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Black Wattle and its Utilisation

Abridged English Edition

**Edited for for the
Rural Industries Research & Development Corporation
by
AG Brown and Ho Chin Ko**

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"Black Wattle and its Utilisation - Abridged English Edition"

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Cover photograph: *Neville Gray stripping bark from Acacia mearnsii (black wattle) in Mt Cole Forest near Elmhurst. Neville sells the bark to Greenhalgh's Tannery, a family-owned business which has been located at Haddon, west of Ballarat, Victoria since the 1890s. This is the last tannery in Australia to use black wattle bark to tan hides.*

First published in Chinese in 1991, edited by Ho Chin Ko and A G Brown
This Abridged English edition, also edited by Ho Chin Ko and A G Brown, published in November 1997

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FOREWORD

Black wattle is a fast growing and adaptable tree indigenous to Australia. Different parts of the tree are put to many uses - from high quality extract used in tanning and adhesives to fuel, railway sleepers, mine timber, tool handles and as raw material for charcoal, particle board and wood pulp.

Also, the species is friendly to soil and water conservation and has been played an important role in the economic development of some countries.

In 1984 a joint research project on black wattle was established between the Chinese Academy of Forestry (CAF) and the Australian Center for International Agricultural Research (ACIAR) to accelerate development of black wattle plantations in China.

This abridged edition presents, for the first time, the central material in English. The contributions prepared originally in English have been reproduced in full, while those prepared originally in Chinese are represented by extensive abstracts.

The report presents important information on the black wattle including its natural distribution in Australia, its ecology and preferred environment, soils and the details of the features that make it such as special tree.

Peter Core

Managing Director

Rural Industries Research and Development Corporation

Preface to 1997 Abridged English Edition

This edition has been prepared to make available in English the central material published in the 1991 Chinese edition. The contributions prepared originally in English have been reproduced in full, while those prepared originally in Chinese are represented by extensive abstracts. Professor Ho Chin Ko organised the translation of this material, and he and his colleagues undertook the actual translation.

The sequence of this edition follows that used in the original edition, but some of the original chapters have been sub-divided in this edition into two or more chapters to permit easier attribution of contributions to their authors.

Since the original contributions were prepared in the late 1980s, additional information has become available in a number of areas. We have made no attempt to update the text to incorporate these developments. One important complementary reference is 'Australian Tree Species Research in China', the proceedings of an international workshop held from 2 to 5 November 1992 in Zhangzhou, Fujian Province, PRC, ACIAR Proceedings No. 48, 1994. Other information will be available in the proceedings of a workshop organised by ACIAR, CSIRO and the Forest Science Institute of Vietnam, and which is to be held from 26 to 29 October 1997 in Hanoi. Other references can be found by using tools such as the CD-ROM TREE-CD.

The preparation of the English edition has been greatly assisted by a grant from the Agroforestry Program of the Australian Rural Industries Research and Development Corporation, Land and Water Resources Research and Development Corporation and the Forest and Wood Products Research and Development Corporation which enabled us to engage Peter Martensz for the word processing and layout.

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Preface to 1991 Chinese Edition

Black wattle (*Acacia mearnsii* De Wild.) is a multi-purpose, fast growing and adaptable tree indigenous to Australia. The bark is used to produce high quality tannin extract, widely used in tanning and adhesives. The hard and dense wood can be used not only as fuel, railway sleepers, mine timber and tool handles, but also as raw material for charcoal, particle board and wood pulp. In addition the species has many favourable features for soil and water conservation, soil improvement, dune stabilisation and decoration. As a result it has been introduced into many parts of the world during the past hundred years and has played an important role in the economic development of some countries.

In 1984 a joint research project on black wattle (ACIAR Project 8458) was established between the Chinese Academy of Forestry (CAF) and the Australian Center for International Agricultural Research (ACIAR) to accelerate development of black wattle plantations in China. Studies included provenance trials at a number of locations, floral biology and tree breeding as well as utilisation. The preparation and publication of this book was later included as a part of the project.

The introduction of black wattle into China commenced in the fifties. The species grows well in many parts of southern China. Social and ecological problems in this region may be solved by establishing large-scale plantations and taking full advantage of their benefits. The plantations are able to increase the supply of fuelwood in the countryside; provide quality raw material for tannin extract; create new resources for the production of particle board, pulp and adhesives; and assist soil conservation. More and more attention is therefore being given to the development of black wattle plantations in southern provinces by government and the people. If this development is to proceed rapidly and be successful, specific knowledge and technical expertise are essential and appropriate organisational and managerial arrangements are needed.

The aim of preparing the Chinese edition of this book was to collect and review available scientific information relating to black wattle in the world, and experience in China, in order to speed up future progress. While the book entitled 'The Black Wattle' by S.P. Sherry of South Africa, published in 1971, is a splendid and comprehensive reference, extensive new research findings and technical developments concerning black wattle have appeared during the last twenty years. It is hoped that this book will serve to update and complement Sherry's work. Although some basic facts are necessarily repeated, this publication concentrates on recent developments in certain important areas. In view of the economic potential of the species, utilisation aspects have received particular attention.

While this book reports many recent research results, some important questions remain to be answered. In recognition of these needs and opportunities, a new 3-year research project involving ACIAR, CSIRO and CAF commenced on 1 July 1989. This project will support pulping studies in Australia and China as well as continuing work on adhesives, floral biology, tree breeding and frost tolerance.

The publication of this book is the result of a collective effort of more than twenty experts in various disciplines from Australia, Brazil, China and Japan. Among the writers are prominent scholars with international reputations as well as skilled younger scientists. All have made every effort to ensure that the book is of a high standard. Most manuscripts written in English were translated into Chinese by corresponding Chinese experts to ensure accuracy. Many other Chinese and Australian scientists have assisted the writers and editors through constructive critical review of manuscripts.

Although there is some repetition (e.g. of protection, utilisation) in chapters on plantations of different countries written by different authors, we have left these accounts as they stand for the sake of completeness of the individual contributions.

As editors we thank ACIAR for its approval and financial assistance to publish this book. The project has been strongly supported by the Coordinator of the ACIAR Forestry Program, Dr J.W. Turnbull, and senior staff in the CSIRO Division of Forestry and Forest Products. We also wish to thank the directors of CAF and its Research Institute of Chemical Processing and Utilisation of Forest Products (RICPUFP) for their encouragement and approval of the expenditure, personnel and facilities needed to prepare the book. Furthermore, the generous support of authors by their respective organizations is appreciated. We are grateful to the authors and translators for their valuable contributions and generous cooperation in the midst of pressing commitments to other activities and to Professors Sun Dawang, Li Chuandao, Zheng Hanye, Lin Jie, Yuan Siling, Zhang Qinghua and Mr Liu Shijun for constructive comments and suggestions on the parts they reviewed. We also wish to record our

indebtedness to Mr Cai Zhiquan and Ms Yan Wenying, both senior engineers of RICPUFP, for their diligence and great help in editorial work and to Wu Peiying, Tan Hongmei and other colleagues for their typing and copying services.

Ho Chin Ko
A.G. Brown

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Ho Chin Ko is now a research professor who graduated from the former National Central University (China) and worked on wood chemistry as a research student in the Division of Forest Products, CSIRO, Australia at an early stage. Since 1951, he has conducted research on chemistry of forest products in the Peoples Republic of China and served as departmental head and Director of the Research Institute of Chemical Processing and Utilisation of Forest Products, Chinese Academy of Forestry. He was elected as Fellow of the International Academy of Wood Science in 1984 and appointed as member of the International Council of IUFRO in 1986. He has been Chairman of the Chinese Society of Chemistry and Chemical Engineering of Forest Products since 1984.

Alan Brown is a graduate of the University of Sydney and the Australian Forestry School, Canberra. He undertook research on breeding radiata pine and lectured in silviculture before taking up roles in research management. He is now Chief of the Division of Forestry of Australia's Commonwealth Scientific and Industrial Research Organisation in Canberra. Since 1986 he has served on the IUFRO Executive Board as a Member from the Western pacific Region.

Chapter 1

***Acacia mearnsii* De Wild. (Black Wattle) in Australia**

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Abstract

Acacia mearnsii De Wild. (black wattle) bark is one of the world's highest yielding sources of condensed tannin. This species occurs naturally only in Australia. The following account briefly describes the species in its country of origin; its geographic and environmental distribution, ecological associations including pests and diseases, some biological characteristics, and past and present utilisation in Australia. Problems in distinguishing between black wattle and other bipinnate acacias frequently arise, and species descriptions and a key are provided to help overcome these difficulties.

Introduction

Acacia mearnsii De Wild. is one of the world's highest yielding sources of condensed tannins (Sherry 1971), and it has been vigorously exploited as such in Australia. The once extensive natural stands of this species were stripped of their bark and destroyed without replacement. Plantations were established in an effort to meet the large domestic demand for tannin but these failed. Black wattle is no longer commercially exploited in Australia and thus there has been little incentive in that country to conduct research to understand the species or increase its productivity.

The following account briefly describes general characteristics of *A. mearnsii* in Australia with emphasis on aspects believed to be of particular relevance to its establishment in China.

The natural distribution

Geographic distribution

Acacia mearnsii is endemic to Australia. Its natural distribution is restricted to south-eastern Australia where it occurs in New South Wales (NSW), the Australian Capital Territory (ACT), Victoria (Vic) and South Australia (SA) on the mainland, and on the island of Tasmania (Tas). Although its distribution has been significantly diminished over the last 200 years of European settlement, records place its most northerly occurrence west of Sydney NSW (33° 43'S 150°24'E Bullaburra), most easterly at Port Jackson NSW (33°51'S 151°16'E), its most southerly, south of Hobart Tas. (42°58'S 147°20'E Browns R. N.N.E. Kingston) and most westerly, north-west of Mt Gambier SA (37°42'S 140°27'E Tantanoola). A map of this distribution is presented in Fig. 1.1.

The species occurs across an altitudinal range of approximately 1050 m, from several coastal locations just above sea level in New South Wales, Victoria and Tasmania, to 1070 m above sea level on Mt Gladstone (36°15'S, 149°05'E) west of Cooma on the Monaro Tableland in New South Wales.

Habitats

A. mearnsii is not strictly limited to any habitat or aspect of the landscape. It occurs across hills, gullies, valleys and plains. Within any population, however, the largest and often the best formed trees are found in situations where there is increased soil moisture availability; along creeks and rivers on deeper alluvial soils and on eastern and southern aspects of hills, and lower slopes of tablelands and ranges.

Ecology

Within eucalypt forests and woodlands of south-eastern Australia, *A. mearnsii* is typically an understorey species. The size and density of these natural stands are variable, as are the factors which interplay to create them. Most significant of these is that the species is a short lived (15-20 years) pioneer that requires soil or other disturbance to regenerate. Like most acacias, it has a hard seed coat that is impervious to water. Germination depends on breakdown of the seed coat, usually over a period of years, and consequently germination is spread over a long period. Heat treatment destroys the impermeability of the seed coat. After a fire there may be a mass germination of seed. Severe fires will kill all but the largest trees but promote rapid regeneration of the next (Pedley 1978).

Thus after fire or land clearing, rapid and profuse germination of seed often occurs to produce dense, even-aged stands. The size of the stand is determined by the extent of the disturbance and the availability of viable seed. The seed can remain viable in the soil for more than 37 years (Maiden 1891). The density of these stands decreases with time as competition for the site increases and environmental hazards of drought, grazing and insect and fungal attack take their toll. The stand continues to decline in vigour and density until regenerated by further site disturbance.

Changes to the natural distribution

The natural distribution of *A. mearnsii* coincided with areas of Australia's earliest European settlement (which began in 1788) and now densest population. Thus it is not surprising that in the last 200 years its distribution has been much reduced as settlers

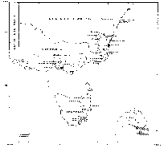


Fig. 1.1 The natural distribution of *Acacia mearnsii* as indicated by collection locations of herbarium specimens and seed.

exploited the species and cleared land for timber, mining, agriculture, urban and industrial development.

Many populations referred to in earlier publications or represented by botanical specimens have been greatly diminished, such as those in the vicinity of Portland Victoria. As a result, the remaining stands are generally small and scattered. The most extensive stands of this species, along the Tambo River in Victoria, for example, exist in areas too difficult and unproductive to clear for alternative use or to protect from fire. In Australia today, *A. mearnsii* is not a commercial species. Any utilisation of the natural populations occurs on a small, local scale. In Tasmania, for example, it is used by local wood turners, and trout fishermen destroy black wattle trees in search of moth larvae for bait.

In New South Wales trees are occasionally stripped for individual tanning needs and branches are used for mulch (Graham 1989).

Although some populations are protected as part of the environment in national parks, state forests and reserves, and along roadsides, the viability of the many stands which exist on private property is subject to the wishes and management of the landholders.

Not only are natural populations of *A. mearnsii* decreasing, they are becoming more difficult to identify. The planting of local native species is being increasingly practiced and promoted by State and local authorities and organisations. *A. mearnsii* is one of hundreds of tree species being provided by nurseries in New South Wales, the Australian Capital Territory, Victoria and Tasmania for roadside, farm, amenity and ornamental plantings. It is recommended for its fast growth, frost tolerance, ability to withstand extended dry periods and adaption to a wide range of soils. Establishing the origins of these plantings is difficult. Some organisations do attempt to replace vegetation with seedlings raised from locally collected seed or to keep records of seed origin if seed was

obtained from elsewhere. Obviously the mixing of provenances in plantings alters the genetic integrity of local stands.

The tree is also being planted alongside other bipinnate acacias, e.g. *A. decurrens*, with which it can hybridise (Moffet 1965 a,b) if flowering is synchronous. Any hybridisation detracts from the quality of seed collected in the field.

