Chapter

Conifers: Species Diversity and Improvement Status in Kenya

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Abstract

A wide range of exotic conifer species have been successfully introduced in Kenya since 1910 for the purpose of supplying wood, mainly for timber, pulp, and plywood industries. Among the conifers introduced, *Cupressus lusitanica* and *Pinus patula* have adapted well to local growing conditions and are now the key species widely planted in commercial plantations. The other conifer species are planted at secondary level or as ornamentals. In order to increase productivity, the key conifer species have been subjected to genetic improvement through selection, breeding, and hybridization. Results of tree improvement work on *C. lusitanica* and *P. patula* showed growth and productivity increase from 20 to 25 m^3/ha/yr. for *C. lusitanica* and from 25 to 30 m^3/ha/yr. for *P. patula*. Scaling up conifer plantations using the tree improvement technologies drawn for the two species is one of the strategies for closing the annual wood supply–demand deficit which is currently estimated at 10.3 million m^3. It is also one of the strategies for achieving 10% tree cover which is currently at 7.2%. The strategy encompasses the application of principles of tree breeding, improved germplasm, silviculture, pests and disease control. This presentation is a review of the status of conifer species since their introduction in Kenya.

Keywords: exotics, indigenous, tree improvement, growth, productivity, breeding, germplasm, silviculture, pests and diseases

1. Introduction

1.1 Background information

The entry of exotic conifer species in Kenya's forest development dates back to 1910's when the government made deliberate policy decision to put the forest sector under organised management [1]. Many conifer species were introduced and tested for their adaptability and growth under plantation conditions. Those species that showed faster growth and good wood and stem quality traits compared to the slower growing indigenous species were incorporated into plantation development programmes. To-date, about 80% of the 186,000 ha state forest plantation estate is composed of the two conifer species, *Cupressus lusitanica* Miller and *Pinus patula* Schiede [2]. They are grown in agriculturally high potential areas between 1500 and 2500 metres above sea level, with mean annual rainfall of between 1000 and 1750 mm. The main reasons for preference of the two species is their fast growth with a short rotation and economic importance in provision of timber for the construction industry, pulp for paper industry, plywood and fuelwood. They are also important in contributing to the country's efforts to raise tree cover from the present 7.2% to over 10% [3]. Also, their management regimes, silviculture, and other growth characteristics are already known because the species have been in the Kenyan landscape for a long time [1].

In order to make growing of conifers attractive to investors, strategies were drawn to increase the yield both in quantity and quality of timber and other tree products. This therefore called for formulation of tree improvement programmes that combines principles of tree breeding, silvicultural management and species-site matching. The programme would ensure a sustainable supply of improved seeds for establishment of highly productive commercial plantations. The first component of the tree improvement strategy was to continue with further introductions and evaluation of conifer species with potential for fast growth and adaptability. The second component was to work within the populations of the species that were already adopted for planting in commercial plantations and identify genotypes that are high yielding for further development. Resistance and tolerance to pests and diseases was among the considerations for species, provenance and genotype suitability. In this regard, the planting of *Cupressus macrocarpa* Hartweg and *Pinus radiata* D. Don, species were discontinued in Kenya from plantation development programme due to their susceptibility to pests and disease [4]. Tree improvement programme is also one of the strategies for addressing the deficit of wood supply, which is currently estimated at 10.3 million m^3 per annum [3]. Over time, the improvement programs have been reviewed and some species such as *Pinus tecunumanii* Eguiluz and J.P. Perry, *Pinus maximinoi* H.E. More, Pine hybrids, in addition to broadleaved non-conifer species have been considered to widen the choices of plantation species in the country [5, 6].

1.2 Introduction of conifers in Kenya

All conifer species that have been introduced to Kenya over the years fall into three families, namely, *Cupressaceae*, *Pinaceae*, and *Araucaraceae*. With the exception of the indigenous *Juniperus procera*, the rest of the conifer species listed in **Table 1**, below, were introduced by testing the species and or their provenances for growth and adaptability as candidate species for commercial plantations. Only two of the 42 listed species are planted on commercial scale, while 39 other conifers are planted on smaller scale as secondary species. This is because initial trials showed them to be either slow growing, have poor timber quality traits or are susceptible to pests and diseases compared to the two key conifer species. Several of these secondary species are planted within residences, in urban centres and along highways as ornamentals while others are still at species and provenance evaluation stage in research plots to determine their growth and adaptation to local growing conditions. The only indigenous conifer species, *J. procera*, is found growing naturally in the Western rainforest and the high-altitude Montane Forest types in the country. It has also been tried in plantations but found to be slower growing compared to the exotic conifers. It attains a productivity of Mean Annual Increment (MAI) of 3.73 m^3/ha/yr [9, 10].

