.*, Azadirachta indica, Casuarina equisetifolium, Eucalyptus camaldulensis, F. albida, Khaya senegalensis, Nauclea diderrichii, P. biglobosa, Prosopis* spp.*, T. grandis, Vichellia* spp. and *Ziziphu*s spp. (FAO, 2001).

In Cameroon, progeny trials were set up according to agroecologic areas. Henceforth, trials for many Acacia species were established in the dryland area of the Northern part of the country, those of *Eucalyptus* spp., *Pinus* spp. and *Araucaria* spp. were planted in the humid highland savannah areas in the western regions while indigenous timber forest species were planted in the coastal (around Kribi) and deciduous (Belabo area) forest zones (Ngueguim *et al.,* 2009). In Senegal, almost 2000 trials involving nearly 30 species have been established in agricultural, forestry, littoral and valley zones of the country by the national tree seed programme (Programme National de Semences Forestières), the PRONASEF, in collaboration with the National Centre for Forestry Research (CNRF).

In the Republic of Congo, improved vegetative propagation techniques have been developed to produce high-quality germplasm of many exotic species including *Eucalyptus*, *Pinus* and *Acacia* species (Matondo, 2013). In this country, genetic gains for adaptability, growth, bole shape, wood quality and rooting ability were obtained with hybrids developed from *E. urophyla* and *E. grandis.* The hybridisation processes included early selection in the field, controlled pollination and mass propagation. The Republic of Congo is reputed for the development of high performing Eucalyptus hybrids used in their forestry plantations in the savannah areas.

In Ghana, techniques have been developed for production of *Milicia excelsa* (Iroko) clones that are resistant to the gall forming insect *Phytolyma lata* using vegetative and tissue culture protocols to capture resistant lines. The techniques and protocols developed have opened opportunities for large scale planting of this important timber species in Ghana and Cote d'Ivoire and as a template for addressing plantation failure of the African Mahoganies (*Khaya* and *Entandrophragma* spp) as well as other indigenous species with endemic pest problems (Aquah *et al.,* 2013). Similarly, effective establishment of *Pinus caribaea* with improved wood physical property has been achieved using a mycorrhizal based technique during the nursery phase to correct certain deficiencies in the growth of the species (Aquah *et al.,* 2013).

In Benin, tree improvement mainly focused on Teak (*T. grandi*s) which is the most used species in reforestation programme. In Gambia, trials have been established using indigenous and exotic species with the objectives of testing their adaptability in different site conditions, identifying their nursery requirements for propagation and to select the most suitable tree species for each of their needed end-products or services (firewood, timber, fruits, fodder, medicine, ornaments and soil improvement). The tested species included *T. grandis*, *K. senegalensis, Albizzia ferruginea, Pterocarpus erinaceus, Prosopis africana, P. biglobosa* and *E. camaldulensis*. These species were selected based on the demand and acceptability by the local communities, legal restrictions, experience and available information on their silviculture, compatibility with other land use systems, among others (Danso, 2001).

A compilation of 88 species involved in improvement research activities, recorded mainly from FAO national reports on forest genetic resources within the region is presented in Table 2. A synthesis of these activities for all priority species is presented in Figure 2.

It can be observed from Figure 2 that tree improvement activities in WCA are still in their early stages for both indigenous and exotic species. Also, many of the provenance and progeny trials were set from external funding and were reported to be poorly managed, with inappropriate monitoring and documentation approach, thus contributing poorly to the species improvement (Kokesla *et al.,* 2014). This could explain the low performance usually reported for many forestry plantations in the region (Ngueguim *et al.,* 2015).

It is therefore important to raise more awareness for the need for more investment into tree breeding for better quality seed sources and associated benefits expected from tree plantations. According to Lillesø *et al.* (2018), a relatively low level of improvement could be appropriate provided specific species/ provenances recommendations are developed for relevant species, and avoiding the use of clearly inferior planting materials. Such low-input breeding strategies have been applied in WCA countries by the World Agroforestry Centre in the framework of their programme on the participatory domestication of indigenous fruit tree species (Tchoundjeu *et al.,* 1998).

Priority forestry and agroforestry tree species for improvement research in WCA. Since 1990s, there has been a rapid development and wide-scale adoption of agroforestry practices in West and Central Africa, because of increased demand for non-timber forest products and increased collection, distribution and use of agroforestry tree germplasm. The domestication strategy usually started with the selection of priority species at national and regional level based on indigenous knowledge, socio-economic and improvement potentials of the candidate species (Franzel *et al.,* 1996). In the African Humid Tropics, agroforestry tree species ranking studies were conducted in Nigeria and Cameroon, which were thereafter validated and generalised for all the humid countries of the region (Franzel *et al.,* 2008). Fourtheen indigenous species were identified as priority for domestication including six fruit trees, three medicinal plants, one vegetable, three spices and oily plants. Six ranking criteria based on the value of expected benefits from domestication were used to identify the top five priority fruit trees species as follows: *Irvingia gabonensis, Dacryodes edulis, Chrysophyllum albidum, Ricinodendron heudelotii* and *Garcinia kola* (Franzel *et al.*, 1996). Although some species had a broad geographical spread

Table 2. Priority forestry species for improvement activities in WCA

No	Species	Provenance & progeny trials	Sexual or veg. propagation	Hybridisation	Molecular analyses
1	*Acacia auriculiformis*	Cmr, Be, CI, Gh, Ma,			
2	*Acacia macrostachya*				Bf
3	*Acacia mangium*	Co, Cmr, Ma		x	
4	*Acacia nilotica*	Bf, Cmr, Ma, Nr, Nia, Sen	Bf, Cmr, Ma, Nr, Nia, Sen		Bf, Cmr, Ma, Nr, Nia, Sen
5	*Acacia senegal*	Bf, Cmr, Ma, Nr, Nia, Sen	Bf, Cmr, Ma, Nr, Nia, Sen		
6	*Acacia seyal*	Bf, Nr			
7	*Acacia tortilis*	Bf, Ma, Nr, Sen			
8	*Acacia albida*	Ma		X	
9	*Acacia holosericea*	Cmr			
10	*Adansonia digitata*	Be, Bf, Cmr, Gh, Ma, Nr, Nia, Sen	Be, Bf, Cmr, Gh, Ma, Nr, Nia, Sen		Be, Bf, Cmr, Gh, Ma, Nr, Nia, Sen
11	*Afzelia africana*	Bf			
12	*Albizialebbeck*	Ma			
13	*Allanblackia floribunda*		Cmr		
14	*Allanblackia parviflora*	Gh			
15	*Anacardium occidentale*	Sen			
16	*Anogeissus leiocarpus*	Be, Bf, Ma,			Be, Bf, Ma,
17	*Aphania senegalensis*	Sen			
18	*Azadirachta indica*	Bf, Cmr, Nr, Sen	Bf, Cmr, Nr, Sen		Bf, Cmr, Nr, Sen
19	*Balanites aegyptiaca*	Bf, Nr, Sen, Ch			Bf, Nr, Sen, Ch
20	*Bombax costatum*			x	
21	*Borassusaethiopum*	Ma			
22	*Boscia senegalensis*	Nr			
23	*Casuarina equisetifolia*	Sen			Sen
24	*Cedrela odorata*	Be, Cmr, Car			
25	*Ceiba pentandra*		Gh		
26	*Cola nitida*		Cmr		
27	*Cola nitida*		Nia		
28	*Cola cordifolia*	Ma			
29	*Combretum ghasalense*	Ma			
30	*Combretum glutinosum*	Ma			
31	*Combretum micranthum*	Ma			
32	*Cordia alliodora*	Gh			
33	*Cordyla pinnata*	Ma			
34	C*rossoptyx febrifuga*	Ma			
35	*Dacryodes edulis*		Cmr	Cmr	Cmr

