



Tannin and Fuel Wood

from Plantation Grown Bipinnate Acacias

**A report for the RIRDC/LWRRDC/FWPRDC
Joint Venture Agroforestry Program**

by Dr Liz Barbour

May 2000

RIRDC Publication No 00/47
RIRDC Project No DCL- 3A

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ISBN 0 642 58077 4
ISSN 1440-6845

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Published in May 2000
Printed on environmentally friendly paper by the AFFA Copy Centre

Foreword

In 1997, Joint Venture Agroforestry Program jointly funded, with local industrial partners, Bunnings Timbagem and DynoIndustries (W.A.) Pty Ltd, the Department of Conservation and Land Management (CALM) and the Chemistry Centre of Western Australia, a project to determine the potential of plantation bipinnate acacias to produce tannin and fuelwood in south-west Western Australia.

This project assessed acacias in the three trials established in 1992 for their wood volume, bark yield and stem form. Non-destructive bark samples were harvested from each provenance of the twelve acacia species represented across the three sites and these were analysed for their Stiasny value and polyflavanoid content. Further bark samples from a single provenance of ten of the species were destructively harvested from the Darkan (Bowelling) site for bulk tannin extraction. Bunnings Timbagem and DynoIndustries assessed the freeze-dried bark extracts for their adhesive attributes. Wood discs cut from the base of the trees and at breast height were used to assess wood density for ten of the species. The stumps were observed for coppice a year later.

This project was funded by the RIRDC, LWRRDC and FWPRDC Joint Venture Agroforestry Program. The aim of the program is to integrate sustainable and productive agroforestry within Australian farming systems. This project identifies three bipinnate acacia species, namely *A. mearnsii*, *A. fulva* and *A. decurrens*, that can supply both tannin for the wood adhesive market and wood for the fuel market. The discussion looks at the prospects of developing these species for commercial markets.

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Peter Core

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Acknowledgments

I would like to express my appreciation to Rural Industry Research Development Corporation (RIRDC) for providing the key funding so that these trials could be analysed and the findings distributed.

There are a number of people that have been involved with these trials and their analysis that I would like to acknowledge:

Mr. John Bartle and Mr. Tim Birmingham (Farm Forestry Unit, Dept. of CALM) for their support and assistance in establishing the trials

Ms Suzette Searle, a forestry consultant, formerly with CSIRO Forestry and Forest Products, for the selection of seedlots and her extensive advice, especially in the writing of this final report.

Mr. Richard Mazanec and his technician, Mr. Chris Velios, (CALMScience, Dept of CALM) for their contribution to the measurement and growth analysis of these trials.

Mr. Nic Spencer and Mr. Antione Meola (technicians with the Genetic Deployment Unit, Dept. of CALM) for his contribution to the trial measurement.

Mr. Mathew Williams (CALMScience, Dept. of CALM) for his statistical advice.

Dr. David Harris (Chemistry Centre, WA) for his encouragement to submit this project for funding and the extraction and assessment of the tannin properties of bark samples.

Mr. John Fletcher (Bunnings Timbachem) for his support and assessment of the tannin adhesives for their commercial potential.

Mr. David Foot and , Ms. Siew Ho (Dyno Industries (W.A.) Pty Ltd) for their support and assessment of the adhesives for their commercial potential.

The information gained from acacia projects funded by the Australian Centre for International Research (ACIAR) in China and Australia, has been invaluable for the assessment of these trials. The ACIAR projects were a collaboration between CSIRO Division of Forestry and Forest Products, Canberra and the Chinese Academy of Forestry.

Ms. Kay Nixon, Institute of Commercial Forestry, Kwazulu-Natal, South Africa, for the inspiring discussions on acacias, especially during my 1998 visit to South Africa.

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Executive Summary

In 1997, Joint Venture Agroforestry Program jointly funded with local industrial partners, Bunnings Timbagem and DynoIndustries (W.A.) Pty Ltd, the Department of Conservation and Land Management (CALM) and the Chemistry Centre of Western Australia a project to determine the potential of plantation bipinnate acacias to produce tannin and fuelwood. The project was to measure and assess three acacia species field trials planted in 1992 across the South-West of the State and the data used to identify bipinnate acacia species with potential to successfully provide fuelwood and tannins for wood adhesive production.

The 12 bipinnate acacias in trial are native to south eastern Australia where historically bark was stripped from wattles in natural stands for leather tanning and the wood was used for fuelwood. Acacias have not been grown on a plantation scale in Australia although there are about 500,000 ha of Australian acacias in plantation in countries such as South Africa, east Africa, Brazil, China and India (Doran and Turnbull 1998). In Western Australia, it is estimated that between 300-500,000 tons of dry fuelwood are consumed locally and Australia as a whole imported 7100 tonnes of wattle (*Acacia mearnsii*) tannin valued at A\$7.3 million in 1995/96. The potential of these species to provide other wood products can only be tested when the trees in trial mature further but, at 5 years of age, these fast-growing species can be tested for their potential to produce tannin for wood adhesives and fuel wood for domestic heating. Identification of species with economic potential to produce tannin and fuelwood will help focus industry to establish a source of trees for product development and provide useful information to guide similar projects elsewhere in Australia.

This project assessed trees in the three trials for wood volume, bark yield and stem form. Non-destructive bark samples were harvested from each provenance of the twelve species represented across the three sites and these were analysed for their Stiasny value and polyflavanoid content. Further bark samples from a single provenance of ten of the species were destructively harvested from the Darkan (Bowelling) site for bulk tannin extraction. Bunnings Timbagem and Dyno Industries (W.A.) Pty Ltd assessed the freeze-dried bark extracts for their adhesive attributes. Wood discs cut from the base of the trees and at breast height were used to assess wood density for ten of the species. The stumps were observed for coppicing a year later.

Whilst the major outcome of the project was to identify that *A.mearnsii*, *A.fulva* and *A.decurrens* were the best performing species in south-western Australia, the latter species particularly on the higher evaporative sites, there were numerous smaller observations that may be of use in the development of this group of species.

Experience during the establishment and management of the trials indicated that:

1. The nursery media chosen for the Manjimup area must have a high air-filled porosity (above 20%) and lower water-holding capacity than 60%.
2. The *Rhizobium* relationship for nitrogen-fixation is important both in the nursery and for initial field establishment.
3. Annual rainfall of 650 mm, together with a high evaporation rate and high summer temperatures at Darkan, was too severe for successful establishment of the bipinnate acacia species in trial.
4. Site preparation incorporating both ripping and mounding in areas subject to water-logging yields better survival and growth.
5. Good weed control is needed prior to planting as no herbicide over-spray has been developed for this species.
6. Where there are signs of African Black Beetle (*Heteronychus arator*) present, the site needs to be pre-treated with an insecticide, such as chloropyrifos.

7. Sites need to be chosen where Port Lincoln Parrot (*Barnardius zonarius*) are unlikely to be a problem.

The assessment of the trials showed that:

1. The Busselton site was the better site for bipinnate acacias compared to Mt Barker and Darkan (near Collie).
2. The species with the greatest wood production across all three sites at 5.5 years of age were *A. mearnsii*, *A. decurrens* and *A. fulva*. At the lower rainfall sites *A. decurrens* was clearly the best species. *A. mearnsii* and *A. fulva* grew better when there was higher moisture availability at the higher rainfall sites.
3. The species with the highest air-dried wood density at 5.5 years of age was *A. fulva* followed by *A. decurrens* and *A. mearnsii*, respectively.
4. This project demonstrated that bark thickness can be measured by a single point compared to the four points on the compass around the circumference of the tree at 5.5 years of age.
5. Bark thickness and mean bark yield per tree at 5.5 years was greatest for *A. mearnsii*, *A. decurrens* and *A. fulva*.
6. Tree form was difficult to assess because of parrot damage, but the species with the fewest number of stems were *A. mearnsii*, *A. fulva* and *A. filicifolia*. The straightest trees were *A. elata*, *A. silvestris* and *A. mearnsii*.
7. The best provenances for stem wood volume across all three sites at 5.5 years were: *A. mearnsii* (Wattle Circle, Victoria and Tarpeena, South Australia), *A. dealbata* (Errinundra Plateau, Victoria), *A. decurrens* (SW of Goulburn and Picton-Mittagong, New South Wales), *A. filicifolia* (Yadboro flat New South Wales), and *A. fulva* (Howes Valley, New South Wales).
8. The best provenances for bark production across all three sites at 5.5 years were: *A. mearnsii* (Wattle Circle, Victoria and Tarpeena, South Australia), *A. decurrens* (SW of Goulburn and Picton-Mittagong, New South Wales) and *A. fulva* (Howes Valley, New South Wales).
9. Comparing the native with commercial *A. mearnsii* seedlots, there was varied performance. Some commercial seedlots were superior in performance whilst others were routinely poor. There is evidence that genetically improved material in a similar environment will express its genetic gain in south-western Australia.
10. Assessment of polyflavanoids in the bark from 5.5 year old trees between sites and provenances showed that there was no statistical difference between site, only between species (provenances). The species that produced the most polyflavanoids was *A. mearnsii* followed by *A. decurrens* and *A. filicifolia*.
11. Assessment of the Stiasny value in the barks between sites and provenances from 5.5 year old trees showed that there was significant differences between sites and species (provenances). The species that produced the most polyflavanoids active in the polyflavanoid-formaldehyde reaction were *A. mearnsii*, *A. decurrens* and *A. filicifolia*.
12. The bulk extraction of tannin from 10 of the species, *A. mearnsii*, *A. decurrens*, *A. trachyphloia*, *A. filicifolia*, *A. dealbata*, *A. fulva*, *A. irrorata*, *A. silvestris*, *A. parramattensis* and *A. glaucocarpa* showed that all these species make an acceptable wood adhesive glue.
13. Based on bark production and the Stiasny value, it appears that *A. mearnsii* and *A. decurrens* may be the best species for commercial tannin production in south western Australia.
14. Based on wood production and density, it appears that the best species for fuelwood production in south western Australia are *A. mearnsii*, *A. decurrens* and *A. fulva*.

1. Introduction

The bipinnate acacias belonging to the taxonomic section Botrycephalae, are native to south-eastern Australia. The bark of one of these, black wattle (*A. mearnsii*), was stripped from trees in native stands to tan leather and its wood was used by bakeries and for domestic heating. Despite extensive cultivation overseas of *Acacia mearnsii* and other bipinnate acacias for a range of wood and non-wood uses, they are not grown in plantations in Australia. In 1992 CALM was the first organisation in Western Australia to test twelve of these bipinnate acacias in a plantation configuration as part of its search for additional species that may extend the commercial tree planting range to nutritionally poor and lower rainfall sites. A number of species in these acacia trials showed promise at two years of age.

Acacia mearnsii, produces the world's most important vegetable tannin (Doran and Turnbull 1997) and is grown commercially for bark and wood products across 500,000 ha in many countries including South Africa, Brazil, India and China. Originally vegetable tannins were used for tanning leather but they are now used to make water-proof wood adhesives and anti-corrosive additives. Australia used to be a net exporter of vegetable tannins but in 1997, A\$7.2 million of tannin was imported to meet Australian demand for wood adhesives (Australian Bureau of Statistics). Although the wood of some of the bipinnate acacias, such as *A. mearnsii* and *A. dealbata* (silver wattle), are used to make high quality paper, rayon, charcoal and composite wood products, this project focuses on the tannin characteristics of their barks. Most of the wood products are more reliably tested when the trees are closer in age to full rotation (10-12 years). However, the moisture content and air-dry density of the wood and the ability of the species to coppice were assessed at half rotation age (c. 5 years) to indicate the potential of the species for fuelwood production.

The identification of a tree crop that produces more than one product will impact on a number of industries. The corollary to the previous statement is that the economic potential of a species will improve with the number of products it can produce. The more products, the greater the profitability and this would mean that these species could be profitably grown on marginal (slower growing) sites. As previously stated, this project only investigates two of the many possible products this group of species can produce at five years of age. There are a number of other products that could be processed from these species (Searle, 1996) which, as the trials mature, will be investigated.

The identification of successful fuelwood and tannin producing species will benefit land-owners, the fuelwood industry and the wood adhesive industry in the manufacture of locally produced composite wood products. In the case of the landowner it will offer a greater choice of tree crops to grow more profitably on particular sites than the present alternatives. The fuelwood market is growing steadily with the population increase of Perth and the purchase of wood-fuelled space and water heaters. Plantation-grown fuelwood offers a more environmentally-friendly alternative to the collection of native timber. The wood adhesive market is presently supplied by the import of tannin from an Australian acacia grown in plantations in South Africa and Brazil. An extraction factory for the bark tannins would have to be established for existing markets to take advantage of local production.

Strategically placed trees on cleared farmland have the potential to prevent top soil erosion and the salt-contamination of land and water whilst maintaining the productivity of the land for agriculture. Benefits gained by the landowner could be both environmental and economic. The number of landowners who will have the option of using the bipinnate acacias for land rehabilitation work as well as a commercial return will be made clear from the outcomes of this project. Whilst there are a number of profitable tree crop choices in the higher rainfall areas, at present only *Pinus pinaster* and lower productivity *Pinus radiata* and *Eucalyptus globulus* are grown in the lower rainfall areas (550 - 700 mm) and on poorer sites. The bipinnate acacias are being tested as options in the south-west of Western Australia and have been planted in trials ranging from north of Perth to Esperance. The trials used for this project are all

south of Perth, from Darkan to Mt Barker where the annual winter rainfall ranges between 650 and 950 mm. In Natal, a summer rainfall region of South Africa, the environment recommended for *A. mearnsii* is that where the rainfall is between 850 and 1200 mm (Nixon, pers.comm). The soil profile in south-western Australia, however, may well hold ample moisture to sustain growth in lower rainfall environments and the symbiotic relationship of the acacias with nitrogen-fixing *Rhizobium* may assist growth in the nutrient deficient soils. Additionally the multiple product potential of the bipinnate acacias could provide an economic advantage over other tree crops.

Developing a plantation-based fuelwood industry would have many advantages. It would reduce the harvest of native timber from ecologically sensitive habitats, reduce the possible spread of the die-back disease, *Phytophthora cinnomomi*, by reducing the traffic into these areas, and improve wood quality (in terms of reduced moisture content after proper drying) and therefore reduce Perth's air-pollution. However the plantations would have to be within economic distance from the Perth fuelwood market.

Various estimates have been made of the size of Perth's fuelwood market. As Bartle (1995) reported "the supply side of the industry has many producers and collectors and records of production are difficult to get. On the demand side there are good records of purchases of wood fuelled space and water heating stoves and, assuming an average consumption per unit, a total figure can be derived (Challis, 1988)." On this basis Bartle (1995) estimated that Perth city consumes between 300 000 to 500 000 tonnes per annum which is some 20% of the residential energy consumption. A survey of wholesalers in the area gave the retail selling price in Perth at \$85/tonne for split, dry Jarrah with producers earning a return of \$25/tonne (Bartle, 1995). Whereas at present this market is highly labour intensive, plantation-grown fuelwood could allow mechanisation to reduce costs because of ease of site access and the uniformity of product. Machines exist that are able to cut and tie neat packs of bundled wood. In South Africa, the wattle debris after the collection of the bark and the timber bole for pulp products, is gathered and converted into charcoal. This fuelwood could also be used for the production of electricity and liquid fuels using technologies which do exist (Bartle, 1995)

The bark of bipinnate acacias contains a group of water-soluble components known as wattle tannins. The amount of tannin extracted from a tree is related to bark thickness and tannin percentage (Schonau, 1973). Thomas (1993) estimates that 7,400 kg/ha of wattle tannin could be produced on a 10 year rotation assuming a tannin content of 40% dry weight of bark.

The tannin chemistry is a complex subject that has been well covered in reviews by Hillis (1997a) and Yazaki and Collins (1997). Parts of these reviews have been summarised here for an understanding on the qualities of tannin.

"Tannin" was a term coined to denote those substances responsible for leather formation (Sequin, 1796 see Hillis 1997b) and subsequently these were found to be of a phenolic nature. It is now accepted that "vegetable tannins" are water soluble phenolic compounds having molecular weights between 500 and 3000, and besides giving the usual phenolic reactions, have special properties such as the ability to precipitate alkaloids, gelatin and other proteins (White 1958, Bate-Smith and Swain 1962). Whilst vegetable tannins have been used historically, and presently in a limited amount, for tanning leather, this was not the focus of this project. Hillis (1997 b) has written an excellent review to cover this tanning interest.

The use of tannin both as a condensing agent and a reactant in the phenol-formaldehyde reaction was first suggested by McCoy in his patent (McCoy 1918). However it was an Australian, Dalton (1950) who showed that the wattle tannins would react with formaldehyde to form resins. With hot water pressing, water-resistant bonds would form which were superior to urea formaldehyde adhesives. Further work on viscosity control showed that sulphite-treated wattle tannin adhesives produced good joint strengths (Dalton, 1953) although this join was not superior to commercial phenolic adhesives.

Work ceased on tannins for adhesives until Plomely (1959) showed that by adding a soluble salt, such as magnesium or zinc acetate, gelation time was reduced and the bonding improved. From this research Plomely established that commercial wattle tannin adhesives produced a strong waterproof bond with veneers of a number of species (Plomely 1966) and they have been in continuous use in Australia since 1966 and for particleboard since 1968. In the early years adhesives were made on site with liquid tannin extract imported from South Africa (Yazaki and Collins, 1997), this has progressed to a more reliable freeze-dried product.

The components of the tannin that are important to the formaldehyde reaction belong to “condensed tannin” which consists of flavanoid units (Mainly flavan-3-ols) that have been condensed to varying degrees (Yazaki and Collins, 1997). The fundamental reaction for wattle tannin adhesives occurs when the flavanoid units react with formaldehyde to produce insoluble polymers.

Searle (1996) reported that companies such as CSR Timber Products are the principle users of the 6 500 tonnes of dry, powdered wattle tannin extract that Australia imports from South African *A. mearnsii* plantations annually (Table 1). This company uses it for adhesives for particleboard flooring (yellow tongue).

The two local companies involved in this project are either using *A. mearnsii* tannin for composite wood products or developing technology for the use of tannin extract in this market. Bunnings Timbachem annually use 12 tonnes of tannin to make a resorcinol tannin adhesive for the production of fire proof doors and a tannin adhesive fortified on site with a phenol/resorcinol resin for marine plywood. Dyno Industries, on the other hand, is researching the potential of using the vegetable tannins to substitute for the expensive import melamine which is used to make their adhesive water-repellent.

Table 1. The importation of *Acacia mearnsii* tannin extract from all countries into Australia
(Australian Bureau of Statistics)

Year	Kg of extract	Value (\$A'000)
Jul 95 - June 96	7 100 000 (7 100 tonnes)	7 291
Jul 94 - June 95	8 630 666	10 190
Jul 93 - June 94	6 722 879	8 695
Jul 92 - June 93	6 519 510	8 065
Jul 91- June 92	5 524 440	5 999
Jul 90 - June 91	5 484 988	5 579

In 1988 Bunnings Timbachem initiated a study into the economic viability of a tannin extraction plant. It concluded that as there was a reasonable local use of tannins (approximately 300 tonnes in 1988), there was an attractive possibility to supply a liquid tannin concentrate as opposed to a dry powder extract. This would eliminate the need for spray drying which requires a large capital investment. The cost of the plant was estimated to be between A\$ 200 - 500 000, with the plant being ancillary to an existing operation.

There have been a small number of comprehensive reviews of *A. mearnsii*. These began with "The Black Wattle" written by Sherry (1971), cover the history of its utilisation for bark in Australia (Searle, 1991) and describe the cultivation and utilisation of the species (Brown and Ho 1997). A paper by Searle (1996) describes the wide range of products harvested from bipinnate acacias.

A survey of the acacia tannin literature indicates the wide interest in tannin based adhesives for the composite wood industry with papers written in Brazil (Santana et al.,1996) South Africa (Thompson and Pizzi, 1995) France (Pizzi et al., 1995), Tanzania (Calve et al., 1995), China (Zhao et al.,1995) and Japan (Mitsunaga et al.,1995, Ohara et al., 1994, Yamaguchi et al., 1994). Whilst *Acacia*

mearnsii appears to be the most popular for making a wood adhesive due to its bond strength and water resistance properties (Fechtal and Reidl, 1993), other species are continually being investigated with recent studies conducted in the Philippines (Manas, 1991) Kenya (Mugedo and Waterman, 1992) and South Africa (Pizzi et al., 1993).

Recent Australian research into bipinnate acacia tannins led by Dr Yoshi Yazaki (CSIRO Forestry and Forest Products) resulted from their involvement with research projects in China funded by the Australian Centre for International Agricultural Research (ACIAR). This research, together with the Chinese, has focussed on the development of better techniques to estimate the tannin characteristics of *A. mearnsii* for making wood adhesives (Yazaki et al., 1993, Yazaki et al., 1994). Although most of their research has concentrated on *A. mearnsii*, one study investigated the tannin production from other bipinnate acacias including *A. parramattensis*, *A. trachyphloia* and *A. silvestris*. The samples were collected from trees of unknown age in natural forests in Australia. The study indicated that *A. parramattensis* bark tannin had a similar high quality for wood adhesives to that of *A. mearnsii* (Zheng et al., 1991). This same group has also investigated the effect of site on tannin production in China (Li Jiuyan et al., 1994, Zheng et al., 1991).

In rural communities world-wide, the sustainable supply of fuelwood as an energy source, is a major concern. This is also true for some communities in Australia (Wall et al., 1993) where the resource is diminishing due to the increase in domestic demand, suppression of eucalypt regrowth by livestock grazing and the lack of replenishment programmes. World-wide, acacias are considered a valuable fuelwood because they are a hardy, fast-growing legume species that produce dense wood.

The most comprehensive study on legume fuelwood characteristics in Australia was conducted by Queensland Department of Primary Industries. Ryan et al. (1994) assessed the following parameters: drying the fuelwood, managing the trees for fuelwood production, nutritional considerations and control of wildfires. They concluded that *A. mearnsii* was one of the outstanding species for fuelwood.