The environment

Climate

Within the dry continent of Australia (68% of its area receives less than 500 mm/annum) *A. mearnsii* occurs in the cooler, moister south-east. Most of its distribution is in the warm subhumid climatic zone, extending in places to the warm humid zone. At the highest altitude on the mainland and in parts of Tasmania, it occurs in the cool subhumid and humid zones. Rainfall varies from a well-defined winter maximum in Tasmania through seasonally uniform to a weak summer maximum in the most northern parts of the species occurrence (Turnbull 1986). Spring droughts on the New South Wales coast and summer droughts in western Victoria are not infrequent (Boland et al. 1984).

Booth and Jovanovic (1988) estimated mean annual precipitation to be between 450-1600 mm with mean precipitation for the driest month ranging between 15 - 75 mm across the distribution of *A. mearnsii*. Annual mean temperatures range between 10-17°C with maximum temperatures of the hottest month averaging 21-29°C. The species is rarely found in areas where the temperature exceeds 38°C. The minimum temperatures of the coldest month range from -3 to 7°C (Booth and Jovanovic 1988). In the most frost-susceptible area of its distribution, around Cooma on the Monaro Tableland NSW, 80 frosts per year occur on average and -12°C is the record low (Hall et al. 1981).

However, in predicting where *A. mearnsii* plantings may be limited by frost damage, absolute temperature alone is an insufficient criterion. With this and any other species the length of time low temperature persists and the suddenness of onset of freezing conditions must also be taken into account (Pryor 1988).

Soils and parent materials

A. mearnsii is not restricted to a particular soil type although predictably its best height growth and form appear to occur on the deeper, moister soils in any given landscape. It grows on a wide range of acid to neutral soils (pH 4.5-7.0) which can be broadly described as sands, loams and podzols. These are derived from alluvial deposits; sedimentary

mudstones, sandstones and conglomerates; metamorphic shales, slates and schists; and igneous granites, dolerites and basalts (Boland et al. 1984). Fertility is usually correlated with texture. The loams and clay loams are much more fertile than the sandy soils.

Due to their parent materials and prolonged weathering, many Australian soils are extremely low in nutrients, particularly phosphorus and nitrogen. It is this low availability which appears to have induced a general tolerance of infertile soils by most Australian plants. In contrast to the generally low availability of nutrients, there is wide variation between soil types in water-holding capacity which is strongly affected by the physical properties of the soil, such as texture, structure and depth to impermeable layers. Thus moderately deep sandy or earthy soils, with higher infiltration rates and good storage of readily available water, usually support better tree growth than those soils with a heavy impermeable clay layer at or near the surface (Boland et al. 1984).

Vegetation types

As a pioneer species, the status of *A. mearnsii* in plant communities alters with time. Following disturbance, seedlings and saplings can dominate a site, but without further disturbance taller and longer-lived eucalypt species will supplant them. Thus *A. mearnsii* is found in pure even-aged and uneven-aged stands which dominate a site, and as an understorey species in eucalypt-dominated tall open forests, open forests and open woodlands. Associated dominant tree species include *E. viminalis*, *E. globulus*, *E. saligna*, *E. ovata*, *E. radiata*, *E. smithii* and *E. cypellocarpa*.

Association with related bipinnate acacia species

A. mearnsii grows in natural association with other bipinnate acacias. These are of note because (i) some may be difficult to distinguish from *A. mearnsii* in the field; e.g. *A. irrorata*, *A. parramattensis* and *A. silvestris*, (ii) they hybridise with *A. mearnsii*, e.g. *A. parramattensis* (Dr M. Tindale 1988, pers. comm.); (iii) they have the potential to provide different products or values in the same environment, e.g. *A. 'blayana'* MS, *A. trachyphloia* and *A. silvestris* are attractive ornamentals and *A. dealbata* and *A. elata* are good quality pulpwoods (Logan 1987).

The species

General description

A. mearnsii is a fast-growing evergreen leguminous shrub or small tree. At maturity the species generally attains 5-15 m in height and 10-35 cm dbh with form that varies from multi-stemmed shrubs to single-stemmed trees with straight boles 2 m long. Although

large trees have been recorded in the past such as 62 cm dbh x 18 m height by von Mueller in 1895, and 46 cm dbh x 26 m height by Sherry in 1957 (Sherry 1971) it is very rare to find any individuals taller than 20 m or larger than 45 cm dbh in Australia today. The form of the species varies, not only with genotype and damage sustained during growth, but also in response to stand density and soil moisture availability. For example, within a population, the better-formed trees generally occur on more favourable southerly to easterly aspects, deeper soils or in denser vegetation.

Taxonomy

In Australia there are 729 described acacia species (family: Mimosaceae) and an estimated 150 undescribed taxa (Hnatiuk and Maslin 1988). All have pinnate or bipinnate seedling leaves and most have flattened phyllodes for adult foliage. However, approximately 70 species have bipinnate adult foliage. According to Pedley's 1978 taxonomic classification these belong to 3 groups; section Botrycephalae (36 species including *A. mearnsii*) and section Pulchellae (27 species) in the subgenus *Heterophyllum* and some 6 species in the subgenus *Acacia* (Maslin and Pedley 1988).

Species in subgenus *Acacia* are generally distinguished from all other bipinnate acacias because they have stipular spines. Within subgenus *Heterophyllum*, the two bipinnate sections can be distinguished from each other by their inflorescences. Species of the Botrycephalae section have racemes or panicles whilst those of Pulchellae have solitary inflorescences. Geographically they are easily separated, the Pulchellae occur only in southwestern Western Australia and the Botrycephalae only occur in southeastern Australia.

The taxonomy within Botrycephalae is still very confused and it requires an expert to precisely distinguish between some closely-related species within the section. There is no complete key to all species of Botrycephalae (Boland 1986)¹.

A. mearnsii was formerly known as *A. mollissima* Willd. or *A. decurrens* (Wendl.). Willd. var. *mollis* Lindl. The species was named after A.R. Mearns (1856-1916), an American army surgeon who collected the type specimen from a cultivated tree near Thika in Kenya (Turnbull 1986).

A botanical description of *A. mearnsii* by Court (1988 pers. comm.) is given in Appendix 1.1.

Hybrids in Australia

Naturally-occurring interspecific hybrids in Australia involving *A. mearnsii* are surprisingly uncommon. Only one, with *A. parramattensis*, has been recorded (Dr M. Tindale 1988 pers. comm.). Differences in flowering times between closely-related bipinnate acacias can create an effective breeding barrier.

On the other hand, species of Botrycephalae are particularly prone to hybridisation with each other when cultivated. Hybrids between *A. mearnsii* and *A. baileyana*, *A. dealbata*, *A. decurrens* and *A. irrorata* (Moffet 1965a, b) have been manipulated or observed in South Africa.

Variation within the species

Little research has been conducted in Australia to explore variation within *A. mearnsii*, although trials in South Africa have identified some potentially frost-tolerant seed sources at high elevations (c. 700 m) in New South Wales (Anon. 1987), and research is currently being conducted by CSIRO Division of Forestry and Forest Products (Canberra, Australia) to examine variation in seedling morphology and frost tolerance of 21 Australian provenances.

There have been ad hoc theories in the past about variation in the species. In 1878 it was stated 'from actual experience, the tanners are satisfied that there is considerable variation in the strength of the bark - due to conditions of the soil and climate, as well as the age and season at which the trees were stripped' (Anon. 1878). Maiden reported that 'the best Tasmanian seed comes from the east coast of Tasmania, Spring Bay and Swansea; the best Victorian comes from the Portland district; the best New South Wales from the Eden district. At the same time, there are considerable areas in all three Colonies which produce fine trees and excellent seed' (Maiden 1891). Boas (1923) stated that 'generally speaking, the percentage of tans increases the further south the wattle is grown. The Victorian variety generally is richer in tans than that from New South Wales'. ACIAR provenance trials planted in 1986 in China will be the first opportunity for the accuracy of these assertions to be objectively assessed.

¹ A useful key is in 'Acacias of Southeast Australia' by Terry Tame, Kangaroo Press, 1992, 206 p.; the forthcoming acacia volume of the 'Flora of Australia' will be a comprehensive reference.

Closely related Australian species grown in China

A. mearnsii (black wattle), *A. dealbata* (silver wattle) and *A. decurrens* (green wattle) are grown in China. These species are known to hybridise with each other

(Moffet 1965a) and many of the *A. mearnsii* trees in China display uncharacteristic flowering and seeding patterns. For example, compared with *A. mearnsii* in Australia some Chinese plantings flower earlier (at 12 months of age) and develop mature seed in a shorter time (6 months after flowering) (Raymond 1987).

Botanical descriptions of *A. decurrens* and *A. dealbata* and a key to distinguish between the three species (A.B. Court pers. comm. 1988) are presented in Appendices 1.1 and 1.2 to aid in distinguishing between the species.

Flowering and seeding

A. mearnsii flowers during the summer months of October, November and December approximately 8-10 weeks after floral initiation when the first visible racemes appear (Moncur et al. 1988). All flowers in a flower head open simultaneously and take 4-5 days to complete the floral cycle. The flower heads in the racemes flower over 14 days though most complete their sequence within 7 days (Moncur et al. 1988 [Grant et al. 1994]). Seed takes 12-14 months to develop from fertilisation to maturity and can be collected from December to March.

A. mearnsii is andromonoecious (Moncur et al. 1988). Flower heads contain both staminate and bisexual flowers, and thus not all flowers have the ability to produce seed. The proportion of male flowers may be determined by environmental factors during the development of the flowers (Moncur 1988 pers. comm.).

This is one of the factors which may in part explain the very low seed yield in many Australian populations. From year to year, population to population and tree to tree, the production of seed is irregular, and the seed that is produced after the long maturation period is often heavily damaged by insect and fungal attack. The timing of seed maturity also varies between years and the mature seed is not retained on the tree for longer than two to three weeks, making timing of seed collection critical.

Nitrogen fixation

Like most legumes, acacias form a mutually-beneficial symbiosis with root nodule bacteria of the genera *Rhizobium* or *Bradyrhizobium* (Roughley 1987). The bacteria penetrate young rootlets in the aerated surface soil layers and multiply to form nodular swellings on the root surfaces. Within these nodules, the bacteria absorb atmospheric nitrogen and convert it to soluble nitrogenous organic and inorganic compounds than can be utilised by the plant (N.A.S. 1983).

Nodules are commonly found on roots of *A. mearnsii* in Australia but little is known of how much nitrogen they fix and whether this varies with different strains of bacteria and *A. mearnsii* genotypes.

Interrelationships with fauna

Insects - general

The total number of insect species and the size of populations associated with *A. mearnsii* in Australia are large and scarcely documented.

New (1984) made insect collections in Victoria which indicated that some bipinnate acacias support more insect species than any phyllodinous acacia he examined. New (1984) suggests this is 'an impression consistent with the opinion that the bipinnates are the ancestral form of *Acacia* in Australia, and thus may have provided the opportunity for colonisation by consumer insects over a longer period'.

In Australia, the number of species which feed on bipinnate acacias rises rapidly over the first few years of the tree's life, and then tends to decrease. At the same time, there is a trend for the taxonomic composition of the insect community to change with increasing age of the plant, or with change in plant condition. Stressed plants, including those heavily attacked by insects in early life, may have a severely weakened appearance, and the succession of species attacking them is accelerated (New 1984). *A. mearnsii* is predominantly insect pollinated.

Ants are often found on the species and may be amongst the most abundant predators, seed harvesters and tenders of sap-sucking insects (Homoptera sub-order). Many ants tending Homoptera do not nest in the trees but in the ground or in adjacent vegetation. They may then forage on one or several acacias.

Insect pests

Although damage caused by insect pests was one of the factors which inhibited planting of *A. mearnsii* on a commercial basis in Australia, little research, other than the identification of the insects, has been conducted in this country to control them. As stated previously the total number of associated insects is large. They attack foliage, wood, bark and seed through eating tissue, sucking sap, or in the case of galls by causing malformation of plant tissue. Sherry (1971) stated that more than 80 different insect species have been recorded attacking the species.

These belong to the orders Lepidoptera, Coleoptera, Hymenoptera and Hemiptera (Homoptera and Heteroptera sub-orders). Foliage is destroyed chiefly by caterpillars of moths and butterflies (Lepidoptera) or by foliage-eating beetles (Coleoptera). In the Chrysomelidae family (Coleoptera) both larvae and beetles feed upon foliage, and one of the most serious pests, fireblight beetle *Pyrgoides orphana*, belongs in this taxa. This species regularly defoliates large areas of *A. mearnsii* in Tasmania during winter and spring (Elliott and de Little 1984). The term 'fireblight'

refers to the reddish-brown scorched appearance of the wattle after it had been completely defoliated and the earlier belief that the damage was caused by a disease. After several years of continuous defoliation, trees can be seriously damaged or killed.

Hymenoptera and Coleoptera destroy seed of *A. mearnsii* and these can significantly reduce annual seed production, while Hemiptera suck sap of leaves, twigs, stems and fruit. Of this latter order, Coccidae and Psyllidae families in the Homoptera sub-order seriously damage growth and can kill young trees. For example, the coccid *Dactylopius albizziae* (Hemiptera: Coccidae) caused serious damage to young trees in plantations in the south coast districts of New South Wales (Froggatt 1923).

The life of *A. mearnsii* is also limited by wood-eating beetle larvae (Coleoptera) and moth and butterfly caterpillars (Lepidoptera) which gain easy entry into trees when bark hardens and cracks with age at around ten or twelve years. These can induce premature senescence in stressed and mature trees.

Birds

A. mearnsii infested with wattle grubs (wattle goat moth *Xyleutes durvillei* Lepidoptera: Cossidae) and longicorn beetles (*Ancita* sp. Coleoptera: Cerambycidae) may be further damaged by yellow-tailed black cockatoos (*Calyptrorhynchus funereus*) excavating for the grubs (Elliott and deLittle 1984). Birds, foraging for pollen and insects such as the yellow-rumped thornbill (*Acanthiza chrysorrhoa*) and grey fantail (*Rhipidura fuliginosa*) and parrots feeding on maturing seed are also commonly observed.