No	Species	Provenance & progeny trials	Sexual or veg. propagation	Hybridisation	Molecular analyses
36	*Dalbergia sissoo*	Cmr	Cmr		
37	*Delonixregia*	Cmr, Ma			
38	*Detarium microcarpum*	Bf, Sen			
39	*Detarium senegalensis*		Sen		
40	*Eucalyptus alba*			Co	
41	*Eucalyptus cloeziana*	Co	Co		
42	*Eucalyptus citriodora*	Co	Co	Co	
43	*Eucalyptus grandis*	Co	Co	Co	
44	*Eucalyptus pelleta*	Co	Co		
45	*Entandrophragma angolense*		Gh		
46	*Eucalyptus camaldulensis*	Bf, Cmr, Car, CI, Ma, Nr, Nia, Sen, To	Bf, Cmr, Car, CI, Ma, Nr, Nia, Sen, To		Bf, Cmr, Car, CI, Ma, Nr, Nia, Sen, To
47	*Eucalyptus urophylla*	Co	Co	Co	
48					
49	*F albida*	Bf, Cmr, Nr, Sen			Bf, Cmr, Nr, Sen
50	*Garcinia cola*		Cmr		
51	*Glyricidia sepium*	Bf, Ma			
52	*Gmelina arborea*	Cmr, Car, Gh			
53	*Gnetum africanum*		Cmr		
54	*Irvingia gabonensis*		Cmr		
55	*Irvingia wombolu*		Cmr		
56	*Khaya ivorensis*	Gh			
57	*K senegalensis*	Be, Bf, Cmr, Ma, Nr, Nia, Sen	Be, Bf, Cmr, Ma, Nr, Nia, Sen		Be, Bf, Cmr, Ma, Nr, Nia, Sen
58	*Landolfia senegalensis*	Ma	Ma, Sen		
59	*Lannea microcarpa*	Bf			
60	*Leucaena leucocephala*	Bf, Cmr, Ma			
61	*Milicia* sp.		Gh		
62	*Moringa oleifera*	Bf, Cmr			
63	*P biglobosa*	Bf, Cmr, Ma, Nr, Sen, Ch	Bf, Cmr, Ma, Nr, Sen, Ch		Bf, Cmr, Ma, Nr, Sen, Ch
64	*Pausinystalia johimbe*		Cmr		
65	*Pericopsis elata*	Cmr, Gh			
66	*Pinus* spp	Co	Co		
67	*Prosopis africana*	Bf, Nr, Sen			
68	*Prosopis juliflora*	Nr, Sen			Nr, Sen
69	*Prosopis juliflora*	Sen			Sen
70	*Prunus africana*	Cmr	Cmr		
71	*Pterocarpus erinaceus*	Be, CI, Ma			
72	*Pterocarpus lucens Ma*				
73	Ricinodendron heudelotii		Cmr		

No	Species	Provenance & progeny trials	Sexual or veg. propagation	Hybridisation	Molecular analyses
74	*Saba senegalensis*	Sen	Sen		
75	*Sclerocarya birrea*	Cmr, Ma	Cmr, Ma		
76	*Senna siamea*		Cmr		
77	*Strychnos spinosa*	Ma			
78	*Tamarindus indica*	Be, Bf, Gh, Ma, Nr, Nia, Sen, Ch	Be, Bf, Gh, Ma, Nr, Nia, Sen, Ch		
79	*Tectona grandis*	Be, Car, CI, Gh, Nia, To	Be, Car, CI, Gh, Nia, To		
80	*Terminalia catappa*	Co	Co		
81	*Terminalia ivorensis*	Cmr, Gh, Co, Nia	Co		
82	*Terminalia superba*	Co	Co		
83	Triplochiton scleroxylon	Cmr, CI, Gh, Nia	Cmr, CI, Gh, Nia		
84	Vepris heterophylla	Ma	Ma		
85	Vitellaria paradoxa	Be, Bf, Gh, Ma, Nia, Sen, Ch	Be, Bf, Gh, Ma, Nia, Sen, Ch		Be, Bf, Gh, Ma, Nia, Sen, Ch
86	Vitex doniana		Cmr		
87	Ximenia americana	Cmr, Ma	Cmr, Ma		
88	Ziziphus mauritiana	Bf, Ma, Nr, Sen	Bf, Ma, Nr, Sen		

Be=Benin, Bf= Burkina Faso, Ch= Chad, CI= Côte d'Ivoire, Cmr=Cameroon, Gh=Ghana, Ma=Mali, Nr=Niger, Nia=Nigeria, Sen= Senegal.

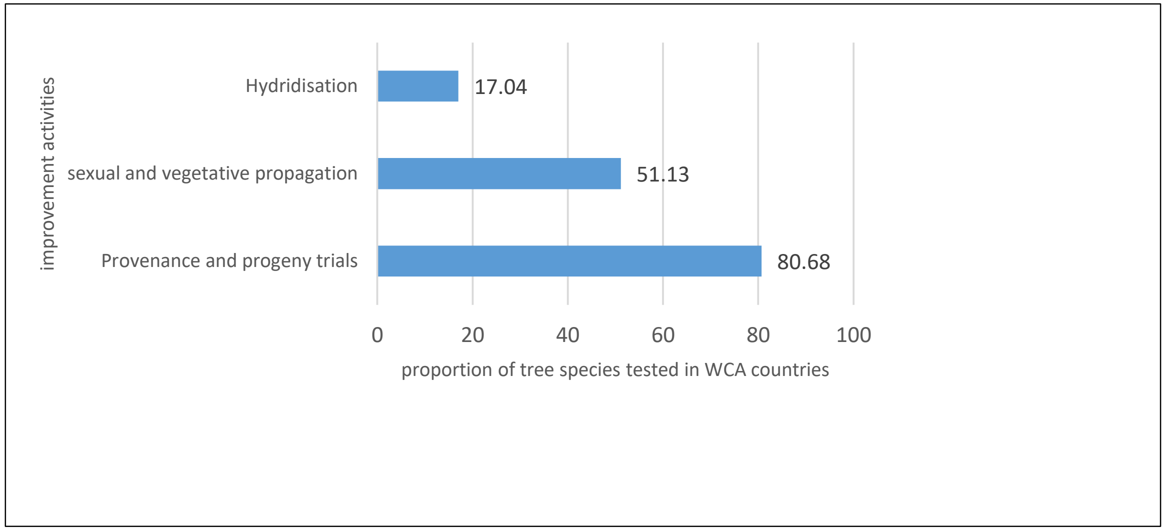

Figure 2. Synthesis of tree improvement activities undertaken on priority trees in West and Central African Countries

within the region, none of them were finally accepted as of interest to the rest of the WCA region. However, two of the priority tree species, namely *I. gabonensis* and *G. kola*, are now gaining importance for domestication in some west African countries (Benin) (Padonou *et al.,* 2017; Codja *et al.,* 2018) showing the recognition of their social and economic value and the need to take in account these countries in the regional domestication programme on these species.

In the semi-arid Sahelian zone of West Africa, more than 28 species were identified as important. The top ten priority species for each of the four countries used for the study are presented in the Table 3. Three species, namely Baobab (*A. digitata*), karite (*Vitellaria paradoxa*), and Tamarind (*Tamarindus indica*) were of general interest throughout the region and therefore recommended for a regional domestication initiative (Franzel *et al.,* 2008).

According to Leakey (2012), existing variability within agroforestry tree species provides great potential for the improvement of marketable characters through selection and vegetative propagation. Therefore, for species under domestication, improvement firstly included phenotypic, molecular, chemical and nutritive characterisation of the species products in order to identify improved varieties that could be used to develop ideotypes (Leakey and Tchoundjeu, 2001). The reduction of tree height to ease harvesting and collection of products and facilitate controlled pollination is also

Table 3. The top priority species for domestication in some dryland countries of WCA (adapted from Franzel *et al.,* 2008)

Species	Burkina Faso	Mali	Niger	Senegal
Adansonia digitata	x	x	x	x
Azadirachta indica				x
Balanites aegyptiaca	x		x	x
Bombax costatum	x			
Borassus aethiopum		x	x	
Cordyla pinnata		x		x
*Detarium microcapu*m				x
Diospyros mespiliformis	x		x	
F. albida	x	x	x	x
Ficus iteophylla				x
Hyphaene thebaica			x	
K. senegalensis		x		
L. microcarpa	x	x		
Parinari macrophylla			x	
P. biglobosa	x	x		x
S. birrea		x		
Tamarindus indica	x	x		x
Vitelaria paradoxa	x	x	x	
Vitex doniana			x	
Ziziphus mauritiana	x		x	x
Total	10	10	10	10

an important characteristic that is included in the improvement programme (Leakey and Akinnifesi, 2008; Makueti *et al.,* 2012). Standard horticultural techniques namely marcotting (air-layering), grafting and rooting juvenile cuttings were developed with the aim of selecting, propagating and mass-producing identified ideotypes. The expansion of tree domestication programme within the region had favoured the integration of many indigenous species providing edible fruits and nuts, vegetables, medicines and other products in tree improvement research. An assessment done in 2008 indicated that 14 provenances trials of *A. digitata, Tamarindus indica, V. paradoxa* and *Z. mauritiana* were established from 1990 to 2002 in Burkina Faso, Mali and Senegal (Kalinganire et al., 2008). In Cameroon, vegetative and seed genebanks were established for *Dacryoides edulis, Irvingia gabonensis* and *Prunus africana* (Tchoundjeu *et al.,* 1998).

