Achievements in forest tree genetic improvement in Australia and New Zealand 2: Development of *Corymbia* species and hybrids for plantations in eastern Australia

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Summary

This paper describes the establishment of provenance seedling seed orchards of three spotted gums and cadaga (all species of *Corymbia* ex *Eucalyptus*). It also discusses the limitations of growing the spotted gums as pure species including: lack of mass flowering, susceptibility to a fungal shoot blight and low amenability to vegetative propagation. These limitations, together with observation of putative natural hybrids of the spotted gums with cadaga, and the early promise of manipulated hybrids, led to an intensive breeding and testing program. Many hybrid families have significant advantages in growth and tolerance to disease, insects and frost, and can be vegetatively propagated. They also exhibit broad environmental plasticity, allowing the best varieties to be planted across a wider range of sites than the spotted gums, resulting in more land being suitable for plantation development.

Keywords: plantations; tree breeding; progeny; hybrids; eucalypts; *Corymbia*; *Corymbia torelliana*; *Corymbia citriodora*; *Corymbia henryi*; *Corymbia variegata*; *Ramularia*; *Quambalaria piterika*

Introduction

In Australia, there has been rapid expansion in recent years of commercial plantations of hardwood species, especially of *Eucalyptus* (Bureau of Rural Sciences 2005). In the tropics and subtropics, the land most readily available for hardwood plantation development is in the 700–1000 mm mean annual rainfall zone where, potentially, millions of hectares of plantations could be planted on cleared land (Lee *et al*. 2001). Based on experience gained in trial plantings in Queensland (Lee *et al*. 2001, 2005), spotted gums (*Corymbia* species) and hybrids between spotted gums and cadaga (*C. torelliana*) were identified as promising taxa due to their superior survival and growth across a broad range of edaphic and climatic conditions. The choice of spotted gums was also supported by the fact that they are the most commonly harvested native hardwoods in Queensland and have excellent wood properties (Underhill and Watts 2004). In northern New South Wales (NSW), the spotted gums are also very important species for plantation development (Bruskin 1999; Johnson *et al.* 2004), and *C. maculata* has a role in farm forestry in some low-rainfall areas of southern Australia (Harwood *et al*. 2007).

The spotted gums and cadaga belong to the genus *Corymbia,* one of the three genera encompassing all eucalypt species. A recent taxonomic revision of the spotted gums by McDonald and Bean (2000) is followed throughout this paper. These authors recognised four distinct spotted gum taxa: *C. citriodora* subsp. *citriodora* (CCC; lemon-scented gum); *C. citriodora* subsp. *variegata* (CCV; spotted gum); *C. henryi* (CH; large-leaved spotted gum); and *C. maculata* (CM; southern spotted gum). *Corymbia torelliana* (CT; cadaga) is the other species of interest. The distributions of these species are described in Hill and Johnson (1995).

This paper focuses on the development of breeding populations of the three spotted gum species that occur naturally in Queensland (CCC, CCV and CH), the establishment of a CT base population, and the development and early performance of hybrids between CT and the spotted gum species in Queensland. Reference is also made to tree improvement with *Corymbia* in NSW and in southern Australia.

Seed orchards and genetic bases of *Corymbia* species established in Australia

There are three tree improvement programs for spotted gum in Australia. In NSW the focus in on CCV (Johnson *et al.* 2004), in southern Australia the Australian Low Rainfall Tree Improvement Group (ALRTIG) program focuses on CM and CCV (Harwood *et al.* 2001, 2007), and in Queensland the emphasis is on CCV (Lee *et al*. 2004) and *Corymbia* hybrids. Seed and information exchanges have taken place, but since each of these programs is targeting taxa for different edaphic and climatic conditions, integration may not be practicable.