The main objective of introducing conifers in Kenya was to supply wood for timber, paper and plywood industries. This was to take advantage of the fast growth of the conifers and the fairly matching climatic conditions in Kenya with that of their native countries. To maximise on the productivity of the conifers, there was formulated a conifer improvement programme whose ultimate goal was to develop high yielding varieties of priority conifer species for industrial plantations. The key outcome of the programme was to establish improved seed sources to enhance planting and ensure

Family	Species from the family	Status of species in Kenya
Cupressaceae	1. *Cupressus lusitanica* Miller	Most widely planted in commercial plantations
	2. *C. macrocarpa* Hartweg	Susceptible to disease
	3. *C. pyramidalis* O. Targ.Tozz	Ornamental
	4. *C. benthamii* Endlicher	Ornamental
	5. *C. torulosa* D. Don	Slow growth
	6. *C. sempervirens* L.	Slow growth
	7. *C. arizonica* Greene	Slow growth
	8. *Juniperus procera* Hochstetter	Indigenous, slow growth
	9. *Thuja occidentalis* Linnaeus	Ornamental
	10. *Cryptomeria japonica* D. Don	Slow growth
	11. *Callitris hugelii* Carrière	Drought resistant
	12. *C. preissii* Miquel	Drought resistant
	13. *C. calcarata* Silba	Drought resistant
	14. *C. rhomboidea* R. Brown	Poor quality poles and posts
Pinaceae	1. *Pinus patula* Schiede	Widely planted in commercial plantations
	2. *P. radiata* D. Don	Susceptible to disease
	3. *P. caribaea* Morelet	Lowland, secondary planting
	4. *P. oocarpa* Schiede	Experimental planting
	5. *P. pinaster* Aiton	Slow growth
	6. *P. kesiya* Royle	Slow growth
	7. *P. maximinoi* H.E. Moore	Experimental planting
	8. *P. tecunumanii* Eguiluz and J.P. Perry	Experimental planting
	9. P. hybrids	Experimental planting
	10. *P. taeda* Linnaeus	Slow growth
	11. *P. canariensis* C. Smith	Slow growth
	12. *P. elliottii* Engelmann	Secondary planting
	13. *P. strobus* Linnaeus	Slow growth
	14. *P. insignis* Douglas	Slow growth
	15. *P. halapensis* Mill.	Slow growth
	16. *P. pseudostrobus* Lindley	Slow growth
	17. *P. massoniana* Lambert	Slow growth
	18. *P. oaxacana* Mirov	Slow growth
	19. *P. montezumae* Lambert	Slow growth
	20. *P. michoacana* Martínez	Slow growth
	21. *P. pringlei* Shaw	Slow growth
	22. *P. ponderosa* Douglas	Slow growth
	23. *P. greggii* Engelmann	Slow growth
	24. *P. ayacahuite* Ehrenberg	Slow growth
Araucariacea	1. *Araucaria angustifolia* (Bertol.) Kuntze	Poor survival, slow growth
	2. *A. cunninghamii* Aiton	Poor survival, slow growth
	3. *A. heterophylla* (Salisb.) Franco	Ornamental
	4. *Agathis lanceolata* Lindley	In some homesteads

Source: adopted from [7, 8].

Table 1.
The diversity of conifer species introduced and tested in Kenya.

higher productivity of conifer plantation species [11]. The objectives of this review is to give the status of the introduction and genetic improvement of conifer species in Kenya, in particular the development of *C. lusitanica*, *P. patula* and *P. radiata*.