With the support of local NGOs, community-based organisations, World Agroforestry Centre (ICRAF) and other international organisations, many forestry and agroforestry projects were implemented or still under implementation in several countries of WCA as a means of creating alternative sources of supply for timber and non-timber products while addressing environmental challenges such as desertification and natural resources degradation. The implementation of these projects has generated demand for improved germplasm of high value for priority tree species within the region. Although it was observed that priority species highly varied according to climatic, agro-ecologic and socio-economic conditions of each country, some species cited in more than 50% of the WCA countries were selected as regional priority and included the following:

a) For agroforestry species: *A. digitata,* B*orassus aethiopum, Cola* spp., *F. albida, Garcinia spp., K. senegalensis, P. biglobosa, Tamarindus indica, Vitellaria paradoxa* and *Ziziphus mauritian*a;
b) For indigenous forest tree species: *Acacia* spp., *Anogeissus leiocarpum, Ceiba pentandra, Diospyros mespiliformis, K. senegalensis, Prosopis africana, Pterocarpus erinaceus, Triplochiton scleroxylon* and *T. superba*; and
c) For exotic forestry and agroforestry species: *E. camaldulensis, Acacia nilotica, A. auriculiformis, T. grandis, Azadirachta indica, C. equisetifolia, Pinus caribaea, Anacardium occidentale* and *Gmelina arborea.*

Techniques for production of improved germplasm and planting stocks. The WCA countries such as Cameroon, Burkina Faso, Congo, Côte d'Ivoire and Ghana have developed technologies for tree seedling production with the assistance of international research and development organisations. Vegetative propagation is critical in improving productivity of timbers species and reducing the time to fruiting of most indigenous fruit trees (Leakey, 2004). The vegetative propagation technologies developed within the framework of the partipatory domestication programmes were of low cost and targeted a few priority species. The technology involved many steps which were:

a) the identification of plus trees in the natural or planted stands based on the end-users's knowledge on the species products and services (quality of the timber, fruits/kernels, straightness of the bole, pest and disease resistance, etc.);
b) pruning and management of the identified trees to induce the production of juvenile and vigorous shoots to be used as cuttings;
c) establishment of the mist and non-mist propagation systems as developed by Leakey *et al.* (1990);
d) fine-tuning and adaptation of the techniques through the identification of best treatments for each of the factors affecting rooting

ability (rooting substrate, cutting length and leaf area, auxin application, etc.);

e) Establishment of clonal orchards using vegetatively propagated seedlings. Species already planted in clonal orchards included among others Eucalyptus, Pinus, Teak and Acacia species in the Republic of Congo, Cameroon, Côte D'Ivoire and Ghana (FAO, 2001).

A few indigenous timber tree species have also received some level of attention in Burkina Faso, Congo, Cameroon, Côte D'Ivoire and Ghana. Within the region, vegetative propagation by stem cuttings is being applied to propagate many indigenous and exotic tree species with the aim of determining their rooting potential and to improve the quantity and quality of planting materials. Species already tested included *A. klaineana* (Okoumé), *Baillonnella toxisperma (Moabi), Ceiba pentandra, Diospyros crassifolia, Entandrophragma angolense, Khaya ivorensis, K. senegalensis, Lovoa trichilioides, Milicia sp., Milletia laurentii, Terminalia* spp., *Lovoa trichilioides, Triplochiton scleroxylon,* and *Pericopsis elata,* among others) (Ofori *et al.*, 1996; Tchoundjeu and Leakey, 1996; 2001; FAO, 2003a; 2003b; Ngo Mpeck and Atangana, 2007; Ky-Dembele *et al.,* 2014; Kenfack, 2016; Na-Karian, 2018).

In Congo, an industrial vegetative propagation process using cuttings was developed by The Centre for International Research for Agricultural Development (CIRAD) and CRDPI (Centre de Recherche pour le Développement des Plantations Industrielles) to optimise the quality and the number of seedlings, reaching 625 million produced per year compared to 25000 cuttings obtained with the formal cutting process.

In Côte d'Ivoire, the process for the selection of improved varieties of teak combined with the development of molecular markers, infrared spectroscopy techniques, chemically-based determination of wood properties and micro-propagation was used to produce improved germplasm for commercial forestry plantation. In both countries, the improved hybrids of eucalypts and teak developed with the contribution of CIRAD were used to establish clonal orchards to produce superior planting materials (Bouvet, 2011). The Society for the Development of Forests (SODEFOR) of Cote D'Ivoire and CIRAD developed a micropropagation technique to produce millions of vitro-plants from the improved clones of teak (Bouvet, 2011).

In Cameroon, the Agricultural Research Institute (IRAD) offices in dryland regions have developed a suite of appropriate techniques which include seed collection, processing, testing and storage, seedling production and vegetative propagation for the production of true-to-type clones for many indigenous and exotic species. In Ghana, Aquah *et al.* (2013) reported the development of successful technologies to produce superior planting materials for major native species including *Khaya ivorensis, Entandrophragma utile, Triplochiton scleroxylon* and *M. excelsa*. The establishment of clonal trials that would allow the assessment of the extent of genotypic variation is not yet a common practice except for a few species such as *T. grandis, Pinus* spp. and *Eucalyptus* spp. in Ghana, Côte D'Ivoire and Republic of Congo (Aquah *et al.,* 2013).

The challenge of WCA countries in producing improved germplasm is the lack of a seed certification scheme. There is no means to distinguish between improved germplasm and unselected or wild seeds. The certification scheme aims to encourage the production and use of forest tree seeds or propagules that have been collected, processed, raised, labeled and distributed in a manner that ensures their trueness to name (Nyoka *et al.,* 2011; OCDE, 2013; Thomas *et al.,* 2015). Burkina Faso is the only country registered by the Organisation for Economic Co-operation and Development (OECD) in the WCA region, and therefore internationally recognised to produce quality certified tree seeds (kokesla *et al.,* 2014).

Existing, seedbanks and gene-bank in WCA. In WCA countries, tree seed centres are the major repositories of tree germplasm. Burkina Faso and Senegal are the only countries with well-established National Tree Seed Centres in the region. However, many countries in the regions have developed ex-situ conservation stands (e.g. Burkina Faso, Senegal, Togo, Nigeria and Niger), botanical gardens, herbaria, seed orchards (Burkina Faso, Nigeria, Ghana, Nigeria, Niger, Senegal and Togo) and experimental plantations such as provenance and progeny trials.

The National Tree Seed Centre of Burkina Faso was established in 1983 and serves almost all the WCA countries (Nikiema *et al.,* 2001). With a storage capacity of 10 tons of seeds and a catalogue of more than 150 species, the Centre (CNSF) has facilities such as a seed laboratory, greenhouses and nurseries distributed in different agro-ecological zones of the country. Several native tree species (*A. nilotica var. adansonii, A. senegal, F. albida, K. senegalensis, P. biglobosa* and *T. indica*) and exotics (*E. camaldulensis, L. leucocephala*, *Prosopis chilensis*, and *Prosopis juliflora*) are conserved in a network of experimental plots including field collections, clone and seed banks under the management of research institutions (CNSF, INERA). The tree species with the largest number of stands are *P. biglobosa*, *F. albida* and *E. camaldulensis* represented by 101 clones in two gene banks (FAO, 2015). In situ conservation of genetic resources is done through traditional agroforestry parklands dominated by *P. biglobosa, V. paradoxa, F. albida, S. birrea, L. microcarpa, B. costatum, K. senegalensis, F. platiphylla, D. mespiliformis, T. indica* and *C. glutinosum.*

In Senegal, PRONASEF (the National Programme for Tree Seeds) operates as the National Tree Seed Centre with a storage capacity of 8 tons. A forest tree seed catalogue exists although not updated since 2010. In Cameroon, tree genetic resources conservation is done mainly through planted or naturally conserved forest reserves distributed according to the agro-ecological zonation of the country. A feasibility study for the creation of a national tree seed centre has been launched, but the proper implementation of the suggested recommendations is still awaited. In Congo, an arboretum of 20 ha exists in Brazzaville and is being used for the conservation of more than 80 indigenous and exotic tree species.

In Togo, agroforestry parklands constitute in situ conservation model and natural gene banks and act as seed sources for certain useful species such as *P. biglobosa, Vitellaria paradoxa, Faidherbia albida, S. birrea, Lannea microcarpa, Bombax costatum, Khaya senegalensis, Ficus phatiphylla, Milicia excelsa, Antiaris africana, Afzelia africana, Diospyros mespiliformis, Tamarindus indica,* and *Combretum glutinosum.* Two managed woodlands (Haho-Baloe (300 ha) and Eto (400 ha) have permitted the conservation of many Eucalyptus species as well as some rare species such as *Garcinia* sp and *Anogeissus leiocarpum*. The presence of a National Tree seed Centre is reported in many forestry documents, but the activities and capacity of the centres are still poorly documented.

Nigeria has two properly equipped seed centres with professional and trained support staff. These tree seeds centres were reported to be the main sources of seed, for all stakeholders involved in the forestry sectors (Oni, 2001). However, an evaluation indicated that the proper operationalisation of these centres will require more sophisticated equipment for seed collection, handling and processing as well as standardised and up to date documentation, gene bank management and computer skills. *Ex-situ* conservation activities started in Nigeria with *P. biglobosa* in 1993 using 94 accessions collected and conserved in the seed gene banks of the Forestry Research Institute (FRIN), 54 of which were collected from the rest of West Africa (Oni, 2001). Seed orchards exist on State and Federal Department of Forestry and Forestry Research stations along with *ex-situ* conservation of some of the indigenous species including *P. biglobosa, V. paradoxa, A. digitata, T. indica, Entada africana, Moringa oleifera, D. mespiliformis, A. senegal* and *A. nilotica*. In 2001, it was reported that within the framework of the World Bank Assisted National Agricultural Research Project, (NARP) the Forestry Research Institute of Nigeria (FRIN) had embarked on the production of one million seedlings for afforestation and agroforestry projects partly supplied by these orchards (Oni, 2001).