The method used to initiate the spotted gum tree improvement program in Queensland has been to establish successive provenance seedling seed orchards (Nanson 1972). Provenances (and families within provenances) were planted in 3–5-tree line plots, which could be thinned to retain the best individuals for seed production and as sources of select trees for establishment of grafted seed orchards and breeding populations. This approach was adopted because it (i) had the potential to quickly provide genetically improved planting stock to the plantation industry; (ii) allowed selection for different product streams (solid wood and pulpwood); (iii) provided information about genetic variation for important traits (phenology, growth and form plus pest and disease resistance); and (iv) facilitated long-term genetic improvement of the species at a reasonable cost.

Since the program began in 1996, broad genetic bases of the spotted gum species occurring in Queensland have been planted in provenance seedling seed orchards (PSSOs); these include 43 natural provenances of CCV, 11 provenances of CCC, 7 of CH and 6 of CT (Table 1). Smaller numbers of superior trees may be selected from these plantings to form sublines, each for improvement by within-family, recurrent selection over several generations (Shelbourne *et al.* 1991).

The improvement program with CCV in Forests NSW has followed a similar path to that in Queensland. Provenance seedling seed orchards were planted in 1999, 2001 (two sites) and 2004 (four sites) (Johnson *et al.* 2004), and subsequently in 2006 (four sites). Two clonal seed orchards have also been established, the first (with 39 clones) includes 37 clones of Queensland origin, reflecting the superior *Quambalaria* shoot blight tolerance and other desirable traits of some Queensland provenances. Several clone tests have also been established including some semi-commercial clonal plantations (M. Henson, Forests NSW, *pers. comm.* 2005).

Impact of *Quambalaria* shoot blight on the spotted gums and *C. torelliana*

Planting programs using spotted gums began in the mid-1990s in NSW and Queensland. However, these programs were curtailed following heavy losses due to *Quambalaria* shoot blight (QSB), a natural disease of *Corymbia* and *Angophora* caused by the fungal pathogen *Quambalaria pitereka* (J.Walker & Bertus) J.A.Simpson 2000 basionym: *Ramularia pitereka, Sporothrix pitereka* and *Sporotrichum destructor*. Subsequently the seedling seed orchards showed significant variation between provenances and families in tolerance to QSB. Hence as a basis of a plantation program it was possible to focus on provenances from the Gympie region in Queensland that had greater tolerance to the disease (Lee *et al.* 1998). This reinstated the spotted gum plantation programs. The plantation estate currently occupies 18 000 ha (primarily CCV) across NSW and Queensland, with an annual planting program of about 2500 ha.

All species and tested provenances of spotted gum are somewhat susceptible to QSB (Dickinson *et al.* 2004), with severity at a specific site being closely associated with local climatic conditions: the higher the annual rainfall the greater the disease incidence. No QSB-tolerant provenance of *C. henryi* has been found. Dickinson *et al.* also found that a provenance's mean annual rainfall was a good indicator of the potential QSB tolerance; high-rainfall provenances of CCV, such as Woondum (south-east of Gympie), were more tolerant of QSB than low-rainfall provenances such as Presho, 120 km north of Roma (Queensland). The most tolerant provenances, however, can have up to 30% of the trees severely damaged by QSB under conditions favourable to the disease. This disease risk has great implications when deciding to grow spotted gum for either pulpwood or sawlogs; many trees affected by QSB do not recover, and therefore reduce the effective stocking of the plantation. In contrast to the spotted gums, CT is recorded as not being susceptible to QSB — under natural conditions, or in trials (Self *et al.* 2002) or field planting (unpublished data).