Marsupials

An unusual association between Australian marsupials and bipinnate acacias has been found (Smith 1982, 1984). The association is between Leadbeaters possum (*Gymnobelideus leadbeteri*) and *A. dealbata*, and the sugar glider (*Petaurus breviceps*) and *A. mearnsii*. These two small marsupials live in the mixed native eucalypt/acacia forests in southeastern Australian and lick gums exuded from either natural wounds or from small incisions in the tree trunks which they make deliberately in order to release the gum. Acacia gums provide a rich source of carbohydrate during times of the year (autumn/winter) when the normal diet of these marsupials (usually insects and arthropods) is in short supply. In the case of the sugar glider its population density is probably regulated by the abundance of plant exudates (especially from *A. mearnsii*). This close association between the marsupials and acacia gums suggests anatomical and physiological adaptations in the marsupials which may include an enlarged caecum to aid in the digestion of gum (Smith 1980). The apparent co-evolution between these marsupials and bipinnate acacias is probably ancient

because other researchers (HersHKovitz 1977; Martin and Bearder 1979) have found small arboreal marsupials in Africa, Malagasy and South American forests which also feed on insects as well as on saps and gums.

Diseases

Little research has been conducted in Australia to identify the causes of disease in *A. mearnsii*. However, symptoms of gummosis, as experienced in plantations in South Africa, do not appear to occur commonly in native trees. Certainly the most obvious diseases are gall-forming fungi. The most common is *Uromycladium tepperianum* which consists of a group of strains capable of infecting a wide range of *Acacia* species (New 1984). This fungus causes the development of aborted tissue, which appears as rusty-red woody growths on branchlets and inflorescences. These can occur in such numbers that they finally kill infested trees. These also attract moths and beetles which lay their eggs in or upon galls and parasites which live on the gall-eating larvae (Froggatt 1923).

Utilisation in Australia

Tannin

Tanning was one of Australia's first manufacturing industries. Bark of many of the native trees and shrubs surrounding the first European settlement (Sydney, NSW in 1788) was soon recognised as being 'well adapted for tanning leather' (Anon. 1915a). A tan-pit was built in Parramatta, Sydney in 1801; bark was proposed as a New South Wales export to England in 1802, and bark and leather samples were sent to England for evaluation in 1803 (Anon. 1915b). The leather samples were reported to be 'good and of a proper quality for making the soles of shoes or boots' (Anon. 1915c). Australia developed as an agricultural country and there was a strong associated demand for leather products such as harnesses, reins, bridles, whips, straps, shoes and boots.

Of all the Australian species which produce tannin, black wattle was regarded as the richest source. It was also cheap to obtain and abundant.

In response to strong local demand by tanners, black wattle was heavily exploited by itinerant bark-strippers and landholders alike. By 1878, demand for bark in Australian, Continental and English markets was large and rapidly increasing. Thousands of hides were being bought by Victorian tanners from New Zealand, Queensland and New South Wales, and Victorian leather exports were continuing to increase (Anon. 1878). On the other hand, New South Wales had exhausted its initially abundant local wattle supplies and its tanneries were kept open almost entirely by means of bark grown in Victoria and

Tasmania (Anon. 1878). The tannin quality of harvested bark fell as the number of mature trees available for stripping declined. To meet demand, seasonal harvesting was replaced by harvesting throughout the year. Shipments of chopped or ground bark were adulterated with bark from other species or poorer-quality trees of *A. mearnsii*.

In response to indiscriminate harvesting of wattle bark, a Board of Inquiry was appointed in Victoria in 1878. It recommended conservation and cultivation of wattle stands; control and licencing of strippers; prevention of wasteful harvesting; regulation of timing of harvesting (15 September–15 January) and size of trees to be stripped (>12 cm diameter at 60 cm above ground) (Anon. 1878). The latter two recommendations were intended to ensure a good tannin content.

The Board of Inquiry made the first of many calls for establishment of *A. mearnsii* plantations in Australia to meet domestic demand. As a result, government and privately-owned *A. mearnsii* plantations were established in in South Australia, Victoria and New South Wales. The largest of all government plantations, 400 ha (Helms 1923), was established at the You Yangs in Victoria in 1887 (Sherry 1971). However, none proved profitable. Coghill (1927) described these attempts as commercial failures because of ‘the prevalence of fires, lack of a market for the wood, high freights, high stripping costs, and the lack of tannin extract plant. Sherry (1971) also lists damage caused by the beetle *Prygoides orphana* as being largely responsible for the cessation of attempts to cultivate the species commercially in South Australia and Victoria. There was a particularly damaging infestation of wattle plantations in Victoria in 1890 (Froggatt 1923).

Exports of *A. mearnsii* bark declined after 1890, as Australia became less able to regularly supply its own tannin industry. After decades of uncontrolled exploitation, mature trees were no longer abundant. Labour costs increased and alternative, less arduous employment became available. Tanners became more and more dependent on overseas sources of tanning materials such as bark from black wattle plantations in South Africa and quebracho heartwood extract (*Schinopsis* spp.) from South America because satisfactory supply was assured (Coghill 1927).

However, *A. mearnsii* bark was collected from natural stands up until the 1970s, generally for domestic use. It was collected when other employment was scarce: during the depression in the late twenties and early thirties, and periods of high immigration after World War II. Farmers also stripped trees on their properties as time permitted.

Today, tannin of *A. mearnsii* used on a commercial basis in Australia is imported as extract. South Africa is the largest supplier of this extract, and the adhesive

and leather industries in Australia are the largest users.

Wood

The wood of *A. mearnsii* was used for cask staves, axle spokes, axe and pick handles and other articles requiring a tough durable grain (Anon. 1878). When dried, it was valued as the best firewood known for ovens, furnaces, household cooking and other domestic purposes because it emitted a clearer and greater heat than other species. The trunks were also used as top rails for fencing. Wood from mature trees was also used as paving blocks (Sherry 1971).

Today in Australia the wood is used on a small local scale for firewood, cottage industries and local crafts such as wood turning.

Plantings

As a fast-growing frost-tolerant species which adapts to a wide range of soils and can withstand periods of drought, *A. mearnsii* is promoted by tree planting authorities and organisations for use in windbreaks, screens, soil erosion control, for shade and shelter and as an ornamental tree.

Pollen

For bee-keepers, *A. mearnsii* is a valuable source of pollen during favourable seasons because it flowers later than most other wattles (Clemson 1985). Its flowers do not produce nectar.

Gum

Gum may be used in certain industrial and pharmaceutical processes e.g. as an adhesive, as a stabiliser (of icecream mixes for example), and as an emulsifying agent or for other purposes in the paper making, cosmetic and food industries.

A. mearnsii exudes gum in response to damage but this has never been commercially exploited in Australia. According to Sherry (1971) Maiden wrote that wattle gums in general were regarded as inferior to gum arabic in terms of colour, freedom from impurities and solubility. Gummosis, the exudation of gum through the bark of roots, stems or branches in the absence of any obvious injury, does not appear to occur in *A. mearnsii* in Australia.

Chemical analyses of the gums of *A. mearnsii* and other species in the Botrycephalae have been conducted by Anderson (1978) and Anderson et al. (1971, 1984).

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Appendix 1.1 - Botanical descriptions

Acacia mearnsii De Wild.

Small spreading tree 5-15 m high and nearly the same across; trunk up to about 35 cm diam.; bark dark-grey, smooth but sometimes tending to be rough on the lower parts of older trunks; branchlets angular, pubescent; foliage dense, darkgreen when mature but often honey- or golden-brown in colour when young; leaves bipinnate, 5-15 cm long and 4-12 cm wide; petiole 1-5 cm long; rachis 5-15 cm long with a prominent hairy gland on the upper surface near the base of each pair of pinnae and with one or more additional hairy glands between at least two pairs of pinnae along the rachis; pinnae 10-25 pairs; pinnules about 30-65 (occasionally as few as 15 on pinnae near the base of the rachis) pairs, close-set and often overlapping one another, 1.2-4 mm long and 0.5-1.0 mm wide, linear oblong, obtuse rarely otherwise, glabrous above and pubescent below; inflorescence in axillary racemes (and sometimes in panicles) of 3-10 flower-heads; flower-heads about 5-10 mm diam., globular, pale-yellow, 20-30-flowered, fragrant; peduncles usually golden pubescent; flowers 5-partite; pods 4-15 cm long and 5-8 mm wide, flat, straight, somewhat constricted between the seeds, glabrous, purple-brown; seeds longitudinal in the pod; funicle short, expanded into a more or less oblique aril.

Flowering from late spring to early summer.

Indigenous to S.E. South Australia, New South Wales, Australian Capital Territory, Tasmania and Victoria.

Acacia decurrens (J. Wendl.) Willd.

Small trees 5-15 m high and up to 10 m across; trunk up to 25 cm diam.; bark dark-grey, smooth; branchlets winged or conspicuously angled; foliage dense, usually light- or yellowish-green at least when young; leaves bipinnate, 5-15 cm long and 8-13 cm wide; petiole angular, decurrent, 1-3 cm long; rachis angular and ribbed, 4-12 cm long with a prominent gland on the upper surface near the base of each pair of pinnae with no additional glands between them; pinnae 5-15 pairs; pinnules 15-35 pairs, usually well separated

from one another, never overlapping, always more than 5 mm long and up to 15 mm long, 0.5-0.75 mm wide, acute, linear, totally glabrous or almost so; inflorescence in axillary racemes (and sometimes in panicles) of 8-20 flower-heads; flower-heads 5-8 mm diam., globular, bright-yellow, 20-30-flowered; peduncles glabrous; or almost so, 3-6 mm long; flowers 5-partite; pods 4-7 cm long and 4-7 mm wide, flat, straight or slightly curved, not or hardly constricted between the seeds; glabrous, purple-brown; seeds longitudinal in the pod; funicle short, expanded into a terminal aril.

Flowering winter and spring.

Indigenous to central New South Wales.

Acacia dealbata Link

Small erect tree from 2 m in sub-alpine provenances (where often distorted) up to a straight forest tree 35 m high in sheltered lowland habitats; trunk 5-75 cm diam.; crown usually open and up to 10 m across; bark grey or silver-grey, often mottled, smooth; branchlets angular, shortly pubescent, foliage usually glaucous, silvery, rarely otherwise; leaves bipinnate, 2.5-15 cm long and 4-10 cm wide; petiole 0.5-3 cm long; rachis 2-12 cm long with a small but prominent hairy gland on the upper surface near the base of each pair of pinnae with no additional glands between them; pinnae 8-25 pairs; pinnules 17-50 pairs, close-set and sometimes overlapping one another, mostly 2-5 mm long rarely less, linear oblong, obtuse or acute, at least minutely pubescent with more or less appressed hairs; inflorescence in axillary racemes (and sometimes in panicles) of 3-10 flower-heads; flower-heads 5-10 mm diam., globular, pale- to bright-yellow, not always conspicuous, fragrant, 25-35-flowered; peduncles pubescent, about 6 mm long; flowers 5-partite; pods 4-8 cm long and 8-12 mm wide, flat, straight or sometimes twisted, slightly constricted between the seeds, glabrous, usually purple-brown and sometimes glaucous; seeds longitudinal in the pod; funicle short, expanded into a small terminal aril.

Flowering from late winter to late spring.

Indigenous to New South Wales, Australian Capital Territory, Victoria and Tasmania.

Appendix 1.2 - Key to bipinnate acacias commonly planted in China

1. Upper surface of the leaf-rachis with a prominent gland at or near the base of each pair of pinnae and with at least one additional gland (usually more) elsewhere on the leaf rachis...*Acacia mearnsii*

Upper surface of leaf rachis with a prominent gland at or near the base of each pair of pinnae but never with additional glands elsewhere along the leaf rachis...2

2. Pinnules always more than 5 mm long, totally glabrous or almost so; branchlets winged or conspicuously angled...*Acacia decurrens*

Pinnules less than 5 mm long, or, if more (very rarely), then branchlets pubescent; branchlets neither winged nor conspicuously angled; pinnules usually pubescent ...*Acacia dealbata*.

Chapter 2

Climatic Factors

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Abstract

Climatic conditions at successful *Acacia mearnsii* plantations around the world are examined. The ranges of annual mean temperature, coldest month minimum temperature, annual mean precipitation and driest quarter precipitation are defined for South African plantations and plantations elsewhere in the world. Locations in southern China experiencing similar conditions are identified. Many of these locations have experienced absolute (i.e. record) minimum temperatures below -5°C and frost damage has been observed in China under these conditions. It is concluded that finding frost-resistant *A. mearnsii* genotypes should be a high priority.

Climatic conditions at successful *Acacia mearnsii* plantations

The purpose of this section is to examine the range of climatic conditions at successful *A. mearnsii* plantations throughout the world and to suggest where similar conditions may be found in China. The information presented here is largely based on the publications by Booth (1988) and Booth and Jovanovic (1988). However, additional information on risk of frost damage is also included.

Booth and Jovanovic (1988) collected climatic information for 60 successful *A. mearnsii* plantations in Africa, Asia and South America. Successful sites were defined as those where the trees were growing well and climatic conditions were not markedly limiting growth. For each location 36 monthly mean values were obtained, consisting of 12 values for average daily maximum temperature, 12 values for average daily minimum temperature and 12 values for total monthly precipitation.

When describing climatic requirements some authors use different measures of monthly temperature and

they do not always specify which measure they are using. It is therefore important to understand the difference between measures that may be used to describe monthly temperature values. Three measures are commonly used; average daily, average monthly and absolute.