In Ghana, several clonal seed orchards have been established to supply genetically high-quality planting materials using a seed production and management technology developed by the council for Scientific and Industrial Research of the Forestry Research Institute (CSIR-RORIG). The same technology has also been used to establish ten priority species for plantation development under the National Forest Plantation Development Programme (Aquah e*t al.*, 2013).

Traditional practice for genetic resources conservation includes planting pits (Zai) in degraded area of Burkina Faso as in many other countries in WCA with rainfall between 300 – 800 mm (Roose *et al.,* 1993; Sawadogo *et al.,* 2001). This practice also provides an effective way of improving the management of degraded lands and reducing soil erosion, vegetation loss and biodiversity as well as crop yields (Danjuma and Mohammed, 2015).

Seed supply, processing and distribution networks. *Seed sources and supply in WCA countries.* The seeds directly collected from natural trees within and outside forests constitute the main and sometimes the only source of planting stocks for reforestation specially for many indigenous species in countries without an operational Tree seed Centre such as Cameroon, Republic of Congo, Gabon, Central African Republic, Chad (Ngueguim *et al.,* 2015; FAO, 2014; Kokesla *et al.,* 2014). Vegetative propagation, even for high value fruit tree species is not yet a common practice within the region except in the Republic of Congo, Ghana and Cote D'Ivoire for some few exotic species (Tchoundjeu *et al.,* 1998; Aquah *et al.,* 2013; Marien *et al.*, 2013; Matondo, 2013). Therefore, the challenge for tree planting in WCA countries is to answer the question on how to achieve adequate supply of genetically superior seeds since existing seed trees are continually being depleted by indiscriminate felling, deforestation and forest degradation.

Most afforestation projects in the WCA region are dominated by exotic species and seed supply and demand can be considered as relatively adequate. For these exotic species, the demand for their germplasm was firstly for large scale tree planting for timber production purpose and later for research and development (Koskela *et al.,* 2014). Consequently, many mature planted stands are spread according to ecological adaptation of each species as well as their end-uses. Within the region, seeds of *Eucalyptus* spp., *Acacia* spp., *T. grandis*, *C. equisetifolia* and others could be collected on existing stands distributed on farmlands, forest plantations, seed orchards and clonal orchards. The orchards are supplemented with many planted forest reserves and private plantations established in almost all the eco-zones of the region. The main constraints for sourcing seeds of exotic species in the region is the poor management of these orchards, provenance trials and forest reserves due to unsustainable funding and limited human and technical capacities. Reports from many countries indicated that the seed stands are under high anthropogenic pressures (FAO, 2012; Ngueguim, 2014; FAO, 2014). Moreover, for many of these planted stands, germplasm is always of unknown and poorly documented origins (Koskela *et al.,* 2014).

Indigenous tree species have often been unsustainably harvested from natural forests, but efforts are now being made to increase their use in reforestation programmes. In general, bulk seeds are collected from natural stands and from remnant trees scattered in farmlands and constitute the major source of planting material for establishing native forest trees. While most indigenous species are collected from the natural forests, a few species of high value and those that are threatened such as *A. senegal, A. digitata, F. albida, K. senegalensis, P. biglobosa*, and *T. indica*, have been tested in provenance trials. Countries with trials include Nigeria, Burkina Faso, Benin, Senegal and Togo. These trials are now the sources of selected seeds for some of these species. In the humid part of the region, seed orchards and provenance trials have been established for *T. scleroxylon, T. ivorensis, T. superba, N. diderrichii, C. pentandra,* and *M. excelsa* in Ghana, Côte d'Ivoire, Cameroon and Congo. However, seed supply for most of the indigenous tree species are grossly inadequate due to poor management of seed orchards, lack of intensive collections for high value species and inadequate facilities for seed collections and storage (Oni, 2001; FAO, 2012, Marien and Gourlet-Fleury, 2013).

Seed distribution networks and seed markets. Many seeds used in reforestation programmes in WCA were reported to be from unknown and non-documented origins. In Gambia, for example, there are no nationally recognised seed sources and seed collection in most cases is contracted to unprofessional individuals in the villages with little or no control of the provenances, collection process, seed handling and storage (Danso, 2001). In Cameroon, the National Agency for Forestry Development (ANAFOR) is the state institution responsible for sourcing and supplying forest tree seeds for reforestation programmes. Indeed ANAFOR had set up three main seed supply channels: (i) seeds collected from felled or standing trees by ANAFOR's trained technicians; (ii) seed collected and supplied by ANAFOR staff after identification and selection of seed trees in the forest or in plantations; (iii) germplasm exchanged between eco-regional offices. However, ANAFOR lacks technical and human capacity for quality seeds control, handling, processing and labelling. Moreover, their production capacity is unable to satisfy the high demand of planting materials needed to supply the numerous reforestation and agroforestry programs within the country (Takoutsing *et al.,* 2013). In Western Cameroon, where a large proportion of industrial forest plantations are found, some private Eucalyptus planters, use practices such as coppicing to increase the productivity of their plantation. The main species planted in this region are *E. saligna, Podocarpus mannii, Pinus* spp. and *C. equisetifolia.*

Limited information is available on tree seed trade in West and Central Africa, unlike other agricultural commodities. Tree seed deployment models in this region are like those described by Lillesø *et al.* (2011) for Eastern African countries and comprise: (i) the government model, (ii) the NGO model and (iii) the decentralised model (Figure 3). In the government model, a central governmental agency takes the lead over seed sources control, technical quality and supply chain. The seeds often go to NGOs, community projects and for some countries to the private sector. This model is characterised by a clear chain of activities, regulations and seed marketing. Seed sales take place in formal or officially recognised seed outlets. This situation is the same in the countries with an operational tree seed centre like Burkina Faso and Senegal for WCA region. In the NGO model, seeds are often collected from available seed trees in farmlands by NGOs themselves or through seed purchases from local communities. The physical (purity, appropriate weight, proportion of non-seeds materials) and physiological (maturity, viability, health status, dormancy) quality of the seeds are not always considered. The seeds are distributed to other NGOs or NGO clients which maintain direct contact with farmers and other stakeholders involved in reforestation programmes (tree seeds users). This model is gaining more and more importance within the region where many national and international NGOs are promoting tree planting as a win-win strategy to improve livelihoods and conserve natural forest resources. As an example, in Cameroon, Nigeria, Mali, Burkina Faso, Sierra Leone, ICRAF has been supporting national NGOs and community-based organisations in the production and distribution of improved germplasm of some high value indigenous tree species (Degrande *et al.*, 2012; Takoutsing *et al.,* 2013).

The decentralised model of seed deployment is characterised by farmers, former and active forest technicians, seeds dealers playing a central role in the control of sources which is often limited to availability of early seeding trees in planted and natural stands. These actors collect seeds which then goes to dealers, suppliers or distributors (some government, some private) and to users that include government, NGOs, farmers' organisations, and private forest companies. This model is common within the WCA region where many countries do not have tree seed centres.

Overall, tree seed markets in WCA region are not well organised. Non-governmental organisations, smallholder farmers and forestry technicians constitute the main tree seed providers especially in countries without Tree Seed Centres. The contribution of the informal seed sector to overall seed supply remains high indicating that the tree seed production and distribution has been devolved to many stakeholders. Private sector is increasingly taking the role of supplier for commercial seeds while NGOs and farmers are supplying seed for most community tree planting projects. However, statistics on tree seed production are missing for most countries (Thomas *et al.,* 2015).

Tree germplasm demand, production and distribution networks. The range of tree planting activities, from commercial to community tree planting requires diversified tree germplasm supply models. Moreover, the main distributors of tree's planting materials are nurseries rather than seeds dealers as tree species are mostly planted as seedlings rather than being sown as seeds (Lillesø *et al.,* 2018). It is not therefore surprising that privately and community owned nurseries play an important role in the production and supply of tree germplasm/ seedlings in many WCA countries. Many types of nurseries are found in the region ranging from industrial to semi-industrial nurseries found in Congo and Burkina Faso, medium-sized nurseries owned by state institutions such as ANAFOR in Cameroon to small-scale nurseries managed by forestry research institutes, individual and community-based organisations. However, most of the nursery's operators are not skilled in terms of appropriate methods of seeds collection, handling and processing as well as techniques to produce improved seedlings. Their performance strongly depends on their communication networks, their technical and financial capacity (Degrande *et al.,* 2012). Yet, as observed by Lillesø *et al.* (2018) many of these nurseries are either owned or committed to supply national and international NGOs in meeting their tree planting targets with limited concern on improving the productivity of the tree species being planted. Consequently, seeds and seedlings sold are always from unknown origins and are of poor genetic quality (Takoutsing *et al.*, 2013). Therefore, technical support should be given to small-scale nurseries if the production of high-quality seedlings is the top priority.

Table 5 shows the main activities and stakeholders involved in the tree seed supply systems in WCA countries as adapted from Lilleso *et al.* (2011) and Nyoka *et al.* (2015). It can be observed that the system is highly decentralised with the responsibilities for many activities shared among different actors. Even in countries with an operational tree seed centres, comminity-based organisations, nursery operators and NGOs are still major players in the the tree seeds/seedling supply chain.