Table 1. Genetic bases of *Corymbia* species established in provenance seedling seed orchards in Queensland[a]

Species	Trial identity	Details of PSSOs			
		Provenances and (seed parents[b])	Latitude (degrees)	Longitude (degrees)	Rainfall (mm y^{-1})
C. citriodora subsp. *variegata*	451 A HWD	12 (132)	25.78	152.83	1295
	451 B HWD	22 (214)	27.50	152.26	839
	451 C HWD	15 (148)	25.77	152.63	1295
	451 D HWD	16 (266)	25.76	152.67	1295
	451 E HWD	9 (158)	25.51	152.31	1000
	451 G HWD	12 (188)	25.67	152.52	900
	451 H HWD	19 (286)	25.52	151.47	770
	397 A HWD	1 (56)	24.28	151.50	1033
	Total	43 (719)			
C. citriodora subsp. *citriodora*[c]	782 A TBS	9 (88+)	23.32	150.26	763
	683 HWD	5 (338+)	24.56	149.97	686
	Total	11 (388+)			
C. henryi	456 HWD	7 (47)	25.78	152.84	1295
C. torelliana	518 A HWD	5 (53)	17.13	145.43	1014
	518 B HWD	5 (53)	17.33	145.50	1413
	518 C HWD	5 (101)	26.99	152.00	926
	Total	6 (113)			

[a]Additional genetic resources for all species are available in taxa trials.
[b]This includes some bulks, so the number of seed parents represented in the PSSOs would be smaller than the number indicated here due to the limited sample planted.
[c]782 A TBS is owned by a joint venture between Stanwell Corp and Forest Plantations Queensland.

Why develop *Corymbia* hybrids?

The spotted gum species tested to date are not amenable to propagation as rooted cuttings. Success rates of 10% rooted cuttings has been achieved for CM (McComb and Wroth 1986), 0.4–3.6% for CCC, CCV and CH (Catesby and Walker 1997) and 2.5% for CCC (de Assis 2000). Thus the only current practical option to commercially deploy improved germplasm from the breeding program will be via seed. However, in the spotted gum seed orchards, heavy synchronous flowering has not occurred in the last 9 y. This mirrors poor flowering in natural stands of desired provenances of spotted gum, which in turn has limited the development of hardwood plantations in Queensland and NSW as spotted gums (particularly CCV) are the species most suited to a large portion of the sites available for plantation development.

Interest in *Corymbia* hybrids stemmed from observations that amenity plantings of CT often included hybrids between CT and spotted gums. These hybrids had the good form of spotted gum, were intermediate in some traits, and did not appear to be attacked by QSB. Further, as CT (de Assis 2000; Lee *et al.* 2005) and its hybrids with CCC (de Assis 2000) were amenable to propagation as rooted cuttings, it was proposed that hybrids with the other spotted gum species might also be propagated commercially in this manner. Another factor encouraging the development of *Corymbia* hybrids is that the wood properties of the parental species are similar; suggesting that wood of the hybrids would be just as acceptable.

A *Corymbia* hybrid controlled-cross-pollination program was initiated in 1999 and the first trial of *Corymbia* hybrids was planted in May 2001. Since then 18 progeny trials have been planted at locations extending from Grafton in northern NSW (in conjunction with Forests NSW) to Mareeba in northern Queensland. In these trials 283 *Corymbia* hybrid families are being evaluated against pure species controls. Of these crosses, 272 have CT as the female parent (Table 2), as the seed yield is up to four times higher when the cross is made in this direction than when a spotted gum is used as the female parent (unpublished data).

Performance of the *Corymbia* hybrids relative to the spotted gums

In replicated trials, many hybrid families have significantly out-performed the best spotted gum provenance (CCV Woondum) in height and diameter growth ($P < 0.001$; Fig. 1). Near Kingaroy on a Red Ferrosol (Isbell 1996) soil the CCV Woondum provenance bulk seedlot reached 9.0 m in height and 7.8 cm in diameter at height breast over bark (dbhob) at age 54 months. At this site, the top four *Corymbia* hybrid families CT × CCV135, CT × CCV143, CT × CCC27, and CT × CH147 had heights of 9.7–10.8 m (8–20% selection differential at this site), and dbhob of 9.6–10.9 cm (23–39% selection differential at this site). Most of the hybrids were also significantly taller and larger in dbhob than the CT parental controls.