2. Objective

To identify plantation-grown bipinnate acacia species that can successfully provide a fuelwood source and tannins for wood adhesive production.

3. Methodology

3.1. Site selection

Three bipinnate acacia trials were established at three sites across the south-west of Western Australia: Darkan (Bowelling), Busselton (Jarrahwood) and Mt Barker. The sites cover a range of climatic conditions (Table 2) with Darkan and Mt Barker having the lowest rainfall but with Darkan having the highest annual evaporation and temperatures.

Table 2. General climatic comparisons of three bipinnate acacia species trial sites in south-west Western Australia

Site	Average annual rainfall	3 months of highest rainfall	3 months of lowest rainfall	Mean max. temp. for hottest month	Mean min. temp. for hottest month	Annual evaporation
Busselton (Jarrahwood)	947 mm	May, Jun, Jul	Jan, Feb, Dec	29°C	7°C	1160 mm
Darkan (Bowelling)	650 mm	Jun, Jul, Aug	Jan, Dec, Feb	31°C	5°C	1270 mm
Mt Barker	650 mm	May, Jun, Jul	Jan, Feb, Dec	26°C	7°C	940 mm

3.2 Genetic material

Table 3. The bipinnate acacia species chosen for the trial across three sites in south -west Western Australia

Species	Species description	No.	Provenance location (CSIRO seedlot no.)
<i>A. dealbata</i> Link, Enum. silver wattle	A slender shrub to tall tree up to 30 m with smooth brown-grey to dark grey bark. Grows in forests and woodlands on a variety of soil types.	15	Errinundra Plateau VIC (S16271)
		14	Captains Flat NSW (S18024)
<i>A. deanei</i> (R.Baker) Welch, Coombs & McGlynn Deane's wattle	A shrub to small tree upto 7 m tall. Grows in woodlands and open country usually on clayey or sandy loams.	25	Dawson QLD (S18063)
		24	Goondiwindi NSW (S15470)
<i>A. decurrens</i> (H.L.Wendl.) Wild. green wattle	Small to medium sized tree 10 - 15 m tall. Grows in eucalypt forests and woodlands on heavy soils.	11	Picton-Mittagong NSW (S15847)
		10	SW of Goulburn NSW (14726)
<i>A. elata</i> Cunn.ex Benth.in Hook. cedar wattle	A tree 20 m tall. Grows in moist eucalypt forests near water courses.	17	Mt Irvine NSW (16673)
		16	Buxton- Hill top NSW (S15848)
<i>A. filicifolia</i> Cheel & Welch ex Welch, Coombs & McGlynn. fern-leaf wattle	A large shrub to tree up to 14 m high. Grows in forests and woodlands, often on sandy alluvial soils near watercourses.	12	Yadboro flat NSW (17893)
		13	19 km SW Singleton NSW (S15841)
<i>A. fulva</i> Tind. soft or velvet wattle	A tall shrub to tree with smooth grey bark which becomes horizontally fractured, to 20 m tall. Grows in euaclypt woodlands, often forming almost pure stands on basalts or clays derived from metamorphic rocks near the top of hills or mountains.	26	Howes Valley NSW (S15843)
<i>A. glaucocarpa</i> MAlden and Blakely	Erect, slender, single-stemmed small tree 6 -10 m tall. Grows in forest, woodland and on the edge f rain forest.	3	Cadarga QLD (S18065)
		4	Bains gully QLD (S17152)
<i>A. irrorata</i> Sieber ex Spreng. blueskin	A small to medium size tree 5 - 12 m high. Grows in forests and woodlands, often on moist soils near water courses, and sometimes on the margins of rainforests.	18	7km E Woodenbong NSW (S15836)
		19	Karuah-Newcastle NSW (S15833)
<i>A. mearnsii</i> De Wild. black wattle	A tall shrub to tree to 20 m tall, with smooth greeninh to blackish bark. Grows in euaclypt forests and wodlands, mostly on heavy soils	9	Tarpeena SA (S17928)
		6	Wattle Circle VIC (S17933)
		8	Commercial seedlot (S15088)
		5	Commercial seedlot (S15087)
		7	Commercial seedlot (SAF56)
		27	Commercial seedlot
<i>A. parramattensis</i> Tind. Sydney green wattle	A large shrub to tree 2-7 (-14) m tall. Grows in euaclypt forest and woodlands, often on heavier soils.	20	Numeralla NSW (S17925)
		21	Tarago NSW (S17711)
<i>A. silvestris</i> Tind., red or Bodalla silver wattle	A tree with smooth grey bark yp to 20-30 m high. Grows in forests and woodlands of the coast and nearby ranges to 1250 m altitude.	1	Deua River, Deua NP NSW (S15852)
		2	Bruthen VIC (S17939)
<i>A. trachyphloia</i> Tind., golden feather wattle	A tall shrub to medium size tree with smooth bark becoming rough and corrugated when old up to 12 m tall. Grows along creek flats on alluvial soils and in forested mountains.	22	Currowan Creek NSW (17894)
		23	River Rd Monga SF NSW (S17128)

Twelve bipinnate acacia species were each represented by two provenances with the exception of *A. fulva* represented by a single provenance (Table 3). Each of the trials also included four South African seed sources of *A. mearnsii*. Species selection was made by Suzette Searle (formerly CSIRO Forestry and Forest Products). With the exception of *A. deanei*, which was included for its possible drought tolerance, all other species grow more than 10 metres in height in natural stands.

3.3 Seedling production

The seedlings were raised in the Department of CALM's Manjimup nursery. Prior to sowing all the seed had the recommended (Australian Seed Centre, CSIRO) pre-germination treatment. Boiling water was poured over seed, left to soak for one minute and then filtered off to let the seed dry prior to sowing. The seed for 1260 seedlings was sown into kwik-pot 64 tray with a media volume of 40 ml and copper painted for root-pruning. The media used was a composted sawdust: sand: peat mix (60:30:10) with a fertiliser supplement. The seed was sown early January with one seedlot (27) sown late in the warmer climate of Perth in late February. The seedlings did suffer some leaf drop which is thought to have resulted from a high water-holding capacity of the media and the lack of establishment of rhizobia (nitrogen-fixing bacteria). The seedlings recovered with reduced watering and a boost of nitrogen. A seedling assessment in May indicated that numbers for the trial designs would be met but both provenances of *A. deanei* had very small seedlings. The seedlings were labelled and sorted in June.

3.4 Trial design

The trials were designed by Trevor Butcher (Senior Research Scientist, Dept.of CALM) using ALPHAGEN, a lattice incomplete block design program (Williams and Matheson, 1994). Each provenance was replicated four times in a twenty-tree plot. There were nine blocks per replicate made up of three provenance plots.

Busselton (Jarrahwood)

Rep 1	3	20	12	8	25	17	22	7	13	6	24	14
	23	27	15	9	26	16	21	4	10	2	5	18
	19	1	11	21	5	27	24	2	13	6	20	11
Rep 2	23	12	9	10	22	8	15	1	25	7	18	19
	14	4	26	18	3	17	14	25	7	21	9	11
Rep 3	26	17	27	19	8	5	16	18	6	20	10	2
	15	3	24	1	12	22	4	13	23	6	26	13
Rep 4	16	1	20	18	8	15	21	17	2	14	19	9
	22	4	5	12	25	27	3	11	23	24	10	7

Darkan (Bowelling)

Rep 4			Rep 3		
24	16	5	17	2	21
19	9	1	11	3	23
20	10	4	24	13	7
18	11	2	27	25	10
26	17	8	4	22	9
21	13	3	12	6	26
25	14	6	20	16	1
23	15	7	18	14	8
22	12		5	19	15
27					
Rep 1			Rep 2		
11	20	8	12	1	25
22	2	13	26	14	4
25	3	15	17	18	27
23	4	12	3	19	16
10	21	1	24	15	2
27	14	24	7	20	9
9	18	5	8	6	13
6	17	19	22	10	5
7	16	26	11	23	21

Mt Barker

Rep 1			Rep 2			Rep 3												Rep 4											
10	8	20	4	18	6	18	1	14	7	3	20	23	12	17	16	2		13	2	14	4	16	7	11	22				
5	2	17	12	1	14	15	6	5	22	21	10	13	4	8	26	19	11	5	23	6	24	26	10	21	3				
3	23	14	11	6	2													19	18	17	15	8	20	1	12				
26	12	18	20	7	21																								
6	7	24	17	8	5																								
19	15	13	19	23	10																								
22	11	4	26	15	3																								
1	21	16	22	13	10																								

3.5 Site preparation

The sites had very different land preparation. The trees at the Busselton site were planted onto second rotation *Pinus radiata* site and hence there was a high proportion of debris and the mounds were high (Appendix 3, Figure 15A). At Mt Barker, the site was prepared with ripping and a smaller mound as it had been previously used for grazing. The area was sprayed with a herbicide mix of Round-up and Simazine (Appendix 3, Figure 16A). The Darkan site was also ex-grazing land but was only ripped (Appendix 3, Figure 15B). In hindsight, this latter site should have been mounded because it had clay soil that easily became waterlogged. (The bipinnate acacias do not grow well in waterlogged soils). The site was sprayed with Vorox but this herbicide was not effective in the waterlogged areas.

3.6. Trial establishment and maintenance

All the seedlings were planted, using a planting tube, in July 1992 at a spacing of 4 x 2 metres (1250 stems per hectare). In August the Busselton site was fertilised with 150 g superphosphate and 50 g muriate of potash per tree (Schonau, 1990) in one hole approximately 15 cm from the stem and 10 cm deep. This trial had a second fertiliser application the following year, with dimonniun phosphate (DAP) at 140 kg/hectare, at the same time as the surrounding *P. radiata* and again in 1995 with DAP 350kg/ha and urea 170 kg/ha. There is no record of the fertiliser history of the other two sites prior to planting or during the trial.

There were signs of African Black Beetle damage at Busselton and Darkan. The Darkan site was sprayed with Chloropyrifos insecticide. Parrots attacked the taller seedlings at all sites. The most severe damage occurred at Darkan, and the least at Busselton. Taller nearby native vegetation at the Busselton site appeared to keep the parrots away whereas attack was reduced at Darkan once Blue Gum plantations completely surrounded the trial.

3.7. Initial measurements at 2 years of age

During a visit by Suzette Searle (CSIRO Forestry and Forest Products) in August 1994, a height and survival assessment was made of one replicate at each of the three trials.

3.8 Growth analysis at 5 years of age

The trial sites were visited by Richard Mazanec (Research Scientist, Dept of CALM) and, together with collaboration with Suzette Searle (CSIRO Forestry and Forest Products) and Kay Nixon (Institute for Commercial Forestry Research, South Africa), it was decided that the following parameters should be assessed. These were modified by observations during measurement.

- *Plot effect or influence from adjacent plots.* This was overcome by measuring only the internal 6 trees of each plot.
- *Dominance.* This identified the runts in the plots.
- *Height*
- *Diameter at breast height of all stems*
- *Bark thickness at north, south, east and west points.* All points were measured, as recommended.
- *Number of stems at breast height,* to give an indication of tree form.

- *The number of straight stems*
- *Crown health.* At measurement all the crowns had good health.
- *Presence of gum.* We were not sure about the identification of gummosis, a disease which occurs in plantations overseas, and therefore simply recorded the presence of gum. This gives an indication of the health of the tree as gum is produced when the bark is damaged, probably through parrot or insect attack.
- *Insect presence in the stem and crown.* An indication of stem health will be seen from the presence of gum. There were no insects observed in the crown.
- *Parrot attack damage.* This had mainly occurred when the trees were between two and three years, thus at five years of age, it was difficult to distinguish whether the cause of poor form was parrot attack or genetic. (Appendix 3, Figure 16 B).
- *Root suckers.* No suckers were observed.
- *Flowering* was not assessed

An assessment form created by Richard Mazanec to enter the data is shown (Table 4).

10

10

3.9 Tannin analysis at five years of age

Bark samples were taken from a sub-sample of trees (four trees at each of the three sites) representing the provenances of all 12 species and the best commercial *A. mearnsii* seedlot. The bark sample was non-destructively collected with a 32 mm diameter wad punch. Ten discs of bark were collected from the north side of the tree at breast height or 1.3 m (five discs above 1.3 m and five below 1.3 m) (Figure 2C). The samples were immediately sealed in plastic bags and placed in a cooler for transport to Perth. Dr David Harris at the Chemistry Centre (WA) assessed the tannin content of the bark discs for water content, tannin content, Stiasny value and the polyflavanoid content. The method developed by Yazaki *et al.* (1990) was followed.

On arrival the bark discs were freeze-dried and then ground to pass through a 2.5 mm retaining screen in a Wiley mill at room temperature. A 1.25g sample of the ground bark was extracted with hot water (2 x 25 ml) for 2 x 15 minutes and the extracts freeze-dried. A sample of the dried extract (0.1g) was dissolved in water (10 ml) and reacted at 100°C with 36 – 38% formaldehyde (2 ml) catalyzed by 10N HCl (1 ml) for 30 minutes. The resultant precipitate (Stiasny precipitate) was accurately weighed and the Stiasny value calculated as a percentage of the weight of the dried extract. The percentage polyflavanoid contents in the barks were calculated by multiplying the extractives yields by Stiasny values and dividing by 100.

3.10 Bulk tannin analysis at five years of age

To obtain sufficient tannin for a bulk tannin analysis, samples from a number of trees (depending on their size) from a single provenance of each species were stripped of their bark. Only 10 of the species had enough bark to complete the exercise as *A. deanei* and *A. elata* trees were too few and too small. The strips of bark were collected using an axe to cut through the bark at the base of the tree and at the top of the straight bole (Figure 1A and B). The bark was then peeled back, stripped off and stacked. The stack of bark was then stored and sealed in cellophane (Figure 1C) and cooled with water until the samples could be transported overnight to Perth. The samples were then stored in a freezer until the Chemistry Centre (WA) were able to process the samples.

The bulk bark tannin extraction commenced in January 1998. The ground bark was steeped in boiling water overnight. The water from the tannin-water mix then needed to be removed. Spray drying the

tannin extract is the method used on a commercial basis in South Africa), however due to the unavailability of a spray-drier, an alternate, slower method using vacuum rotovaps was used. Eleven kilograms of freeze-dried tannin from each species were passed onto Bunnings Timbchem and Dyno Industries for wood adhesive quality and tannin additive assessments respectively. Bunnings Timbchem used 10 kg of each of the freeze-dried tannins to manufacture 10 adhesives (resorcinol-tannin, commercial formulae). These adhesives were tested for their efficacy as wood adhesives using the tests detailed in AS1328 and the results compared with those obtained from Bunnings Timbchem commercially manufactured adhesive. The 10 samples of the 1 kg of freeze-dried tannins were given to Dyno Industries to be used as an additive to make 12 water-repellent adhesives. These adhesives were tested for their water repellency and quality.



C

A

B

Figure 1. Stripping the bark off bipinnate acacia trees at the Darkan site for bulk tannin extraction. A. Stripping the bark. B. The appearance of the trees with the bark stripped. C. The gathering of the bark into bundles for transport.



A



B



C

Figure 2: Harvesting the destructive wood samples for analysis at the base and at breast height (A), labelling and storing the discs for transport to Perth (B). Non-destructive harvest of the bark for tannin analysis (C).

C

3.11 Wood analysis at five years of age

The standing trees stripped of their bark for tannin analyses were also sampled for wood. Only a single provenance of each species was sampled and the number of samples taken depended on the number of trees stripped of bark. Stem discs were removed from the base of the tree and across all stems at breast height (Figure 2A) These were labelled and immediately placed into plastic bags (Figure 2B). The discs were soaked on arrival at the laboratory and weighed for 'as received' green weight of discs. The discs were then air-dried and re-weighed until the weight stabilised for air-dry weight of discs. The discs were then soaked overnight and the volume of the disc calculated by using green volume method described by the T 258 om-94: Basic density and moisture content of pulpwood. To calculate the green volume, the measurement given after the suspension of the disc in water was added to the green weight.

These measurements were used to calculate:

$$\text{Moisture content of the discs (\%)} = \frac{[(\text{as received green weight of the disc} - \text{air-dry weight of the disc}) / \text{as received green weight of the disc}] \times 100.}$$

$$\text{Basic density (kg/m}^3\text{) of the discs} = \text{air dry weight of the discs} / \text{green volume}$$

3.12 Coppice observation

The cut stumps (5 - 20 cm above ground level) were observed a year later for signs of coppice growth.

4. Results

4.1 Twoyear old growth assessment of the trials

After two years of growth, the trial with the highest survival was Mt Barker (94.1%) followed by Busselton (81%) and Darkan (49.6%) (Table 5). The average tree height also followed the same trend with Mt Barker producing trees that were on average 3.1 m tall, Busselton 3.2 m tall and Darkan 1.5 m tall.

The best performing species across the three sites was *A. mearnsii* for both height and survival. The next four tallest species also showed the best survival and they were *A. dealbata*, *A. irrorata*, *A. decurrens* and *A. fulva*. The four poorest performing species were *A. elata*, *A. silvestris*, *A. trachyphloia* and *A. deanei*. At the provenance level, all the *A. mearnsii* seedlots, whether native and commercial, appeared in the top ten for growth and survival. The other species/provenances that performed well were all from New South Wales and included *A. decurrens* (Picton-Mittagong NSW), *A. fulva* (Howes Valley NSW), *A. irrorata* (7 km E Woodenbong NSW) and *A. filicifolia* (19 km SW Singleton NSW) (Table 5).

Table 5. Height and survival of the 12 bipinnate acacia species at 2 years of age in one replicate from each of the sites.

Acacia species	Prov No	DARKAN *				MT BARKER **				BUSSELTON **			
		Height	Rank	Survival	Rank	Height	Rank	Survival	Rank	Height	Rank	Survival	Rank
DEALBATA	14	53	25	20	13	306	13	100	1	281	18	85	4
DEALBATA	15	228	6	75	3	248	17	90	4	284	17	85	4
DEANEI	25	115	17	45	9	***		***		202	21	60	8
DEANEI	24	64	22	25	12	226	20	80	6	294	14	90	3
DECURRENS	11	247	4	70	4	398	4	100	1	378	9	90	3
DECURRENS	10	140	16	50	8	386	7	100	1	167	23	50	9
ELATA	16	58	24	45	9	194	22	95	2	63	26	50	9
ELATA	17	185	10	95	1	123	23	80	6	153	24	70	7
FILICIFOLIA	13	142	15	55	7	374	8	100	1	324	13	80	6
FILICIFOLIA	12	12	27	5	15	398	6	100	1	292	15	85	4
FULVA	26	172	11	45	9	402	3	95	2	488	4	90	3
GLAUCOCARPA	4	39	26	15	14	301	14	100	1	331	11	85	4
GLAUCOCARPA	3	67	21	30	11	331	11	95	2	289	16	100	1
IRRORATA	19	102	18	40	10	241	18	95	2	366	10	100	1
IRRORATA	18	251	3	70	4	371	9	90	4	406	8	90	3
MEARNSII	9	206	7	60	6	***		***		499	2	100	1
MEARNSII	27	202	8	55	7	***		***		445	7	85	4
MEARNSII	5	283	2	75	3	490	1	100	1	562	1	100	1
MEARNSII	6	197	9	60	6	435	2	100	1	491	3	100	1
MEARNSII	8	313	1	85	2	308	12	90	4	458	6	81	5
MEARNSII	7	230	5	65	5	398	5	90	4	468	5	95	2
PARRAMATTENSIS	21	94	19	40	10	258	16	94	3	326	12	95	2
PARRAMATTENSIS	20	151	14	50	8	207	21	90	4	217	19	85	4
SILVESTRI	1	159	13	60	6	***		***		74	25	50	9
SILVESTRI	2	160	12	50	8	240	19	95	2	62	27	30	10
TRACHYPHLOIA	22	61	23	25	12	354	10	100	1	173	22	70	7
TRACHYPHLOIA	23	84	20	30	11	262	15	85	5	213	20	85	4
Average		148.7		49.6		315.3		94.1		307.6		81.0	

* replicate 4 only

** replicate 1 only

*** data missing

4.2 Five year old growth assessment of the trials

The Busselton trial was measured between 16th and 18th September, the Mt Barker trial 23rd-24th September and the Darkan trial 7th-8th October 1997. At this time the trials were 5 years and 2 months old.

The best site for growing acacias for wood production was at Busselton (Jarrahwood) which gave an average of 4.6 m³ per hectare with an overall survival of 89.3 % (Table 7). This was followed by the Mt Barker site which produced a wood volume of 4.2 m³ per hectare with an overall survival of 90.4 % (Table 8). The poorest site was at Darkan, which produced a wood volume of 2.1 m³ per hectare with an overall survival of 48.2 % (Table 9).

