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African mahogany (*Khaya senegalensis*) plantations in Australia - status, needs and progress

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Abstract

The Australian African mahogany estate comprises over 12,000 ha of industrial plantations, farm-forestry plots and trials, virtually all derived from Africa-sourced wild seed. However, the better trees have given high-value products such as veneers, high-grade boards and award-winning furniture.

Collaborative conservation and improvement by the Northern Territory (NT) and Queensland governments since 2000 realised seed orchards, hedge gardens and genetic tests revealing promising clones and families. Private sector R&D since the mid 2000s includes silvicultural-management and wood studies, participatory testing of government material and establishing over 90 African provenances and many single-tree seedlots in multisite provenance and family trials. Recent, mainly public sector research included a 5-agency project of 2009-12 resulting in advanced propagation technologies and greater knowledge of biology, wood properties and processing.

Operational priority in the short term should focus on developing seed production areas and 'rolling front' clonal seed orchards. R&D priorities should include: developing and implementing a collaborative improvement strategy based on pooled resources; developing non-destructive evaluation of select-tree wood properties, micropropagation (including field testing of material from this source) to 'industry ready' and a select-tree index; optimising seed production in orchards; advancing controlled pollination techniques; and maximising benefits from the progeny, clone and provenance trials.

Australia leads the world in improvement and ex situ conservation of African mahogany based on the governments' 13-year program and more recent industry inputs such that accumulated genetic resources total over 120 provenances and many families from 15 of the 19 African countries of its range. Having built valuable genetic resources, expertise, technologies and knowledge, the species is almost 'industry ready'. The industry will benefit if it exploits the comparative advantage these assets provide. However the status of much of the diverse germplasm introduced since the mid 2000s is uncertain due to changes in ownership. Further, recent reductions of government investment in forestry R&D will be detrimental unless the industry fills the funding gaps. Expansion and sustainability of the embryonic industry must capitalise on past and current R&D, while initiating and sustaining critical new work through all-stakeholder collaboration.

Keywords: domestication, collaboration, tree improvement, conservation, R&D, alliance

Introduction

Annual plantings of African mahogany (*Khaya senegalensis* - Ks) currently constitute approximately 20% of the national yearly increase of Australian hardwood plantations, the highest among tropical species (1; our records). The estate of over 12,000 ha comprises industrial plantations (Fig. 1), farm-forestry plots (c. 260 ha) and trials (c. 40 ha) across northern Australia. The most extensive area is in the Douglas-Daly, Northern Territory (NT) where over 11,000 ha of plantations have been established since 2006 with annual increments currently around 1,500 ha.

Virtually all these plantings are derived from Africa-sourced wild seed, the rest being from Australian-landrace or locally-improved seed. Many trees have poor stem straightness, short merchantable boles and low diameter. However, the better trees can yield high-value products such as veneers, high-grade boards and award-winning furniture (2, 3). Miller (4) considered the 'pros and cons' of growing Ks commercially in northern Australia, specifically in the Douglas-Daly, NT. He predicted a sound future for the venture through the combined efforts of industry and government.

A low-input R&D partnership of the NT and Queensland (Qld) governments since 2000, with early assistance from the RIRDC (3, 5), realised small grafted clonal seed orchards (CSOs) and clone, provenance and progeny tests. Outputs include promising clones and seedlots from orchards and good trees suitable for commercial testing/pilot-scale planting and inclusion in breeding and propagation populations. The best of this germplasm would improve profitability of new plantings using it, as indicated by early results of clone and progeny tests mentioned below.

Recent, mainly public sector research included a 5-agency project undertaken during 2009-12 resulting in advanced propagation technologies and greater knowledge of reproductive biology, diversity, wood properties and processing of the species including suitability for veneer production (2, 6, 7, 8, 9). Another collaborative project is addressing water usage by mahogany plantations in the Douglas-Daly, NT (10).