In a trial near Gympie, frost resistance also varied significantly among taxa at nine months ($P < 0.001$). Here the *Corymbia* hybrid families had similar frost resistance to the CT parental controls, and both CT and the *Corymbia* hybrids (CT × CCC, CT × CCV and CT × CH) had living shoots significantly higher on the stem after frosting than the CCV Woondum bulk seedlot (Fig. 2). Other traits with a similar pattern — where the better hybrid families show a clear benefit relative to the parental controls or follow the high parent for the trait — are detailed in Table 3. Commercially the most important of these are height and diameter growth, frost tolerance, straightness, QSB tolerance, erinose mite tolerance, and the seedling or coppice rootability of the *Corymbia* hybrids. Another important observation is that many *Corymbia* hybrid families are stable across disparate sites, for example, in three trials with 64–76 hybrid families under test, seven families ranked in the top 20 for volume across all sites at age 3 y (well ahead of the CCV Woondum bulk seedlot; data not presented).

When all the benefits of the hybrids are considered relative to the spotted gums and other taxa with plantation potential for Queensland, it is clear that the focus of the breeding program must be on the *Corymbia* hybrids. Forests NSW is also attempting to produce hybrids and is studying the potential of hybrids in conjunction with the Queensland program.

Table 2. Number of *Corymbia* hybrid families being evaluated in progeny trials in Queensland and NSW

Female parent	Male parent (= pollen parent in cross)				
	C. citriodora subsp. *variegata*	*C. citriodora* subsp. *citriodora*	*C. henryi*	*C. maculata*	*Corymbia* hybrid[a]
C. torelliana[b]	162	36	30	15	29

[a]These are spontaneous *Corymbia* hybrids and their pedigree is therefore unknown. Some of these hybrids have been used in crosses as the female parent.

[b]Hybrids with spotted gums as the female parent have been developed with limited success. These include five with *C. citriodora* subsp. *variegata* and two with *C. henryi* as the female parent.

Current status of *Corymbia* hybrid breeding program and future development

Breeding strategy

The first series of hybrid progeny trials planted 2001–2006 in Queensland were developed in an ad-hoc breeding program using CT trees selected at low intensity in amenity plantings. These were crossed with phenotypically selected CCC, CCV and CH from both plantations and seed orchards. As a broad genetic base of all spotted gum species has been developed (including collaboration with Forest NSW and Ensis), and genetic parameters can be estimated from progeny trial data, it is time to devise appropriate breeding strategies for the pure species and hybrids. This important matter is now being addressed. In the meantime, developing grafted clone banks and seed orchards to facilitate breeding work are priorities. These will also facilitate a deployment