Table 6. Analysis of variance table for across site analysis of the bipinnate acacia trials at Busselton, Mt Barker and Darkan. The first figure presented in each column is the degrees of freedom followed by the average and then level of significance. The level of significance is indicated by * (p<0.05), ** (p<0.01) and * (p<0.001). Note Provenances 9, 25 and 27 were excluded from the analysis as they were not present at all sites.**

Source	d.f. Mean height	d.f. dbh	Df Mean stem volume	Df Mean bark thickness	Df Mean bark yield	Df volume/ha MAI	Df Mean stems at 1.3m	Df % single stem trees	Df Mean straightness	Df Mean survival
Site	2 113.0706**	2 0.0521ns	2 1.2854*	2 0.1059**	2 0.1950***	2 1.2867*	2 0.1843*	2 4.3411***	2 40.7949***	2 4.9290**
Rep(site)	8 8.2612***	8 0.0176***	8 0.1926***	8 0.0059**	8 0.0565**	8 0.1799***	8 0.0268***	8 0.0878ns	8 0.5337ns	8 0.4883***
Species	12 20.4613***	12 0.1132***	12 0.7659***	12 0.0449***	12 0.4602***	12 0.3320***	12 0.1154***	12 0.5333***	12 1.2317**	12 0.1469*
Prov(Species)	11 2.9878***	11 0.0161***	11 0.1053***	11 0.0078***	11 0.0684***	11 0.1064***	11 0.0287***	11 0.4065***	11 0.5076ns	11 0.1038ns
Site*Species	24 1.7540***	24 0.0101***	24 0.0620***	24 0.0030*	24 0.0365**	24 0.0481***	24 0.0116**	24 0.1887**	24 0.8704*	24 0.1902***
Site*Prov(Species)	22 0.9849ns	22 0.0047ns	22 0.0405*	22 0.0037**	22 0.0274*	22 0.0423**	22 0.0127**	22 0.1704*	22 0.7203ns	22 0.0635ns
Error	171 0.6539	169 0.0040	168 0.0220	169 0.0019	171 0.0166	169 0.0201	170 0.0060	172 0.0986	163 0.4601	171 0.0661

Table 7. Five year growth and form data from the Darkan site. Wattle (commercial *A. mearnsii* seed source) has been included in the table for interest but has not been referred to in the species discussion as it has been genetically improved. Letters indicate statistically significant groupings, those numbers with the same letter are not significantly different.

Acacia <i>Acacia</i> species	R A N K	Height (m)	R A N K	Dbh (cm)	R A N K	Mean stem Vol (dm ³)	R A N K	Mean bark thickness (mm)	R A N K	Mean Bark Yield (kg/stem)	R A N K	Volume/ ha MAI (m ³)	R A N K	Mean No. Stems at 1.3m	R A N K	Mean % Single Stemmed Trees	R A N K	Mean Straight- ness	R A N K	Mean Survival %
Wattle	1	7.7a	2	8.9ab	2	16.7ab	1	6.8a	1	8.5a	1	4.8a	2	2.0a	7	8.0ab	11	1.9a	1	69.8a
fulva	2	7.5ab	6	7.0abcd	5	10.2abcd	4	6.0ab	5	5.7abcd	4	2.8ab	2	2.0a	2	33.3a	10	2.0a	5	50.0a
mearnsii	3	7.4abc	4	8.1abc	3	13.7ab	3	6.1abc	3	6.9abc	2	4.4a	8	2.2a	4	16.1ab	3	2.4a	2	68.7a
decurrens	4	7.3abc	1	9.4a	1	18.4a	2	6.2ab	2	7.7ab	3	2.9ab	2	2.0a	8	4.3ab	13	1.1a	8	41.1a
filicifolia	5	6.7abcd	3	8.6abc	4	12.9abc	4	6.0abc	4	5.9abcd	6	2.1ab	6	2.1a	1	34.9a	6	2.2a	9	41.0a
trachyphloia	6	6.2abcd	6	7.0abcd	6	8.8abcd	8	5.8ab	6	4.8abcd	5	2.7ab	9	2.7a	11	0.0b	6	2.2a	3	57.7a
silvestris	6	6.2abcd	8	6.4abcd	7	8.3abcd	9	5.3abc	8	3.7abcd	10	1.4bc	2	2.0a	6	10.9ab	6	2.2a	12	35.2a
parramattensis	8	5.9abcd	9	6.1abcd	9	6.3abcd	6	5.9ab	7	4.1abcd	8	1.6bc	11	2.8	9	1.7ab	1	2.9a	10	38.0a
glaucocarpa	9	5.6bcde	10	5.1cd	11	4.2de	12	4.7b	11	2.4de	9	1.5bc	9	2.7a	3	25.0	3	2.4a	10	38.0a
irrorata	10	5.4cde	12	4.7de	12	3.6de	11	4.9ab	10	2.5cde	7	1.7bc	13	5.1b	11	0.0b	5	2.3a	7	42.7a
dealbata	11	5.3de	5	7.2abcd	8	7.6abcd	10	5.2ab	12	2.3de	10	1.4bc	1	1.6a	5	12.1ab	6	2.2a	6	43.2a
deaniii	12	4.7e	13	3.0e	13	1.5e	13	3.1c	13	0.9e	13	0.4c	12	3.3a	11	0.0b	12	1.8a	13	24.2a
elata	12	4.7e	11	5.4bcd	10	4.5dce	7	5.9ab	9	3.1bcde	12	1.2bc	6	2.1	9	1.7ab	2	2.6a	4	54.3a
Site mean± STD		6.4± 1.4		6.6± 0.4		8.1± 2.1		5.5± 0.2		4.3± 0.8		2.1± 1.8		2.5± 1.3		14.7± 24.1		2.1± 1.1		48.2± 7.8

Table 8. Five year growth and form data from the Mt Barker site. Wattle (commercial *A. mearnsii* seed source) has been included in the table for interest but has not been referred to when the results have been discussed as it is genetically improved. Letters indicate statistically significant groupings, those numbers with the same letter are not significantly different.

<i>Acacia</i> species/	R a n k	Height (m)	R a n k	Mean dbh (cm)	R a n k	Mean stem volume (dm ³)	R a n k	Mean Bark Thickne ss (mm)	R a n k	Mean Bark Yield (kg)	R a n k	Vol/ha MAI (m ³)	R a n k	Mean Number of stems at 1.3m	R a n k	Mean % single stem trees	R a n k	Mean straight- ness	R a n k	Mean Survival (%)
fulva	1	8.6a	4	7.5abc	3	13.1ab	2	5.4b	3	6.0abc	9	3.5abc	1	1.5a	1	61.3a	7	3.4abc	10	77.2a
Wattle	2	8.1a	1	8.9a	1	17.1a	1	6.2a	1	7.9a	2	5.6ab	2	1.6a	11	8.1b	11	2.8bc	5	92.2a
decurrens	3	7.8ab	2	8.8ab	2	16.7a	2	5.4b	2	6.7ab	1	6.1a	4	1.7a	2	24.8ab	1	3.9a	4	92.3a
mearnsii	3	7.8abc	3	7.6abc	4	12.9ab	5	5.0bc	4	5.3bcd	4	4.9ab	2	1.6a	9	12.9ab	8	3.3abc	8	90.8a
filicifolia	5	7.6abc	4	7.5abc	5	11.4abc	8	4.7bcd	5	4.7cde	3	5.1ab	5	1.8a	6	21.9ab	2	3.8ab	3	96.7a
silvestris	6	7.0bcd	8	6.8c	7	8.8bc	11	4.5	9	3.8de	7	3.9abc	7	2.0a	4	23.3ab	3	3.7ab	5	92.2a
glauocarpa	7	6.8bcde	11	6.2c	10	7.2bc	8	4.7bcd	10	3.5de	7	3.9abc	10	2.2ab	12	1.2b	10	3.0bc	2	98.6a
trachyphloia	7	6.8cde	6	7.0bc	6	8.9bc	10	4.6cd	7	4.1cde	6	4.0abc	7	2.0a	8	13.7ab	13	2.6c	11	76.0a
irrorata	9	6.7def	9	6.5	9	7.7bc	5	5.0bc	6	4.2cde	5	4.4ab	12	3.2b	13	0.0b	9	3.2abc	12	75.1a
dealbata	10	6.0efg	9	6.5c	11	7.0c	12	4.2d	12	3.1e	10	3.2bc	7	2.0a	7	20.1ab	6	3.6ab	9	84.6a
parramattensis	11	5.9efg	11	6.2c	12	6.8c	7	4.9bcd	11	3.3de	11	3.1bc	10	2.2ab	5	23.0ab	3	3.7ab	1	98.9a
elata	12	5.8fg	7	6.9c	8	7.8bc	2	5.4b	7	4.1cde	12	2.9bc	5	1.8aa	3	23.6ab	3	3.7ab	7	92.0a
deanii	13	5.2g	13	3.7d	13	2.1d	13	3.2c	13	1.0	13	1.5c	13	5.2c	10	9.2b	12	2.7c	13	67.8a
Site mean± STD		7.0± 1.2		7.2± 1.6		9.7± 0.7		5.0± 0.8		4.7± 2.2		4.2± 2.3		2.0± 1.5		14.7± 12.1		3.4± 0.6		90.4± 10.6

Table 9: Five year growth and form data from the Busselton site. Wattle (commercial *A. mearnsii* seed source) has been included in the table for interest but has not been referred to when the results have been discussed as it has been genetically improved. Letters indicate statistically significant groupings, those numbers with the same letter are not significantly different.

<i>Acacia</i> specie	R a n k	Height (m)	R a n k	Dbh (cm)	R a n k	Mean stem Vol (dm ³)	R a n k	Mean Bark Thickness (mm)	R a n k	Mean Bark Yield (kg)	R a n k	Volume/ha MAI (m ³)	R a n k	Mean stems at 1.3m	R a n k	%single stems trees	R a n k	Mean Straight- ness	R a n k	Mean Survival %
mearnsii	1	10.7a	1	10.4a	1	32.7a	2	5.5ab	1	10.9a	1	9.4a	2	1.3a	5	68.5ab	1	4.3a	3	97.5ab
Wattle	2	10.4ab	2	10.2ab	2	30.0a	1	5.7a	2	10.5a	2	8.1ab	1	1.2a	4	68.6ab	5	3.8a	5	95.1ab
fulva	3	10.3ab	5	8.0abcd	3	25.2ab	6	4.6abc	5	6.7ab	3	6.5abc	5	1.5ab	3	69.1ab	8	3.7ab	1	100.0a
filicifolia	4	9.2abc	3	9.2abc	5	21.5abc	9	4.3c	4	6.6ab	6	5.5abc	2	1.3a	2	72.7ab	5	3.8a	7	89.6abc
decurrens	5	9.1bc	4	9.1abc	4	22.2abc	3	5.0abc	3	7.5ab	4	6.1abc	2	1.3a	1	78.6a	4	3.9a	6	90.8abc
irrorata	6	8.7dc	10	6.8def	10	11.5d	7	4.4bc	9	4.7bcd	5	5.6abc	12	2.3cd	12	19.4b	11	3.6ab	2	98.3a
glaucocarpa	7	8.7dc	9	7.3cde	9	13.1cd	5	4.7abc	7	5.2bc	6	5.5abc	11	1.9abc	13	17.3b	8	3.7ab	3	97.5ab
trachyphloia	8	8.4dc	8	7.4cde	7	14.1bcd	10	4.0c	9	4.7bcd	8	4.4abc	9	1.8abc	11	24.2ab	8	3.7ab	9	84.4abc
parramattensis	9	8.3dc	7	7.5cde	8	13.4cd	4	4.8abc	6	5.3bc	10	4.0cd	7	1.7abc	7	50.7ab	11	3.6ab	10	82.0abc
dealbata	10	8.1dc	6	7.9bcd	6	15.2bcd	10	4.0c	8	4.8bc	9	4.2bc	7	1.7abc	10	30.1ab	2	4.0a	8	88.0abc
silvestris	11	7.3de	11	6.0ef	11	9.3d	10	4.0c	11	3.0cd	11	2.0de	6	1.6abc	6	56.8ab	2	4.0a	13	59.1c
elata	12	6.1ef	12	5.3f	12	5.0e	7	4.4bc	12	2.5d	11	2.0de	9	1.8abc	8	47.5ab	5	3.8a	12	65.9bc
deanii	13	5.6f	13	3.4g	13	1.8f	13	2.4d	13	0.7e	13	0.8d	13	2.4d	9	39.0ab	13	3.0b	11	81.1abc
Site mean± STD		8.6±1.7		7.5± 0.3		14.3± 1.2		4.5± 0.2		5.3± 0.8		4.6± 0.8		1.6± 0.3		49.9± 15.3		3.7± 0.5		89.3± 9.6

4.2.1 Genotype x site interactions

The genotype by site interactions (Site*Species) for the different traits measured in the trials are summarised in Table 6. In all cases, site had a significant impact on all traits except for breast height diameter (dbh). Replications within sites were also significantly different except for forking (% single stem trees) and straightness. Species were significantly different for all traits whilst at the provenance level, they were all significantly different except for straightness and survival. Interactions of site with species are all significant indicating that there is a high genotype by environment interaction, especially for survival. The site by provenances interactions are also significant for all traits except for height, breast height diameter, straightness and survival.

4.2.2 Survival

Species survival was affected by site. At 62 months of age the average survival was 89.3% at Busselton (range 59.1% – 100%), 90.4% at Mt Barker (range 67.8% to 98.9%) and 48.2% at Darkan (range 24.2% to 69.8%) (Table 7 - 9). When one replicate at each site was measured at 2 years of age the survivals were similar to the survival at 5.5 years (Survival at 2 years was Busselton 81.0%, Mt Barker 94.1% and Darkan 49.6%) (Table 5) indicating that the greatest impact on survival occurred during initial establishment. The low survival at Darkan was due to the waterlogged nature of the site and the poor weed control. Additionally, trees at both Darkan and Busselton suffered from African Black Beetle attack. Frost was not a contributing factor at any of the sites.

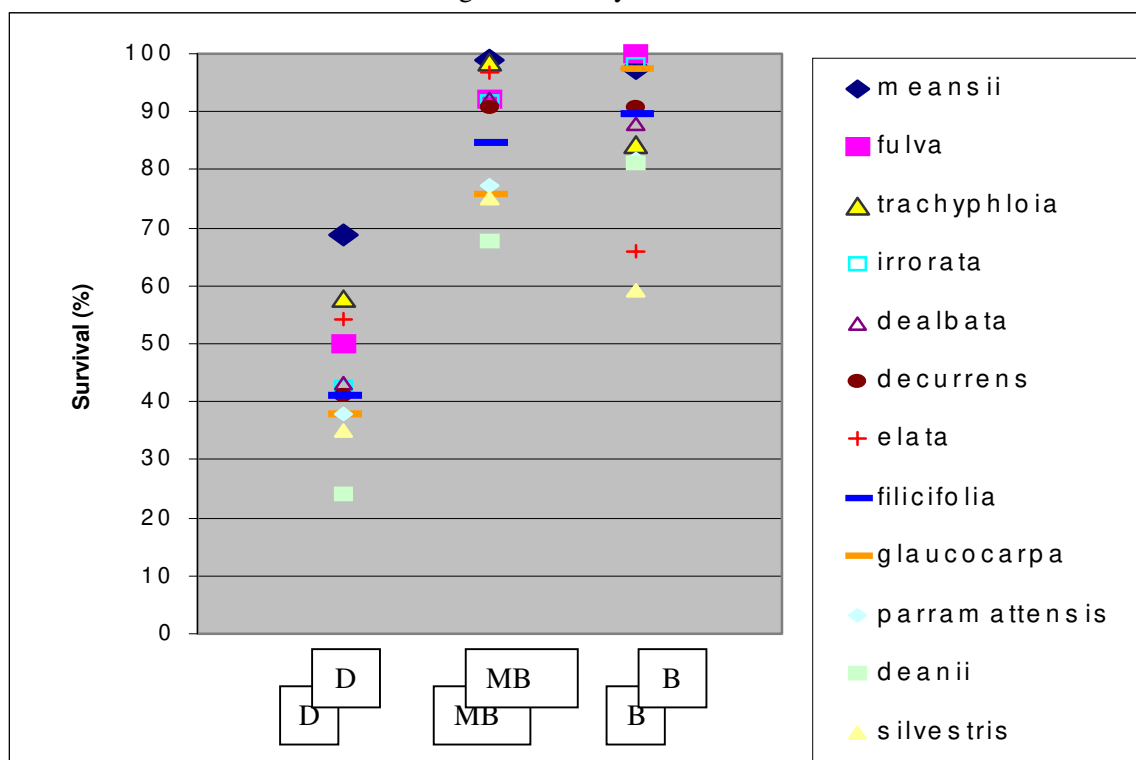


Figure 3. Survival of bipinnate acacia species at 62 months of age across three sites in South - West Western, Darkan (D), Mt Barker (MB) and Busselton (B). The species legend is in ranking order of average survival across all three sites.

Based on the ranking of the species at each site, the best survival was shown by *A. mearnsii* (Figure 3). This was followed by *A. fulva* and *A. trachyphloia*, with *A. deanii* and *A. silvestris* clearly the poorest performing species across all three sites.

4.2.3 Height, diameter and volume

The tallest species across all three trials at 62 months of age were *A. mearnsii*, *A. fulva*, *A. decurrens* and *A. filicifolia*. The average tree height at Busselton was 8.6 m (ranging from 10.7 m to 5.6 m) while at Mt Barker it was 7.0 m (ranging from 8.6 m to 5.2 m) and at Darkan it was 6.4 m (ranging from 4.7 m to 7.7 m) (Table 5-7). Since the first measurement at two years of age, the trees at Busselton had grown 5.5 m, the trees at Mt Barker 3.8 m and at Darkan 4.9 m. The height growth, especially at Mt Barker and Darkan, may also have been reduced by parrot attack. The parrots land on the tallest trees and ring-bark the stems. As a result, they break with the next strong wind.

The tallest trees also produced the greatest breast height diameter and mean stem volume. The breast height diameter ranged from 10.4 cm to 3.4 cm for Busselton, 8.9 cm to 3.7 cm for Mt Barker and 9.4 cm to 3.0 cm for Darkan. Across the three sites, the species that produced the most wood were *A. mearnsii* (19.8 dm³) followed by *A. decurrens* (19.1 dm³) and *A. fulva* (16.2 dm³) (Figure 4). The best species at Busselton, *A. mearnsii*, produced on average 32.7 dm³ per tree, whereas at Mt Barker, the best species, *A. decurrens*, produced 17.1 dm³ per tree and at Darkan, this same species produced 18.4 dm³ per tree.

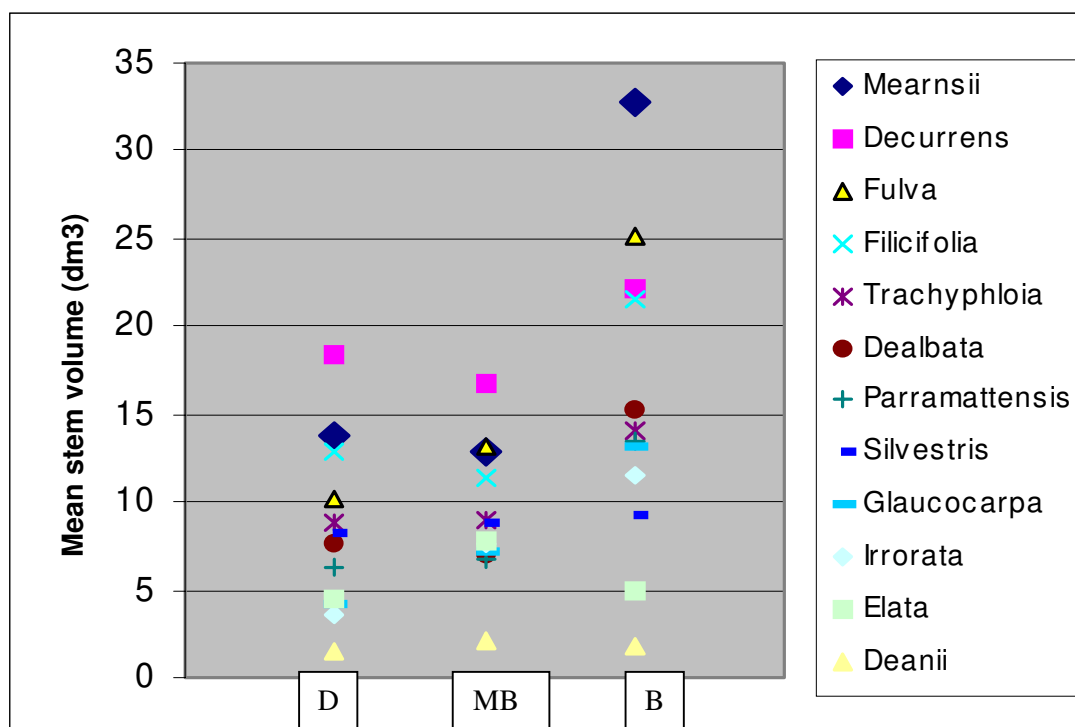


Figure 4. Mean stem volume (dm³) of the bipinnate acacia species at 62 months of age at three sites in South - West Western Australia, Darkan (D), Mt Barker (MB) and Busselton (B). The species legend is sorted on the average mean stem volume production across all three sites.

If this volume production is expressed on a per hectare basis, taking into account survival which is an integral part of species performance, then the impressive single stem production is reduced to 9.0 m³ per hectare for the best species at Busselton (*A. mearnsii*), 5.6 m³ per hectare for Mt Barker (*A. decurrens*) and 4.4 m³ per hectare per year for Darkan (*A. mearnsii*). Across the three sites, the best performing species is *A. mearnsii* (6.23 MAI), followed by *A. decurrens* (5.03 m³ MAI) and *A. fulva* (4.27 m³ MAI) (Figure 5). Survival is an integral part of species performance on a per hectare basis.