Let us consider minimum temperatures as an example. Average daily figures are calculated from the minimum temperature values for every day within a particular month, whilst the average monthly figures are based on the single coldest day within the month. So, for a location with 10 years of records the January mean minimum based on **average daily** records would be the mean of 310 measurements (i.e. 10 x 31), whilst the mean minimum based on **average monthly** values would be the mean of only 10 observations. The **absolute minimum** temperature for the 10-year period would be the one record from the coldest day from the 310 January observations. Both average daily and absolute values are mentioned in the following descriptions.

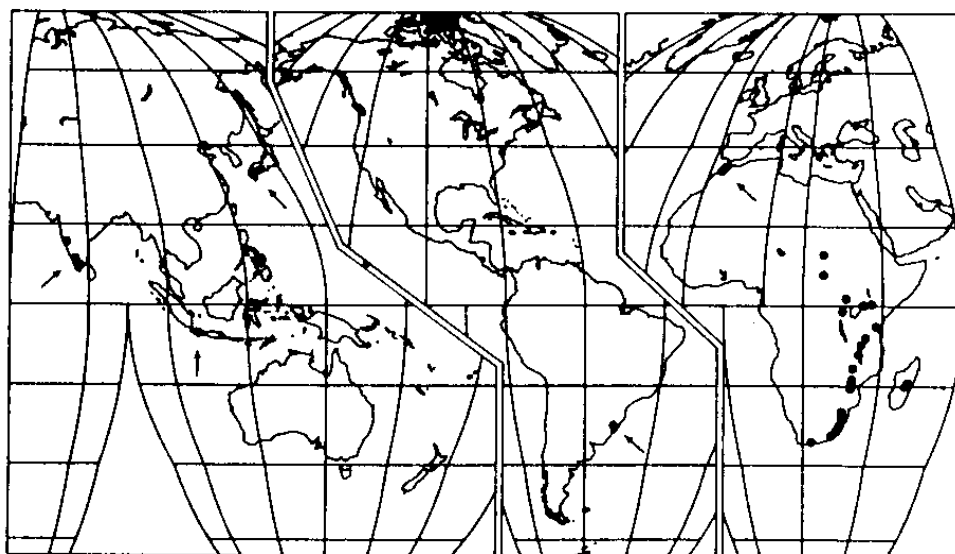


Fig. 2.1 Location of 60 successful *Acacia mearnsii* trial sites and plantations.

South Africa is one of the world's most important centres for growing *Acacia mearnsii*. Location and rainfall data for 33 plantations were obtained from Schönau (1969) (see Fig. 2.1). Temperature estimates were made for these sites using interpolation surfaces developed by Booth et al. (1988). These allow mean conditions to be estimated for any location in Africa given its latitude, longitude and elevation. The ranges of conditions for four important climatic factors are shown in Table 2.1. For example, 13.9°C was the lowest annual mean temperature at the 33 sites and 19.1°C was the highest.

Twenty-one other African locations mentioned by Sherry (1971) were chosen to represent successful *A. mearnsii* plantations outside South Africa. These included the following : Zimbabwe: Mt Selinda, Melsetter, Chipinga, Inyanga, Umtali; Kenya: Eldoret,

Turbo, East of Rift Valley region; Tanzania: Njombe, Usambara region, Iringa; Madagascar: Antsirabe, Antananarivo; Morocco: Rabat, Larache; Sudan: Gilo, Gebel Mara; Uganda: Kigezi; Zaire: north-east region. The locations of these sites are shown in Figure 2.1 and their range of climatic conditions are summarized in Table 2.1.

Estimating climatic conditions for sites outside Africa was difficult as interpolation surfaces, such as those developed by Booth et al. (1988) for Africa, are not available for many other parts of the world. However, a small number of other sites are listed in Table 2.1. and shown in Figure 2.1. The location in Brazil is probably the most important, as there are about 60 000 ha of *A. mearnsii* plantations in this area.

The data in Table 2.1 provide an indication of the range of conditions under which *A. mearnsii* grows,

Table 2.1 Climatic conditions at successful *A. mearnsii* trials and plantations

Location(s)	Annual mean temperature (°C)	Coldest month minimum temperature (°C)	Annual mean precipitation (mm)	Driest quarter precipitation (mm)
33 South African sites	13.9/19.1	-0.6/8.5	693/1608	39/155
21 other African sites	16.7/23.9	5.3/16.7	536/2263	0/235
Taquari, Brazil	19.7	10.1	1458	297
Bandung, Indonesia	17.7	13.8	1799	173
Belgaum, India	24.0	13.9	1551	10
Nilgiri, India	14.3	5.1	1630	86
Palni, India	14.2	8.0	1672	159

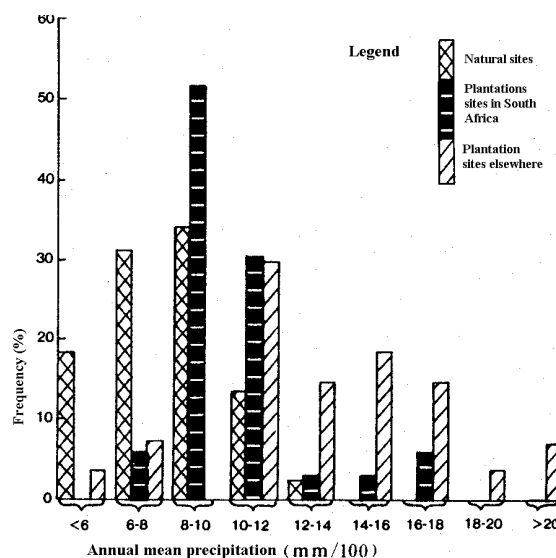
but they do not indicate which conditions are most common. Figures 2.2 and 2.3 show the variation within and between these geographic groupings for annual mean temperature and precipitation. Data are summarized for 287 sites within the natural distribution, as well as the 33 South African sites and 27 locations elsewhere in Africa and in other parts of the world. As the numbers of observations in the three groups were so different, the data in the figures are shown in percentage terms, so observations for any one group total 100. It is thus easy to see which classes were most common within any group and how these compare with the other two groups.

Figures 2.2 and 2.3 show how *A. mearnsii* is being grown in locations which are generally wetter and warmer than within its natural distribution. The peaks in the histograms for South African plantations (i.e. - 16-20°C for annual mean temperature and 800-1200 mm for annual mean precipitation) correspond well to the conditions for optimum growth suggested by Schönau and Schulze (1984).

Identifying climatically suitable areas in China

Booth (1988) examined where suitable conditions to grow *A. mearnsii* might be found in southern China (Fig. 2.4a). Climatic data for locations in China were taken from the GLOCLIMEANMTH (Global Climate Mean Monthly) database compiled by Nix and McMahon (McMahon 1986). Mean monthly values of average daily maximum temperature, average daily

Fig. 2.2 Variation in annual mean temperature for *Acacia*



mearnsii sites.

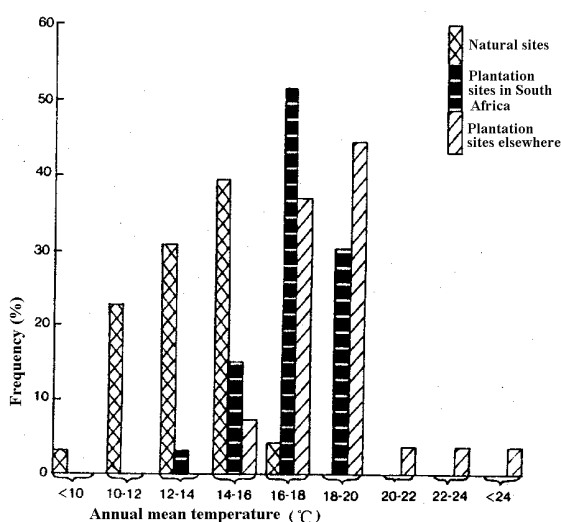


Fig. 2.3 Variation in annual mean rainfall for *Acacia mearnsii* sites.

minimum temperature and total precipitation were obtained for each location. Climatic conditions at each location in China were then checked to see if they satisfied the limits for South African plantations (see Table 2.1). The South African plantations were considered separately because they are the largest *A. mearnsii* plantations in a single region. Annual mean temperature had to be between 13.9°C and 19.1°C, coldest month minimum temperature had to be greater than -0.6°C, but less than 8.5°C, annual mean precipitation had to be greater than 693mm but less than 1608 mm, whilst driest quarter (i.e. 3 months) precipitation had to be between 39 and 155 mm. Figure 2.4b shows the locations in China that satisfy the four climatic factors for South African plantations.

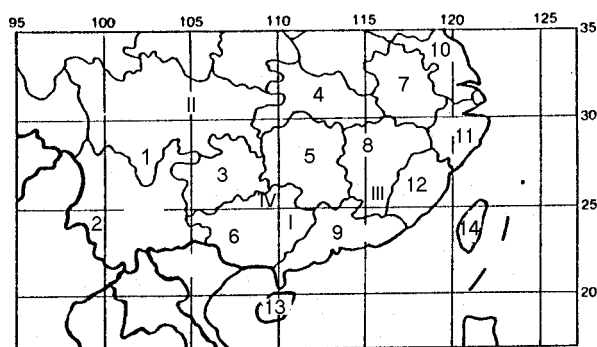
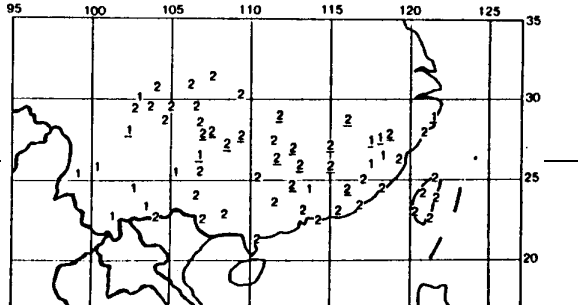


Fig. 2.4a Provinces of southern China and the bordering countries of Burma, Laos and Vietnam. I. Coastal areas of Zhejiang, Fujian and Guangdong provinces. II. Sichuan basin area. III. Mountainous region of the southern ridge. IV. Valleys in Yunnan, Guangxi and Guizhou provinces. (1) Sichuan (2) Yunnan (3) Guizhou (4) Hubei (5) Hunan (6) Guangxi (7) Anhui (8) Jiangxi (9) Guangdong (10) (11) Zhejiang (12) Fujian (13) Hainan (14) Taiwan.

Fig. 2.4b Locations in China satisfying climatic requirements of *Acacia mearnsii* determined from 33 plantations in South Africa. The '1' and '2' symbols are equivalent, but those underlined have experienced absolute minimum temperatures below -5°C.

Figure 2.4c shows the locations in China that satisfy the climatic limits for *A. mearnsii* plantations outside South Africa. The limits used were derived from Table 2.1. The data were compiled from sites widely scattered around the world and the ranges of conditions were broad in comparison to those found in South Africa. The ranges were 14.2-24.0°C for annual mean temperature, 2.2-16.7°C for coldest month minimum temperature, 536-2263 mm for annual mean precipitation and 0-237 for driest quarter precipitation (mm).

The locations shown in Figure 2.4b are mostly well inland, whilst the plantations in South Africa are close to the coast (see Fig. 2.1). Though the Chinese



locations experience similar monthly mean values of average daily minimum temperatures to the South African locations they occasionally have more extreme low temperatures. These can cause frost damage to *Acacia mearnsii*.

On the basis of experience in China, Pan and Yang (1987) suggested that locations where the absolute (i.e. all-time record) minimum temperature was less than -5°C were unsuitable for growing *A. mearnsii*. Locations shown in both Figures 2.4b and 2.4c, which also had absolute minimum temperatures below -5°C are circled. These locations have some climatic similarity with conditions at successful *A. mearnsii* plantations, but may have problems with frost

damage. As large areas are affected, finding more frost-tolerant provenances of *A. mearnsii* should have a high priority.

Some locations within the natural distribution of *A. mearnsii* experience absolute minimum temperatures below -5°C. So provenances with a greater cold tolerance than those currently used may be available. Experiments should be carried out in frost-prone areas in China to indicate if these provenances are resistant or if extremely unseasonal frosts cause problems not experienced within the natural distribution.

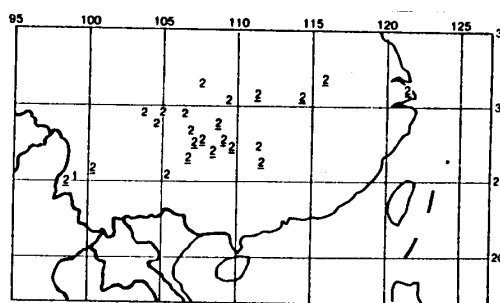
Frost damage is less likely at the locations which are not underlined in Fig. 2.4b and c. However, the chance of damage at long intervals, particularly at the more inland sites, cannot be excluded as the duration of meteorological records for many locations are quite short.

The locations shown in Figures 2.4b and 2.4c, especially those without underlining, provide a first indication of regions where *A. mearnsii* would be worth testing in China. In general, conditions appear favourable in parts of Yunnan, Sichuan, Guangxi, Guangdong and Fujian. The species may also be suited to carefully chosen sites in Guizhou, Hunan

and Jiangxi. The example of frost resistance suggests that care is needed to select appropriate provenances for different regions. A well-chosen provenance may succeed at sites where the species has failed in the past.

Fig. 2.4c Locations in China satisfying climatic requirements of *Acacia mearnsii* determined from 27 plantations and successful trials in Africa (excluding South Africa) Brazil, Indonesia, India and Japan. The '1' and '2' symbols are equivalent, but those underlined have experienced absolute minimum temperatures below -5°C.

The best sites may well be those with annual mean temperatures of 16-20°C and annual mean precipitation of 800-1200 mm as suggested by the peaks for South African plantation sites shown in Figures 2.2 and 2.3. These are similar to conditions in China recommended for *A. mearnsii* by Pan and Yang (1987). As more results from provenance trials in China become available these should be used to improve the knowledge of optimum, as well as suitable, conditions.