Table 5. Synthesis of actors and their potential roles in the Tree germplasm production and supply chain in WCA countries (Adapted from Lillesø *et al.* (2011) and Nyoka *et al.* (2015).

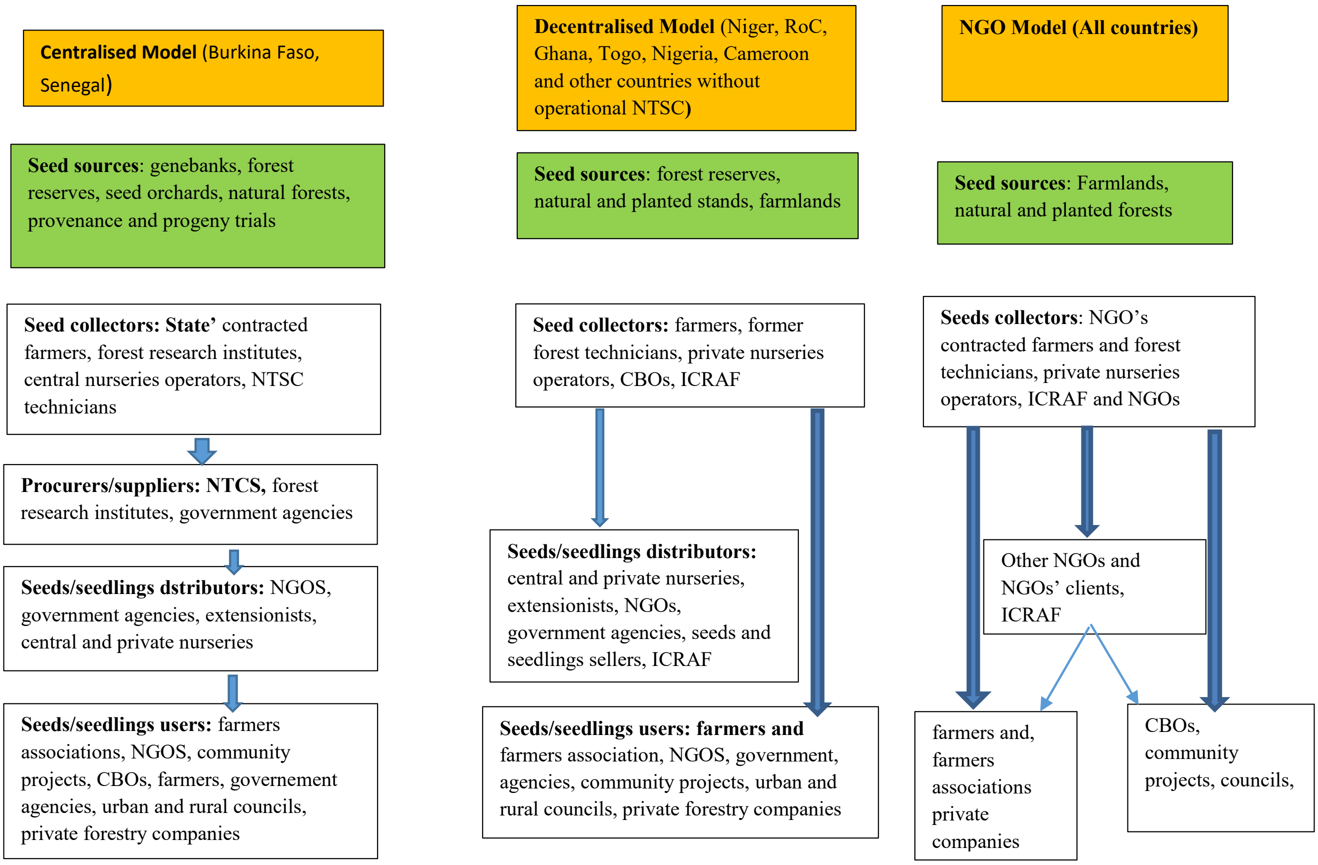

Figure 3. Tree germplasm procurement and deployment pathways in West and Central African Countries (adapted from Lilleso *et al.* (2011) and Nyoka *et al.* (2015).

Table 5. Synthesis of actors and their potential roles in the Tree germplasm production and supply chain in WCA countries (Adapted from Lillesø *et al.* (2011) and Nyoka *et al.* (2015).

Activities	Actors					
	Farmers, farmer's associations and private companies	CBOs and councils	NTSC	Public forestry Agencies	Nursery operators	NGOs
Regulations, Policies, laws and programmes				x		
Seed sources development and mapping			x	x		x (research-oriented NGO)
Seed sources establishment	x	x	x	x	x	x
Seed collection	x	x	x	x (ANAFOR and SNR)	x	x
Trees and seeds improvement research			x	x (Forestry Research Institute)		x (research-oriented NGO)
Seedling production	x	x	x	x (ANAFOR and SNR)	x	x
Seed testing/certification	x			x (ANAFOR and SNR)		
Seeds/seedlings quality control			x (compulsory)	x (compulsory)		x (voluntary) (research-oriented NGO)
Germplasm distribution/marketing	x	x	x	x (ANAFOR and SNR)	x	x
Seed reserve/seedbanks establishment and management			x	x (ANAFOR and SNR)		x (research-oriented NGO)
Germplasm conservation and maintenance (research-oriented NGO (ICRAF))			x	x		x
Facilitation for Germplasm translocation and exchange		x	x	x	x	x
Germplasm use for tree planting	x	x	x	x	x	x

*ANAFOR (Cameroon Agency for Afforestation and Forest Development) and SNR (Congo Service of Tree Planting) are public forestry institutions operating like National Tree seed Centres in their resective countries. CBOs: Community-based Organisations

Seeds storage behaviour of trees species used in Forestry plantation in WCA. The storage of seeds is one of the most important activities in germplasm management as a mean of securing the supply of good quality seeds for a planting programme whenever needed. This is particularly important for many tree species in WCA which exhibits irregular fruiting behaviour with one year of mass fruiting followed by three to four years of poor or sporadic seed production (Sacande *at al.,* 2004). However, the ability of storing many tropical seeds is limited by the lack of information on their seed storage behaviour known to be related to their desiccation tolerance ability. Seeds have been classified in 3 main categories according to their desiccation tolerance and longevity: orthodox, recalcitrant and intermediate seeds (Hong and Ellis, 1996). Out of the 59 Sub Saharan Forest genetic resources (SAFORGEN) listed priority species, 60% indicate good potential for medium to long term conservation (Sacande *et al.,* 2004). However, the storage requirements in terms of desiccation tolerance and conservation conditions are still very poorly documented for many of WCA priority species (Sacande *et al.*, 2004).

Many species in the region have dormant seeds, with seed-coat dormancy being the most common type observed. In fact, many species exhibit hard seed-coats that either prevent seed imbibition or constitute a physical barrier limiting the growth of radicle during germination. Methods used to break seed coat dormancy varied from soaking seeds in water from 24 to 72 hours for moderately hard seeds species such as *Combretum* spp., *Isoberlinia doka*, *Pterocarpus* spp., *T. grandis*, *Saba senegalensi*s and *S. birrea,* to manual scarification, thermal and chemical treatments for more harder seed species such as *Ricinodendron heudelotii* (Djeugap *et al.*, 2014), *Canarium schweinfurthii*, *Tamarindus indica, Prosopis* spp. *Pilostigma* spp. among others. The Burkina Faso tree seed centre has proposed in their 2012-2015 catalogue a list of 15 pre-treatments to break seed coat dormancy for many WCA priority tree species (CNSF, 2012).

Assessing tree germplasm adaptability to climate change. Tree plantation has been well documented to contribute both to climate change mitigation through reduction of greenhouse emission and adaptation by providing products and services to vulnerable populations. However, tree establishment, growth and development require a specific set of environmental conditions also known to be affected by climate change, therefore impacting on their geographic distribution and performance. Studies conducted in west African countries have contributed to assessing germplasm adapatability to climate change through the evaluation of their response to environmental stresses (Bayala *et al.,* 2017; Vihotogbe *et al.,* 2018). Moreover, the potential impact of a changing climate to geographic distribution of some high value indigenous species was evaluated using climatic parameters-based niche modelling (Kakai *et al.*, 2011; Djotan *et al.*, 2018; Vihotogbe *et al.,* 2018). This knowledge is important to identify future planting areas, facilitate germplasm translocation potential, determine species plasticity potentials and therefore fulfil species response to climate change (Dawson *et al.,* 2011). For example, climate change was proved to have positive consequences on the distribution in Benin protected area network and municipalities for Garcinia kola, a threatened medicinal tree species identified as regional priority for domestication in WCA (Djotan *et al.,* 2018). In the same line, Vitellaria paradoxa seedlings response to drought stress was not related to the climate at origin of the seed provenance, indicating that germplasm translocation within the species range will not affect growth performance of such species (Bayala *et al.,* 2018). In fact, shea butter tree morphology and productivity were found to vary according to bioclimatic conditions, demonstrating an ecological adaptation of the species to climate gradient (Kakai *et al.,* 2011). From ecological niches modelling, it was observed that *I. wombulu* was highly suited to Volta forest of the Dahomey Gap while *I. gabonensis* showed very poor environmental suitability, implying different ecological adaptation for the 2 species. These results, together with genetic investigation and field trials in contratsting ecological conditions could better guide the future domestication strategy of this top priority species (Vihotogbe *et al.,* 2018).