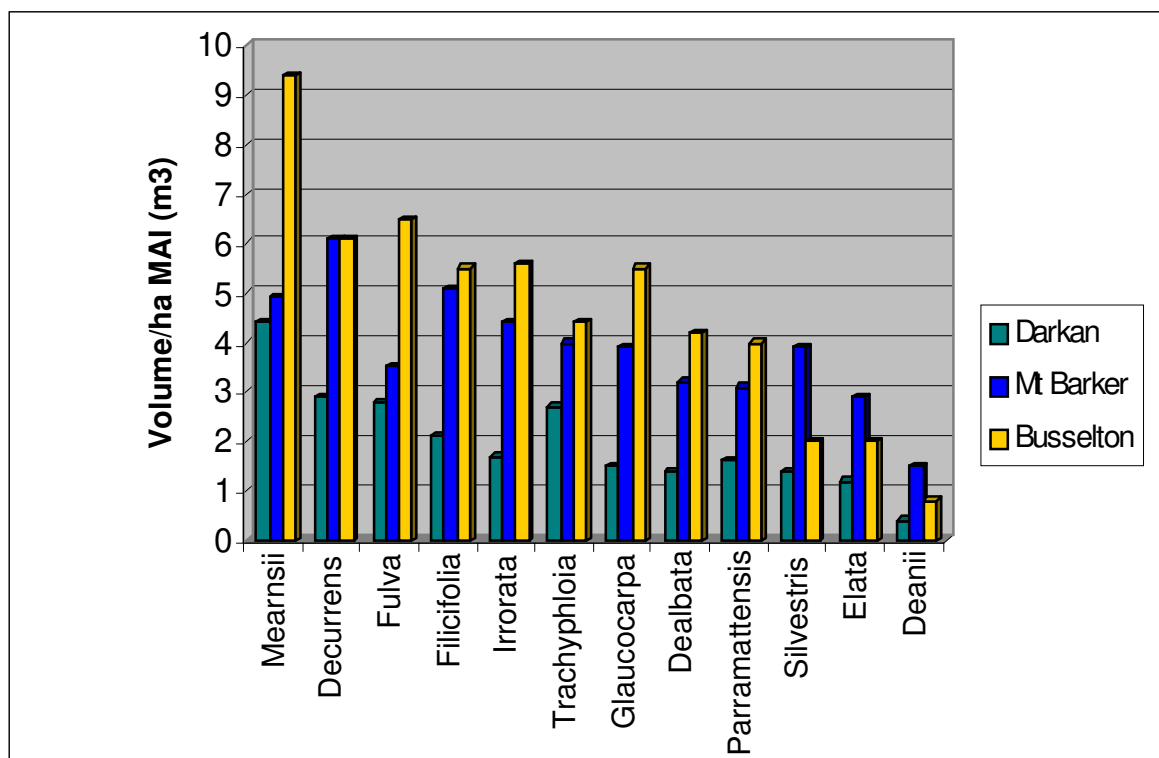


Figure 5. Mean annual increment (m³/ha) of twelve bipinnate acacia species at 62 months of age at three sites in South - West Western Australia. The species are listed in the legend in order of their sorted on the average mean annual increment across all three sites.

4.2.4 Form characteristics

Good stem form is important for ease and cost of harvesting and transport especially in the stripping of the bark. The form was shown to be better at the Busselton site compared to Mt Barker and Darkan. This is shown by the number of single-stemmed trees at each of the sites, the number of stems and the mean straightness of the bole. This difference between the sites has been contributed to by the degree of parrot attack. The Busselton site was reasonably protected by tall native bush on one side of the trial and suffered little attack while on exposed sites such as Darkan, the taller, faster-growing acacias were the first to have their dominant stems damaged by parrots.

Number of stems

Busselton trees had fewer stems on average at breast height (1.6 stems) compared with the parrot-attacked trees at Darkan (2.5 stems) and Mt Barker (2.0 stems). The lowest average for number of stems was 1.3 (Busselton; *A. mearnsii*), and the highest was 5.2 (Mt Barker, *A. deanei*). Overall the best species with the fewest stems were *A. mearnsii*, *A. fulva* and *A. filicifolia*.

The other indicator of tree form is the percentage of trees with a single stem. At the Busselton trial, on average 49.9% trees had single stems, the Darkan and Mt Barker trials both had only 14.7% trees with single stems. The species that had the most trees with single stems were *A. fulva*, *A. filicifolia*, *A.*

decurrens and *A. silvestris*. Thus the species with the best form, based on the fewest stems per tree and most single-stemmed trees across the trials were *A. fulva* and *A. filicifolia*.

Stem form in this trial has been judged on mean straightness where the straighter the stem, the higher the rating. Poor form has a low rating. The bipinnate acacias on the Busselton site showed a mean straightness of 3.7, on Mt Barker it was 3.4 and on Darkan it declined to 2.1. Overall the straightest species were *A. elata*, *A. silvestris* and *A. mearnsii*.

4.2.5 Bark thickness and bark yield

In the market place bark is sold on its weight and not on the tannin content. Thus attributes of importance for a grower are the length of the bole from which the bark can be stripped and the thickness of the bark. The South African experience has shown that there is a positive correlation between bark thickness and tannin and between bark thickness and tree diameter. So the bigger the tree, the thicker the bark and the more bark that can be stripped and tannins extracted. The formula used to calculate the bark mass in this study was generated by Shonau for *A. mearnsii* and used by the Institute for Commercial Forestry Research in South Africa (Nixon, pers.comm.)

$$\text{LogBM} = 1.87253 (\log D) + 0.72118 (\log H) + 0.152919 (\text{BT}) - 0.11767 (\text{BT} * \log D) + 0.037728 (\text{BT} * \log H) - 2.04586$$

where

BM = undried bark mass in kg, and D = diameter (breast height) in cms, and H = total height in metres and BT = bark thickness in mm at breast height.

Bark thickness generally increased with harsher site conditions. At Darkan the bark averaged 5.5 mm thick (range 6.8 to 3.1 mm), Mt Barker was less at 5 mm (range 6.2 to 3.2 mm) whilst Busselton only produced a 4.4 mm bark thickness (range 5.6 to 2.4 mm). Across all sites the species that produced the thickest bark were *A. mearnsii*, *A. decurrens*, and *A. fulva*.

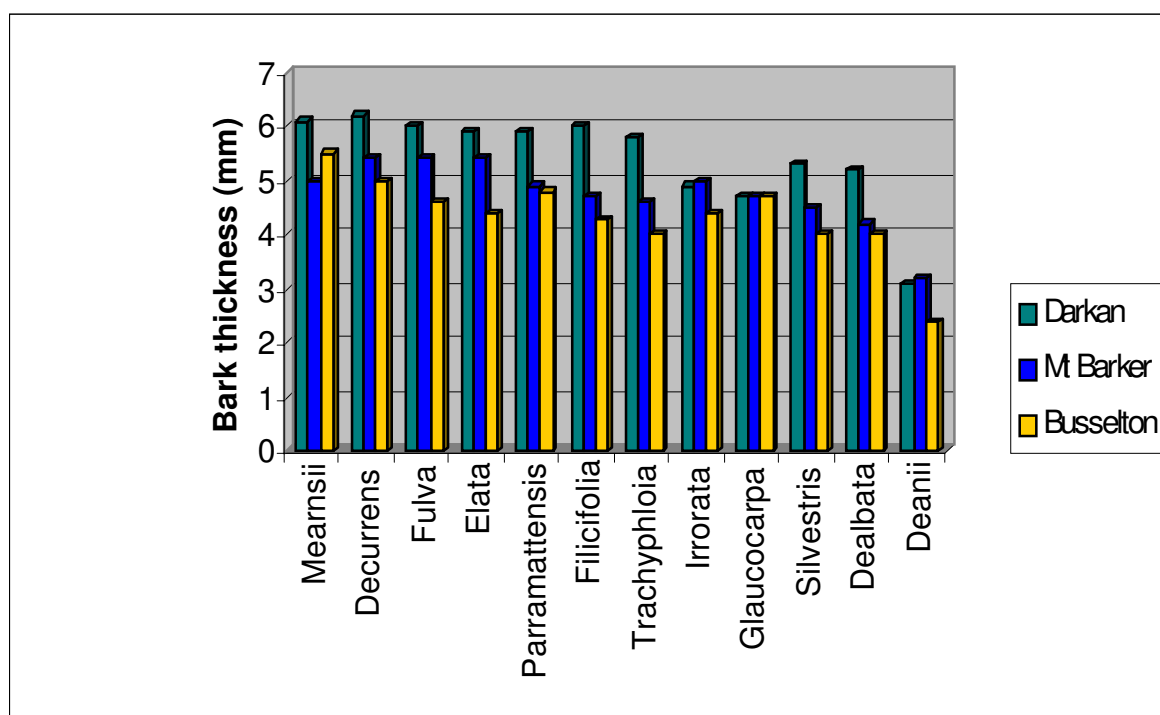


Figure 6. Bark thickness (mm) of the bipinnate acacia species at 62 months of age at three sites in South - West Western Australia with the species sorted on average bark thickness across all three sites.

Included in this study was an investigation of the best sampling site on the tree for bark thickness. All the trees at all three sites were measured for bark thickness on the north, east, west and south aspect of the trees. It was concluded that a single sampling at any one aspect of the tree could have been used because there was no significant difference in bark thickness between them (Table 10).

Table 10. Mean bark thickness of bipinnate acacias at 62 months of age by aspect across three sites in south - west Western Australia. Letters indicate statistically significant groupings, those numbers with the same letter are not significantly different. There was no significant difference between the aspects.

Aspect of tree	Trial sites in South - West Western Australia		
	Darkan	Mt Barker	Busselton
North	5.5 a	4.9 a	4.3 a
East	5.4 a	4.9 a	4.3 a
West	5.4 a	4.8 a	4.3 a
South	5.3 a	4.8 a	4.3 a

When values for breast height diameters, total heights and bark thickness are combined in the above formula for bark mass/tree, it was found that the Busselton site is capable of producing the largest bark mass per tree, 4.9 kgs (range 10.9 to 0.7 kgs). This compares with 4.3 kgs at Darkan (range 8.5 to 0.9 kgs) and Mt Barker (7.7 to 1.0 kgs). Across all sites, the same species (*A. decurrens*, *A. mearnsii* and *A. fulva*) that had the thickest bark also produced the greatest bark mass.

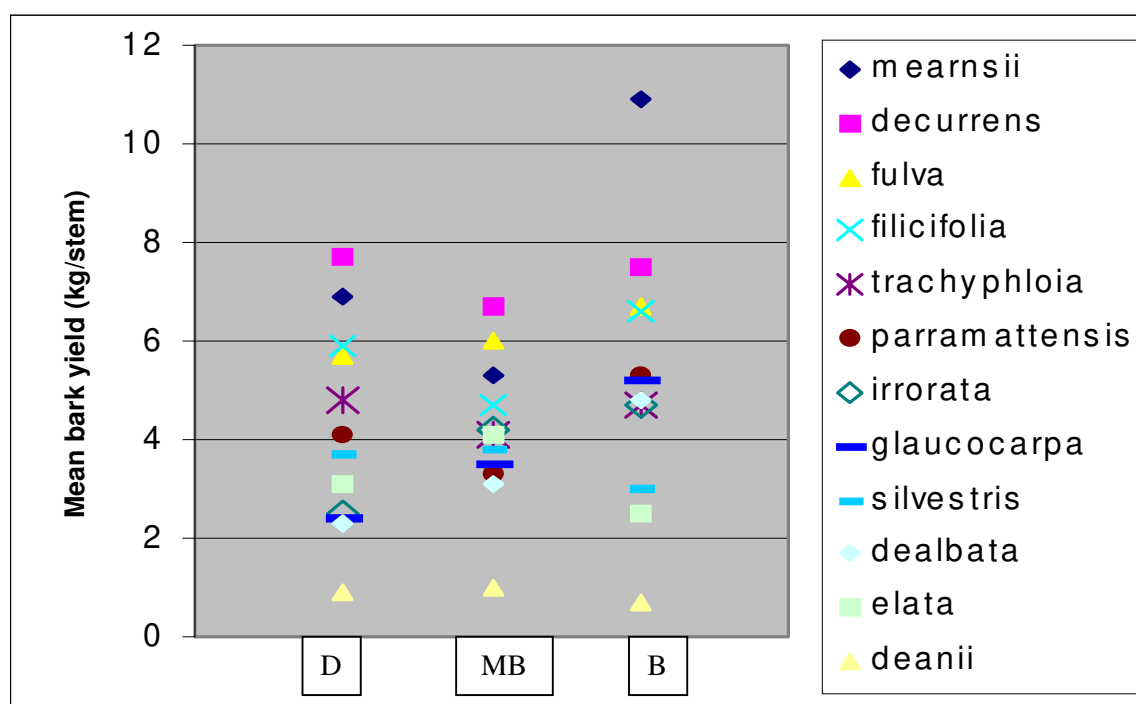


Figure 7. Mean bark yield (kg) of 12 bipinnate acacia species at 62 months of age at three trial sites in south - west Western Australia, Darkan (D), Mt Barker (MB) and Busselton (B). The species are ranked in the legend on average bark yield across all three sites

4.2.6 Coppice and root sucker production.

There was no evidence of root suckers or coppice growing from the stumps after 12 months when the trees were harvested at 62 months of age, although the coppice may have been grazed by sheep.

4.2.7 Comparison between native and commercial *A. mearnsii* seedlots

Of interest regarding the genetic development of *A. mearnsii* is the comparison between native *A. mearnsii* seedlots and those seedlots acquired from a commercial *A. mearnsii* (wattle) programme (Table 11). In the South African *A. mearnsii* breeding program, the emphasis has been on the traits that produce more bark and less gummosis. The tannins extracted from *A. mearnsii* bark have been the main reason for planting the species in South Africa. The interest in *A. mearnsii* as a fibre source for paper and rayon has been a relatively recent development.

The mean bark thickness for all *A. mearnsii* seedlots across the three sites ranged from 5.9 mm to 6.8 mm (Table 11); whilst the bark yield ranged from 7.4 kgs to 11.6 kgs.. The best three seedlots for bark thickness and bark yield were the commercial wattle seedlots No. 27 (11.1 kgs bark yield) and No. 7 (10.4 kgs) and the native seedlot No. 9 from Tarpeena South Australia (8.8 kgs).

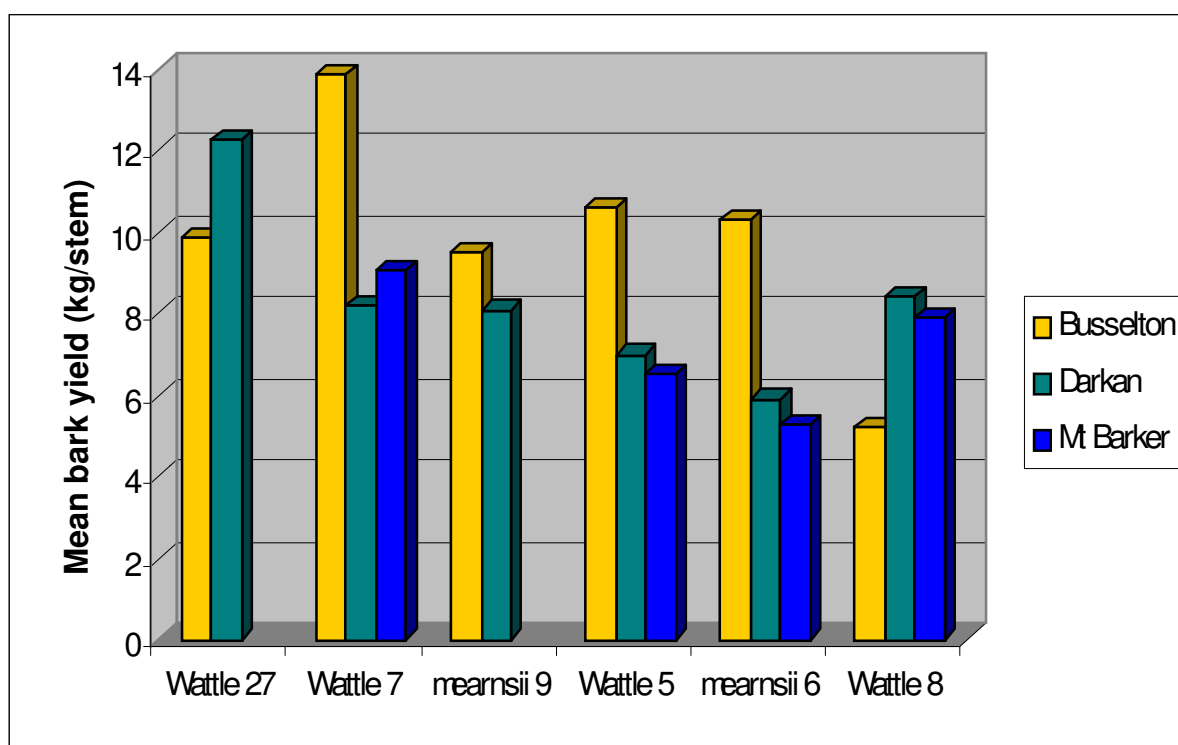


Figure 8: Comparison of bark yield between unimproved and improved *A. mearnsii* at 62 months of age across three sites in South - West Western Australia. The seedlots are ranked in the order from the greatest average bark yield to smallest

The height of the *A. mearnsii* seedlots ranged across the three sites from 9.5 m to 8.4 m; the mean breast height diameter ranged from 10.5 cm to 8.6 cm and the stem volume ranged from 29.7 dm³ to 17 dm³. Over these three measurements, the same seedlots, (numbers 27, 7 and 9) performed the best.

Table 11. The comparison between native seed sources of *A. mearnsii* and commercial seed sources which for clarity are termed Wattle. Rank is relative to all the other provenances of all the other species in the trial. Letters indicate statistically significant groupings, those numbers with the same letter are not significantly different.

Seed source	R A N K	Height (m)	R A N K	Dbh (cm)	R A N K	Mean stem Vol (dm ³)	R A N K	Mean bark thicknes s (mm)	R A N K	Mean Bark Yield (kg/stem)	R A N K	Volume/ ha MAI (m ³)	R A N K	Mean No. stems at 1.3m	R A N K	Mean % single stemme d trees	R A N K	Mean straight- ness	R A N K	Mean survival %
Darkan																				
Wattle 5	7	7.4a	8	8.2a	8	13.8a	8	6.3a	8	7.0a	3	5.2a	10	1.9a	5	31.6a	17	1.9a	1	92.3a
mearnsii 6	8	7.4a	10	7.5a	9	11.2a	14	5.7a	9	5.9a	2	5.2a	21	2.8a	9	10.8a	6	2.6a	3	75.0a
Wattle 7	6	7.4a	4	8.9a	5	16.3a	4	6.7a	4	8.2a	4	4.9a	8	1.8a	13	5.3a	25	1.36a	6	67.4a
Wattle 8	2	7.7a	7	8.6a	7	15.4a	3	6.8a	2	8.4a	1	5.2a	12	2.1a	15	0.0	16	2.0a	4	68.2a
mearnsii 9	3	7.6a	6	8.7a	4	16.6a	6	6.5a	5	8.1a	6	3.8a	4	1.6a	6	22.1a	13	2.1a	8	62.3a
Wattle 27	1	8.6a	1	10.6a	1	25.8a	1	7.7a	1	12.3a	7	3.6a	13	2.2a	10	9.2a	9	2.5a	20	32.2a
Mt Barker																				
Wattle 7	2	8.3a	1	9.5a	1	20.5a	1	6.5a	1	9.1a	5	5.2a	6	1.6a	21	1.1a	19	2.7a	17	86.2a
Wattle 5	3	8.2a	3	8.1a	6	14.5a	3	5.7a	5	6.5a	3	6.0a	10	1.8a	17	5.5a	21	2.6a	11	93.4a
Wattle 8	5	7.8a	5	9.0a	3	17.0a	2	6.4a	2	7.9a	4	5.4a	1	1.4a	7	25.2a	17	3.1a	7	95.6a
mearnsii 6	7	7.8a	9	7.6a	7	13.1a	14	5.0c	7	5.3b	7	5.2a	6	1.6a	14	12.9a	16	3.3a	13	90.8a
Busselton																				
Wattle 7	1	11.6a	1	10.6a	1	42.1a	1	5.4a	1	13.9a	1	10.2a	2	0.2a	14	56.7a	5	4.0a	15	90.4a
mearnsii 6	2	11.3a	2	9.9a	2	35.7a	5	4.3a	3	10.3a	2	9.5a	6	0.3a	9	67.5a	3	4.1a	7	95.6a
Wattle 27	4	10.3a	4	9.4a	4	29.8a	3	4.9a	4	9.9a	5	6.6a	1	0.1a	5	70.3a	8	4.0a	7	95.6a
Wattle 5	5	10.2a	3	9.6a	3	31.0a	2	5.1a	2	10.6a	3	8.2a	11	0.2a	3	77.8a	22	3.5a	7	95.6a
mearnsii 9	6	10.0a	6	8.9a	5	28.1a	4	4.7a	5	9.5a	4	7.4a	6	0.3a	6	69.6a	1	4.5a	3	98.9a
Wattle 8	9	9.6a	13	7.4a	13	17.6a	25	2.4a	13	5.2a	13	4.1a	2	0.2a	8	68.8a	21	3.6a	5	97.7a

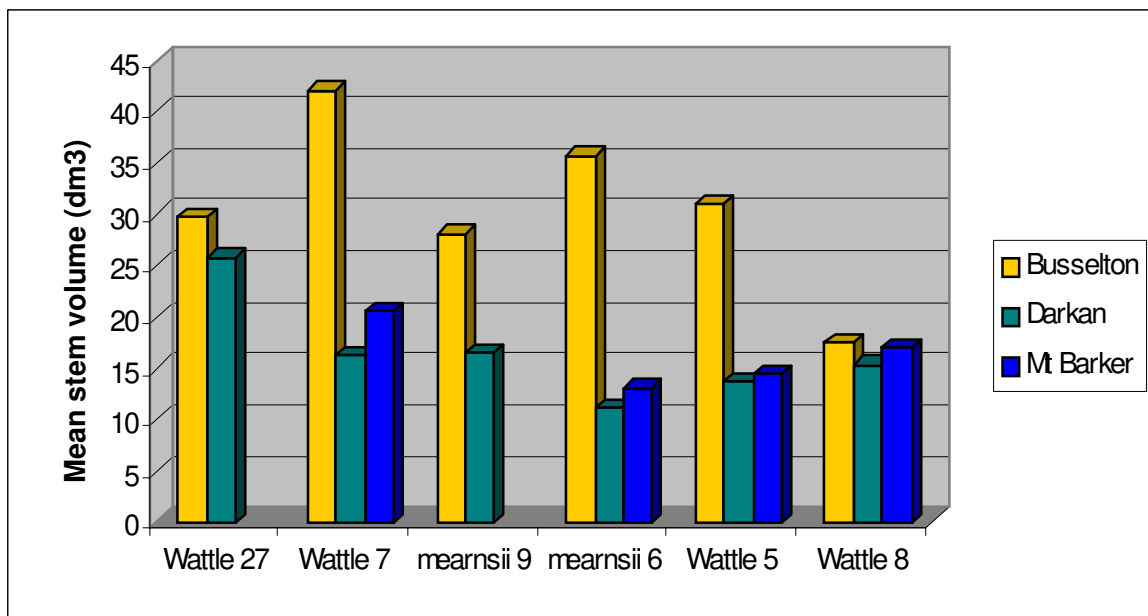


Figure 9: Comparing the stem volume (dm³) of native seedlots and commercial seedlots (termed Wattle) of *A. mearnsii* at the three sites. The seedlots are ranked in the order of greatest stem volume to the smallest.