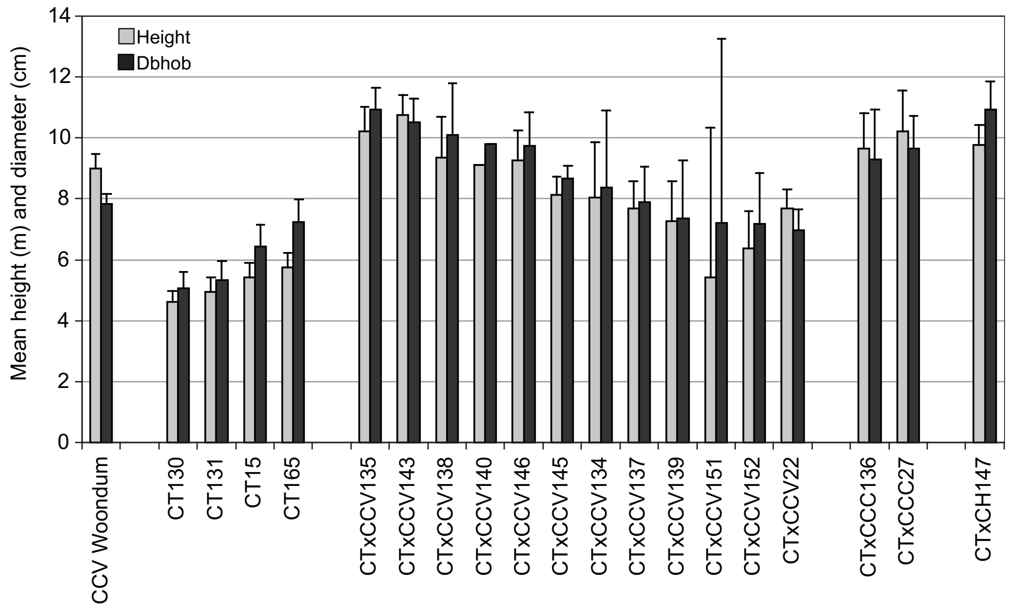

Figure 1. Fifty-four-month height (5% LSD = 2.9) and diameter at breast height over bark (5% LSD = 3.6 of the top 15 of 22 *Corymbia* hybrid families (CT × CCV, CT × CCC, CT × CH) ranked by mean dbhob) relative to CCV Woondum bulk (85-tree bulk) and *C. torelliana* (CT) controls in a trial on a Ferrosol soil near Kingaroy (780 mm MAR). Bars indicate standard errors.

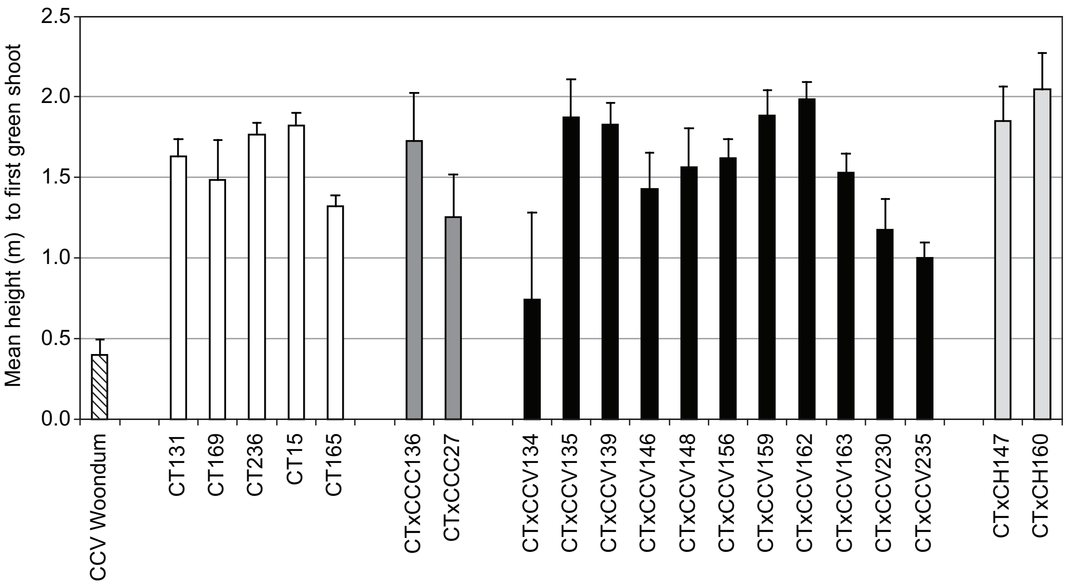

Figure 2. Height to highest living shoot following severe frosts at Amamoor (5% LSD = 0.53) of top 15 of 38 *Corymbia* hybrids families (CT × CCC (dark grey), CT × CCV (black), CT × CH (light grey)) relative to CCV Woondum bulk seedlot (85-tree bulk, hatched) and CT (white) ranked by mean dbhob at age 3 y in a trial on a black Dermosol soil near Gympie (1090 mm MAR). Bars indicate standard errors.