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Chapter 3

Flowering Biology, Genetics and Breeding

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Abstract

Any breeding strategy for *Acacia mearnsii* is constrained by the biology of the species. In order to plan an effective strategy information is required on reproductive mechanisms, potential for asexual propagation, relationships between characters of economic importance and extent of variation and the heritability of such characteristics.

A. mearnsii is an outcrossing species but control pollination is not feasible in a breeding program as emasculation of flowers is not possible, and thus selfing rates may be high. Both pod and seed set are low. In addition, the potential for using vegetative propagation is severely restricted due to low success rates.

The pattern of variation within the species is currently unknown and little information exists about any genetic parameters for characters of economic importance. There are indications that tannin content, bark thickness, stem diameter, stem form and gummosis incidence are all reasonably heritable and that, for the first four of these characters, the correlations are advantageous.

A breeding strategy based on open pollination and extensive seedling seed orchards has been developed for China. The strategy relies on planting large progeny trials which are used for a variety of purposes before being converted into seedling seed orchards via a two-stage thinning process. The strategy is relatively

simple and robust and allows for a broad genetic base to be maintained over many generations, for short generation intervals and for provision of progressively-better, genetically improved seed.

Introduction

It is vital to have information about the biology of a species in order to develop a breeding strategy. Aspects of biology which are relevant include reproductive mechanisms, potential for asexual propagation, relationships between characters of economic importance, and the extent of variation and the heritability of these characters. At present there is almost no such information available from China about the biology of *Acacia mearnsii*. Thus, a collation of relevant biological information is presented, most of which came from the Annual Reports of the Wattle Research Institute, University of Natal, South Africa. For the sake of brevity in the following summary these annual reports will be referred to as WRI, together with the date of the annual report.

Using this information, alternative options for future breeding strategy may be evaluated. A breeding plan for *A. mearnsii* has been developed (Raymond 1987) and an outline is presented below.

Flowering biology

A. mearnsii is regarded as an outcrossing species with partial self-compatibility but information regarding pollination mechanisms and outcrossing rates is inconsistent. The basic unit of reproduction in *Acacia* may be regarded as the inflorescence and not the individual flower, as flowers tend to be tiny, numerous and densely massed (Arroya 1981). Thus most studies on flowering in *Acacia* species have concentrated on inflorescences or other larger units.

The inflorescence consists of numerous small flowers, up to 45, all subtended by a series of overlapping bracts (Moncur et al. 1988). The inflorescences first appear about 8-10 weeks prior to flowering, at which stage the stamen primordia are initiated and the ovary developing in the centre (Moncur et al. 1988).

Floral morphology

A. mearnsii is protogynous (Philp and Sherry 1946; Kendrick and Knox 1981a) with the stigmas being receptive before the pollen is shed. A moist exudate is present on the stigma which apparently permits pollen adhesion during the female phase of flower opening (Kendrick and Knox 1981a). The length of the style is variable and may not extend beyond the corolla lobes in some cases, whilst in others it protrudes beyond the anthers (Sherry 1971). Some florets, usually near the base of the flower head, may be wholly male and trees bearing only male flowers have been observed (Sherry 1971). In a recent study of a population in NSW, Moncur et al. (1988)

reported that 90% of flowers were wholly male. Flowers are pale creamy-yellow in colour and strongly scented.

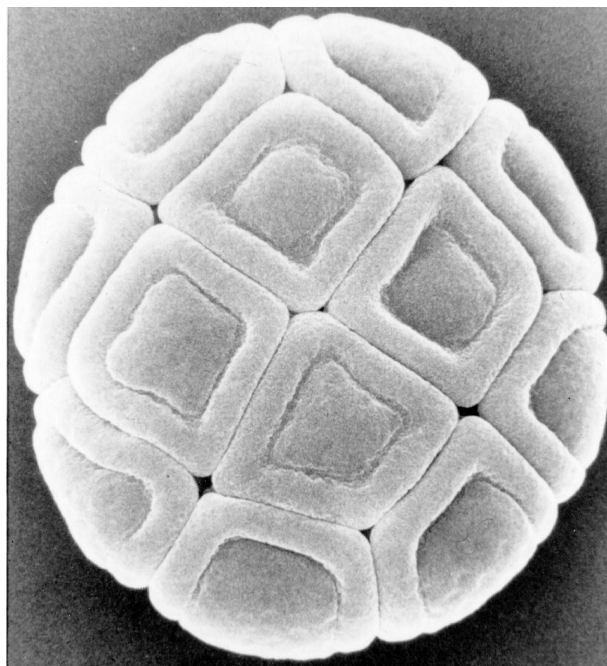


Fig. 3.1 A polyad containing 16 pollen grains.

Between 30 and 45 anthers are present within each floret, with filaments up to 2.5 mm in length (Sherry 1971). The pollen is packed in polyads each of which contain 16 pollen grains (Sherry 1971; Kendrick and Knox 1982). Each polyad is formed from a single sporogeneous cell which undergoes two mitotic divisions, to form four pollen mother cells, before meiosis to form the 16-celled polyad (Kendrick and Knox 1982). The polyad forms a biconvex disc with eight cells in the centre, arranged in two tiers of four cells, with eight cells arranged in a single layer around the edge - see Figure 3.1 (Sedgley 1987). As there are eight loculi in each anther the total pollen production per anther is 128 grains packed in eight polyads (Kendrick and Knox 1982).

Polyads are assumed to give a selective advantage in reproduction, as composite pollen units provide an efficient means of dispersal by insects (Kendrick and Knox 1982). A relationship also exists between the polyad grain number and the number of ovules, with *A. mearnsii* having 14 ovules per ovary (Moffett and Nixon 1974; Kendrick and Knox 1982). A single polyad has the potential to fertilise all ovules within

the ovary, and thus only a single pollination is required. The use of polyads may thus be a mechanism to ensure seed set (Sedgley 1987).

The morphology of the polyad and the stigma in other *Acacia* species (Kendrick and Knox 1981b, 1982) indicates that this mechanism may be effective. The morphology of the stigma is similar in many Australian species with the stigma having a simple blunt end which is non-papillate and forms a cup-shaped depression at the tip of the style (Kendrick and Knox 1982; Sedgley 1987). The polyads of these species are of such a size that they fit neatly into the stigma cup (Kendrick and Knox 1982). The success of the pollination may not depend upon the accurate placement of the polyad as following pollination an aqueous solution, secreted from the stigma, forms a large droplet of fluid at the tip of the stigma (Kendrick and Knox 1981a). This exudate may serve several functions. Firstly it may act as a germination medium for all pollen grains in the polyad, including those which are not in direct contact with the stigma (Marginson et al. 1985); secondly it may contain chemotrophic substances for pollen tube growth; and finally it may serve as a device to attract insects during the male flowering phase and thus ensure efficient pollen transfer (Kendrick and Knox 1981a).

Given this form of floral morphology it seems likely that all seeds within a single pod could be considered to form a full-sib family resulting from a single polyad, although the male parent would not be known. Recent work with *A. melanoxylon* using isozymes (G.F. Moran pers. comm.) indicates that this is the case. Fathers of pods within an inflorescence may also be related. How such information may be used in the future for further development of the breeding strategy is uncertain and will depend largely upon the number of seeds per pod. When collecting seed to use in establishing progeny trials it would be wise to collect and maintain the identity of each pod separately. If there are fewer than five seeds then it would be best to limit the number of seeds taken from any single pod to make up a family bulk seedlot, thus avoid introducing a bias due to differences in relatedness of progeny. If there are eight or more seeds per pod, then the seeds could be used as replications of each full-sib family and the family structure included in the design of progeny trials.

Pollination biology

A. mearnsii has been reported to be insect pollinated. Early examination of the pollen and stigmas indicated that the species is not adapted for wind pollination (WRI 1948). *Acacia* pollen is not copiously shed but, when plants are in full bloom, polyads may be collected from the air (Bernhardt 1982). Pollen may also be dispersed by wind and in South Africa pollen was found up to 450 m from an isolated stand (WRI 1952). Observations of flowers in South Africa have

revealed many bees working the inflorescence and trapped bees were found to have wattle pollen on their legs (WRI 1948). Honey bees were also observed by Moncur et al. (1988) and were considered to be the most important pollinators due to their methodical foraging (i.e. visiting large numbers of flowers in one raceme before moving on to another). Trapped bees had large numbers of polyads adhering to most parts of their body. Observers of other *Acacia* species in Australia have recorded other insects including beetles, flies, native bees, introduced honey bees, native wasps and psyllids, all of which were carrying wattle pollen (Bernhardt 1982). Thus a number of insects appear capable of effecting pollination and appear to be attracted by the floral colour and scent. At present there is no information available about what insects may pollinate *A. mearnsii* flowers in China.

A. mearnsii is regarded as an outcrossing species with partial self-compatibility (Moffett and Nixon 1974) but estimates of the degree of outcrossing are inconsistent. Differences in genetic material, methods, criteria, conditions of cultivation and climate between studies make comparison of the results difficult. Estimates of outcrossing rates include 85% (Moffett 1956), 48%-96% with an average of 82% (WRI 1970) 10%-96% with an average of 69% (WRI 1974) and 100% (Kendrick and Knox 1987).

Little information is available about the sequence of floral development throughout the year. Moncur et al. (1988) observed that flower buds appear 8-10 weeks prior to flowering. Flowers within an inflorescence develop at different rates but all open simultaneously. The flowering cycle took 4-5 days to complete but, within a raceme, individual inflorescences flowered over a 14 day period. The species flowers between October and December in Australia (Turnbull 1986) and between late August and early October in South Africa (Sherry 1971) and the period between fertilization and seed ripening is about 14 months in both countries. The timing of bud opening and of maximum flowering period was found to differ between families in seedling seed orchards in South Africa but there was considerable overlap in flowering stages and thus cross pollination should occur (WRI 1968, 1969). However, the effective pollination distance appeared to be relatively short and cross-pollination may be largely between close neighbours (WRI 1974).

Control pollination

Two techniques have been used for making control crosses. In South Africa (WRI 1973) inflorescences were bagged prior to any flowers opening. Once flowers begin opening the bags were taken off at regular intervals and the inflorescence brushed lightly with a bunch of mature flowers from the chosen

pollen parent before the bag was replaced. As emasculation of the flowers is not feasible there is a chance of self-fertilization occurring (WRI 1973). Also, while the bags are removed there is a chance of contamination from other pollen sources.

A different technique was used by Moncur et al. (1988). Inflorescences were selected when flowers were in the female phase and all buds and male flowers removed. Polyads were collected by pressing a small vial over fully open flowers. The polyads were then transferred to the stigma of another flower by pressing the inner wall of the vial against the stigma. The flowers were then bagged. Five weeks after pollination 21% of flowers which were control pollinated had set pods, compared with only 1.3% for open pollination.

The South African technique resulted in both the number of pods set per inflorescence and the number of seeds per pod being reduced, when compared to open-pollination (WRI 1961, 1963). The degree of cross-fertilization was estimated by using seedling recessive characters carried by some of the parent trees. Estimates of cross-fertilization varied between parent trees and included 24%-100% (WRI 1963), 57%-100% (WRI 1964), 27%-100% with a mean of 74% (WRI 1965), 22% and 89% (WRI 1973). Use of control cross-pollination in the South African breeding program was eventually rejected due to the problem of self seed occurring in unknown proportions, and time and cost considerations which made it difficult to obtain sufficient numbers of crosses (WRI 1979). The use of open-pollinated progenies for screening selected trees was considered preferable.

Collection of seed in seed orchards

Initially pods were collected by hand from all trees in the South African seed orchards. This proved to be a slow and unsatisfactory method due to variation in ripening time of the pods and the need to either use ladders or to climb the trees (WRI 1969). Additionally, *A. mearnsii* seed is shed once the pods are mature. If collection of pods is delayed due to poor weather or other circumstances during the ripening period a considerable amount of seed may be shed before the pods are collected (WRI 1971). Thus collection of pods by hand proved difficult and damage was done to both the bark and branches of the trees and to the current season's flowers (Poggenpoel 1978).

An alternative method of collecting seed by waiting until all seed was shed from pods and then sweeping the orchard floor proved more successful (WRI 1972 and Poggenpoel 1978). The litter on the orchard floor is swept up, sieved, winnowed and cleaned to recover the seed. This method proved to have several advantages. Firstly, seed collection can be done

during the winter months when labour is more readily available and seed from large areas can be collected easily. In addition, the seed collected appears to be more uniform in character, possibly because non-viable and soft-coated seeds may be eliminated during the months on the ground. Treatment of seed prior to germination is thus simplified, and germination percentages increased.

This method of seed collection has two main disadvantages: firstly, the identity of the female parent cannot be maintained and the seed collected is thus a bulk seedlot. Hand-collection of pods from individual trees is necessary to retain the pedigree information for each seedlot. Secondly, the orchard floor must be kept free of grass and weeds, either by shading or by use of herbicides (Poggenpoel 1978). An alternative may be to cover the floor of the orchard with shadecloth or hessian prior to the commencement of seed shed and then later collect the seed from on top of the covering.

Vegetative propagation

Attempts to vegetatively propagate *A. mearnsii* have generally had limited success. Early attempts to produce rooted cuttings from mature trees failed (WRI 1952) even after treatment with indolebutyric acid. Subsequent attempts to root cuttings from mature trees under mist (WRI 1964, 1979) had varied success (4.4%-19.8% rooted but varied between families in 1964; 32 out of 1051 cuttings survived in 1979). The use of lower branches as a source of cuttings appeared to increase the percentage developing roots (Zejilemaker 1976) but again the success varied between families. Coppice shoots will root readily (WRI 1979) but the stumps rarely stay alive for long enough to produce suitable shoots. Cuttings from young seedlings (3-4 months old) will root with up to 90% success depending upon family (WRI 1980) and from slightly older seedlings (8-9 months) with about 60%-70% success (WRI 1960, 1963). Splitting or splicing of the bark at the base of the cutting material was found to be beneficial, and the use of a nursery bed with heat from the base is essential (WRI 1980).