When the survival is taken into account to calculate mean annual increment, seedlots 27 and 9 drop in the ranking due to their poor survival. Across the three sites, Wattle no. 27 had the poorest survival of the *A. mearnsii* seedlots and this may be related to its late sowing rather than its genetic performance. Until survival was included, Wattle no. 27, together with Wattle no. 7, were outstanding. Wattle 8 (a commercial *A. mearnsii* source) routinely performed poorly.

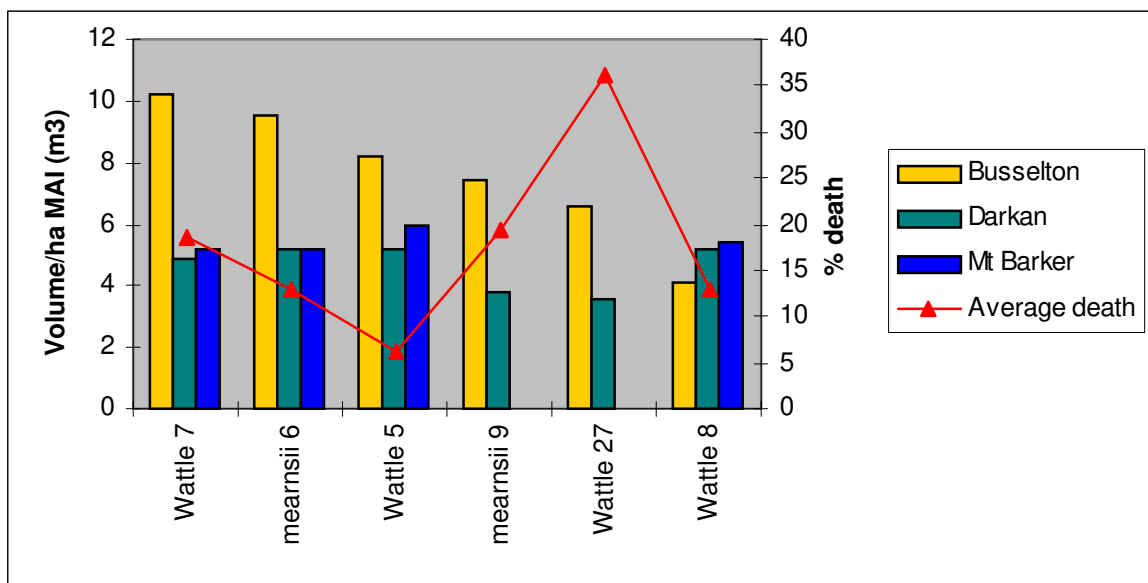


Figure 10. Comparison of wood volume/hectare (MAI) of native seedlots and commercial seedlots (termed Wattle) of *A. mearnsii* at the three sites. The seedlots are ranked in the order of greatest MAI to the smallest. Percentage death is indicated as a line.

Little is known of the source of the four South African seedlots but it is thought that Wattle no. 7 was collected from a seed orchard and Wattle no. 8 from routine commercial plantings. There is no history of the overseas origin of Wattle no. 5 or Wattle no. 27.

4.2.8 Comparison of provenance performance within species

Each species was represented by two provenances except for *A. fulva*, which was only represented by one. Testing multiple provenances of a species will provide an indication of the genetic diversity of the species, which is useful for two reasons. Firstly, it gives a thorough assessment of a species ability and potential. Secondly, it indicates the possible improvements a breeding program could offer. A two provenance sample will only provide indicative trends.

Provenance performance has been recorded at each site as depicted in the following tables (Table 12,13 and 14) and sorted according to the trial number allocated to each provenance. Investigations into correlations of height in successive years in ACIAR *A. mearnsii* provenance trials in China (Yulin et al., 1994) indicates that a significant correlation appears between the second and third years and persisted until the fifth year. This suggests that, by the age of 5 years, the ranking of the provenances will remain.

Based on wood volume production per stem, the top ten ranking provenances were identified (Table 15). Across all three sites, the best provenance for wood production was *A. mearnsii* (Tarpeena SA), although it was not represented at Mt Barker, followed by *A. decurrens* (SW of Goulburn NSW), *A. mearnsii* (Wattle circle VIC), *A. fulva* (Howes Valley NSW) and *A. decurrens* (Picton-Mittagong NSW). Thus the top species had both provenances, and *A. fulva*'s only provenance, ranked in the best five performing provenances.

Table 15: Ranking of the top ten provenances (excluding the commercial *A. mearnsii* seedlots) at each site based on mean stem volume (dm³) at 62 months of age. (Mt Barker has only 9 provenances listed as *A. mearnsii* (Tarpeena SA) was not included at that site.

Trial sites in south - West Western Australia			
Rank	Busselton	Mt Barker	Darkan
1	<i>A. mearnsii</i> (Wattle circle VIC)	<i>A. decurrens</i> (SW of Goulburn NSW)	<i>A. decurrens</i> (SW of Goulburn NSW)
2	<i>A. mearnsii</i> (Tarpeena SA)	<i>A. trachyphloia</i> (Currowan Ck NSW)	<i>A. decurrens</i> (Picton-Mittagong NSW)
3	<i>A. dealbata</i> (Errinundra Plateau VIC)	<i>A. decurrens</i> (Picton-Mittagong NSW)	<i>A. mearnsii</i> (Tarpeena SA)
4	<i>A. fulva</i> (Howes Valley NSW)	<i>A. fulva</i> (Howes Valley NSW)	<i>A. filicifolia</i> (Singleton NSW)
5	<i>A. filicifolia</i> (Singleton NSW)	<i>A. mearnsii</i> (Wattle circle VIC)	<i>A. mearnsii</i> (Wattle circle VIC)
6	<i>A. decurrens</i> (Picton-Mittagong NSW)	<i>A. filicifolia</i> (Yadboro flat NSW)	<i>A. filicifolia</i> (Yadboro flat NSW)
7	<i>A. decurrens</i> (SW of Goulburn NSW)	<i>A. irrorata</i> (Woodenbong NSW)	<i>A. silvestris</i> (Deua River NSW)
8	<i>A. trachyphloia</i> (Currowan Ck NSW)	<i>A. silvestris</i> (Deua River NSW)	<i>A. fulva</i> (Howes Valley NSW)
9	<i>A. filicifolia</i> (Yadboro flat NSW)	<i>A. dealbata</i> (Errinundra Plateau VIC)	<i>A. trachyphloia</i> (Monga NSW)
10	<i>A. irrorata</i> (Woodenbong NSW)		<i>A. dealbata</i> (Errinundra Plateau VIC)

Table 12: The bipinnate acacia species provenance data collected from Busselton W.A. at 62 months of age. Letters indicate statistically significant groupings, those numbers with the same letter are not significantly different.

Seed source	R a n k	Height (m)	R a n k	Dbh (cm)	R a n k	Mean stem Vol (dm ³)	R a n k	Mean Bark Thickness (mm)	R a n k	Mean Bark Yield (kg)	R a n k	Volume/ha MAI (m ³)	R a n k	Mean stems at 1.3m	R a n k	%single stems trees	R a n k	Mean straightness	R a n k	Mean Survival %
1	21	7.6defgh	22	5.1ghi	18	10.0defgh	19	3.0defg	22	2.3ef	22	1.8cde	6	0.3def	10	65.8ab	7	4.0abc	24	67.8ab
2	22	7.1efgh	19	5.8efghi	19	9.3defgh	20	2.9defg	19	3.1def	23	1.5de	11	0.4cdef	16	47.5ab	6	4.0abc	27	50.0b
3	10	9.5abcde	14	7.1abcdefgh	15	15.9abcdefg	15	3.7abcdefg	14	5.1bcde	6	5.9abcd	18	0.7bcdef	26	8.8ab	15	3.7abc	1	100a
4	18	7.9cdefgh	20	5.6efghi	21	9.0efgh	13	3.7abcdefg	18	3.3de	18	3.3abcd	21	1.0abcde	22	27.9ab	20	3.6abc	15	90.4ab
5	5	10.2abc	3	9.6ab	3	31.0ab	2	5.1a	2	10.6ab	3	8.2ab	11	0.4cdef	3	77.8ab	22	3.5abc	7	95.6ab
6	2	11.3ab	2	9.9ab	2	35.7ab	5	4.3abcd	3	10.3ab	2	9.5a	6	0.3def	9	67.5ab	3	4.1ab	7	95.6ab
7	1	11.6a	1	10.6a	1	42.1a	1	5.4a	1	13.9a	1	10.2a	2	0.2def	14	56.7ab	5	4.0ab	15	90.4ab
8	9	9.6abcd	13	7.4abcdefg	13	17.6abcdefg	25	2.4g	13	5.2bcde	13	4.1abcd	2	0.2def	8	68.8ab	21	3.6abc	5	97.7ab
9	6	10.0abcd	6	8.9abcd	5	28.1abc	4	4.7abc	5	9.5abc	4	7.4abc	6	0.3def	6	69.6ab	1	4.5a	3	98.9ab
10	14	9.0bcdef	9	8.2abcdef	10	20.9abcdef	6	4.1abcde	10	6.3abcde	12	4.4abcd	6	0.3def	1	89.8a	10	3.9abc	20	84.3ab
11	11	9.2abcdef	10	8.1abcdef	9	21.5abcdef	9	3.9abcdef	8	6.6abcde	7	5.9abcd	11	0.4cdef	12	64.6ab	14	3.8abc	7	95.6ab
12	15	8.9bcdef	5	9.0abcd	12	18.7abcdef	22	2.7defg	17	3.5cde	14	4.1abcd	6	0.3def	13	63.2ab	19	3.6abc	18	88.8ab
13	8	9.6abcd	8	8.3abcde	8	22.2abcde	10	3.7abcdefg	9	6.4abcde	11	4.7abcd	2	0.2ef	2	81.3ab	4	4.0ab	15	90.4ab
14	23	7.0efgh	18	6.0defghi	20	9.0efgh	24	2.6fg	20	2.4ef	19	2.7abcde	18	0.7bcdef	21	29.3ab	13	3.9abc	7	95.6ab
15	13	9.1abcdef	7	8.9abcd	6	24.9abcd	11	3.7abcdefg	6	8.2abcd	17	3.7abcd	11	0.4cdef	19	30.9ab	2	4.1ab	13	92.3ab
16	24	6.8fgh	24	4.7hi	24	5.3hi	12	3.7abcdefg	23	2.2ef	26	0.3e	24	1.4abc	17	40.9ab	16	3.7abc	23	73.0ab
17	26	5.5h	25	4.6i	25	2.7ij	18	3.2cdefg	25	0.8f	24	1.5de	21	1.0abcde	15	54.0ab	11	3.9abc	26	58.5ab
18	7	9.6abcd	15	7.0abcdefgh	14	16.3abcdefg	8	4.0abcdef	11	5.6abcde	9	5.3abcd	20	0.8bcdef	20	30.6ab	12	3.9abc	5	97.7ab
19	19	7.8cdefgh	23	4.8hi	23	6.5ghi	21	2.9defg	24	2.2ef	15	4.0abcd	26	1.8ab	25	10.3ab	25	3.3bc	3	98.9ab
20	17	8.1cdefg	17	6.3cdefghi	17	10.8cdefgh	14	3.7abcdefg	16	3.5cde	20	2.1bcde	11	0.4cdef	11	65.4ab	18	3.6abc	19	87.3ab
21	16	8.5cdef	16	6.8bcdefghi	16	14.1bcdefgh	7	4.0abcdef	15	5.0bcde	16	3.8abcd	24	1.4abc	18	35.8ab	23	3.5abc	21	76.0ab
22	12	9.2abcdef	12	7.6abcdefg	11	20.4abcdef	17	3.3bcdefg	12	5.5abcde	10	5.2abcd	17	0.5cdef	23	25.0ab	9	4.0abc	14	90.8ab
23	20	7.6defgh	21	5.4fghi	22	8.1fgh	23	2.7efg	21	2.3ef	21	2.0cde	23	1.1abcd	24	23.3ab	24	3.5abc	21	76.7ab
24	25	5.7gh	26	2.7j	26	1.2jk	26	1.5h	26	-0.1g	25	0.4e	27	2.2a	27	7.4b	27	2.8c	7	95.6ab
25	27	5.5h	27	2.1j	27	0.5k	27	1.2h	27	-0.4g	27	-0.8f	2	0.2ef	4	77.2ab	26	3.1bc	25	59.6ab
26	3	10.3abc	11	7.9abcdef	7	24.2abcde	16	3.6abcdefg	7	7.4abcd	8	5.5abcd	11	0.4cdef	7	69.1ab	17	3.7abc	2	100a
27	4	10.3abc	4	9.4abc	4	29.8ab	3	4.9ab	4	9.9ab	5	6.6abcd	1	0.1f	5	70.3ab	8	4.0abc	7	95.6ab

Table 13: The bipinnate acacia species provenance data collected at 62 months of age from Mt Barker W.A. Letters indicate statistically significant groupings, those numbers with the same letter are not significantly different.

Seed source	R a n k	Height (m)	R a n k	Dbh (cm)	R a n k	Mean stem Vol (dm ³)	R a n k	Mean Bark Thickness (mm)	R a n k	Mean Bark Yield (kg)	R a n k	Volume/ha MAI (m ³)	R a n k	Mean stems at 1.3m	R a n k	%single stems trees	R a n k	Mean straightness	R a n k	Mean Survival %
1	11	7.2bcdef	8	7.7abcd	11	11.5abcdefg	17	4.8defgh	10	4.7bcdefgh	6	4.6ab	14	1.0c	8	23.5ab	10	3.5abcd	7	93.4a
2	14	6.7defgh	23	5.9d	17	6.7efgh	21	4.3hi	22	2.9h	19	2.8ab	14	1.0c	11	23.0ab	2	3.9ab	14	90.8a
3	12	7.1bcdefg	15	6.5bcd	15	8.3cdefgh	19	4.4fghi	16	3.6efgh	8	4.5ab	16	1.2c	20	1.3ab	14	3.4abcde	3	98.9a
4	15	6.6defgh	21	5.9d	20	6.3fgh	10	5.0cdefg	17	3.4efgh	18	3.0ab	16	1.2c	22	1.1ab	24	2.3f	12	91.2a
5	3	8.2abc	5	8.0abcd	6	14.5abc	3	5.7bc	4	6.5abc	3	5.7a	10	0.8c	16	5.5ab	22	2.6def	10	93.4a
6	7	7.8abcd	11	7.5abcd	8	12.9abcd	13	5.0cdefgh	9	5.2bcdefg	9	4.3ab	5	0.6c	19	2.0ab	16	3.3abcdef	13	90.8a
7	2	8.3ab	1	9.5a	1	20.5a	1	6.5a	1	9.0a	4	5.3a	5	0.6c	21	1.1ab	20	2.7cdef	17	86.2a
8	5	7.8abcd	2	8.9ab	3	17.0ab	2	6.4ab	2	7.7ab	5	5.1a	1	0.4c	6	25.2ab	18	3.1bcdef	6	95.6a
10	6	7.8abcd	3	8.9ab	2	17.2ab	5	5.5cd	3	6.8abc	1	6.8a	13	0.9c	5	26.4ab	8	3.6abcd	5	95.6a
11	4	7.8abcd	4	8.6abc	5	16.2ab	15	4.9cdefgh	5	6.3abc	7	4.6ab	2	0.5c	10	23.3ab	1	4.3a	16	88.2a
12	8	7.8abcd	10	7.6abcd	9	12.3abcde	22	4.2hi	12	4.5cdefgh	2	6.3a	16	1.2c	15	7.1ab	12	3.4abcde	4	98.9a
13	10	7.5abcde	14	7.2abcd	13	10.6bcdefg	9	5.1cdef	11	4.5cdefgh	13	3.3ab	2	0.5c	2	42.0a	6	3.8abc	9	93.4a
14	17	6.2efghi	19	6.0d	19	6.4fgh	20	4.3ghi	21	2.9h	15	3.3ab	21	1.6bc	17	4.4ab	13	3.4abcde	11	91.2a
15	23	5.7hi	7	7.9abcd	12	11.1abcdefg	23	3.9i	20	3.1gh	23	2.4ab	5	0.6c	1	43.5a	4	3.8abc	21	76.7a
16	22	5.7hi	17	6.3cd	18	6.5efgh	7	5.2cde	15	3.6efgh	22	2.5ab	9	0.7c	7	23.7ab	7	3.6abcd	15	90.4a
17	21	5.8ghi	13	7.3abcd	14	9.3bcdefgh	4	5.6bcd	13	4.5cdefgh	17	3.1ab	10	0.8c	9	23.5ab	3	3.9ab	8	93.4a
18	13	6.9cdefgh	9	7.6abcd	10	11.9abcdef	8	5.2cde	8	5.5bcdef	11	3.6ab	19	1.5bc	24	0.0b	17	3.1bcdef	19	77.2a
19	16	6.5defghi	18	6.2cd	23	5.3h	14	4.9cdefgh	14	3.6defgh	10	3.9ab	23	3.2ab	23	0.0b	15	3.3abcdef	23	73.0a
20	19	6.0fghi	16	6.4cd	16	7.5defgh	16	4.9defgh	18	3.3fgh	20	2.8ab	10	0.8c	4	34.4ab	5	3.8abc	1	98.9a
21	20	5.9fghi	20	6.0d	22	6.0gh	11	5.0cdefgh	19	3.2gh	12	3.3ab	22	1.7bc	12	13.4ab	9	3.5abcd	2	98.9a
22	9	7.6abcd	6	8.0abcd	4	16.6ab	12	5.0cdefgh	6	6.1abcd	14	3.3ab	5	0.6c	14	7.7ab	23	2.4ef	18	78.4a
23	18	6.0fghi	22	5.9d	21	6.1gh	18	4.5efghi	23	2.7h	21	2.5ab	19	1.5bc	18	2.3ab	19	2.9bcdef	22	73.5a
24	24	5.2i	24	3.7e	24	2.1i	24	3.2j	24	1.0i	24	1.4b	24	4.2a	13	9.2ab	21	2.7def	24	67.8a
26	1	8.6a	12	7.4abcd	7	13.1abcd	6	5.4cd	7	5.8abcde	16	3.2ab	2	0.5c	3	39.0a	11	3.4abcde	20	77.2a

Table 14: The bipinnate acacia species provenance data collected at 62 months of age from Darkan W.A. Letters indicate statistically significant groupings, those numbers with the same letter are not significantly different.