Table 3. Relative performance for key traits of *C. torelliana* (CT), *C. citriodora* subsp. *variegata* (CCV) and *Corymbia* hybrids based on observations in 3-y-old progeny trials in Queensland (Mareeba to Gympie)

Trait	CT (Kuranda provenance)	CCV (Woondum provenance)	*Corymbia* (F_1) hybrid families
Quambalaria shoot blight tolerance	Very high (immune?)	Moderate	High
Erinose mite tolerance	Very high (immune?)	Very low	High
Red-shouldered leaf beetle tolerance	Low	High	Moderate to high
Longicorn beetle tolerance	Moderate	High	Moderate to high
Height and diameter growth	Low to moderate	Low to high	Low to very high
Straightness	Moderate	Moderate	Moderate to high
Taper (low desirable)	High	Low	Moderate
Branch quality, including shedding	Low	High	Moderate to high
Canopy density (high results in good site capture)	High	Low to moderate	Low to high
Frost hardiness	High	Low to moderate	High
Environmental plasticity	High	Moderate	High
Seedling or coppice rootability	Moderate to high	Low	Moderate to high
Wood properties	Unknown in plantations	Showing potential for sawlogs and pulpwood[a]	Showing potential for sawlogs and pulpwood[a]

[a]Based on unpublished results of tests carried out on 42-month-old hybrids and CCV.

crossing program based on selecting and reproducing the top hybrid families identified in the progeny trials. All work associated with the breeding of hybrids will be integrated with studies of silviculture and wood properties.

Deployment strategy

In order to deploy hybrids operationally, the best families or clones must be amenable to vegetative propagation as it is impractical to produce sufficient hybrid seed for direct commercial use. There are two options for commercial deployment of hybrids: (i) vegetative family forestry where seedlings from hybrid families selected for superiority and stability across sites are bulked up as rooted cuttings (Nikles 1992; Henson and Smith 2004); and (ii) clonal forestry where individuals with proven clonal superiority are vegetatively propagated (Shelbourne 1991).

Corymbia hybrid seedling families are now averaging 72% rootability (64–86%, unpublished data), using mini-cutting techniques (de Assis 2001). Similar results appear possible using stump coppice from 3-y-old trees. In the progeny trials there appear to be families that are stable high performers across sites, with relatively low within-family variation. This offers the opportunity to deploy such families operationally if they are amenable to propagation as rooted cuttings (through vegetative family forestry, for which a pilot program is underway with Forest Plantations Queensland). Within the top families, and some poorer families with high variances (e.g. CT × CCV151, Fig. 1), there are a few outstanding individuals that may have potential as clones. In five hybrid progeny trials assessed at 3 y of age, 127 superior trees (across 11 families) have been selected, based on growth, pest and disease tolerance, and form attributes. Currently 79 of these have been propagated successfully for clonal evaluation. The first clonal test was planted in April 2006. In addition, 8 clones from good families (a subset of the 79 above) have been provided to a commercialisation partner (Dendrotech Pty Ltd), and are now being bulked up as partially-tested clones for commercial deployment. These clones will be the first release from the 7-y-old hybrid breeding program. Ongoing selection of families and clones for operational deployment, using more information about growth, form, wood properties, rootability, and pest and disease resistance is planned.

Conclusions

The development of the *Corymbia* hybrids is likely to underpin establishment of a sustainable hardwood plantation sector in Queensland and NSW, by providing germplasm with superior early growth rates, pest and disease tolerance, environmental plasticity and wood properties similar to those of the current best alternatives (the spotted gum species). The breeding program is in its infancy: field tests need to be run for several more years to achieve full confidence in the hybrids. In the interim, preliminary decisions on how to further develop the strategy for breeding the pure species and the hybrids are needed. Steps to gain the required information are in hand. Meanwhile, *Corymbia* hybrids will soon be available to the plantation industry to meet current demands for this material — despite, perhaps, small risks involved in planting these hybrids on a commercial scale so soon after the first test plantings in 2001.

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