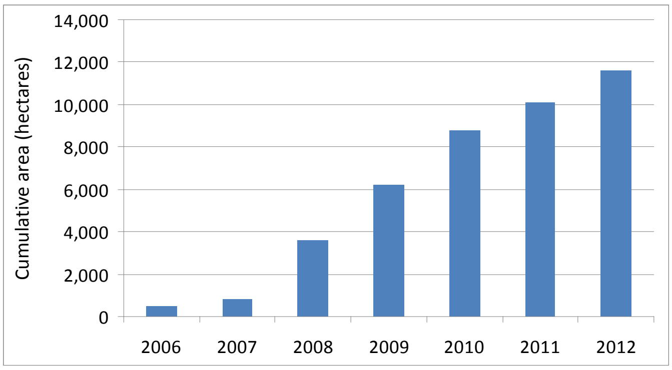

Figure 1. The cumulative area of industrial plantations of *Khaya senegalensis* established across northern Australia since 2006. D. Reilly.

Private sector R&D since the mid 2000s, some reported (11, 12), includes silvicultural-management and wood studies, provision of test sites for government genetic material and establishment of over 90 new, wide-ranging African provenances in plantations and, with many single-tree seedlots, in multisite provenance and family trials. These accessions greatly extend and complement the governments' genetic base. However, the status of much of this new germplasm in trials is uncertain due to change of land tenure, inadequate maintenance or protection and cyclone damage.

Development of a viable Ks industry, underpinned by sustained R&D, is also threatened by the recent reductions in government investment in Ks R&D due to lack of co-investment by industry. This paper updates conservation and improvement aspects of Ks domestication in Australia, suggests critical areas for follow-up work and indicates how the support required for ongoing R&D might be secured.

Domestication status

Tree selection

This has focused on improving straightness and bole length without losing relative growth. There is evidence of genetic variation in these traits (see sections below) so selection should be effective. Heartwood percent is highly variable (2, 7, 13) with indications of genetic variation among provenances at 9.5 years, and families and clones at 5.5 years (7). Future selection should use an index that weights these and other traits conferring high yields and suitability of logs for veneer production, which is the best use for the species (14). The NT DOR has completed microsatellite screening of the first-generation breeding population captured in the CSOs, and selected plants of the diverse hedge garden (see Seed orchards and Clone tests below), using the 10 markers identified by Karan (9). Extension of molecular genetics work to genomic selection would further improve efficiency in the future.

Since the 1990s, and especially since 2005, a large estate has been established. It includes broadly-based operational plantations, farm-forestry plots and provenance, progeny and clone tests, providing an extremely valuable new base for tree selection that could resume soon.

Reproductive biology, controlled pollination, breeding

Ks has separate male and female florets within clusters on the same tree and appears to be insect pollinated (6). Flowering occurs during July-November (dry season) in the NT seed orchards and November-February (latter part includes two wet-season months) at Walkamin, Qld. Pods mature a year after flowering, each with c. 45 seeds, averaging c. 6000/kg. Flowering is highly synchronous among diverse clones, so extensive crossings are expected in seed orchards. Recent controlled pollination (CP) efforts (Fig. 2) have resulted in some seed; however, the technique needs refining (6). So far, the breeding program has used open pollinated seed from the CSOs and good trees in older plantings. It could use CP soon as superior parental and young trees are being identified (see Clone and Progeny tests below).

Figure 2. Flowers bagged for controlled pollination in 2011 in DAFF's clonal seed orchard at Walkamin Research Station, Queensland. G. Dickinson.

Seed orchards

Small, genetically-diverse CSOs were established from grafts of 98 good, NT trees aged 28-30 years in the NT at Howard Springs (1.3 ha), and the Berrimah Agricultural Research Centre (0.56 ha) in 2001 (5), with a subset of 68 clones (0.7 ha) at the Walkamin Research Farm in 2003 (6). All CSOs have additions from other local selects; fertiliser was applied in each CSO and irrigation supplied at Walkamin (6).