2. Genetic improvement of conifers in Kenya

The process of tree improvement is long-term. It starts with drawing a strategy which defines the scope in terms of the species of priority, the diversity within the populations of the species, and setting objectives of the programme. This is followed by field activities which involve selection of superior trees in the population, multiplication of the selected trees (genotypes), controlled pollination, hybridization, and genetic testing. Propagation of the selected superior genotypes and establishment of seed orchards is a key operation in the process [12]. These steps were followed in the programme to improve the two key conifer species in Kenya. However, since the whole process takes a long time before high quality seeds become available, a supplementary component of the programme ensures seeds for planting are available before the seed orchards from the main programme become productive. This involves the use of general forest stands that are inspected and certified to have a high proportion of phenotypically good trees to be used as sources of seed for expansion of plantations. In such cases, seed collection is confined to the trees that are bigger and more straight since the end market for these species is mainly sawn timber [11].

The method used to identify and select superior mother trees is based on visual observation followed by assessment of morphological features of the potential mother tree which has to be the most outstanding in comparison with the other trees in its neighbourhood. Total tree height and diameter at breast height (Dbh), are the main measurable traits for assessing growth of trees. Other quality traits such as tree form and stem straightness are also considered in such multi-trait selection [13]. Silvicultural and management operations to enhance seeding include thinning to obtain adequate spacing of trees in a stand. Vegetative propagation techniques and controlled pollination are often used to raise material for establishing seed orchards. In most cases, progeny tests are done in order to use the progeny trial data to assist in rogueing out poor performing mother trees in the seed orchards [14]. Further activities involve continuous infusion of new germplasm from other countries and broadening of the genetic base of the commercially prioritised tree species. New germplasm of species such as *P. tecunumanii*, *P. maximinoi* and pine hybrids have been introduced and are undergoing evaluation tests [5, 15].

2.1 Improvement status of the main conifer species

2.1.1 C. lusitanica improvement

Cupressus lusitanica (Mexican cypress) is native to Mexico but was introduced in Kenya in 1910 mainly from South Africa and France. It has since become an important industrial plantation species in high elevation areas between 1500 to 2500 m above sea level and annual rainfall of between 1000 and 1750 mm [16]. It is planted on commercial scale for production of sawn timber, plywood, pulp and poles for building and construction. It also provides services such as live fence, shade and ornamental [2, 17, 18].

Improvement of *C. lusitanica* has been carried out mainly to meet the requirements of sawn timber market. Therefore, the improvement objective was to raise productivity of volume of wood, and quality of tree stems. Mother tree selection was based on traits for rapid growth, stem form and shape, light branching and resistance to pests and diseases. Over the years, the programme progressively selected 453 outstanding *C. lusitanica* mother trees from commercial plantations. Those mother trees formed the base for improvement work. The mother trees are a source of propagation material and are multiplied through grafting, cuttings and progeny seeds which are used to establish seed orchards (**Table 2**). The breeding strategy for *C. lusitanica* has since been revised to incorporate recurrent selection of mother trees in progeny trials of subsequent generations [12].

Recent selections from F1 generation of progeny trials and from plantations has been carried out to yield mother trees to be used in establishing more seed orchards, further progeny trials, and expanded commercial plantations [12, 21].

Generally, it has been shown that plantations raised from seeds collected from seed orchards has led to improved performance with the crop attaining a mean height and diameter at breast height of 25.8 m and 30 cm, respectively, at sawn timber rotation of 30 years [12]. Other levels of height growth achieved at different ages are as shown in **Table 3** below [12]. Results from several progeny trials [4, 12, 19] show high heritability and genetic gains of key traits required in timber production. For example, heritability for diameter, height and volume was 0.89, 0.77 and 0.89, respectively, at 25 years while the genetic gain estimations was 7%, 6% and 12% for height, diameter and volume respectively [12]. Genetic improvement programmes elsewhere have shown that substantial gains were achieved through selection of superior trees for improved productivity of plantations and quality of products [14]. In terms of productivity, assessment of the F1 progeny trials yielded data which showed MAI improved from 20 to 25 m^3/ha/yr. [2, 22, 23]. The data was used to select another set of plus trees to form the F2 generation that is currently being tested in progeny trials. The F2 seed orchards similar to **Figure 1**, below, are in the process of being established. Demand for improved cypress planting materials (seeds and seedlings) has been increasing hence the need for more seed orchards and further genetic improvement of the germplasm [24].