Grafts made using young scion material (from seedlings less than 8 months old) were successful (WRI 1960). A modified budding technique using budwood from lower branches of mature trees and young seedlings as stock plants has also proved successful (Garbutt 1971) provided nurse branches are retained.

Air-layering, by placing a ball of moist spagnum moss over a ring-barked area and holding it in place with a plastic membrane, has proved generally successful (WRI 1952, 1959, 1960). The plants obtained retained, to a large extent, the mature characteristics of the branch from which they were taken and

flowered freely in tins after 12-18 months (WRI 1955). Air-layers were less successful on well-grown trees in normal plantations and the number of air-layers that could be placed on a single tree was restricted (WRI 1958). In general, although this technique was successful, it was considered cumbersome, time-consuming and not entirely satisfactory for the establishment of seed orchards (WRI 1964).

Genetic parameters

Genetic variation

Few data are available regarding patterns of genetic variation within *A. mearnsii*. The only information regarding provenance variation comes from seedlots introduced to South Africa. In 1957 Mr S.P. Sherry undertook a collection of seed from throughout most of the natural distribution in Australia (WRI 1959). Exactly what was collected is uncertain as the report of the collecting trip (WRI 1958) gives little detail, but a series of trials was planted to compare the new seedlots with South African material.

One trial containing 15 seedlots from New South Wales and Victoria (WRI 1967) was planted in 1958 (WRI Project Gen 3.1, WRI 1962). Survival was poor and the trial was uneven (average survival 55% ,WRI 1967). Bark samples were taken in 1964 (WRI 1964) and diameter at breast height measured on all trees. There were significant differences between families for both diameter and bark thickness. The mean diameter of the Australian seedlots was the same as the South African seedlots but the Australian material had significantly thinner bark. The trial was harvested in 1966 (WRI 1967) and significant differences were found between the Australian seedlots for diameter at breast height and tannin content of bark samples. In general the Australian seed lots had a lower tannin content than the South African seedlots.

A second trial (WRI Project Gen 3.2, WRI 1962) containing 20 seedlots (19 seedlots of *A. mearnsii* and one of *A. silvestris*) was planted in a replicated block design in 1959. Most of these seedlots appear to have been bulk collections (WRI 1963, 1964). At age 3 years significant differences were found between seedlots for diameter and gummosis (WRI 1963), and the range of variation observed within the Australian seedlots was similar to that for the South African seedlots in the same trial. Bark samples, taken at age 5 years, again indicated that the Australian seedlots had thinner bark than the South African seedlots but no difference was found between the two groups for diameter over bark at breast height. Further assessment of the trial for gummosis revealed some interesting results (WRI 1967). At age 3 years the Australian seedlots had a higher incidence of

gummosis than South African seedlots. But, by age 8 years the situation was reversed as the incidence of gummosis in the Australian seedlots had remained constant or decreased, whilst the incidence increased in the South African seedlots. For 17 out of the 20 Australian seedlots the incidence had decreased and, for 6 of these, the decrease was significant ($P=0.05$). Stem form was assessed at age 9 years (WRI 1968) and significant differences ($P=0.01$) were found between the Australian seedlots.

The trial was harvested in 1969 and no differences were found between seedlots for mean height or diameter (WRI 1969). Average yield of bark per unit area was similar for the Australian and the South African seedlots, but examination of the components of yield revealed some differences (WRI 1969). In general the South African seedlots had greater weight of bark per tree, thicker bark and higher tannin content than the Australian seedlots. However, the percentage of trees which could have the bark stripped was higher for the Australian seedlots. As the South African seedlots were progenies from selected local parent trees and the Australian seedlots were bulk collections from native stands any comparisons must be made with care. However, within the group of Australian seedlots there were significant differences between seedlots for bark thickness, tannin content and weight of bark per tree.

Project Gen 4.1 (WRI 1962) contained 12 seedlots from colder areas in Australia planted in a randomised block trial on a frosty site (WRI 1960). Following the first winter there were significant differences between these 12 seedlots for height but not for cold damage although there was variation in number of seedlings damaged and the degree of damage by frost. Seedlots from Cooma, NSW and from Swansea, Tasmania seemed promising as they appeared to have a fairly high degree of frost resistance combined with a reasonable growth rate (WRI 1962).

A second trial (WRI Project Gen 4.2) of 9 Australian seedlots was planted on a frosty site in 1961 in a latin square design (WRI 1962). The seedlots included are listed in Table 3.1.

Height was measured after 5 months, before the first frosts, and survival estimated. Frost damage was scored in June 1962 using a points system and an index of frost damage derived by dividing the total points allocated by the number of seedlings surviving at 5 months. There was little difference between the seedlots for growth, with Omeo Highway, Victoria being the only seedlot significantly worse than the others. For survival there were large differences, seed from the relatively low-rainfall areas of the south-east coast of Tasmania having the highest survival of the Australian seedlots. The Cooma, NSW seedlot, which suffered the least frost damage, came from the highest elevation at which *A. mearnsii* was found growing

naturally during the seed collection. Although seed was collected from only one tree at this location, it would appear to be a promising area for collecting seed for use on cold sites.

In 1985 a collection of NSW and Victorian provenances was organised by the South African

Wattle Growers Union (ICRF 1987). Nine provenances were represented by 89 single-tree collections and 2 bulk collections but full details of the collections was not presented. Trials were established on 3 sites in 1986. One site was extensively damaged by frost in the first winter.

Table 3.1 Seedlots planted in Wattle Research Institute trial (Project Gen 4.2) in 1961 (from WRI 1962).

Location	Collection	Altitude (m)	Latitude (S)
Near Cooma NSW	Single tree	885	36°16'
Bogong Village VIC	Bulk	700	36°43'
Omeo Highway VIC	Bulk	610	37°06'
Germantown, Ovens Valley VIC	Bulk	520	36°43'
Lal Lal VIC	Bulk	375	37°40'
Mount Nowa Nowa VIC	Single tree	335	37°44'
Between Cranbrook & Apslawn TAS	Single tree	107	42°00'
Near Swansea TAS	Single tree	15	42°07'
Natal South Africa (commercial)	Bulk	-	-

Table 3.2 Published estimates of heritabilities for *Acacia mearnsii*.

Character	Source	Heritability estimates		
		Individual	Family	Parent-offspring
Tannin content	WRI 1963	.55		
	WRI 1964	.69	.18	.50
	WRI 1967			.54
	WRI 1968		.19	.25
	Moffett &	.22	.83	.55
	Nixon 1963	.27	.75	.62
Bark thickness	WRI 1963	.22		
	WRI 1964	.27	.79	.42
	Moffett and	.12	.71	
	Nixon 1963	.20	.68	.24
Diameter	WRI 1963	.14		
	Moffett and	.08	.60	.20
	Nixon 1963	.37	.83	
Gummosis	WRI 1963	.29		
Wound	WRI 1964	.79	.26	
Natural	WRI 1964	.60	.12	
	Moffett and	.23	.84	
	Nixon 1963	.36	.76	
Stemform	WRI 1968		.77	
	WRI 1968		.70	

Table 3.3 Correlations between characters for *Acacia mearnsii* based on a collation of estimates of correlations between family means (from WRI 1953, 1954, 1955, 1956, 1957, 1958, 1959, 1961, 1962, 1965, 1966, 1967, 1968, 1969, 1970, 1976, 1977; Moffett and Nixon 1963 and Nixon 1969).

Character	Diameter	Bark thickness	Height	Gummosis	Stemform
Tannin content	+	++	0	0	0
Diameter		++	++	?	0
Bark thickness			0	0	0
Height				?	0
Gummosis					0

++ All estimated correlations were positive

+ Most estimated correlations were positive, remainder zero

0 All estimated correlations close to zero

? Some correlations positive, some negative and some zero

Two Australian provenances (Lake George and Mittagong, NSW) from high altitude ($\pm 700\text{m}$) received the least frost damage whilst all coastal provenances (Bateman's Bay and Merimbula, NSW, and Stratford, Victoria) were severely damaged. Height was measured nine months after planting. For the two unfrosted sites, the Bateman's Bay, NSW and Kyneton, Victoria provenances were tallest but they were not significantly taller than most other provenances.

Heritabilities and correlations

Published estimates of heritabilities for different characters are presented in Table 3.2. No standard errors were given for these estimates and thus their reliability is unknown.

No published estimates for genetic correlations between characters were found, but many estimates of simple correlations between family means are given in the WRI Reports (1953, 1954, 1955, 1956, 1957, 1958, 1959, 1961, 1962, 1965, 1966, 1967, 1968, 1969, 1970, 1976, 1977) and in two conference papers (Moffett and Nixon 1963 and Nixon 1969). These many estimates are presented in a general form in Table 3.3.

Early assessment

When developing a breeding program it is vital to know the youngest age at which characters of economic importance may be assessed with accuracy. For most characters of importance for *A. mearnsii*, assessment at about 5 years of age will give a reliable guide to the relative ranking of seedlots at harvest age (Nixon 1974).

As this species is grown for bark yield and quality it is necessary to develop 16 techniques for assessing mature bark characteristics from young trees. Pellets of bark, removed from the tree by a punch and sampled at about 5 years of age, were found to give reliable indications of the relative tannin content at maturity (WRI 1956, 1965, 1966, 1969; Nixon 1974). Although such samples did not provide an accurate estimate of the actual tannin content at maturity, they were able to correctly rank seedlots (WRI 1956, 1965, 1966). Estimates of average bark thickness may also be gained by weighing these pellets, as little variation was found for specific gravity of bark samples (WRI 1961). As the samples were of equal surface area the weight of the samples provided a good estimate of the average bark thickness. When checked against caliper measurements this method gave good agreement (Moffett and Nixon 1963). Sampling for these two bark characteristics before 5 years of age is essential; thus the minimum age for early assessment of trials is 5 years (Nixon 1974).

Assessment of gummosis is difficult due to the sporadic nature of the disease, the subjective scoring system used and the fact that the extent and severity of the disease is not constant over time (Moffett and Nixon 1963). In South Africa it was considered that scoring trees at age one year, when the disease lesions were first apparent, gave the best estimate of the relative rankings of seedlots (Nixon 1974). Later assessments were complicated by the healing of earlier lesions, development of new lesions and possibly secondary infection from pathogens.

Table 3.4 Mean measurement and percentage inbreeding depression per 10% increase of the coefficient of inbreeding (F) for S1 and S2 generations (from WRI 1976).

Character	Mean measurement			Inbreeding depression (%) per 10% increase in F	
	Outcross	S1	S2	S1	S2
Height (m)	16.71	13.35	11.62	4.02	4.06
Diameter (cm)	13.74	11.15	10.44	3.77	3.20
Tannin (%)	40.7	39.4	40.3	0.64	0.13
Trees stripped (%)	74.3	41.0	27.8	8.96	8.34
Bark mass (kg/tree)	20.97	22.72	18.23	-	1.74
Bark yield (t/ha)	22.26	13.31	6.99	8.04	9.15

Table 3.5. Mean measurements and percentage inbreeding depression per 10% increase in the coefficient of inbreeding (F) for open-pollinated and half-sib cross progeny relative to out-cross progeny (from WRI 1979).

Character	Out-cross	Open-pollinated	Half-sib cross	Inbreeding depression (%)	
				Mean ¹	Per 10% increase in F
No. of progenies	10	9	5		
Height 2 yr (m)	8.53	8.76	8.11	5.59	4.47
Diameter 5 yr (cm)	11.87	11.81	11.10	5.45	4.36
Bark thickness 5 yr (mm)	4.18	4.09	4.11	2.23 ²	1.78
Survival 5 yr (%)	71	80	68	18.75	15.00
Stemform 5 yr (%)	69.10	68.8	71.32	-	-
Gummosis 1 yr (%)	12.82	13.74	9.79	-	-
Gummosis 5 yr (%)	8.75	7.74	7.36	-	-

¹ Calculations based on comparison with open-pollinated progenies² Calculations based on comparison with out-cross progenies

Inbreeding depression

Self-fertilization, and thus inbreeding, will cause a decrease in fertility and vigour in *A. mearnsii* (Moffett and Nixon 1974). The amount of inbreeding present is quantified by the coefficient of inbreeding (F) with outcrosses having a value of zero and selfs have an F value of 0.5. From a trial containing openpollinated and selfed progenies of 12 parent trees, the following estimates of the effects of inbreeding were calculated (expressed as percentage depression per 10% increase in the coefficient of inbreeding): height 5.2%; diameter 6.6%; percentage survival 6.6%; percentage of trees stripped 8.9%; bark mass per tree 12.0%; bark yield per unit area 16.2%. In this trial the outcross and inbred progeny were planted together, and thus these estimates of the effects of inbreeding may be biased due to effects of competition with the more vigorous open-pollinated progeny.

Two other small trials were planted in South Africa to assess the effects of inbreeding depression. The first

trial, including eight first generation self (S1) and six second generation self (S2) families, was felled at maturity in 1976 (WRI 1976). Outcross progeny of some of these families had been planted in an adjacent trial; thus a rough estimate of the effects of inbreeding could be obtained and are presented in Table 3.4 (from WRI 1976).

The second trial contained progeny resulting from control-crosses between first-generation selections, including some half-sib matings, and open-pollinated progeny of the same parents (WRI 1979). Results of this trial at half-rotation age are presented in Table 3.5.

One important conclusion from this trial was that progeny resulting from half-sib crosses could not be detected by eye in the trial (WRI 1979). The importance of planning seedling seed orchards to avoid the possibility of crosspollination by related trees is thus stressed.