The first substantial flowering in the Howard Springs and Walkamin CSOs occurred on 5.5 and 7 years old grafts respectively (6). Flowering has increased to 60% and 90% of clones respectively. Less than half of the flowering clones have produced seed and yield is variable between clones. The best CSO seed yield was c. 3 kg per ha from Howard Springs in 2010. A provenance seedling seed orchard at Walkamin (0.8 ha, 11 years old) has produced little seed. High viability in fresh seed (90+%) quickly reduces, although, under dry, cold storage (5% moisture content, 5° C) initial viability is retained for at least four years (15).

Productivity of these orchards is insufficient to support a 1500 ha annual plantation program. Additionally, African seed supplies are unreliable, putting the industry at risk. However, substantial areas of local stands produce seed, while much larger areas of industrial plantations, some farm forestry plots and government genetics trials established since 2005, are at 'selection age' and could produce seed shortly. This highlights the need to fast-track local seed procurement and improvement. Seed production options may include/combine mass selection, 'seed production areas (SPAs)', 'seedling seed orchards', new 'clonal seed orchards'; vegetative multiplication of good seed or clones, would herald 'family forestry' and 'clonal forestry' (16). Operationally, priority should be on developing SPAs and, in view of the incremental industrial plantings (Fig. 1), 'rolling front' CSOs that could include periodic selections throughout the estate plus the governments' most promising first- and second-generation clones, the former clone selection based in part on the progeny tests. Conversion of some progeny and clone tests to seed orchards should be considered. To maximise seed production in new sources, it is essential to locate such in areas with climates favourable for abundant, early seed production. Application of paclobutrazol to promote flowering (6), use of irrigation to increase pod set and retention respectively need to be practiced in all seed orchards.

Vegetative propagation

Macro-propagation from seedling hedges (17) has been undertaken since 2004 to establish clone tests. A commercial nursery in Qld can mass propagate clones from juvenile hedges.

Potentially, improved seed could be multiplied vegetatively using tissue culture, with deployment initially via 'orchard bulk forestry' and later, via 'family forestry' when superior families are identified. Protocols for micropropagation and 'synthetic seed' production have been developed for Ks (8, 18, 19). The first field tests of this tissue culture material are planned for the coming wet season. Tissue culture is expensive, so only seed of families or clones with proven field performance should be used commercially. Identities of such clones and families are being determined via the Clone and Progeny tests mentioned below.

Technology for vegetatively propagating Ks selection-age trees as juvenile clones would facilitate clone testing and selection, benefitting breeding and, potentially, enabling clonal forestry. Research in this area is highly recommended.

Progeny tests

Eight tests were established between 2005 and 2012, four collaboratively with growers. A milestone was reached in 2009 when the first of several tests that include second-generation families from CSO seed were planted (Fig. 3). The most recent of the progeny tests also include families from wild trees in Africa and selects in Australia. Early results of the first tests indicate many families are superior to commercial controls. The tests will enable forward and backward selection and could be converted into seedling seed orchards in the future. This highlights the need to maintain these valuable tests (and CSOs).

Figure 3. A superior tree at early age in a progeny test of local second-generation families from clonal orchard seed planted at DOR's Katherine Research Station, Northern Territory in 2010. The superior tree is 5 m in height, 8.0 cm in dbh and 1.75 years old. G. Dickinson.

Clone tests

Four hundred clones are under test in trials established between 2005 and 2011 across 12 sites in the NT (20) and four in Qld. All trials have rooted cuttings derived from hedge-garden seedlings of diverse NT and Qld sources, and seedling controls from local and/or African sources (Figs 4, 5). Early assessments show great variation between clones with some clones superior to controls. Across the older trials, 10 clones combining superiority for most commercial traits have been nominated; some of these clones are showing adaptability across diverse sites. These are worthy of further testing, inclusion in new grafted seed orchards and the breeding population. The new suite of promising clones is preferable to an earlier cohort chosen in tests aged up to only 1.5 years.