2.1.2 Pinus patula and pine hybrids improvement

Pines are fast growing exotic softwood tree species introduced to Kenya from South Africa (Ex-Mexico) in early 1920's to provide raw material for the rapidly expanding wood-based industry. Many pine species were also introduced and planted in species site matching trials in the 1940s to determine their adaptability and growth patterns [25]. From these trials, *P. patula* and *P. radiata* were initially

Species	No. of seed orchards	Total area (ha)	Annual seed production (kg)
C. lusitanica	22	39.5	550

Source: adopted from [19, 20].

Table 2.
Seed production status of C. lusitanica.

Age (yrs)	1	3	5	8	10	15	20	25	30
Mean Ht (m)	0.9	3.9	7.0	11.5	13.3	18.2	21.2	23.6	25.8

Source: adapted from [12].

Table 3.
Mean height growth of improved C. lusitanica on average sites in Kenya.

Figure 1.
(Left) A seeding 12-year-old C. lusitanica seed orchard with (right) a zoomed in branch, at Londiani, Kenya. Source: Photograph by Mbinga J.

selected for large-scale planting due to their fast growth and their relative ease of establishment. However, *P. radiata* was subsequently discontinued from plantation establishment due to its susceptibility to *Dothistroma pinii* fungal disease. Currently, *Pinus patula* is the main pine species being planted on commercial scale. It grows well in areas where elevation ranges from 1500 m to 2500 m a.s.l, with annual rainfall above 1000 mm., predominantly in Central Kenya and parts of Rift valley. Its silvics is well developed where it is planted at a spacing of 2.75 x 2.75 m and 2.5 x 2.5 m for pulpwood and sawn timber cycles respectively. There is no thinning for pulpwood cycle, but for timber, the plantations are thinned from the initial density of 1600 stems per ha to 800, 600, and 356 stems per ha at ages of 10, 18, and 25 years respectively [8]. The primary market for *P. patula* is sawn timber, paper and plywood. The species has undergone improvement through breeding with the objective of increasing wood volume productivity per unit area and stem quality. Main traits considered are fast growth, good form, light branching, and resistance to pest and disease. For breeding purposes, *P. patula* heritability for various traits were found to be as follows; 0.44, 0.82 and 0.40 for height, diameter and stem form respectively [26]. Therefore, selections of best performers based on the trait of diameter at breast height will give significant gains since the trait has a high heritability. *P. patula* is also used as a main hybrid parent where it is crossed with many other pines to produce pine hybrids. The strategy guiding the improvement of *P. patula* [12] was revised to provide for mass selection of superior mother trees from existing plantations and using them to establish clonal seed orchards (**Table 4**), (**Figure 2**). The performance of the selected mother trees were tested through progeny trials. Over the years, the cumulative number of breeding mother trees selected for this species are 464 trees which forms the base for further improvement work [12].

Species	No. of seed orchards	Total Area (ha)	Annual seed production (kg)
P. patula	16	62.5	380
Source: adopted from [19, 20].			

Table 4.
Seed production status of P. patula.

Figure 2.
A six year grafted P. patula clonal seed orchard at Kamara, Kenya. Source: Photograph by Mbinga J.

The plus trees were also conserved in a clonal Tree Bank at Muguga [27], and their progenies used to establish progeny trials. The programme set target of raising its productivity from 25 m^3/ha/yr. to 30 m^3/ha/yr., thereby making genetic gains in the traits under consideration [12, 22]. The gains have contributed to increases of 10%, 5%, and 11% in height, diameter at breast height and volume production per hectare respectively [6, 28].

In the hybridization component, *P. patula* has been crossed with other pines to produce hybrids some of which perform better than parent trees while others are more adaptable to different growing conditions. Kenya Forestry Research Institute collaborates with the Conifer Improvement and Conservation (CAMCORE) programme, based in North Caroline, United States of America, and through this initiative, several pines and pine hybrid germplasm have been accessed and are being tested to determine their performance.

Preliminary results of hybrid trials indicate that hybrids of *P. patula* and *P. tecunumanii*, (Low elevation provenance), outperforms all the other hybrids, as listed in **Table 5**, and the pure *P. patula* control with respect to survival, height, and diameter at breast height. New germplasm of *P. maximinoi* and *P. tecunumanii* were also showing good growth and adaptability at Turbo site in western Kenya.