Seed source	R a n k	Height (m)	R a n k	Dbh (cm)	R a n k	Mean stem Vol (dm ³)	R a n k	Mean Bark Thickness (mm)	R a n k	Mean Bark Yield (kg)	R a n k	Volume/ha MAI (m ³)	R a n k	Mean stems at 1.3m	R a n k	%single stems trees	R a n k	Mean straightness	R a n k	Mean Survival %
1	13	6.5abcde	12	7.3abcd	11	10.4abcd	15	5.5abc	12	5.0abcde	15	2.2abcde	12	2.2bc	7	20.3c	8	2.5a	16	44.3ab
2	18	6.0abcde	20	5.6abcd	21	5.0abcdef	19	5.2abc	22	2.8abcdef	24	0.7cdef	14	2.3bc	14	4.1c	20	1.8a	23	26.7ab
3	14	6.5abcde	19	6.0abcd	17	6.5abcdef	21	5.0abc	16	3.8abcdef	12	2.8abcd	24	3.5ab	21	0.0c	24	1.5a	13	50.0ab
4	27	4.2e	26	3.6de	26	1.4ef	25	4.0bcd	26	0.8ef	27	0.1f	1	1.0c	1	100a	1	4.0a	25	16.7b
5	8	7.4abcd	8	8.2abcd	8	13.8abc	8	6.3abc	8	7.0abcd	3	5.2a	9	1.9bc	5	31.6bc	17	1.9a	1	92.3a
6	6	7.6abc	10	7.5abcd	9	11.2abcd	14	5.7abc	9	5.9abcd	2	5.2a	21	2.8bc	9	10.8c	6	2.6a	3	75.0ab
7	2	7.9ab	4	8.9ab	5	16.3ab	4	6.7ab	4	8.2abc	4	4.9ab	7	1.7bc	13	5.3c	25	1.4a	6	67.4ab
8	3	7.7ab	7	8.6abc	7	15.4ab	3	6.8ab	2	8.4ab	1	5.2a	11	2.1bc	26	0.0c	16	2.0a	4	68.2ab
9	4	7.6abc	6	8.7abc	4	16.6ab	6	6.5abc	5	8.1abc	6	3.8abc	5	1.6bc	6	22.1c	13	2.1a	8	62.0ab
10	9	7.1abcde	2	10.0a	2	20.2ab	5	6.5abc	3	8.3ab	14	2.7abcd	3	1.5bc	8	16.4c	27	0.8a	15	44.3ab
11	5	7.6abc	5	8.9ab	3	16.7ab	12	5.9abc	7	7.1abcd	9	3.1abcd	14	2.3bc	19	0.0c	26	1.3a	18	38.0ab
12	11	6.8abcde	9	7.8abcd	10	10.8abcd	23	4.9abc	13	4.5abcdef	8	3.4abc	22	3.1ab	20	0.0c	23	1.6a	11	50.0ab
13	10	6.8abcde	3	9.2ab	6	15.5ab	2	7.2a	6	7.6abc	19	1.2abcdef	1	1.0c	2	90.8ab	4	2.8a	21	32.2ab
14	22	5.0bcde	14	7.1abcd	16	7.0abcdef	16	5.5abc	23	1.6bcdef	23	0.7cdef	5	1.6bc	22	0.0c	22	1.8a	22	27.4ab
15	19	5.9abcde	13	7.3abcd	14	8.7abcde	22	4.9abc	18	3.5abcdef	17	2.0abcdef	3	1.5bc	3	42.5bc	5	2.8a	5	67.8ab
16	23	4.9bcde	21	5.5abcd	22	4.6bcdef	13	5.8abc	21	2.9abcdef	18	1.8abcdef	14	2.3bc	12	6.7c	2	3.3a	9	58.5ab
17	24	4.5cde	23	5.3abcd	23	4.4bcdef	11	5.9abc	20	3.2abcdef	20	1.0bcdef	8	1.8bc	25	0.0c	18	1.9a	12	50.0ab
18	15	6.2abcde	22	5.5abcd	20	5.5abcdef	20	5.1abc	19	3.5abcdef	10	3.1abcd	26	4.0ab	16	0.0c	10	2.4a	7	62.0ab
19	26	4.4de	25	3.7cde	25	1.7def	24	4.5abc	24	1.5cdef	25	0.4def	27	6.3a	27	0.0c	15	2.0a	27	16.7b
20	16	6.2abcde	18	6.0abcd	18	6.4abcdef	17	5.4abc	17	3.7abcdef	13	2.8abcd	22	3.1ab	15	0.0c	7	2.5a	10	55.7ab
21	20	5.8abcde	17	6.3abcd	19	6.1abcdef	7	6.4abc	14	4.4abcdef	21	0.8cdef	17	2.4bc	11	6.7c	3	3.2a	24	21.8b
22	12	6.6abcde	16	6.4abcd	15	7.8abcde	18	5.3abc	15	4.0abcdef	5	4.0abc	19	2.7bc	23	0.0c	12	2.1a	2	83.3ab
23	17	6.1abcde	11	7.4abcd	13	9.6abcde	9	6.1abc	11	5.4abcde	16	2.1abcdef	19	2.7bc	24	0.0c	11	2.3a	17	38.7ab
24	21	5.3bcde	24	3.9bcde	24	2.3cdef	26	3.7cd	25	1.3def	22	0.8cdef	25	3.9ab	17	0.0c	21	1.8a	19	32.6ab
25	25	4.4de	27	2.2e	27	0.9f	27	2.6d	27	0.6f	26	0.1ef	18	2.6bc	18	0.0c	19	1.8a	26	16.7b
26	7	7.5abcd	15	7.0abcd	12	10.2abcd	10	6.0abc	10	5.7abcd	11	2.8abcd	10	2.0bc	4	33.3bc	14	2.0a	14	50.0ab
27	1	8.6a	1	10.6a	1	25.8a	1	7.7a	1	12.3a	7	3.6abc	12	2.2bc	10	9.2c	9	2.5a	20	32.2ab

A similar study of the rankings of the provenances comparing their mean bark yield per stem shows that the same provenances produce the greatest amount of bark as well as wood. The best provenances were *A. mearnsii* (Tarpeena SA), *A. decurrens* (SW Goulburn NSW), *A. decurrens* (Picton-Mittagong NSW), *A. mearnsii* (Wattle Circle VIC) and *A. fulva* (Howes Valley NSW).

4.3 Collection and analysis of the non-destructive bark samples

The non-destructive bark samples were collected before the Darkan trial was destructively harvested for the bulk bark and wood samples. The samples were collected from the Darkan trial between 30 and 31st October, the Mt Barker trial 3rd and 4th November and the Busselton trial 4th and 5th November 1997.

Moisture content of the bark

The moisture content of the bark was significantly different between the sites and between provenances. The moisture content bark from Mt Barker ranged from 57.8 to 40.3%, whereas at Busselton it ranged from 61.8 to 47.1% and Darkan from 59.4 to 46.8%.

In the literature, total solids is used more regularly than moisture content to discuss tannin suitability for adhesives, as it is the solid component that contains the polyflavanoids. The data was grouped so that each species made up of the two provenances (except *A. fulva*) and across the three sites was expressed as an average (Figure 11). Expressed this way *A. fulva*, *A. glaucocarpa*, *A. deanei*, *A. filicifolia* and *A. decurrens* have more total solids compared to the commercial wattle.

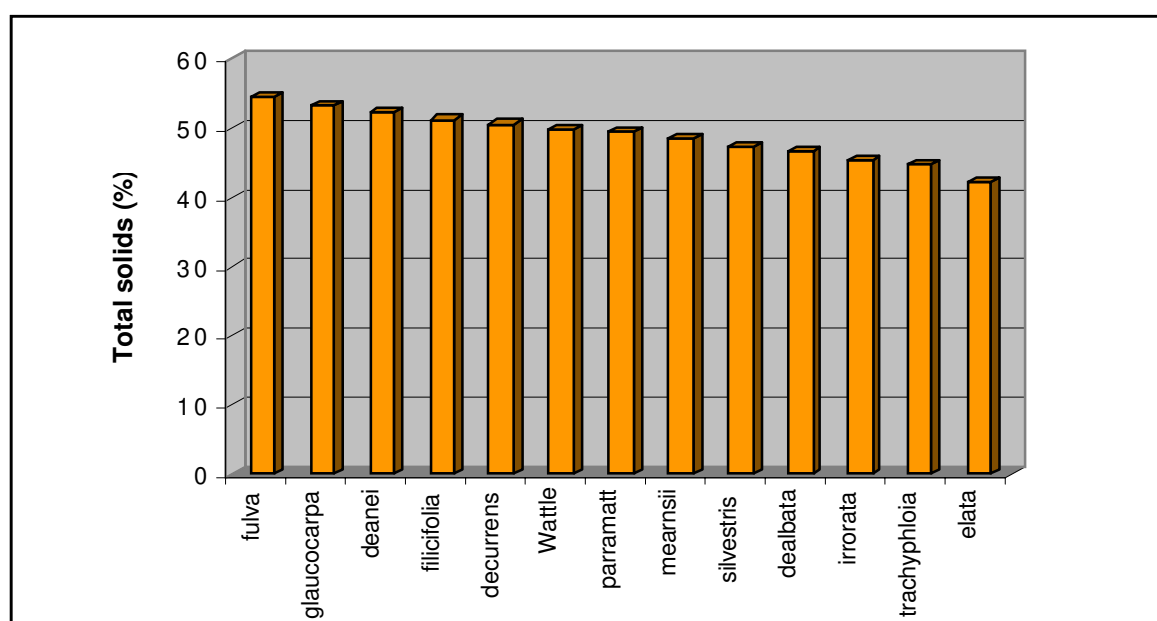


Figure 11. The total solids (%) extracted from the bark samples taken from three sites and from two provenances except in the case of the single provenance of *A. fulva*.

Hot water soluble extractives

Site had an effect on the percentage of hot water soluble extractives in the bark. The water soluble extractives found in the 12 species ranged from 63.1% to 37.0% at Mt Barker, 56.3% to 29.8% at Busselton and 85.8% to 67.9% at Darkan. The species with the most soluble extractives included *A. mearnsii*, *A. decurrens*, *A. filicifolia*, *A. irrorata* and *A. parramattensis*. *A. silvestris* from Bruthen Victoria also appeared to be above average. Provenances were significantly different within species (Figure 12).

The average across all trials and bipinnate acacia species was 46.7% (Table 15). This is a lower value than recorded for an *A. mearnsii* family trial (Jiyuan et al., 1992). The *A. mearnsii* across the three sites averaged 57.6% which was higher than the average of 54% found in *A. mearnsii* trials in China (Jiyuan et al., 1992) and higher than *A. mearnsii* bark samples collected in native stands (53%) in eastern Australia (Yazaki et al., 1990).

Stiasny value

The Stiasny test is used to estimate the amount of polyflavanoid components in tannin extracts which react with formaldehyde in adhesive formation (Yazaki et al., 1994). The Stiasny values varied between 94.4 to 67.9 % and the mean of the trials across the three sites was 83.3% (Table 15). The Stiasny value produced from each of the seedlots across the three sites was significantly different between sites and provenances within species, the former more so than the latter. The species with the highest Stiasny value included *A. mearnsii* (87.9%), *A. decurrens*, *A. filicifolia*, *A. irrorata* and *A. parramattensis* (Figure 12). The provenance of *A. silvestris* from Bruthen Victoria and the one provenance from *A. fulva* also performed above average.

Polyflavanoid content

Polyflavanoid content ranged from 53.2 to 24.3% across all three sites. In this case, there was no statistical difference between the sites. There was however a significant difference between the species (and provenances)(Table 15). The same species that showed high Stiasny values also had above average polyflavanoid contents. The overall average of all three sites and all the bipinnate species was 39% which is lower than measured for an *A. mearnsii* family trial in China (48.4%) The species that produced the most polyflavanoids was *A. mearnsii*, followed by *A. decurrens* and *A. filicifolia* (Figure 12).

Table 15. Tannin analysess of the non-destructive Acacia bark samples collected from trials at Mt Barker (A), Busselton (B) and Darkan (C) in W.A.

* samples missing

Acacia species	Provenance	Moisture content				Total Solids				% Hot water soluble extractives				Stiasny value				Polyflavanoid content			
		A	B	C	Avg.av g	A	B	C	Avg.	A	B	C	Avg.	A	B	C	Avg.	A	B	C	Avg.
A. dealbata	Captains Flat NSW	51.27	51.87	51.68	51.61	48.73	48.13	48.32	48.39	40.95	35.17	37.31	37.81	80.37	83.60	74.00	79.32	32.95	29.62	27.73	30.10
A. dealbata	Errinundera VIC	53.92	53.87	56.52	54.77	46.08	46.13	43.48	45.23	37.03	29.77	35.29	34.03	76.92	81.52	70.74	76.39	28.45	24.37	25.06	25.96
A. deanei	Dawson QLD	*	47.90	47.60	47.75	*	52.10	52.40	52.25	*	32.75	33.70	33.23	*	79.17	72.24	75.71	*	25.90	24.32	25.11
A. deanei	Goondiwindi NSW	44.12	49.20	48.53	47.28	55.88	50.80	51.47	52.72	45.70	36.90	38.58	40.39	67.97	83.35	74.05	75.12	31.10	30.60	28.68	30.13
A. decurrens	Picton-Mittagong NSW	45.15	51.27	51.48	49.30	54.85	48.73	48.52	50.70	57.03	47.83	55.69	53.52	81.53	92.13	83.84	85.83	46.65	44.20	46.78	45.88
A. decurrens	SW Goulburn	41.47	55.75	51.19	49.47	58.53	44.25	48.81	50.53	57.73	47.65	55.62	53.67	74.15	90.38	86.19	83.57	42.92	43.15	47.99	44.69
A.elata	Buxton-Hill Top NSW	57.80	60.15	59.47	59.14	42.20	39.85	40.53	40.86	49.75	45.40	43.55	46.23	78.67	90.70	81.54	83.64	39.23	41.25	35.54	38.67
A. elata	Mt Irvine NSW	52.60	61.80	53.84	56.08	47.40	38.20	46.16	43.92	46.60	39.95	40.73	42.43	76.70	86.25	83.07	82.01	35.75	34.45	33.96	34.72
A. filicifolia	SW Singleton NSW	41.10	51.45	46.81	46.45	58.90	48.55	53.19	53.55	59.35	47.20	51.37	52.64	85.85	90.00	88.69	88.18	50.90	42.25	45.59	46.25
A. filicifolia	Yadboro Flat NSW	47.60	53.40	52.27	51.09	52.40	46.60	47.73	48.91	48.65	49.60	48.56	48.94	76.20	88.10	82.51	82.27	37.05	43.97	40.14	40.39
A. fulva	Howes Valley NSW	40.67	47.17	48.41	45.42	59.33	52.83	51.59	54.58	51.50	43.60	43.37	46.16	81.92	93.92	90.21	88.68	42.22	40.37	39.08	40.56
A. glaucocarpa	Bains Gully QLD	40.32	47.82	47.17	45.10	59.68	52.18	52.83	54.90	40.07	32.83	41.89	38.26	76.13	92.55	86.28	84.99	30.55	30.37	36.19	32.37
A. glaucocarpa	Cadarga QLD	44.02	50.67	49.55	48.08	55.98	49.33	50.45	51.92	45.90	33.70	41.60	40.40	75.40	89.40	83.62	82.81	34.75	30.20	34.94	33.30
A. irrorata	Karuah-Newcastle NSW	53.27	55.77	56.57	55.20	46.73	44.23	43.43	44.80	50.25	47.52	45.38	47.72	77.72	94.35	83.49	85.19	39.02	44.90	37.95	40.62
A. irrorata	Woodenbong NSW	47.52	57.80	57.28	54.20	52.48	42.20	42.72	45.80	57.52	48.50	50.69	52.24	77.28	90.63	84.28	84.06	44.55	44.03	42.86	43.81
A. mearnsii	Tarpeena, SA	*	53.80	53.04	53.42	*	46.20	46.96	46.58	*	57.70	58.78	58.24	*	92.45	88.14	90.30	*	53.40	51.87	52.64
A. mearnsii	Wattle circle VIC	45.73	53.95	49.22	49.63	54.27	46.05	50.78	50.37	62.42	48.00	60.21	56.88	76.95	91.65	88.13	85.58	50.30	44.17	53.19	49.22
A. parramattensis	Tarago NSW	48.75	55.80	51.62	52.06	51.25	44.20	48.38	47.94	54.97	43.92	54.03	50.97	74.62	91.22	88.16	84.67	40.97	40.10	47.83	42.97
A. parramattensis	Numeralla NSW	43.30	51.35	51.76	48.80	56.70	48.65	48.24	51.20	52.92	43.20	47.05	47.72	76.40	92.67	82.99	84.02	40.62	40.10	39.06	39.93
A. silvestris	Bruthen VIC	44.95	54.25	54.47	51.22	55.05	45.75	45.53	48.78	52.40	45.90	48.90	49.07	75.47	91.38	83.09	83.31	39.55	41.92	40.86	40.78
A. silvestris	Deua river NSW	53.85	54.25	53.66	53.92	46.15	45.75	46.34	46.08	44.13	44.05	46.75	44.98	78.98	84.93	78.44	80.78	34.90	37.38	36.80	36.36
A. trachyphloia	Currowan Ck NSW	55.08	57.15	56.50	56.24	44.92	42.85	43.50	43.76	41.20	40.57	46.75	42.84	78.05	91.00	82.86	83.97	32.25	37.22	38.81	36.09
A. trachyphloia	Monga SF NSW	51.05	57.37	53.73	54.05	48.95	42.63	46.27	45.95	42.50	37.27	43.61	41.13	72.72	87.52	83.87	81.37	31.65	32.67	36.65	33.66
Wattle		44.50	54.70	51.34	50.18	55.50	45.30	48.66	49.82	63.15	56.32	56.84	58.77	77.87	92.13	92.03	87.34	49.25	51.93	52.29	51.16
Site average		47.42	53.68	52.23	51.11	52.58	46.32	47.77	48.89	50.14	43.14	46.93	46.74	76.89	89.20	83.02	83.04	38.87	38.68	39.34	38.96
+ SE		0.47	0.44	0.44	0.74	1.04	0.75	0.69	0.74	0.59	0.55	0.55	1.45	0.66	0.62	0.62	0.77	0.59	0.55	0.55	1.49

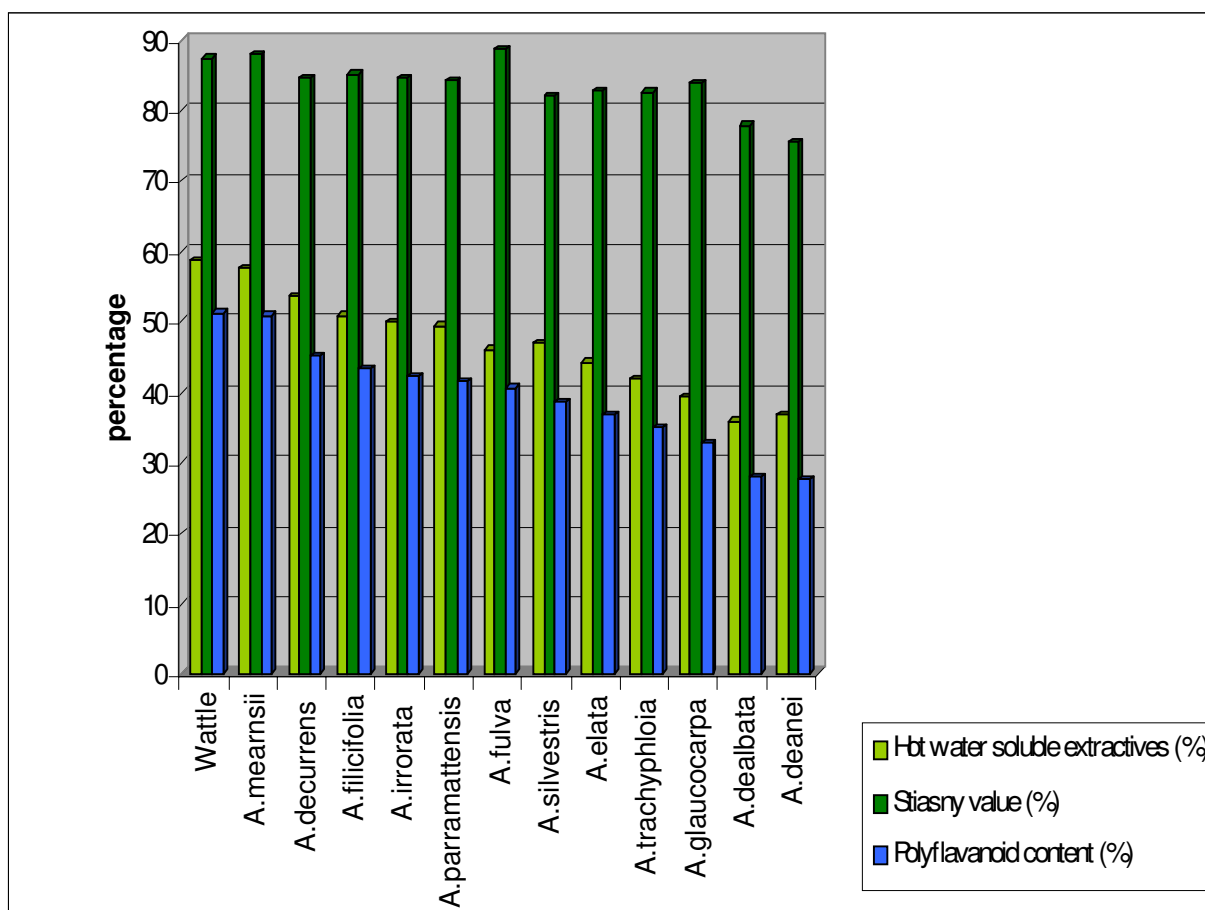


Figure 12. Summary of % hot water extractives, the Stiasny values and polyflavanoid contents of the bark of 12 bipinnate acacia species across three sites in South - West Western Australia. The species are ranked in order of their polyflavanoid content.

4.4 The collection of bulk bark samples and their analysis

The collection of the bulk bark samples required the felling of trees, hence destroying the on-going scientific value of the trial. The poor survival at Darkan made this trial the preferred choice. Only 10 of the 12 species could be collected, due to the poor survival and growth of *A. deanei* and *A. elata*.

4.4.1 The extraction of the whole tree bark samples

The first observation is that tannin yielded from bark by a bulk extraction method is much less than that extracted in the laboratory (Table 15 and Table 16). The percentage of hot water extractives from the disc samples was in the upper 40% range, whereas the percentage hot water extractives from the bulk sample was in the lower teens. The most extractive was produced from the same two species, *A. mearnsii* and *A. decurrens*, regardless of the extraction procedure. The bulk freeze-dried tannin extractives were then passed on for commercial analysis.

Table 16. The tannin extraction efficiency from bulked tree bark samples.

<i>Acacia</i> species	Provenance	Number of trees	Weight of milled bark (kg)	Weight of extract (kg)	% extract as received
<i>A. mearnsii</i>	Commercial	8	27.0	4.8	17.8
<i>A. decurrens</i>	Picton-Mittagong NSW	6	44.5	7.1	16.0
<i>A. trachyphloia</i>	Currowan Creek NSW	8	28.0	4.0	14.3
<i>A. filicifolia</i>	Yadboro flat NSW	7	29.3	3.4	11.6
<i>A. dealbata</i>	Errinundra Plateau VIC	12	21.0	2.4	11.4
<i>A. fulva</i>	Howes Valley NSW	8	41.2	4.6	11.2
<i>A. irrorata</i>	7 km E Woodenbong NSW	9	27.0	3.0	11.1
<i>A. silvestris</i>	Bruthen VIC	9	26.0	2.8	10.8
<i>A. parramattensis</i>	Numeralla NSW	10	38.0	4.0	10.5
<i>A. glaucocarpa</i>	Cadarga QLD	8	42.0	4.1	9.8

4.4.2 The analysis of the whole tree bark samples.

The reports on the analysis of each of the species for wood adhesive glues from Bunnings Timbchem and Dyno Industries are attached (Appendix 1 and Appendix 2)

4.5 The collection of the Acacia wood samples and their analysis

The physical wood properties of one provenance for each of 10 of the bipinnate acacia species were assessed. The two species omitted were *A. elata* and *A. deanei* as neither had sufficient bole for bark collection (Table 17).

The average moisture content of the wood varied from 32 % (*A. decurrens*) to 27% (*A. fulva*). The green volume equates to the average amount of wood harvested and was needed to calculate the air-dry density of the species. The air-dry density of the species ranged from 661 kg/m³ for *A. fulva*, down to 501 kg/m³ for *A. dealbata*. This air-dry density was determined from the average of wood discs taken from the base and at breast height from for each tree. The number of trees used for each sample is recorded in Table 17. The sample ranged from 6 to 12 trees.