Figure 4. A rooted-cutting tree of widely-adapted clone 99 in a 7.5-year-old replicated, single-tree-plot test of government clones planted at DOR's Coastal Plains Horticultural Research Station, Northern Territory in 2005. Dbh 23.1 cm, bole length 6.5 m, straightness score 5 (6 best). D. Reilly.

Provenance trials

Trials established in the NT in the 1970s included 23 Ks provenances from 11 of the 19 African countries of its native range (3). A further 5 provenances from Burkina Faso were included in a Qld seedling orchard planted in 2001. During 2006-11, eight new provenance trials were established by the private sector, several in conjunction with the Qld government, in the NT (Douglas-Daly and Melville Is.) and in Qld at Abergowrie (21, 22, 23; pers. comm., M Johnson, 2007). Fig. 6 shows part of a trial planted in the Douglas-Daly in 2007. Across all trials planted since the 1970s, over 120 provenances from 15 African countries are represented in Australia, the most extensive ex situ collection of Ks germplasm in the world.

Four trials planted in 2008 were assessed at age three years. Results indicate better growth from some African sources, while others exhibit better stem quality; statistically significant differences were also found for axis persistence, a canker disease and lean (cyclone effect) (22, 23). Several exceptional trees (age three) for good growth, bole length, form and low lean survived Cyclone Yasi at Abergowrie. This may indicate we can select effectively for traits including windfirmness as achieved with Caribbean pine in Qld (24). Provenance performance may change with age so trials need to be maintained long-term.

Figure 5. A stand of 5.3-year-old rooted cuttings trees in a replicated, single-tree-plot test of government clones planted on industry land in the Douglas-Daly, Northern Territory in 2007. DBH of largest trees: 20 cm. D. Reilly

Figure 6. A stand of 5.3-year-old seedling trees of a Senegal provenance in a replicated trial planted on industry land in the Douglas-Daly, Northern Territory in 2007. D. Reilly

Conservation

The genetic resources of all six *Khaya* species are vulnerable or endangered in Africa (25). African or 'dry-zone' mahogany (*K. senegalensis*) has many uses across its native range but over-exploitation threatens its sustainability. A proposal to preserve the genetic diversity of K. senegalensis in Africa and ex situ has been identified as an international conservation priority (26). Results of the local provenance trials and molecular studies of population diversity (next section) will help plan future conservation efforts. Meanwhile, the best trees across all plantings since the 1990s in Australia should be selected and captured as grafts in clone banks.

Diversity

A preliminary molecular study of population diversity was based on range-wide samples and novel microsatellite markers (9). Results indicate two groups: western (more diverse) and eastern, with an overlapping, central zone. Further work is in progress (G. Sexton, University of Queensland, pers. comm., 2012).

Finger printing

Molecular genetics studies by NT DOR mentioned under 'Tree selection' included finger printing of the breeding population and selected clone parents from the hedge garden for quality control and protection of IP.

Wood evaluation

Plantation wood evaluation studies have been reported (2, 7, 13). Furniture made from 30-32 year old NT trees won several awards (3). Veneer recovery (83% versus 49% sawn, green) from the better 18- and 20- year old Qld trees was especially promising (2, Fig. 7). Even 10-y-old thinnings logs can have a very high proportion of desirable, dark-coloured wood (Fig. 8). Nine advantages of veneer technologies for processing tropical and sub-tropical hardwood plantation resources including thinnings have been listed (14). Prospects for producing high-value products from plantations are good, especially if trees with high volumes and recoveries of face veneers and quality boards can be developed by combined breeding and stand management.