CONCLUSION

The study has shown that there has been an overall significant increase in the area of forest plantation despite the inadequacy of statistics on planted forests in WCA. The scale of forest plantations in the dryland areas is still far from adequate to meet the need for round wood, fuel wood, as well other forest economic good and environmental services (fight against desertification, climate change).

Throughout the region, there is a growing interest of public, private and community-based organisations for forest plantation activities. Many projects and programmes funded by international organisations are being promoted and are positively impacting on the demand for improved germplasms. The growing demand for quality tree seeds in recent decades has fueled much interest in tree germplasm production and improvement. Vegetative propagation has been developed for common commercially important exotic species and there but is an emerging interest for testing and adapting these techniques on indigenous fruit and forest tree species within the region.

The responsibilities of the development of the seed sector are shared among various institutions and individuals. The study showed that there is no effective coordination. Most of the government institutions in charge of tree germplasm, tree improvement and forest plantations lack adequate funding to perform their activities. The contribution of the informal seed sector to overall seed supply remains high. There is a widespread lack of trained personnel and laboratory facilities as well as an overall poor system of quality control over seeds distributed to end-users. Seed documentation capacities are limited. Hence, the seeds sold are often of poor quality, and improved germplasm is only produced at high cost by some few private research institutions, NGOs and nurseries operators. Most countries do not have viable seed centres as well as productive seed orchards and tree germplasm improvement has not yet taken advantage of biotechnology because of poor scientific and human capacity as well as unsustainable funding of forestry research institutions.

The following are the suggested priority intervention areas to address these shortcomings:

1. Capacity building and technology transfer specifically on tree germplasm improvement combining formal provenance trial with molecular technologies, taking into account emerging constraints associated with climate change.
2. Development of plant breeding and seed technology curricula in forestry research and education institutions and facilitate access to graduate fellowship opportunities in order to train future technicians and scientists needed in the private and public sectors.
3. Development of a network of seed systems actors to facilitate technology transfer among countries with advanced seed sectors and those with seed sectors in development.
4. Seed production quality assurance and certification: In almost all WCA countries, except for Burkina Faso, there is no quality control scheme for germplasm production and therefore no means to distinguish between improved and wild

seeds or germplasm sources. There is a need to strengthen national seed production programmes, support the emergence of a well organized local, private seed enterprises sectors through capacity building activities, infrastructure development, putting in place quality control schemes for priority species.

5. Because of the importance of the informal seed sector, there is also a need to strengthen stakeholder capacities in seed production and collection.
6. Seed storage, distribution and marketing: There is a need to support the establishment of seed storage infrastructure and seed processing equipment and assist farmers to improve traditional methods of seed packaging and storage. Also, facilitating the development of local and regional seed distribution networks is another priority intervention to consider.

ACKNOWLEDGEMENT

Funds for undertaking this study were provided by the African Forest Forum through the support of Swedish International Development Cooperation Agency (Sida). The authors express their gratitude to all staff of AFF and participating institutions for their collaboration.

STATEMENT OF NO-CONFLICT OF INTEREST

The authors declare that there is no conflict of interest in this paper.

REFERENCES

Acquah, S.B., S. Pentsil, N. Appiah, W.K. Dumenu and B. Darimani, 2013. Technologies for forest management, utilization and development (1965-2012). In E.G. Foli and M. Sraku-Lartey (eds). CSIR-Forestry Research Institute of Ghana Report, University KNUST, Kumasi, Ghana. 50 pp.

Ariori, S.L. and Ozer P. 2005. Évolution des ressources forestières en Afrique de l'Ouest soudano-sahélienne au cours des 50 dernières années. *GeoEco-Trop* 29: 61-68.

Aoudji, A.K.N., Adégbidi, A., Ganglo, J.C. and Lebailly, P. 2014. Teak (*Tectona grandis* L.f.) planting in smallholders' farming system in southern Benin. *Bois For. Trop*. 319: 7-17

Baskaran, K. D., Bariteau, M., El-Kassaby, Y.A., Huoran, W., Kigomo, B.N., Mesén, F.; Midgley, S., Nikiema, A., Patiño V.F., Prado, J.A. and Ståhl, P.H. 2004. Regional Updates. Paper prepared for the Thirteenth Session of the FAO Panel of Experts on Forest GeneResources, Rome, Italy, 10-12 November 2003. Forest Genetic Resources Working PaperFGR/73E. FAO. Rome, Italy.

Bayala, J., Sanon, Z., Bazie, P., Sanou, J., Roupsard, O., Jourdan, C., Ræbild A., Kelly B., Okullo J.B.L., Thiam, M. and Yidan J. 2018. Relationships between climate at origin and seedling traits in eight Panafrican provenances of *Vitellaria paradoxa* C.F. Gaertn. under imposed drought stress. *Agroforest Syst.* 92: 1455–1467.

Buongiorno, J. and Zhu, S. 2014. Assessing the impact of planted forests on the global forest economy. From Third International Congress on Planted Forests Bordeaux, France; Dublin, Ireland; and Porto and Estoril, Portugal. 16-21 May 2013. *New Zealand Journal of Forestry Scienc*e 44 (Suppl 1): 1–9.

Chamshama, S.A.O. and Nshubemuki, L. 2011. Plantation forestry management in Tanzania: Current situation and future focus. pp. 45-75. In: Proceedings of the workshop on insect pests, diseases and soil problems in forest plantations.

Chamshama, S.A.O., Nwonwu, F.O.C., Lundgren, B. and Kowero, G.S. 2009. Plantation forestry in Sub Saharan Africa: Silvicultural, ecological and economic aspects. *Discov. Innov* 21 (1): 42-49.

Codjia, S. Augustin Aoudji, A. Koura, K. and Ganglo, J.C. 2018. Systèmes Agroforestiers à Garcinia kola Heckel au Sud-Est du Bénin:

Distribution Géographique, Connaissances Endogènes et Retombées Financières. *European Scientific Journal* 14 (12): 188 – 208.

Conseil National de l'Environnement pour un Développement Durable (CNEDD)/ FEM/ PNUE. 2014. Cinquième rapport National sur la Diversité Biologique. Février 2014. 60 pp.

Danso, A.A. 2001 State of Forest genetic Resources in The Gambia. Sub-Regional Workshop FAO/IPGRI/ICRAF on the Conservation, management, sustainable utilization and enhancement of forest genetic resources in Sahelian and North-Sudanian Africa, Ouagadougou, Burkina Faso, 22-24 September 1998. Forest Genetic Resources Working Papers, Working Paper FGR/19E. Forestry Department, FAO, Rome, Italy.

Danjuma, M.N. and Mohammed, S. 2015. Zai Pits System: A catalyst for restoration in the dry lands. *Journal of Agriculture and Veterinary Science (IOSR-JAVS)*. 8 (2): 01-04.

Dawson, I.K., Vinceti, B., Weber, J.C., Neufeldt, H., Russell, J., Lengkeek, A.G., Kalinganire, A., Kindt, R., Lillesø, J.P. B., Roshetko, J. and Jamnadass, R. 2011. Climate change and tree genetic resource management: maintaining and enhancing the productivity and value of smallholder tropical agroforestry landscapes. A review. *Agroforest Syst.* 81:67–78. DOI 10.1007/s10457-010-9302-2

Dedefo, K., Derero, A., Tesfaye, Y. and Muriuki, J. 2017. Tree nursery and seed procurement characteristics influence on seedling quality in Oromia, Ethiopia. *Forests, Trees and Livelihoods* 26 (2):96-110. DOI: 10.1080/14728028.2016.1221365

Degrande, A., Tadjo, P., Takoutsing, B., Asaah, E., Tsobeng, A. and Tchoundjeu, Z., 2013. Getting trees into farmers' fields: success of rural nurseries in distributing high quality planting material in Cameroon. *Small-scale Forestry* 12 (3): 403-420.

Diouf, D., Neyra, M., Sougoufara, B. and Lesueur, D. 2001. Le Plan d'action forestier du Sénégal : bilan et perspectives des activités de reboisement de 1993 à 1998. *Bois et Forêt des Tropiques* 270 (4): 1 – 9.

Djeugap, F.J., Bernier, L., Dostaler, D., Fontem, D.A. and Avana, M.L. 2015. Germination Constraints on *Ricinodendron heudelotii* in Cameroon. *Seed Technology* 36 (1): 61-72.

Djotan, A.K.G., Aoudji, A.K.N., Codjia, S.A.F., Gbetoho, A.J., Koura, K. and Ganglo, J.C. 2018. How far can climate changes help to conserve and restore *Garcinia kola* Heckel, an extinct species in the wild in Benin (West Africa). *Int. J. Biodivers. Conserv.* 10 (5): 203 – 213.