Table 17 : The moisture content, green volume and air-dry density of 10 bipinnate *Acacia* species (each represented by one provenance) at 62 months at Darkan, Western Australia at age 5 years and 5 months.

<i>Acacia</i> species	Provenance	Number of trees	Average Moisture content (%)	Average Green volume (ml)	Average Air-dry density (kg/m ³)
<i>A. fulva</i>	Howes Valley NSW	8	27 + 2.8	377 + 109.4	661 + 23.1
<i>A. decurrens</i>	Picton-Mittagong NSW	6	32+2.9	772 + 180.9	641 + 32.2
<i>A. mearnsii</i>	Commercial	8	32 +4.4	479 + 136.8	622 + 52.4
<i>A. glaucocarpa</i>	Cadarga QLD	8	30 +2.6	418 + 134	618 + 37.7
<i>A. filicifolia</i>	Yadboro flat NSW	7	32 + 2.4	463 + 97.8	608 + 39.0
<i>A. parramattensis</i>	Umaralla NSW	10	31 +2.1	349 + 90.3	594 + 45.8
<i>A. irrorata</i>	7 km E Woodenbong NSW	9	31 + 2.2	291 + 129.8	564 + 61.8
<i>A. trachyphloia</i>	Currowan Creek NSW	8	35 +2.8	366 + 151.2	555 + 47.9
<i>A. silvestris</i>	Bruthen VIC	9	33 + 1.7	316 + 154.9	544 + 95.6
<i>A. dealbata</i>	Errinundra Plateau VIC	12	42 + 4.0	463 + 171.6	501+51.6

5. Discussion

The main focus of this research was to determine if *A. mearnsii* had potential as a commercial species in Western Australia. The *Acacia* genus is one of the better choices for land rehabilitation as they can contribute to the nutrition of ecosystems in which they grow by fixing N and making P more accessible to associated plants (Brown 1998). *A. mearnsii* is well known in the forest product industry as a source of vegetable tannins and wood fibre. Even though there was little commercially known about the other 11 species, they were included as a comparison with *A. mearnsii* and for future product investigations such as this one. Impediments to wider use have been lack of knowledge about genetic resources (interspecific and intraspecific variation), adaptability in cultivation to different climatic factors, optimum symbiotic rhizobia and threats posed by insects (Brown, 1998).

Site selection

From the trial assessment made during this project it has become evident that, of the three trials planted across the south-west of Western Australia, the superior site for the bipinnate acacias was at Busselton. This site differed from the others in having a greater rainfall (947 mm compared to 650 mm at Mt Barker and Darkan).

The lower limit of rainfall for *A. mearnsii*, as recommended by Shonau and Schultz (1984) based on their experience of site selection in South Africa, is 850 mm although the range planted in South Africa varies from 693 mm to 1608 mm. Note that no commercial plantings in South Africa are planted at the rainfall levels experienced at Darkan and Mt Barker. Other places in the world (including other countries in Africa) have *A. mearnsii* plantations planted at rainfalls between 536 mm to 2263 mm with the greatest proportion of plantations being in the 1600-1800 mm rainfall zone (Booth and Jovanovic, 1988). Whilst this is a far higher rainfall than occurs in Western Australia, the natural distribution of *A. mearnsii* in eastern Australia covers a rainfall distribution between 600 mm and 1200 mm (Booth and Javanovic, 1988). Breeding programmes in South Africa, Brazil and China will have favoured selections that perform in high rainfall climates and so the species has yet to prove itself at lower rainfall levels.

A key criteria, however, for site selection of tree crops, especially *Eucalyptus globulus* (Harper, pers.comm.) is annual evaporation. Whilst annual rainfall is a general indicator of moisture availability for tree growth, annual evaporation must also be taken into account especially with a winter rainfall climate. This parameter is difficult to obtain because only a small number of weather stations are measuring evaporation, however, there was a marked difference between Darkan and Mt Barker (1270 mm compared to 940 mm respectively) whilst their average annual rainfall was similar (650 mm). This appears to be a key parameter for determining where *A. mearnsii* can be successfully grown in south-west Western Australia where annual rainfall is less than 1000 mm per annum.

Additionally, south-west Western Australia is known for its extreme heat during the months of January and February. Within natural populations of *A. mearnsii*, mean maximum temperatures reach 28.6°C (Booth and Javanovic, 1988) whereas the mean maximum temperatures for the trial sites reached 26°C (Mt Barker), 29°C (Busselton) and 31°C (Darkan).

Thus taking the available climatic data from the trial sites and comparing it with *A. mearnsii* climatic averages summarised in Booth and Jovanovic (1988) *A. mearnsii* may be at its limit for commercial growth at the Darkan site.

Experience within CALM has shown that site selection is determined by a fusion of both climate and soils. A shortfall of this project was the lack of soil data and this should be gathered for a better interpretation of species performance.

Trial establishment

The establishment of these three bipinnate species trials was the first time that these species had been planted under plantation conditions in south-west Western Australia. Initial survival was 94.1% at Mt Barker, 81% at Busselton and a poor 49.6% at Darkan. Species survival is site specific and therefore only broad generalisations of the better species can be made. There were greater similarities of species performance between the Darkan and Mt Barker site compared to either of these sites with Busselton (Figure 3) and this may be related to available moisture. Overall the better species for survival were *A. mearnsii*, *A. fulva* and *A. trachyphloia*. With better silvicultural knowledge, it is felt that these survival percentages could have been improved, especially at Darkan.

It appears that world-wide there have been problems with raising bipinnate acacia seedlings (Brown, 1998; Nicholson, 1992; Bayley, 1995). In the raising of the seedlings for these trials, their response indicated that a nursery medium with a higher air-filled porosity and faster drainage should have been chosen. It became acutely obvious that the majority of the species did not favour the high water-holding capacity and low air-filled porosity of the media chosen (composted sawdust: sand: peat 60:30:10). Added to this, was the high nitrogen draw-down status of the composed sawdust component of the medium. As a result, the seedlings displayed leaf abortion, which was only overcome when watering was reduced and a liquid application of nitrogen applied. The latter treatment may have been avoided if, at the time, there had been a greater understanding of *Rhizobium* interactions and species-specific collections of the nitrogen-fixing bacteria available for nodulation. The feeding of an elemental nitrogen source can cause media toxicity problems as has shown to be the case in South Africa (Nicholson, 1992; Bayley pers. comm.). Recent research into understanding and providing the appropriate *Rhizobium* cultures (Abbot pers. comm., Burdon et al., 1998, Brockwell and Searle pers. comm.) will be an essential contribution to the domestication of the bipinnate acacia species.

Plantation establishment of *A. mearnsii* overseas has occurred in summer rainfall climates where a land preparation of a rip-line was sufficient for successful establishment. Therefore it was not fully appreciated that the bipinnate species do not tolerate water-logging and it is essential to mound sites where this may be a problem, for example at Darkan. Furthermore, this water-logging condition caused problems with weed control, especially at the Darkan site. From 1993 onwards, CALM has mounded all sites in the high rainfall areas and continue to experiment with different weed control procedures to achieve a totally weed-free environment for successful establishment.

At the planting of the trials, it was a concern that the seedlings had different levels of *Rhizobium* nodulation and this may have caused a bias in establishment success. This concern was further supported by an honours project completed at University of Western Australia which showed that the best surviving species, *A. mearnsii*, had superior nodulation compared to *A. elata*, a poor surviving species (O'Halloran 1998). Additionally research in China has shown that the best-performing strains of *Rhizobium* can increase seedling dry mass by 2.8 times (Lihua and Sucui, 1998).

Another factor to affect initial survival was insect grazing. On establishment of *A. mearnsii* in South Africa, a chemical treatment for the African wattle bagworm (*Cryptothoelea junodi*) is standard practice. For these trials established in Western Australia, no pre-treatment was done so that the insect pests could be observed. Severe damage was caused by the African Black Beetle (*Heteronychus arator*), which grazed at soil level causing partial to total ring-barking of the acacia stems. The damage became so severe at Darkan that the seedlings were sprayed with the insecticide, Chloropyrifos, one month after establishment. Many of the bipinnate acacias were able to recover but this often caused multiple stems and reduced the initial growth rate.

The trial seedlings were established at the standard *E. globulus* spacing of 4 x 2 metres (1250 stems per hectare). In South Africa, seedlings are planted at a spacing of 1.3 m x 3 m giving a density of 2,564 seedlings per hectare. After 12 months, the seedlings are assessed and thinned to 5 seedlings per 10 metres, and a final spacing of 1666 stems per hectare. The South African approach has many advantages in that it

provides competition so that the seedlings are forced upwards and straight and shed their side branches. Additionally the runts can be culled from the commercial stand giving a more even crop. *A. dealbata* has been shown to grow successfully up to 20,000 stems per hectare (Gonzalez–Rio, Celulosas de Asturias, S.A., Spain pers. comm.). This approach needs to be considered.

Thus, taking into account these lessons in establishment, it is felt that initial establishment survival could be greatly improved by:

- growing the seedlings in a well composted media with a high air-filled porosity and low nitrogen draw-down
- introducing effective *Rhizobia* into the nursery mix for good growth and survival
- ripping and mounding the site
- pre-treating for African Black Beetle if there is evidence of their presence in the area
- planting the seedlings at a higher density

Initial trial growth

In the first year of the trials, little above-ground growth was observed. It appeared that the seedlings were overcoming their transfer shock and perhaps establishing their root system. In the second year rapid shoot growth occurred at such a rate that at the Busselton site, one tree was measured to be over 7 meters tall. However, it was not long after these two-year height measurements that the presence of parrot damage was observed. The parrot that appeared to be doing the majority of the damage to the bipinnate acacias was the Port Lincoln Parrot (*Barnardius zonarius*). Two different behaviours were observed; either these parrots would settle on the tallest stems and ring-bark the stem or they would land on the ground and ring-bark stems at ground level. Either way, this damage did not necessarily kill the tree but destroyed any accurate assessment of form as multiple shoots resulted. The Darkan and Mt Barker sites were initially severely attacked but this lessened with the increasing growth of the surrounding plantations. It was felt that the Busselton site was protected by tall native bush on one side of the trial.

Although various sucking insects were observed grazing on the young shoots, their damage did not appear to be severe enough to reduce overall growth.

Wood production

The wood production focus of the study was to determine the potential of these species to produce fuelwood. It is well appreciated that wood of the bipinnate acacias can be used for other, more high value, products but the youthfulness of these trial trees hindered any meaningful study of these products. A number of reviews cover such studies (Balodis, 1991; 1992; Nicholson, 1991; Hillis, 1997).

A disc taken from a bipinnate acacia shows sapwood that is pale in color and heartwood that is darker, in some cases with reddish markings (Figure 2B). The growth rings are indistinct although tension wood can be present. Dominant stems in commercial plantations of *A. mearnsii* in South Africa on ten year rotations seldom exceed 23 cm in diameter (Hillis, 1997). Mean diameters in this study at 5.5 years reached 10 cm at the best site.

The trials give an estimate of wood available for product production. The highest producers were *A. mearnsii*, *A. decurrens* and *A. fulva*. At the lower rainfall sites *A. decurrens* was clearly the best species.

Whilst there are limitations with trying to compare the wood production figures from these trials with other productivity figures, these species can be compared with 6-year-old plantation *Eucalyptus globulus* in each area. In the Busselton area *E. globulus* produces on average 22.3 MAI (*A. mearnsii* 9.0 MAI), in the Darkan area 5.4 MAI (*A. decurrens* 4.4 MAI) and in the Mt Barker area, 9.3 MAI (*A. decurrens* 5.6 MAI) (Edwards, pers.comm.). Whilst this is an interesting comparison, it may not be justified when taking into account the former concerns on trial establishment and the low survival. Perhaps for these trials, a more realistic comparison would be wood production per tree.

Wood is sold in bone-dry units which is made up of both wood volume and density. The most notable aspect of the bipinnate acacias is their high basic density, even as young ages. A study in New Zealand showed that *A. mearnsii* averaged 550 kg/m³ for 7 year old logs whilst *A. dealbata* was only 380 kg/m³ (Shelbourne et al., 1997). All the reports describe *A. mearnsii* within the range of 530 to 598 kg/m³ (Sakata et al., 1959; Kingston and Risdon, 1961; Bolza and Keating, 1972; Hannah et al., 1977; Bootle, 1983; Logan, 1987). This is comparable to the basic densities measured for *E. globulus*, a eucalypt species known for its high density. A study in south-west Western Australia showed *E. globulus* to have an average wood density of 539 kg/m³ within a range of 406 to 661 kg/m³ from 829 disc samples collected from 219 *E. globulus* trees of varying ages (Inions, pers.comm.). Other *Eucalyptus* species have not been able to better *A. mearnsii* for wood density. The basic density of young *A. mearnsii* wood chips at 591 kg/m³, sampled from a large export chip pile at Richards Bay in South Africa, were compared with similar chips of *E. grandis* at 450 kg/m³ (Nicholson, 1991).

The wood analysis in this project only measured air-dry density as wood is only handled to air-dry density for fuel wood production. *A. fulva* and *A. decurrens* were shown to have a higher air-dried density (661 kg/m³ and 641 kg/m³ respectively) than *A. mearnsii* (622 kg/m³) (Table 18) whilst *A. dealbata* had the lowest air-dry density (501 kg/m³). This air-dry density of *A. mearnsii* is in agreement with various studies which have found the range between 550 to 750 kg/m³ (Sakata et al., 1959; Kingston and Risdon, 1961; Bolza and Keating, 1972; Hannah et al., 1977; Bootle, 1983; Logan, 1987).

Fuelwood potential

Wood density is a key factor in assessing a species for its fuelwood potential. Ryan et al., (1994) assessed the following parameters for identifying superior fuel wood species; drying the fuelwood, managing the trees for fuelwood production, nutritional considerations and control of wild fires. They concluded that *A. mearnsii* was one of the outstanding species. When comparing various species and genera for firewood in New Zealand (Miller and Young, 1989), *A. mearnsii* was wrongly assumed a too-low basic density (474 kg/m³) which invalidated some conclusions on ranking this species for wood heat content. *A. mearnsii* should rank with high-density, stringy-bark eucalypts for wood heat content and amongst the leaders on combined heat content and volume (Shelbourne, pers. comm.).

The observations in this study indicate that the top wood producing species, *A. decurrens*, *A. mearnsii* and *A. fulva* could be adapted to a successful, short rotation fuelwood industry. These species would need a site with rainfall near the 850 mm mark so that they could be planted at a high density (2000 stems or higher). With good fertilisation, there could be acceptable growth and wood density for a harvest between 5 to 6 years. The economics would depend on the distance to market and whether the stumps coppice. If sheep are controlled and the stumps were cut 1 meter above the ground, coppicing has a greater chance of occurring (Ryan et al., 1994) and thus reduce re-establishment costs. This short-rotation will reduce the chance of a seed crop developing.

Thus whilst the bipinnate acacias do not stand strongly in competition with *E. globulus* on wood production alone, they may be commercially viable if their bark tannin products are also included.

Bark production

Hillis (1997b) has produced an excellent review on *A. mearnsii* bark properties. As there is little written on the other species, this review will be used to provide an understanding of what was measured, harvested and extracted from the bark.

The mean bark thickness at breast height of *A. mearnsii* in this study was 6.8 mm at 5.5 years of age. Whilst the bark thickness of these young trees is expected to increase with age, bark thickness of mature trees is expected to be more than 1.3 cm at the base of the tree (Hillis, 1997b). It has been mooted that, as bark thickness varies irregularly around the circumference of the stem at any given level, thickness determinations should be taken as the mean of at least four sample points equally spaced around the stem

(Hillis, 1997b). Whilst this protocol was followed in this project, this results showed that, given the sample number, this was unnecessary and that a single point measurement would have sufficed. Of concern, however, is being aware that bark thickness tends to increase with decreasing stand density and this may explain the greater bark thickness measured at the low survival Darkan site compared to the two other sites.

High altitudes and low winter temperatures generally favour thicker bark compared to trees of same diameter and age grown at lower altitudes (Sherry, 1971). The sites chosen appear to favour bark production even though they are at low altitude. A 6 year old trial grown in a frost-susceptible area in Japan produced between 4.5 and 5.5 mm bark thickness which is generally less than measured in our trials. The overall bark yield per tree of *A. mearnsii* from the project trials at 5.5 years of age ranged from 6.9 – 10.9 kg whereas full rotation (11 years) plantation-grown trees in South Africa yield between 13.6 to 22.7 kg.

The bark is made up of a cork layer as protection and then various tissues of which phloem parenchyma cells contain the most tannin although deposits can also be found in the cortical parenchyma cells. Tannin rarely occurs in the sieve tubes and companion cells (Luckoff, 1943). An indicator used for when the bark is ready to harvest is small white flecks about 2 cm in diameter (Sherry 1971). These were never observed in this project.

Tannin production

Tannin chemistry is a complex subject that has been well covered in reviews by Hillis (1997a) and Yazaki and Collins (1997).

The components of the tannin that are important to the formaldehyde reaction belong to “condensed tannin” which consists of flavanoid units (mainly flavan-3-ols) that have been condensed to varying degrees (Yazaki and Collins, 1997). The fundamental reaction for wattle tannin adhesives is when the flavanoid units react with formaldehyde to produce insoluble polymers.

This project asked two main questions; firstly if tannin production in the bark was at an acceptable level and secondly, if these flavanoids that were distinct to *A. mearnsii* were also present, or similar flavanoids present, in the other bipinnate acacia species to allow the adhesive reaction to occur. The latter question was answered in an indirect manner so that the commercialisation of the tannin extraction system could also be assessed.

The first study looked at the differences in tannin production (moisture content, total solids, hot water soluble extractives (“tannins”), Stiasny value and polyflavanoid content) across site and between species and provenances.

The overall tannin levels measured in this project were higher than those measured elsewhere. The hot water extractives from a study of *A. mearnsii* across Australia yielded levels between 40 and 70% with an average of 55.3% (Yazaki et al., 1990). In this project *A. mearnsii* levels were recorded at 58.8 and 60.2 % for each of the provenances. However the amount of polyflavanoids measured was lower with the native Australian average being 54.9% for *A. mearnsii*, whereas the trials gave 51.8 and 53.2 %.

Of note was that both the Stiasny value and the polyflavanoid content had statistically significant differences between the species (provenance). The Stiasny test was developed to determine the amount and nature of the phenolic components present in the extract. The test, standardised by Zheng and Yazaki (1987), quantifies the yield of polyphenol-formaldehyde precipitate which is formed from the reaction of polyphenols with formaldehyde. This suggests that overall polyphenol concentration is not effected by site, but the active components for the polyphenol-formaldehyde reaction are. Bark of trees growing at the higher rainfall site had the highest Stiasny value.

The efficacy of the vegetable tannins in adhesive production

Two reports from the commercial partners, Bunnings Timbachem and Dyno Industries have been attached.

The first company, Bunnings Timbachem, concluded that that whilst the adhesives from each of the species was very thick, they all performed well when compared to similar adhesive manufacture from commercially available wattle tannin.

The second company, Dyno Industries, concluded that due to the shortage of the samples, it was not possible to perform any optimisation of the different tannins. Five of the ten tannin samples were selected to be used in the manufacture of particle boards, *A. mearnsii*, *A. dealbata*, *A. silvestris*, *A. glaucocarpa* and *A. parramattensis*. The other five tannin sample showed too high viscosity at 45 and 50% solids. Even though the board manufactured with the five selected tannins showed detrimental results, *A. dealbata* (sample 109) and *A. silvestris* (sample 110) were shown to be the most appropriated tannins for further development work. The low properties results of the boards manufactured could be mainly due to the glue mix application system.

It is thus clear that, if the viscosity problem were resolved, each of the species has the potential to be used as a vegetable tannin source.

Effect of tree breeding on A. mearnsii

The breeding of *A. mearnsii* has been carried out in South Africa at the Institute of Commercial Forestry (formerly the Wattle Research Institute) since 1946. Raymond (1987) and Li (1997) have reviewed the work published in annual reports. The program has focussed on reducing gummosis disease and increasing bark yield. Trials have demonstrated an improvement in bark thickness and tannin content together with some improvement in bole straightness. Nixon (1977) reported that open pollinated seed orchard gains from the best 12 progenies at two sites, were 2% for breast height stem diameter, 8% for height, 2% for bark thickness, 5% for tannin content, 34% for gummosis and 20% for stem straightness. The little gain in growth rate may be due to the positive correlation between diameter growth and gummosis, and the overriding importance of gummosis as a trait affecting bark yield.

Whilst the breeding research in South Africa is apparently much further advanced than anywhere else in the world, other breeding programs are developing. The ACIAR-sponsored collaboration between CSIRO Forestry and Forest Products, Canberra and the Chinese Academy of Forestry, established a breeding program in China based on a 177 open pollinated families from 19 provenances from 1997 (Raymond, 1988; 1997). The breeding program to support a 200 000 ha plantation program in Brazil was only started in 1984 (Higa and Resende, 1994).

The source of the four plantation *A. mearnsii* material (wattle) is unknown, although it is suspected that seedlot 7 is from South Africa seed orchard material and seedlot 8 from routine plantation material. The results from these trials show that seedlot 7 is superior to seedlot 8 for both wood volume and mean bark yield (Figures 8, 9, 10). Significant is the greater difference between these seedlots on the wettest site, Busselton, which would have greater similarity to South African conditions. Thus these trials indicate that material bred in a similar environments can demonstrate superior performance in Australia.