Securing industry development

Goal - greater plantation profitability including:

- Increased stand productivity, uniformity and proportion of logs suitable for veneering from thinnings and full rotation trees.
- Reduced rotation length without compromising yield and recoveries of face veneers and quality boards of good colour.
- Increased heartwood proportion.
- Fast-tracked deployment of improved germplasm.
- Improved stand health.
- Maintained R&D on other factors affecting profitability.

Means for achieving the goal include:

Forming an African mahogany improvement alliance (AMIA) linking stakeholders throughout the value chain

The benefits of sustained collaboration and pooled resources in forest tree domestication are well demonstrated in, e.g. USA-based and Australia-New Zealand-region cooperative programs. An AMIA model necessarily would be different. Collaboration in Ks domestication has been advocated frequently (16, 27, 28). Pooling all-stake-holder resources could address the recent reductions in government investment in R&D. Fortunately, there exists a cadre of Government and University researchers and support staff experienced in Ks R&D. Forming an Alliance, perhaps on the lines of the proposed subtropical tree improvement alliance (29), linking stakeholders across the whole value chain, should be canvassed vigorously.

Figure 7. Veneer from a log harvested at 20 years of age from a stand at Burdekin Agricultural College, Queensland. The colour darkens on exposure. K. Harding

Securing sustained funding for R&D

Forestry R&D is necessarily long-term and requires sustained funding (27). "Tree breeding is a slow but proven process to deliver gains to plantation forestry" (30, p 17). Securing sustained resourcing would be a prime task of an AMIA supported by regular contributions of cash or in kind from all stakeholders in the value chain, including nursery owners, tree growers, processors and research providers, with others in the future.

Achieving transition from imported seed to locally-produced seed and juvenile ramets

Seed sources that could be developed progressively or in combination were mentioned under 'Seed orchards' above. Priority should be given to developing suitable stands into 'seed production areas' and establishing one or more, 'rolling front' CSOs comprising promising clones in the governments' program, and new selections in the latter, farm-forestry plots and the older industrial plantations. Research to develop the micropropagation technology to 'industry ready' and to propagate selection-age trees as juvenile clones is recommended.

Figure 8. Logs from thinning of a 10-year-old, farm forestry stand in coastal lowlands north of Townsville, Queensland. Note the high proportion of dark-coloured wood of the log end. K. Harding.

Conserving the best trees across all post-1990s plantings

Maintaining a diverse genetic base is the best option for coping with changes in selection criteria e.g. following appearance of a serious pest. Conservation is practiced in most tree improvement programs (31, 32). Hazards such as cyclones and fire, as well as the need for a diverse base for recurrent selection gains, confirm the need for selecting and grafting the best trees across all plantings since the 1990s and their conservation in breeding clone banks.

Pooling old and new germplasm in a collaborative domestication program

Intuitively, pooling the best material developed in the governments' improvement program with the unimproved farm-forestry plantings and the broadly-based industry plantations nearing selection age would be a good strategy for the industry as a whole. This broad base of selected trees would enable maximum genetic gain and hedge against future changes of selection criteria. Nikles (16) illustrates how this could be achieved.

Developing and using a tree selection index

The most efficient method of selection is by index (33) supported by genomic selection. Indices are in use with many crops and animals. For Ks an initial index using weighted selection criteria such as diameter, bole length, straightness and heartwood percent is needed.

Conclusions

African mahogany forestry is potentially an important new industry with capacity to expand in northern Australia producing high-value products and benefitting the whole value chain. Having built up very valuable genetic resources, expertise, technologies and knowledge of the species to almost 'industry ready' status over the past 13 years, every effort should be made to exploit the comparative advantage these assets and knowledge provide. Priorities for some operational and R&D work suggested in this paper should be considered among such efforts.

Capitalising on current R&D, and initiating new work through all-stakeholder collaboration via an African Mahogany Improvement Alliance, are essential actions to achieve the goal of greater plantation profitability proposed in this paper and underpin expansion of the embryonic Ks industry in Australia..

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