Breeding strategy

An outline of the breeding strategy proposed by Raymond (1987) is presented below. As *A. mearnsii* is grown commercially to produce tannin and pulp, the objective of any breeding strategy must be to maximise the yield of bark and tannin per unit area. Tannin yield per tree is a complex character relating to survival, age of tree, percentage of bark which may be stripped, bark thickness and tannin content and tree vigour. As the breeding objective is complex it is essential to determine which tree characteristics can be assessed and their relative importance. To maximise progress in the overall objective the following characters are considered essential:

- adaptation to environmental conditions as determined by survival and health of trees in field trials.
- vigour as expressed by height and diameter growth
- good bark thickness and high bark yield
- high tannin content of the bark
- good stem form.

The major genetic resource available is the native Australian stands where provenance and single-tree collections have been undertaken throughout the natural range of the species. Seedlots from these collections have been supplied to China by the Australian Centre for International Agricultural Research.

Given the restrictions imposed by the biology of *A. mearnsii* a strategy which does not depend upon control pollination or vegetative propagation is required. Such a strategy, based on open pollination and extensive seedling seed orchards, modelled on the strategy used in Florida for *Eucalyptus grandis* (Franklin and Meskimen 1983; Meskimen 1983) is proposed.

The strategy is based on planting large progeny trials which are converted into seedling seed orchards by a two-stage thinning process. The first thinning is done at about one-third rotation age and is mainly a within-family thinning with the worst trees in each family being removed and only the very worst families being totally removed. The seed set in the next flowering season is collected from all trees to provide the basis of the breeding population for the next generation. A second thinning is then done to convert the progeny trial to a seedling seed orchard. Only the very best trees are retained to produce high quality seed for immediate plantation establishment.

By using one trial for a variety of purposes, this strategy optimises use of limited resources whilst remaining flexible. The initial trials may be

established as combined provenance/progeny trials which will also serve as the current breeding population, and will provide seed for the next generation's breeding population, before being converted to seedling seed orchards to produce seed for plantation establishment. A large number of imported seedlots may thus be evaluated in a common environment and selection for adaptation under the relevant growing conditions is possible. Each time a progeny trial is established it is possible to incorporate new seedlots into the breeding population for testing and evaluation, while the two-stage thinning process ensures that the seed produced from the orchard is of the highest quality possible.

The use of a two-stage thinning process allows a broad genetic base to be maintained in the breeding program. Very few families are removed in the first round of thinning prior to collection of seed to establish the next breeding population. Subsequently, only the very best trees are retained after the second thinning to ensure the best genetic quality of the seed orchard trees from which large amounts of seed are required to establish plantations. The narrowed genetic base resulting from the second thinning is not used for further breeding purposes.

This strategy relies on the use of reasonably large field trials using single-tree plots. At approximately one-third rotation age all trees are assessed for desired characteristics and all selection decisions are based on these data. The first thinning is then undertaken and following the first subsequent general flowering in the trial seed is collected. This seed, plus any additional seedlots, is then used to establish the next generation's breeding population. The generation interval is thus minimised and is determined by the age of the first general flowering for the species. By planting such trials at a range of sites it will be possible to obtain reasonably robust estimates of genetic parameters and family mean performance, to determine whether genotype by environment interactions are important and to provide genetically improved seed to the major growing regions for the species within the shortest possible period. By using trial sites within the most important growing regions the selection work will be undertaken in the environment and under the silvicultural conditions in which the orchard seed will be established. Thus, selection for adaptation is incorporated in the program.

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Chapter 4

Black Wattle Plantations in South Africa: Introduction, Silviculture and Management

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Introduction of black wattle to South Africa

History

This species was introduced from Australia to South Africa around 1864, and systematic establishment of plantations began early this century. By the nineteen-fifties, the total area of plantations had reached 360 000 ha, but has now stabilised at 124 000 ha ^[1].

Research, especially on silviculture, has been carried out since 1920. The Wattle Research Institute (Wattle Research Institute) was established in 1946; in 1984 this organisation became the Institute for Commercial Forestry Research (ICFR). Systematic, thorough studies of cultural techniques, breeding, and pest and disease control have been undertaken. The standard of plantation management has been raised by applying the results of this research.

Geographic distribution in South Africa

Black wattle plantations in South Africa are mainly between longitudes 27° and 30°E and latitudes 25° and 33°S, including the whole of the eastern and southern part of Natal and Transvaal provinces as well as Transkei. The distribution extends to riverside areas from Pondoland to Capetown in Cape Province^[2] (see Fig. 4.1).

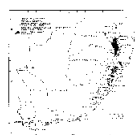


Fig. 4.1 Location of black wattle plantings in Swaziland and the Republic of South Africa (Sherry 1971).

Climatic factors in the distribution

Rainfall is the major climatic factor limiting commercial cultivation of black wattle in this country.

Most plantations are in the summer rainfall region where the annual average precipitation is 870-1050 mm, although at some sites it may exceed 1200 mm. Few plantations are in the region where precipitation is uniform throughout the year (average 700-875 mm per year) or mainly in winter.

Temperature is also an important factor. The species has only limited cold tolerance and consequently it grows poorly at high altitudes. The mean annual

temperature in the main planting areas in South Africa is 16 to 19°C, the mean minimum of the coldest month is -0.6 to 8.5°C and the absolute lowest temperature is -6 to -8°C^[3].

Soil conditions in plantation areas^[4]

The soil in most of the summer rainfall zone is developed from coarse basalt, shale, sandstone and granite gneiss of the Karoo series. Some soils are duplex. Soil texture varies from fine sandy loam to loam. The best growth occurs on soil which has a high content of organic matter, good permeability and water-holding capacity, and a depth of 40-150 cm.

Growth is poor on shallow soil developed from granite and old rocks which contain a lot of quartz.

In the uniform-rainfall zone, black wattle grows vigorously on well-drained soil derived from sandstone or granite, but not on poorly-drained soils.

Most plantations in the winter rainfall area occur on alluvial soil; the underlying rocks are mainly Table Mountain Sandstone or granite.

A study by Darby (1954, cited in ^[2]) shows that growth of *Acacia mearnsii* is directly affected by the drainage of soil - that is, growth is poor on soil with impeded drainage - but is little affected by parent material. He considered that the assessment of soil for black wattle should depend firstly on its drainage and secondly on its parent material. The parent rocks for well-drained soil are coarse basalt, sandstone and gneiss. These soils are deep and rarely have hardpans. The soil developed from shale has poor drainage, and the yield of plantations on such soil is 2/3-1/2 of that of plantations on well-drained soil ^[2].

The aspect and topography of plantations are also important. The best aspects are southern or eastern slopes. These slopes have good moisture conditions, whereas the top or middle of northern and western slopes are dry and unfavourable for growth of wattle.

Silviculture

Seed

Black wattle in South Africa generally first flowers when 2-3 years old, and it seeds well by 4-5 years. It blooms from September to October and the fruit ripen in November-December of the following year. The 1000-seed weight is 14-18 g.

Seed for the initial plantations was obtained from commercial (trade) sources. Establishment of seedling seed orchards began in 1965, and now seed is mainly derived from orchards which have an annual yield of about 250 kg ^[5].

Collecting seed

The mature seed is collected manually from trees in November - December or by sweeping ^[6]. In the manual method, the pods are cut off, or knocked from the tree with a stick, onto a sheet placed on the ground. The collected pods are warmed in the sun or a kiln until they open and seeds drop out, when the seeds are sieved from the pods. Alternatively naturally-shed seed and litter may be swept into piles with a broom; empty pods, twigs and large litter are removed with a coarse sieve; the remainder is winnowed, resieved, and lastly washed and rinsed with running water to remove earth and other impurities. The clean seed is spread on a bamboo sheet to dry in the sun, and then put into storage. The

advantages of this method are its suitability for use on a large scale, the purity and uniformity of the seed, and the fact that the work can be undertaken in winter. A constraint is the presence of weeds in the plantation. Weeds in many seed orchards were initially controlled manually or by mechanical cultivation, but now chemical weeding is used.

Storage of seed

Seeds should be soaked in hot water (>90°C) for 30-60 min, rinsed in cool clean water to remove impurities, then dried on a bamboo sheet under shelter before storage. Some lime should be added to the seed, and the mixture put into bags for storage in dry, ventilated conditions. The stored seed retains high germination for more than 3-5 years.

The purity of seed sold by seed orchards in South Africa is up to 98% and the 1000-seed weight more than 15 g. There are about 60 000 viable seeds per kg with an average germination of 97% (range 93.6% to 99%).

Treatment of seed

Before use in nurseries or for direct seeding, the seed should be put into boiling water (three times the

volume of water as seed), soaked for 12 hours, and the remaining water poured off. Clean cool water is added and stirred for a while to remove impurities and mucus on the seed. This rinse water is changed two to three times, and then the seed is spread to dry under shade. The seed can then be sown. It germinates 7-10 days after sowing.

Nursery practice

Before the sixties, black wattle plantations in South Africa were established mainly by direct sowing or natural regeneration. Bare-rooted seedlings have been used since the seventies when the technique for raising such seedlings was improved. Many nursery methods have been used in that time. In the early sixties seedlings were mainly cultivated in wooden boxes, while the use of polyvinyl cylinders and serving-tray containers was just commencing. In 1976, the speedling tray was introduced from USA and this has now become the main production method.

The commonest is the '128' container. It is made of polystyrene and has 128 inverted truncated pyramids, without bottoms. The pyramid is 63 mm deep, 37 mm square at the top and 9 mm square at the bottom, with a volume of 36 ml. The pyramids are placed in a base tray 340 mm x 480 mm. The tray is held up by wires or an aluminium or a wooden frame to ensure air pruning of emerging roots. The tray was formerly carried to the field with the seedlings, but now the

seedlings are taken from the tray before transport to the field^[1].

Nursery management^{[1][2][8]}

Selection of nursery sites

Primary factors are accessibility, the nursery technique to be used, the life expectancy and scale of operations, local topography, topographic position, aspect, soil type, drainage and water supply. For the widely-used bare-root seedlings, operations are largely mechanized, so the nursery sites are accessible, level or with a slope of less than 5° and well drained. The soil should be deep and friable, with no more than 15% clay or 10% silt, and a pH of 4.5-6.0. Soil fertility is not critical.

Soil sterilization

In most small nurseries, the growing medium is sterilized by heating or steaming. In large nurseries or for container-grown seedlings raised in soil, sterilization is commonly by methyl bromide: 1 kg of methyl bromide is sprayed on each nursery bed or heap containing 2 m³ of soil, which is then covered by plastic sheet for one to two days. One week after the sheet is removed, the bed or soil can be used.

The medium for container seedling cultivation is generally taken from the nursery site. It is usually amended by mixing in ground pine bark or peat and decayed sawdust and NPK fertilizer.

Sowing

The seed used in South African nurseries is usually genetically improved. The genetic gain in volume of trees grown from this kind of seed is 15-20%. In addition, characters like tree form, branching and disease resistance are also improved.

To ensure the quality of seed, it is obtained from reputable sources. One kg of clean seed generally yields about 30 000 seedlings. In container systems, two seeds are sown in each container at a depth of 2-3 cm and covered by sawdust or fine sand.

Fertilization

The method of fertilization varies with the nursery technique used. For bare-rooted seedlings, or containerised ones using soil as a growth medium, complete (2:3:4 N:P:K) inorganic granular fertilizer may be used. A total of 1 g of fertilizer per seedling is applied in three applications - 0.2 g, 0.4 g and 0.4 g - at intervals of six to eight weeks over the seedlings.

With the tray method, inorganic granular fertilizer is also used, but the ratio is 2:3:2 because the growing medium contains bark which has a high potassium content. The '128' tray container has a small root volume, so the interval between fertilizer applications

is seven to ten days. The fertilizer (15 g/tray) is applied over dry foliage, and shaken down before irrigation. In large nurseries where the tray method is used, fertilization may be combined with irrigation.

Irrigation

Manual watering is used in most small nurseries, and mechanical irrigation in larger ones. In large nurseries the irrigation system may be completely automatic, being controlled by computer.

Weeding

Few weeds develop when trays are used, since the growing medium is a mixture of powdered bark, sawdust and peat.

Weeds may be abundant in bare-rooted seedling nurseries. Manual weeding was used before the sixties (and may still be used in small nurseries), but has now been largely supplanted by herbicides (especially in large nurseries). Goal 24 EC is used at a rate of 3 l/ha. It is applied to the nursery beds before the seedlings emerge, and gives effective weed control for 8-10 weeks.

Pests and disease control

The common nursery diseases of seedlings are damping-off, root rot caused by fungi, mould and wilt. The main harmful insects are white grubs, Noctuidae moths, giant crickets, grasshoppers, locusts and snails. The pests and diseases are controlled by an integrated approach using suitable cultural techniques and chemical insecticides, that is, selecting disease-free soil, other growing media and water as far as possible; adopting strict measures to prevent infection; if necessary sterilizing the soil with methyl bromide and treating irrigation water with chlorine; and chemical control of the pests and diseases of seedlings before germination or soon afterwards.

Root pruning^[1]

This is an important operation in South African nurseries. The methods used are:

In tray-type operations, the container is soaked in a polyvinyl acetate and Cu dip. The main roots wither naturally when they emerge into air, because the container has no bottom. The treatment prevents roots penetrating the wall of the container, and promotes dense, fibrous root systems.

Boxed seedlings, and those grown in plastic cylinders, are also subject to root pruning. The fine roots which emerge from cracks in the boxes are removed. With plastic cylinders it is important to keep the roots out of the soils beneath the tubes, so the roots should be pruned throughout the nursery period.

Bare-rooted seedlings are root-pruned to induce dormancy before the seedling reaches planting height. The method is to pull a taut wire under the nursery bed, from one end to the other, by hand.