Eba'a, A.R., Lescuyer, G. and Gouhouo, P. J. 2015. Etude de l'importance économique et sociale du secteur forestier et faunique dans les Etats d'Afrique Centrale : Cas du Cameroun, Rapport d'étude CIFOR

EDF, 2013. The Forests of the Congo Basin - State of the Forest 2010, Eds: de Wasseige C., de Marcken, P., Bayol, N., Hiol Hiol, F., Mayaux, Ph., Desclée, B., Nasi, R., Billand, A., Defourny, P. and Eba'a Atyi, R. 2013. Publications Office of the European Union. Luxembourg. 276pp. ISBN: 978-92-79-22716-5, doi: 10.2788/47210

Endamana, D., Akwah-Neba, G., Angu-Angu, K. and Shepherd, G. 2015. Linkage between forest resources, the livelihoods of rural households and possible contributions to sustainable development goals in the developing countries of the Central African region. XIV World Forestry Congress, Durban, South Africa, 7-11 September 2015. 10 pp.

Eyog Matig, O., Gaoué, O. G. and Dossou, B (Eds.). 2002. Réseau« EspècesLigneuses Alimentaires ». Compte rendu de la première réunion du Réseau tenue 11–13 décembre 2000 au CNSF Ouagadougou, Burkina Faso. Institut International des Ressources

Phytogénétiques. IPGRI Regional Office for sub-Saharan Africa. 241pp.

Food and Agriculture Organisation (FAO). 2014. State of the World's Forests (SOFO). Enhancing the socioeconomic benefits from forests: Putting people at the centre. ISSN 1020-5705. 133pp.

Food and Agriculture Organisation (FAO). 2012. Regional Workshop Report on the State of the World Forest Genetic Resources for Western Africa. Forest Genetic Resources Working Papers, Working Paper FGR/xxxx. Forest Assessment, Management and Conservation Division. FAO, Rome

Food and Agriculture Organisation (FAO). 2010. Global Forest Resources Assessment 2010. Main report, FAO Forestry Paper 163, 340pp.

Food and Agriculture Organisation (FAO). 2003a. Forestry outlook study for Africa: sub-regional report Central Africa. FAO, Rome, Italy.

Food and Agriculture Organisation (FAO) 2003b. Forestry outlook study for Africa. FAO Sub-regional report for West Africa.

Food and Agriculture Organisation (FAO). 2001. Criteria and indicators for sustainable forest management: A compendium. FAO Working Paper FM/5. Rome . also available at www.fao.org/docrep/004/ ac135e/ac135e00.htm.

Food and Agriculture Organisation (FAO). 2000. Global Forest Resources Assessment 2000. Main report, FAO FORESTRY PAPER 140, 479 p

Franzel, S., Akinnifesi, F. and Ham, C. 2008. Setting priorities among indigenous fruit tree species in Africa: Examples from southern, eastern and western Africa. pp. 1-27. In: Akinnifesi, F.K., Leakey, R.R.B., Ajayi, O.C., Sileshi, G., Tchoundjeu, Z., Matakala, P., and Kwesiga, F.R. (Eds.). Indigenous Fruit Trees in Southern Africa: Domestication, Use, and Commercialisation. Wallingford, UK: CAB International.

Franzel, S., Jeanicke, H. and Janssen, W. 1996. Choosing the right Trees: Setting priorities for multipiurpose tree improvement. Isnar Research Report no. 8. International Service for National Agricultural Research, The Hague, The Netherlands.

Haines, R. 1994. Biotechnology in forest tree improvement with special reference to developing countries. FAO Forestry Paper, 118pp.

Harris, M.S. 1993. Working towards the wider distribution of tree seed in Africa: the activities of the Henry Doubleday Research Association. 12pp. http://www.cifor.cgiar.org/publications/ntfpsite/pdf/NTFP-Africa-R.PDF

Hetemäki, L. and Hurmekoski, E. 2016. Forest products markets under change: Review and research implications. *Current Forestry Report* 2:117 – 188.

Kalinganire, A., Weber, J.C., Uwamariya, A. and Kone, B. 2008. Improving rural livelihoods through domestiction of indigenous fruit trees in the Parklands of the Sahel. pp. 186-203. In: Akinnifesi, F.K., Leakey, R.R.B., Ajayi, O.C., Sileshi, G., Tchoundjeu, Z., Matakala, P., and Kwesiga, F.R. (Eds.). Indigenous Fruit Trees in Southern Africa: Domestication, Use, and Commercialisation. Wallingford, UK: CAB International.

Kana Nguemo, N. 2009. Fonctionnement du re´seau de pe ´pinie´ristes dans la Re ´gion de l'Ouest Cameroun : Cas du De´partement du Nde. Rapport de stage de pre´-insertion professionnelle, Universite´ de Dschang, Cameroun.

Keenan, R.J., Reams, G.A., Achard, F., de Freitas, J.V., Grainger, A. and Lindquist, E. 2015. Dynamics of global forest area: Results from the FAO Global Forest Resources Assessment 2015. *Forest Ecology and Management* 352:9-20.

Koskela, J., Vinceti, B., Dvorak, W.;, Bush, D., Dawson, I.K., Loo, J., Kjaer, E.D., Navarro, C., Padolina, C., Bordács, S., Jamnadass, R., Graudal, L. and Ramamonjisoa, L. 2014. Utilization and transfer of forest genetic resources: A global review. *Forest Ecology and Management* 333: 22 –34.

Leakey, R.R.B. and Akinnifesi, F.K. 2008. Towards a domestication strategy for indigenous fruit trees in the tropics. pp: 28-49. In: Akinnifesi, F.K., Leakey, R.R.B., Ajayi, O.C., Sileshi, G., Tchoundjeu, Z., . Matakala, P. and Kwesiga, F. (Eds). Indigenous fruit trees in the tropics: Domestication, utilization and commercialization. CAB International, Wallingford, UK.

Leakey, R.R.B. and Van Damme, P. 2014. The role of tree domestication in green market product value chain development. *Forests, Trees and Livelihoods* 23 (1-2): 116-126, DOI: 10.1080/14728028.2014.887371

Laestadius, L., Buckingham, K., Maginnis, S. and Saint-Laurent C. 2015. Before Bonn and beyond: the history and future of forest landscape restoration. *Unasylva* 66: 11 – 18.

Lillesø, J. B. L., Graudal, L., Moestrup, S., Kjær, E. D., Kindt, R., Mbora, A., Dawson, I., Muriuki, J., Ræbild, A. and Jamnadass, R. 2011. Innovation in input supply systems in smallholder agroforestry: seed sources, supply chainsand support systems. *Agroforestry System* 83 :347–359.

Lillesø, J.P.B., Harwood, C., Derero, A., Graudal, L., Roshetko, J.M., Kindt, R., Moestrup, S., Omondi, W.O., Holtne, N., Mbora, A. and van Breugel, P. 2018. Why institutional environments for agroforestry seed systems matter. *Development Policy Review* 36: 89-112.

Kenfack, C. P. 2016. Domestication de *Pericopsis elata* (Fabaceae): Etude de la germination et du bouturage. Mémoire de Master of Science en Biologie Végétale, Université de Dschang. 85pp.

Liu, S., Wu, S. and Wang, H. 2014. Managing planted forests for multiple uses under a changing environment in China. *New Zeland Journal of Forestry Sciences* 44 (Suppl 1): S3

MacDicken, K.G., Sola, P., John, E., Hall, J.E., Sabogal, C., Tadoum, M. and De Wasseige, C. 2015. Global progress toward sustainable forest management. *Forest Ecology and Management* 352: 42 – 57.

Makueti, J.T., Tchoundjeu, Z., Kalinganire, A., Nkongmeneck, B.A., Asaah, E., Tsobeng, A. and Kouodiekong, A. 2012. Influence de la provenance du géniteur et du type de pollen sur la fructification sous pollinisation contrôlée chez *Dacryodes edulis* (Burseraceae) au Cameroun. *International Journal of Biological and Chemical Sciences* 6 (3): 1202-1222.

Malhi, Y., Adu-Bredu, S., Asare, R., Lewis, S.L. and Mayaux, P. 2018. African rainforests: past, present and future. *Philosophical Transactions of the Royal Society* B 368: 20120312. 10pp.

Marien, J.N. and Mallet B. 2004. Nouvelles perspectives pour les plantations forestières en Afrique Centrale. *Bois et Forêts des Tropiques* 282 (4) :67 – 80.

Marien, J.N. and Gourlet-Flreury, S. 2013. Les plantations forestières en Afrique centrale : Des sylvicultures nouvelles pour répondre aux nouveaux besoins des sociétés. pp.197 – 212. In: De Wasseige, C., de Marcken, P., Bayol, N., Hiol Hiol, F., Mayaux, Ph., Desclée, B., Nasi, R., Billand, A., Defourny, P. and Eba'a Atyi, R, (Eds.). 2013. –Etat des Forêts du Bassin du Congo (EDF).

Matondo, R. 2013. La stratégie nationale d'afforestation et de reboisement comme opportunité d'affaire en république du Congo. Forum international sur le développement durable de la filière bois dans les pays du bassin du Congo. 11pp.

Ministry of Forest and Fauna (MINFOF). 2006. Programme national de reboisement du Cameroun. 68pp.