6. Implications

Environmental strategists and the plantation forestry industry are continually searching for potential deep-rooted woody species that can be used on farmland for land rehabilitation whilst at the same time produce a viable return to the land-owner. If the challenge were confined to just revegetating the landscape with deep-rooted perennials, the task would be complete. The challenge lies in the development of a tree crop that can produce a viable return and often within the life of a landowner. This challenge becomes more difficult when the plantations stretch into the low rainfall areas with lower productivity rates. One of the solutions (as has been adopted by the Oil Mallee project) has been to look for multi-product trees. The bipinnate acacias are favourable candidates for this approach with a variety of commercial products already being made from different parts of the tree. The bole of timber is being used for dissolving pulp; the bark extractives are being used to make adhesives and the remainder of the limbs are being chopped up for firewood or made into charcoal. Additionally, the nitrogen-fixing ability of the symbiotic *Rhizobium* relationship in the roots favours the species for the leached soils of the south-west.

The commercial species that have been successful to date in south-west Western Australia, *Eucalyptus globulus*, *Pinus radiata* and *Pinus pinaster*, have been recognised as plantation species and grown and developed in other parts of the world besides Australia. Thus the raw products from these species are familiar to a wide audience that reaches beyond Australia's borders and this is a great advantage when marketing these species either for forestry projects or for the sale of their product. *Acacia mearnsii* is one of the Australian native species, like *E. globulus*, that has been developed outside of Australia as a plantation species. It is grown commercially in South Africa, Brazil and China and thus is well known in the market place.

Of the three trials that were used in this project, two were placed on low *E. globulus* productivity sites, that is below 800 mm rainfall. In hind sight these trials should have been linked to a comparative plot of *E. globulus* as this species in its low productivity areas is the main competition to the establishment of a bipinnate acacia plantation program. With the lack of an *E. globulus* comparison, only the species included within these trials can be compared against each other.

Whereas the bark and wood production figures give a good comparison between the bipinnate acacia species, these figures can not be taken to be an indication of growth performance of the species. Firstly these trials were the first "plantation-style" plantings of these species in Western Australia and they had to be accommodated in the *E. globulus*-system which did not necessarily optimise bipinnate acacia seedling production or field survival and growth. Secondly, the design of the trials (replicated 20 tree blocks in a 4 row by 5 column design) only gave an internal plot of 6 trees. The vast difference between the species allowed only the internal plot to be assessed and therefore did not give an insight to a mass planting effect. Thus the purpose of these trials was to rank the 12 species against each other for their performance in overall wood production and fuelwood capacity, and bark production and tannin production for adhesive manufacture. Further trials will be needed to investigate the identified best species in large area plantation establishment and observe their genetic diversity.

The project clearly indicates that three bipinnate acacia species of value in south-west of Western Australia for tannin production for adhesives are *A. mearnsii*, *A. decurrens* and a little known species, *A. fulva*. Adhesives made from the tannin of these species have acceptable performance. The same three species would make excellent short-rotation fuelwood species based on their growth rate and wood density. Based on their ranking at the three sites, it appeared that *A. mearnsii* and *A. fulva* performed better with higher rainfall whereas *A. decurrens* would be of greater use on the drier sites.

With greater understanding of the breeding development of *A. mearnsii*, it is apparent that none of the present world-wide breeding programs select to survive in a lower rainfall environment. This was further demonstrated with the commercial *A. mearnsii* seedlots attained. Whereas much experience has been

gained for provenance selection for *E. globulus* drought-tolerance, the same level of understanding has not been reached with these bipinnate acacia species. It thus leads to the question as to whether, through provenance plantings at these sites, especially *A. decurrens*, survival and growth may improve to easily compete with *E. globulus*.

7. Recommendations

This project identified three bipinnate acacia species that have potential in south-west Western Australia, *A. mearnsii*, *A. fulva* and *A. decurrens*. To develop these species further, three areas of research need further attention.

Firstly these three species need to be tested in a series of larger plantings across a variety of sites (with complete soil classification and climatic monitoring), ideally 2 to 5 hectares in size. This type of planting would be able to give a better indication of their impact on land rehabilitation and the impact of the style of planting on growth performance of the species. Of special interest would be the water usage control of the species as the canopy develops both for environmental and productivity reasons.

Secondly, these large plantings of a single age could also be used for product development. As acacia species were not popular candidates for arboretum, there is little mature resource of a known age that can be used for product development. A case in point was when Westfi offered to run a medium density fibreboard trial of *Acacia mearnsii* through its plant and the study could not proceed due to the lack of a representable resource (approximately 10 years in age) in the tonnage required.

Thirdly, each of the species needs to be investigated for its genetic diversity and these trials could also act as gene conservation plantings. These three species each have a gene conservation concern. *A. fulva* has a limited distribution in New South Wales that was threatened in the 1997 fires whilst *A. mearnsii* and *A. decurrens* are distributed through the most populated areas of Australia. The trials assessed for this project were limited to only two provenances to represent each species. To plant a complete provenance trial of each species would capture the genetic diversity. Within CALM, however, family/provenance trials are planted in preference, even though they are more expensive, as these trials then have a dual purpose of exploring the genetic diversity whilst laying the foundation of a breeding program if the need arises.

Family trials (with approximately 100 families) have been planted of *A. mearnsii* in Western Australia next to two of the species trials at Darkan and Mt Barker. Due to the lack of funding neither has been measured to date. With most breeding programs (South Africa and Brazil) concentrating on the selection of *A. mearnsii* in the high rainfall areas, these trials may lay the foundation of the first low rainfall *A. mearnsii* breeding program.

8. Appendices

Appendix 1. Report from Bunnings TimbaChem R&D Department

Introduction

This work is part of a RIRDC project to ascertain the efficacy of tannin extracted from the bark of plantation bipinnate acacias as a raw material for tannin adhesive manufacture.

Dried samples of warm water extract of the bark were supplied to Bunnings Timbachem for adhesive manufacture and testing as wood glue.

The efficacy was determined by comparison with an adhesive of known performance based on commercial Mimosa Tannin (from the Black Wattle *A. mearnsii*).

Method

Tannin (3.6 kg) was added to 3.4 kg of water in a 10 litre reactor. After stirring to disperse the tannin, resorcinol (1.8 kg) was added and stirred.

When a homogenous slurry was evident, 37% W/W formaldehyde solution (600 mls) was added and allowed to mix.

Caustic soda solution (500 mls of 45 % W/W) was added.

The mixture was heated to 70°C and this temperature maintained for 60 minutes.

The product was cooled and transferred into airtight drums.

A sample was retained for viscosity and gel time determination.

Viscosity was determined at 25°C on a Brookfield viscometer.

Gel time was determined at 100°C with paraformaldehyde powder.

A mixture was made consisting of 100 parts by weight of tannin adhesive, 10 parts by weight of 96% paraformaldehyde powder and 10 parts by weight of ground, dry macadamia nut shell, flour (150µm top size).

This adhesive mixture was applied at a rate of 0.25 kg/m² to both faces of freshly machined dry pine timber lamina (70 x 35 mm). The timber was clamped at 800 kPa in a hot box; set at 45°C and left overnight.

After cooling and removal from the press, the glued sections were sampled and tested for shear at the glue line according to AS1328.

Results and Discussion

A summary of the results is shown in Table 1.

Table 1: Results of Adhesive Manufacture and Testing

Bipinnate acacia species	Viscosity (PaS ⁻¹)	Gel Time (sec)	Dry Shear Strength (Mpa)	Dry Wood Fibre Failure (%)	Wet Wood Fibre Failure (%)
<i>A. mearnsii</i>	2600	20	8.9	80	45
<i>A. decurrens</i>	2500	21	11.9	80	80
<i>A. filicifolia</i>	2800	20	10.4	90	85
<i>A. fulva</i>	3000	20	8.9	85	95
<i>A. glaucocarpa</i>	2400	21	10.9	95	90
<i>A. parramattensis</i>	2500	19	9.6	85	75
<i>A. dealbata</i>	Insufficient sample				
<i>A. irrorata</i>	2500	21	7.8	80	45
<i>A. trachyphloia</i>	2600	21	10.7	80	80
<i>A. silvestris</i>	Insufficient sample				
<i>A. elata</i>	Insufficient sample				
<i>A. deanii</i>	Insufficient sample				
Mimosa Tannin	620	23	10	90	70

The plantation adhesives were very thick. This is possibly due to large molecular weight fractions. It was noticed that viscosity increased markedly on storage at 25°C. This would be a severe disadvantage for commercial use.

All adhesives gave acceptable gluing performance and exhibited good wet strength. They all conform to Class A bonds.

Conclusion

Tannin from the bark of plantation bipinnate acacias was used to make adhesives using formaldehyde and resorcinol reinforcement. Although very thick, this adhesive performed well when compared with a similar adhesive manufacture from commercially available Mimosa tannin.

Acknowledgements

The contribution of A. Hudson, G. Chandler and P. Preston is acknowledged for their help in manufacture, fabrication and testing.

John S. Fletcher CChem
R&D and Timbachem Manager
2nd November 1998

Appendix 2. Report from Dyno Industries (W.A.) Pty Ltd.

Tannin resin

Objective

To conduct a feasibility study on tannin utilisation as a wood-based panel adhesive a series of 10 tannin samples from different species of bipinnate acacia trees were received from Conservation and Land Management and the Chemistry Centre (WA) in Western Australia through Dyno Industries Pty. Ltd.

Summary

Due to the shortage of the samples, it was not possible to perform any optimisation of the different tannins. Five of the ten tannin samples were selected to be used in the manufacture of particle boards, *A.mearnsii*, *A.dealbata*, *A.silvestris*, *A.glaucocarpa* and *A.parramattensis*. The other five tannin sample showed too high viscosity at 45 and 50% solids. Even though the board manufactured with the five selected tannins showed detrimental results, *A.dealbata* (sample 109) and *A.silvestris* (sample 110) were shown to be the most appropriated tannins for further development work. The low properties results of the boards manufactured could be mainly due to the glue mix application system.

Experimental

Tannin solutions

According to the instructions received a 50 % (w/w) tannin solution should be prepared and then the pH of the solution should be adjusted to ca. 7.6 which is assumed to be the optimum pH for the control tannin. Small amounts of 50 % (or 45 %) tannin solutions were prepared from the different acacia species. Some of these tannin solutions have too high viscosity (Table 1).

Table 1. Initial pH and viscosity of the different tannin solutions.

tannin type (50 % solution)	PH	Viscosity (sec.) (25°C, Din Cup 4)	tannin type (50 % solution)	pH	Viscosity (sec.) (25°C Din Cup 4)
Tannin control	5.90	39 (180)**	A. filicifolia 116 *	5.24	186
A.mearnsii 112	5.14	103	A.trachyphloia 106 *	5.04	303
A.dealbata 109	5.0	57 (270)	A.decurrrens 122	3.23	340
A.silvestris 110	4.79	53 (250)	A.irrorata 114	5.70	340
A.glaucocarpa 12A	5.09	209	A.fulva 118		extremely high
A.parramattensis 120	5.25	155 (672)			

* 43 % tannin solution. ** Viscosity in mPa-s at 25°C.

In order to find out the amount of NaOH needed to adjust the pH to 7.6 the buffering capacity of these solutions was determined (Table 2 and Figure 1).

Table 2. Amount of NaOH (10%) needed adjust pH to 7.6.

Tannin type	ml NaOH (10%)	Tannin type	ml NaOH (10%)
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(50 % solution)		(50 % solution)	
Control tannin	4.70	A.filicifolia 116 *	5,00
A.mearnsii 112	10.00	A.trachyphloia 106*	-.**
A.dealbata 108	9.80	A.decurrens 122	-
A.silvestris 110	8.50	A.irrorata 114	-
A.glaucocarpa 124	10.00	A.fulva 119	-
A.parramattensis 120	8.10		

* 45 46 tannin solution. ** no performed.

After adjusting pH of the tannin solution to 7.6, a glue mix was prepared using 84% tannin and 16% UPC 80 as recommended. All solutions prepared showed a very high viscosity or gel at room temperature. The results of adjusting the pH to 7.6 was detrimental for the glue mix properties. When glue mixes, tannin-UPC 80 (16%), were prepared without adjusting pH of the tannin solution, i.e., using the initial pH, the viscosity of the glue mixes decreased, but not enough to be handled.

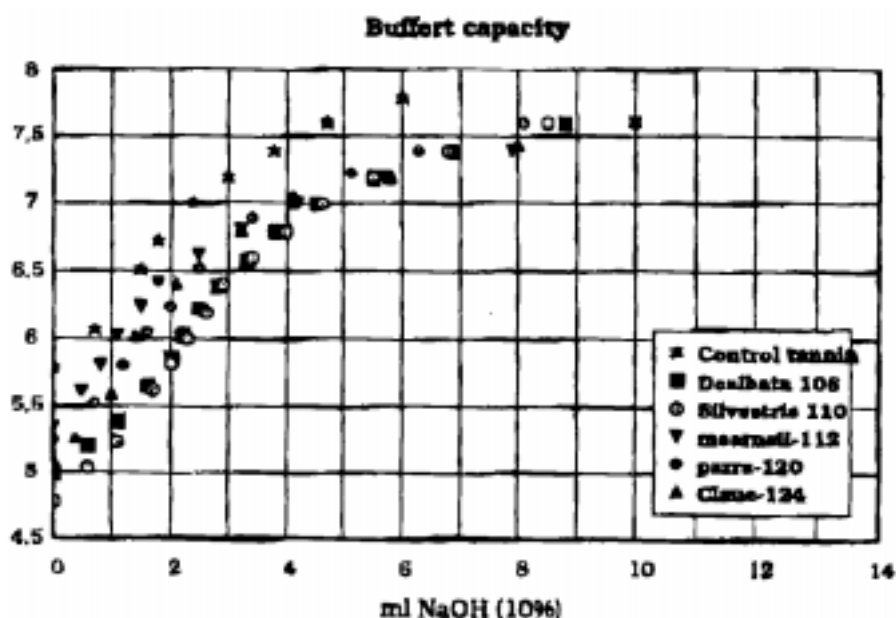


Figure1 : Buffer capacity of the tannin solutions evaluated. The amount of tannin solution (50%) used was 117.6 g.

Tannin-UFC 80 solutions

As time and the amount of samples left were running out, it was decided to reduced the amount of UFC 80 to 4% and manufacture particle boards knowing that the properties of the glue mix were not optimised. However, the initial viscosity of 50 % tannin solutions was already high. In order to spray the different tannin-UFC solutions on the wood chips, a much lower solids content was needed than that used when tannin control-UFC 80 was applied.

Table 3. Properties of the tannin – UFC 80 solutions used.

Tannin solution	pH of neat	% Solids	viscosity	Gel time
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4 % UFC 80	tannin solution	(%)	(mPa-s; 25°C)	(min)
A.dealbata	5.00 .	45,33	265	8
A.silvestris	4.79	46,86	235	7
A.mearnsii	5.34	45,15	280	25
A.glaucocarpa	5.09	43.78	330	7
A.parramattensis *	5.25	43.78	360	-**
Control tannin (16% UFC)	7.6	48.90	270	3

* The amount of UFC 80 was reduced to 2 % due to fast viscosity development otherwise. ** Not determined.

The *A.parramattensis* - UFC 80 (2%) solution did not gel, which can be a result of too low amount of UFC 80, and this is discussed in a later part of this report.

Our glue mix application system is not appropriated to handled such a high viscosity, and the application time of the tannin-UFC 80 solution was long, longer than the usual time needed when using standard UF-resin systems.

Particleboard properties

One layer 350 x 550 x 14 mm particle board was manufactured on laboratory scale with woodchips with a 2 % moisture content. The woodchips came from Kvarn, Norway. The target panel density was 690 kg/m³ and two panels were made for each tannin type. The application rate was 10.6% (calculated as solids weight over oven dry wood weight). Tannin and UFC 80 were blended just prior resination. The formed material was pressed at 185° C for 4 minutes and 40 seconds, that is 20 seconds/mm. This length of time was chosen due to the low solids contents of the tannin-UFC 80 mixes (Table 3). The boards were cut and enough samples of 50 X 5 mm were conditioned according to European standards. Internal bond strength and 24 hour thickness swelling were evaluated according to EN 319 and EN 317.

Table 4. Panel properties

Tannin	Mat moisture Content (%)	Board density (kg/m ³)	Internal bond strength (N/mm ²)	2-h thickness swelling (%)	24-h thickness swelling (%)
Control*	10.34	685	0.78	32.5	38
A.dealbata	11.3	669	0,2	130	**
A.silvestris	11.7	649	0,38	83	**
A.mearnsii	11.4	Delaminated	?	-	**
A.glaucocarpa	9.5**	633	0,21	117	?
A.parramatensis	12.2	Delaminated		?	?

The panel made with control tannin had 16% UFC80 based on solids weight.

** The application was about one hour, which lead to drying the chips.

The detrimental results obtained are mainly due to the poor application of the tannin solution. However, there is a difference between the control tannin and the other types of tannins. The high swelling of the sample shown by the control tannin confirmed the inadequate resination conditions of the tannin solutions.

Gel time and pot life of tannin-UFC 80 solutions

Figure 2 compares the gel times of different tannin-UFC 80 solutions and different amount of UFC 80. The gel time was characterised with a Techne Gelation Timer accurate to 0.5 minutes. A 10 ml tannin-UFCw 80 solution sample was placed in a 17 mm wide test tube, which was in turn placed in boiling water bath. Gelation was considered to occur when the resistance of the resin to a metal plunger moving through it was sufficient to trip the timer.

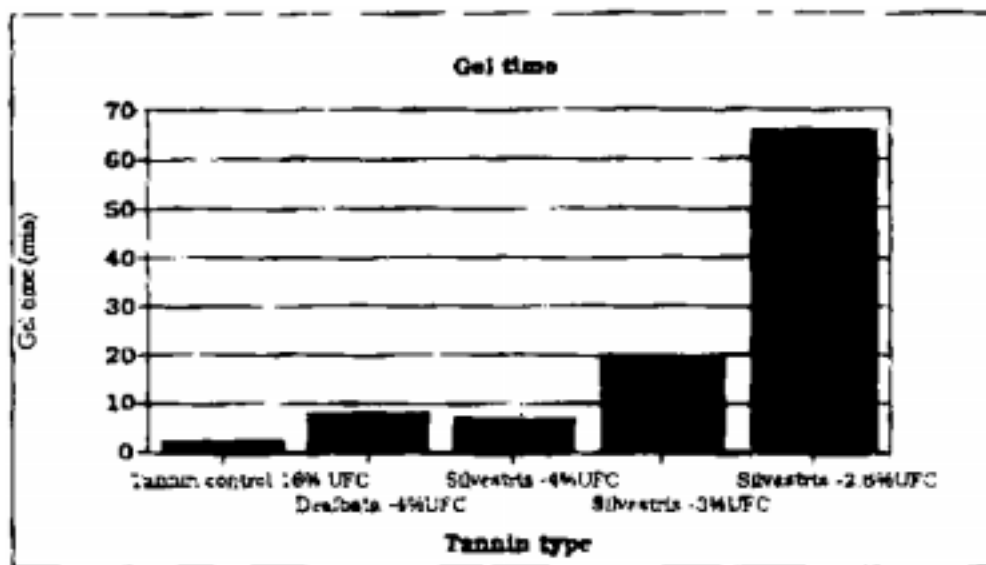


Fig. 2 Effect of UFC 80 on the get time of tannin-UFC 80 solutions at 100°C. The amount of solid is the same as shown in table 3.

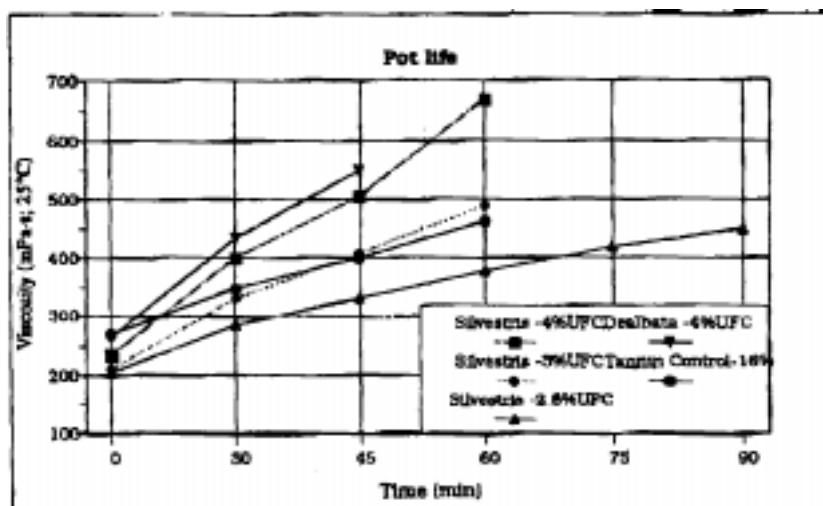


Fig. 3 The pot life of different tannin - UFC 80 solutions at 25°C. The % solids are the same as in table 3.

The tannins evaluated showed a high reactivity at the initial pH, when compared to the control tannin, which showed the lowest gel time after adjusting pH to 7.6.

The tannin types that could be evaluated further are *A.dealbata* and *A.silvestris* which showed similar behavior to the control tannin when gel time and pot life were evaluated. The reduction of UFC 80 from 4 to 3% gave a pot life for *A.silvestris* similar to that obtained with the control tannin, regardless of the higher gel time. It needs to be appreciated that the solids were lower than the control tannin. Furthermore, the choice of UFC 80 could be not the adequate for these tannins .

Conclusions

Due to the small amount of the samples recieved and not being able to optimise the application system for these tannin types we were not able to evaluate, in a competent way, the potential of the different tannins. However, with some change in the pH of tannin solutions, as in the case of *A.dealbata* and *A.silvestris*, and with the use of another type of formaldehyde source, we could expect much better results than those presented in this report.

Appendix 3. Pictures taken during the development of the trial.



A



B

Figure 12: A: The Busselton site at 4.5 years of age showing the deep mounding. B: John Bartle and Liz Barbour inspecting the problems with establishment at the Darkan site with the rip line.



A



B

Figure 13: A: Inspecting the Mt Barker site after one years growth. Note the ripping and mounding land preparation and the heavy grass cover. B. The wounding from parrot-damage on the bipinnate acacia stem.

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