2.1.3 Improvement of Pinus radiata in Kenya

In Kenya, *P. radiata* was the most favoured species for pulp and paper products. It has good pulp and paper qualities, produces higher volume yield per unit area, has higher wood density, longer and narrow tracheids, low lignin content and less extractives. However, the species is highly susceptible to *D. pinii* fungal disease that led to discontinuation as a plantation species in Kenya [29]. Efforts to control the fungal disease were initiated in 1970s through breeding for disease resistance where selection of trees on the basis of lower severity of disease symptoms was done and supplemented with infusion of more progenies from Australia and New Zealand. Such trees were propagated into seed orchards and progeny trials to test the persistence of their observed tolerance to *D. pinii* disease. The trials were established in areas that are prone to *D. pinii* fungal infestation namely: Timboroa, Nabkoi and Kaptagat [30, 31].

S/no.	Hybrid	Survival %	Height (m)	Dbh (cm)
1	*Elliotii* x *tecunumanii*, High elevation	43	1.55	2.31
2	*Elliotii* x *taeda*	73	3.15	5.00
3	*Patula* x *greggii*	65	4.33	5.34
4	*Patula* x *taeda*	47	4.37	6.36
5	*Elliotii* x *caribaea*	78	4.44	7.36
6	*Caribaea* x *tecunumanii* Low elevation	70	4.72	7.13
7	*Patula* x elliotii	39	5.18	7.01
8	*P. patula* Pure spp	60	5.41	6.99
9	*Tecunumanii*, Low elevation x *caribeae*	82	5.43	7.64
10	*Tecunumanii*, High elevation x *oocarpa*	76	5.52	7.39
11	*Patula* x *tecunumanii*, High elevation	63	5.77	7.74
12	*Patula* x *oocarpa*	69	6.06	8.43
13	*Patula* x *tecunumanii*, Low elevation	85	6.49	8.69

Source: [6].

Table 5.
Summary statistics for pine hybrids at Turbo, Kenya at age 4 years.

Results from trials established using material imported from New Zealand show the 28-year-old trial at Timboroa, Kenya had the best growth with an MAI productivity of 40 m^3 /ha/yr. and mean Dothistroma disease score of 2, which translates to susceptibility level of 25-50% (**Table 6**).

To-date, the new *P. radiata* families infused from New Zealand, as well as the local selections forms the base population of the species. Since 75% levels of disease resistance or tolerance showing a mean disease score of 1 [31], has not been achieved, the genetic material present have been conserved in conservation plots to provide opportunities for future improvement [30]. Lessons learnt from the experience of breeding for disease and pest tolerance such as in *P. radiata* indicates that gains can be small and take long to be realized. also the future of plantation forestry

Site	Source of material	Age (yrs)	Mean ht (m)	Mean Dbh (cm)	Mean disease score (scale 1-5) Where; 1=least susceptible 5=most susceptible	Mean volume (m^3/ tree)	Productivity MAI m^3/ha/ yr
Nabkoi Compt. 9	New Zealand	29	29.3	30.4	2	1.24	21
Timboroa compt. 2 J	New Zealand	28	33.0	39.4	2	2.25	40
Kaptagat Compt.1Y	Local selections	24	28.9	33.5	2	1.37	29
(comparison) *P. patula*	In general plantations	30	30.0	34.5	—	1.8	30

Source: [31].

Table 6.
Growth and productivity of Pinus radiata progenies in areas with prevalence of Dothistroma needle blight disease in Kenya.

requires a diversity of species with populations having a broad genetic base in order to safeguard against negative effects of pests and diseases.

3. Conclusions

Among the conifer species introduced in Kenya to supply timber for construction, pulpwood and plywood industries, two of them have performed well enough to meet the intended purpose. The two species, *C. lusitanica* and *P. patula*, are currently the most widely planted and dominate the 186,000 ha of public forest plantations. The other less successful conifers are planted at secondary level. Tree improvement work on the key conifer species has been done using the classical approach of selections, testing and propagation. Even though this approach is slow, it ensured continuous supply of improved seeds that yield timber trees of a quality that meets market requirements. Continuous improvement work focusing on pine hybrids promises to sustain higher timber productivity in traditional plantation areas and have potential to grow in marginal sites thereby expanding the area available for commercial forestry as well as an adaption to climate change. For the future, it may be necessary to hasten tree improvement process by reviewing the classical approach and adopting modern molecular tools and biotechnology to meet tree improvement objectives faster.

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