Na-Karian, K. 2018. Domestication du Wenge (Milletia laurentii, Fabaceae) : Effet de la surface folaire, du substrat et et du traitement hormonal sur l'aptitude au bouturage sous chassis de propagation. Mémoire de fin d'étude d'ingénieur de conception en Forêt et Agroforesterie. Université de Dschang, Cameroun, 70p.

Ngueguim, J. R., Chokona, G.H., Ayobami, S. T. and Orimoogunje, O. O. 2009. Evaluation of logging impacts on tropical rainforest in Eastern Cameroon using Remote Sensing and GIS techniques. *Int. J. Biol. Chem. Sci.* 3(4) : 771-785.

Ngueguim, J.R. 2014. Productivité et diversité floristique des ligneux en forêt dense d'Afrique tropicale humide du Cameroun : sites de Mangombé, Bidou et Campo. PhD thesis, Muséum National d'Histoire Naturelle de Paris (MNHN). 195pp.

Ngueduim, J.R., Zapfack, L., Noiha, N.V., Onana, D., Betti, J. L. and Riera, B. 2015. Expériences sylvicoles au Cameroun: Croissance, mortalité et adaptabilité des espèces de bois d'œuvre dans la station forestière de Mangombé (1964 - 2010). *Int. J. Biol. Chem. Sci*. 9 (6) : 2889-2806.

Nikema, A., Ouedraogo, S.J. and Boussim, J. 2001. Situation des ressources génétiques forestières du Burkina Faso. Atelier sous-régional FAO/IPGRI/ICRAF sur la conservation, la gestion, l'utilisation durable et la mise en valeur des ressources génétiques forestières de la zone sahélienne (Ouagadougou, 22-24 sept. 1998). Note thématique sur les ressources génétiques forestières. Document FGR/22F. Département des forêts, FAO, Rome, Italie. OECD, 2013. The OECD Codes and Schemes on the African Continent. Information Leaflet. 10pp.

Nyoka, B,. Ajayi, O., Akinnifesi, F., Chanyenga, T., Mng'omba, S., Sileshi, G., Jamnadass, R. and Madhibha, T. 2011. Certification of agroforestry tree germplasm in Southern Africa: opportunities and challenges. *Agrofor Syst* 83 (1):75–87.

Nyoka, B.I., Roshetko, J., Jamnadass, R., Muriuki, J., Kalinganire, A., Lillesø, J.P.B., Beedy, T. and Cornelius, J. 2015. Tree seed and seedling supply systems: a review of the Asia, Africa and Latin America models. *Small-scale Forestry* 14 (2):171-191.DOI 10.1007/s11842-014-9280-8

Organisation for Economic Co-operation and Development (OECD). 2013. Forest seed and plant scheme: scheme for the certification of forest reproductive material moving in international trade: rules and regulations. Paris, Organisation for Economic Co-operation and Development.

Ofori, D.A., Newton A.C., Leaker, R.R.B. and Grace, J. 1996. Vegetative propagation of *Milicia excels* by early stem cuttings: effect of auxin concentration, leaf area and rooting medium. *Forest Ecology and Management* 84: 39-48.

Okali, D. and Eyog-Matig, O. 2004. Rainforest Management for Wood Production in West and Central Africa. A Report Prepared for the Project: Lessons Learnt on Sustainable Forest Management in Africa. Rome: Food and Agriculture Organization (FAO)/African Forest Research Network (AFORNET)/ Royal Swedish Academy of Agriculture and Forestry (KSLA) Project.

Oni, P.I. 2001. State of Forest genetic Resources in the dry north of Nigeria. Sub-Regional Workshop FAO/IPGRI/ICRAF on the conservation, management, sustainable utilization and enhancement of forest genetic resources in Sahelian and North-Sudanian Africa (Ouagadougou, Burkina Faso, 22-24 September 1998). Forest Genetic Resources Working Papers, Working Paper FGR/16E. Forestry Department, FAO, Rome, Italy.

Padonou, E.A., Tovissodé, F. C., Idohou, R., Salako, V. K., Fantondji, L.,Vihotogbé, R., Fandohan, B. and Assogbadjo, A. E. 2017. Pilot assessment of locally acknowledged morphotypes of *Irvingia gabonensis* (Aubry-Lecomte) Baill. in southwestern Benin (West Africa). *Fruits* 72 (5):306-316.

Phartyal, S.S., Thapliyal, R.C., Koedam, N. and

Godefroid, S. 2002. Ex situ conservation of rare and valuable forest tree species through seed-gene bank. *Current Science* 83 (11): 1351 – 1358.

Payn, T. Carnus, J.M., Smith, P.F, Kimberley, M., Kollert, W. and Liu, S. 2015. Changes in planted forests and future global implications. *Forest Ecology and Management* 352: 57–67.

Payn, T., Carnus, J.M., Freer-Smith, P., Orazio, C. and Nabuurs, G-J. 2014. Third International Congress on Planted Forests: Planted Forests on the Globe – Renewable Resources for the Future. Proceeding of the Third International Congress on Planted Forests, Bordeaux, France; Dublin, Ireland; and Porto and Estoril, Portugal. 16-21 May 2013. *New Zeland Journal of Forest* Science 44 (suppl. 1)

Peprah, T. 1999. National report on forest genetic resources in Ghana. Training workshop on FGR. 6–11 December 1999, Nairobi, Kenya.

Rasmussen, L.V., Cristy Watkins, C. and Agrawal, A. 2017. Forest contributions to livelihoods in changing agriculture-forest landscapes. *Forest Policy and Economics* 84: 1 – 8.

Roose, E., Kabore, V. and Guenat, C. 1993. Le zaï: fonctionnement, limites et amélioration d'une pratique traditionnelle africaine de réhabilitation de la végétation et de la productivité des terres dégradées en région soudano-sahélienne (Burkina Faso). Cahiers ORSTOM. *Série Pédologie* 28 (2): 159-173.

Sawadogo, H., Hien, F., Sohor, A. and Kambou, F. 2001. Pits forTrees. How farmers in semi-arid Burkina-Faso increase and diversify plant biomass. In: Reij, C. and Waters-Bayer, A. (Eds.). Farmer Innovation in Africa: a source of inspiration for agricultural development. Earthscan, London, UK.

Shu, G.N. 2013. Assessment and prediction of above-ground biomass in selectively logged forest concessions using field measurements and remote sensing data: case study in south east Cameroon. M.Sc. Thesis, University of Helsinki Department of Forest Sciences Viikki Tropical Resources Institute (VITRI). 84pp.

Sloan, S. and Sayer, J.A. 2015. Review and synthesis: forest resources assessment of 2015 shows positive global trends, but forest loss and degradation persist in poor tropical countries. *Forest Ecology and Management* 352: 134 -145.

Sacandé, M., Pritchard, H.W. and Dullo, E.M. 2004. Seed science and technology needs of SAFORGEN trees for conservation and sustainable use. *Pl. Gen. Res. Newslet.* 139: 53 – 58.

Sacande, M., Berrahmouni, N. and Hargreaves, S. 2015. Community participation at the heart of Africa's Great Green Wall restoration model. *Unasylva* 66 (3): 44 – 51.

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

Takoutsing, B., Tchoundjeu, Z., Degrande, A., Asaah, E., Gyau, A., Nkeumoe, F. and Tsobeng, A. 2014. Assessing the quality of seedlings in small-scale nurseries in the highlands of Cameroon: the use of growth characteristics and quality thresholds as indicators. *Small-scale Forestry* 13 (1): 65-77.

Tchoundjeu, Z., Duguma, B., Fondoum, J.M. and Kengue, J. 1998. Strategis for domestication of indigenous fruit trees in West Africa: case of *Irvingia gabonensis* in southern Cameroon. *Cameroon Journal of Biology and Biochemical Sciences* 4: 21-28.

Thomas, E., Jalonen, R., Loo, J. and Bozzano, M. 2015. Avoiding failure in forest restoration: the importance of genetically diverse and site-matched germplasm. *Unasylva* 66 (3): 29-36.

Toyi, M.S., Barima, Y.S.S., Mama, A., André, A.M., Bastin, J.F., De Cannière, C., Sinsin, B. and Bogaert, J. 2013. Tree plantation will not compensate natural woody vegetation cover loss in the Atlantic Department of Southern Benin. *Tropicultura* 1: 62 – 70.

Vihotogbé, R., Watson, C., Kakaï, R. Glèlè, Wichern, F., Sinsin, B. and Gebauer, J. 2017. Effects of salinity on seedling emergence and early seedling growth of *Irvingia gabonensis* (Irvingiaceae). *Seed Sc. and Tech.* 45 (2): 285 – 292.

Vihotogbe, R., Idohou, R., Gebauer, J., Sinsin, B. and Peterson, A.T. 2018. Estimation of cultivable areas for *Irvingia gabonensis* and *I. wombolu* (Irvingiaceae) in Dahomey-Gap (West Africa). *Agroforest Syst.* 1-10pp. https://doi.org/10.1007/s10457-018-0193-y.

Whiteman, A., Wickramasinghe, A. and Piña, L. 2015. Global trends in forest ownership, public income and expenditure on forestry and forestry employment. *Forest Ecology and Management* 352: 99-108.