Lifting and transportation

If seedlings are grown in boxes, they are lifted with a small shovel; the total dry matter of roots retained is 25-38%. With cylinders, the container should be removed at planting time, when any root mat should be cut off on two sides. For trays, the seedling is extracted in the nursery. Bare-rooted seedlings should be lifted with care to avoid root damage. Weak and abnormal seedlings should be discarded, and any over-long main roots or laterals should be pruned. For long distance transportation, seedlings are often put into waxed cardboard containers. Lifting should be carried out in early morning when the temperature is not high, and the leaves should be kept dry.

Future trends in South Africa

Before the 1960s nurseries were mainly small and sometimes temporary, but now large permanent ones are prominent.

Speedling tray and bare-rooted seedlings have largely replaced those grown in boxes and cylinders.

The seed used in nurseries is genetically improved. Nursery techniques will be further improved: a bark-based mixture is replacing soil as a growing medium, except for bare-rooted stock. The fertilization of seedlings will better match the needs of the plants, and will entail microbial inoculation. Critical operations - irrigation and fertilization - will be assisted by computer, using a model of seedling growth to estimate requirements of water and nutrients.

Site preparation ^{[2][3][14][15][16]}

Three kinds of land are used for afforestation with black wattle in South Africa: virgin land, agricultural land and land previously cropped with the same species.

Cleaning up before site preparation

The method of clearing varies on different types of afforestation sites. Native vegetation on virgin land is composed mainly of grass and xerophytic, deep-rooting weeds. This vegetation should first be burnt and the site then ploughed to about 10 cm depth in autumn. Previously-cultivated land should be ploughed in late winter. Clear-felled areas should be wholly cleared, the roots [stumps?] between planting lines being dug out then piled with the branches in planned windrows or burnt.

Complete and intensive site preparation is an important factor in the yield of black wattle plantations in South Africa. The following methods of site preparation are used ^[14].

Complete preparation

This is the best and most economical way to control weeds and improve site conditions. The depth of ploughing should be more than 10 cm. The operation is best done when the soil is moist in autumn or, if this is not possible, in winter.

Strip preparation

This method can be used in a planned manner on steep slopes in high-rainfall areas. Uncultivated strips alternate with ploughed strips. The width of ploughed strip is generally one metre; a seedbed 50 cm wide is re-cultivated in the middle of the strip and then sown with seed (or planted).

Hole-type preparation

The effectiveness of this method is very poor, so it has been abandoned. It was used on very steep slopes. The holes used were 50 cm x 50 cm x 40 cm.

Preparation of cultivated land

Because these sites have been repeatedly ploughed they have a compacted horizon beneath the cultivated zone, which should be fractured before afforestation by ploughing to a depth of about 30 cm in winter when the soil is dry.

Four methods of site preparation were compared by the Wattle Research Institute of South Africa —

- 1) holes of 50 cm diameter dug with a hoe;
- 2) ploughed to 45 cm depth along planting rows with a multi-toothed rake;
- 3) complete preparation;
- 4) weed killer sprayed in a band 1.2 m wide along the planned planting rows.

Fifty g per tree of ammoniated superphosphate fertilizer was added at planting and again in following spring.

Observation of three-year-old trees showed: Complete preparation was outstanding, the breast-height sectional area of this treatment being 8.45 m²/ha. The treatment ploughed along the planting line had 5.44 m²/ha; the hole treatment had 3.01 m²/ha. The differences in height were also very significant, the means being 7.97 m, 5.28 m and 2.69 m respectively.

Site preparation for regeneration of clear-felled sites^[18]

Several methods have been compared. The use of a stump-jump cultivator to break up the superficial layer of roots and litter prior to planting appears to be beneficial. Vegetation between rows is desirably controlled by shallow cultivation.

Stand establishment^{[2][13][17][20]}

Three methods of establishment are used for black wattle plantations in South Africa: direct seeding (band and spot sowing), planting seedlings and prompted natural regeneration.

Direct seeding

This method was used exclusively in large scale black wattle plantations before the seventies. There are three ways of seeding: (1) Broadcast, that is, to broadcast seeds evenly on soil which has been intensively cultivated, and then cover them with earth; (2) Spot sowing, that is to sow seeds at fixed intervals into prepared holes; (3) Band sowing by hand or machine in a continuous line. Band seeding is much better for seedling survival and height growth than spot or broadcast seeding. The spot and broadcast methods have now been abandoned.

Method of band seeding

Seed is applied by hand or machine in prepared planting rows at a rate of 2.0-2.5 kg/ha^[13]. The distance between seeds is 2.5-4.0 cm and between rows is 1.8-2.7 m. The depth of sowing is about 5 cm but can be up to 7.5 cm in dry and hot places or soil conditions.

Sowing time^[21]

In summer rainfall areas (i.e. September to April) the best sowing time is October to December. In regions prone to winter frost, seeding is done March to April in order to avoid frost damage in the coldest period of June to August.

Transplanting^[22]

This technique is increasingly popular and will replace direct seeding. Seedlings are of three types: bare root, containerised and raised in trays. Containerised stock - mainly in paper or plastic tubes - is being replaced by bare rooted and tray- raised plants. In 1981, 3.74 million containerised transplants were produced nationwide, 71% were in 'planter flats'.

Planting density^[23]

Many studies of density have been carried out by the Wattle Research Institute. The general trend (within limits) is that the greater the density, the greater the early yield of timber and bark, but the cost of seedlings and establishment also increases as the density is increased.

If the final density is reduced through thinning, the yield may be substantially altered (see Table 4.1). The yield differentiation between densities of 1250-1750 trees per ha and 750 - 1000 trees per ha is significant (up to $p < 0.01$). The experiment also showed that the initial density must be greater than the final one for best results.

The density of planting at present in South Africa is 2400 trees per ha, and the spacing of trees and rows is 1.5 m x 2.7 m. With a ten-year rotation, the final density of the stands on medium sites is 1500 per ha; on good sites 1250 per ha and on poor sites 1750 per ha.

Timing of planting operations

The wet season is preferred for planting when no irrigation is available - generally October to March, of which October to December is best.

Natural regeneration

Many seed are present in the surface soil of harvested wattle plantations. Some can germinate and develop into a satisfactory crop given suitable conditions of sunlight, rainfall and soil. There are two methods of artificially promoting natural regeneration. One is to dig 'regeneration' rows with a large hoe along the stump lines, incorporating the dry litter in the soil, in order that the accompanying seed can establish contact with the mineral soil and germinate. The other is to burn litter in strips along stump-lines after felling. The litter is raked up to a depth of 5-7 cm and a width of 15 cm. This treatment generally results in abundant germination.

The results from the various methods of regeneration differ. Experiments show planted seedlings have much better growth than the alternative methods- the yield of fresh bark and timber is increased by 6 t and 25 t per ha over the other two methods of establishment (direct seeding, natural regeneration) respectively.

Table 4.1 Growth rate and yield of ten-year-old stands of different density

Final density (trees/ha)	Diameter at 1.3 m (cm)	Fresh bark (t/ha)	Tannin content in base of trunk (%)	Total tannin yield (t/ha)
750	14.7	20.8	40.6	3.88

1000	13.2	20.4	39.3	3.85
1250	12.4	22.3	38.4	4.28
1500	12.4	24.3	38.8	4.93
1750	11.7	24.2	38.3	4.85

Fertilization^{[2][25]}

Fertilization is essential to ensure good yields from wattle plantations in South Africa. Research on inorganic fertilizer use began in the twenties. The type of fertilizer, rate of application and composition were systematically studied in the late forties and early fifties. The result shows phosphatic fertilizer can promote the growth of wattle and increase yield. Different soil types needs different phosphatic fertilizers. If the stand is fertilized at 449 kg/ha with this fertilizer, final yields may be increased by 7.8 t of bark and 52 t of timber per ha.

Herbert (1984) summarised results of applying NPK and agricultural lime over three rotations of wattle^[26]. In the three rotations, the most significant effects were obtained with single superphosphate at rates of 224 kg/ha and 448 kg/ha respectively. The role of lime was variable, depending on the rotation: it increased yield initially but there were decreased responses in the second and third rotations. A single application of KCl at 122 kg and 224 kg/ha had some effect. When KCl was combined with superphosphate the response to superphosphate was enhanced. An elemental ratio of P:K of 1:3 was best within the range tested. There was no response to $(\text{NH}_4)_2\text{SO}_4$. The fertilizing response in each rotation depended on the effectiveness of weeding. The report also pointed out that while the yield of bark and timber was obviously increased by fertilizing with superphosphate, the incidence of gummosis disease also increased. The experiment also showed that the response to fertilization persists. Fertilizing with superphosphate at 448 kg/ha at the time of direct sowing can increase bark yield by 6 t and timber by 32 t when harvested at age eleven years. A response to lime was confined to the first rotation, when the low Ca status of the site was presumably corrected.

Recent research^[27] also shows the improvement in yield is greatest if particular ratios of NPK are used: some combinations are better than single superphosphate alone.

Rates of fertilization^{[13][28][29]}

The best rate differs between sites. The optimum quantity of super-phosphate is about 110 kg/ha on good sites and 448 kg/ha on poor sites for line sowing, or 100 g per tree for transplants.

Time and method of fertilization^{[25][28][31]}

The best time for fertilization is at planting and in spring of the following year. Methods of application include placing in a circle, in a slit or in planting holes. The depth of application is generally 15-20 cm beneath the surface.

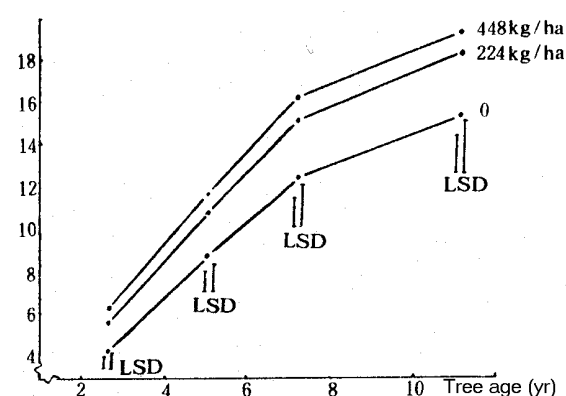


Fig. 4.2 The effect of calcium super-phosphate on the diameter of trees in a stand established with planted seedlings.

Weed control^[2]

Three types of weeds occur in wattle plantations in South Africa: ephemeral and perennial weeds, and long-lived shrubs and climbers.

Weeding time

Experiments over many years show weeding must be carried out meticulously before crown closure. Results are poor if weeding is left until the stand is three years old. The timing of the weeding effort varies on different sites. In young plantations (<1 yr old) on previously-uncultivated grassland few perennial grasses emerge, so a single weeding may suffice. On direct-seeded sites, weeding should be undertaken before the weeds flower (they usually seed in late summer or early autumn) and again when the weeds re-emerge. Naturally regenerated clear-cuts should be weeded before felling.

Weeding methods

(1) Weeding between rows with disk plough or other machines; (2) Manual uprooting of weeds; (3) Cutting the weeds.

Mechanical weeding is mainly used to remove weeds before afforestation. Manual uprooting is used in direct seeding in combination with the first seedling thinning. If the stand cannot be cultivated by machine after this first weeding, weeds remaining between rows may be cut with a sickle to prevent them overtopping the saplings. Weed-killer has been used recently in places where weeds have been a major problem.

Weeding methods and disease incidence

Weeding may easily damage the shallow roots of black wattle. Severe root damage not only affects the growth of trees but also permits infection by decay fungi. Root damage can also increase the incidence of gummosis. A study of weeding over the first five years of stand growth revealed that the percentage of trees which had symptoms of wood-decay fungi in hoed plots was higher than the percentage in plots in which weeds were uprooted or cut. A weeding study in a ten-year-old stand, carried out by the Wattle Research Institute, assessed the effect on average height, b.h.d. and incidence of disease: differences for height and b.h.d. were not significant; the extent of disease in weed-cutting or uprooting plots was clearly lower than in the hoed ones.

Wounds to the root-collar or large lateral roots often permit infection by wood-decay fungi. Infection occurs most readily when the wounded root has a diameter over 1 cm. The tree height is about 2 m when roots attain this diameter. Infection by these fungi can induce black-bark disease or severe gummosis and death. Thus hoeing or cultivating close to the base of trees when they are two metres or more in height must be avoided.

Pruning ^{[2][13][33]}

Aims

The timber of black wattle in South Africa is mainly used for stakes, mine-props, pulp and hardboard. These products do not need very straight or knot-free stems. The aim of pruning is to correct or improve tree form - i.e. to increase straightness and decrease the incidence of forked trees and allied wind damage.

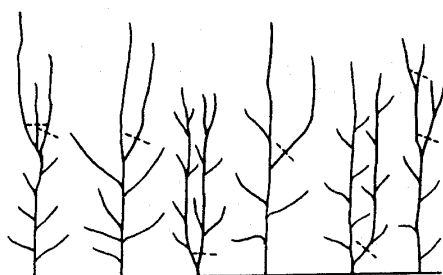


Fig. 4.3. Pruning a young tree to improve form (the dashed lines show the correct places to prune) (Sherry 1971).

Principle of pruning

Pruning is limited to abnormally formed or forked trees. The pruning should not too severe, and is best undertaken in winter. Branch stubs 15 cm long are retained.

Thinning ^{[2][33][34][35]}

Many wattle plantations in South Africa were established by direct seeding. The initial density in such stands can up to several thousand or tens of thousands of stems per ha. These must be thinned repeatedly in order for the trees to attain the desired diameter by the end of the rotation and yield as much timber and bark as possible.

The relationship between thinning aim and stand management

The first aim of thinning is to adjust the density of the stand and so maintain rapid growth. The trees removed include those damaged by pests and diseases, mechanically damaged, deformed or suppressed. The second aim is to raise the quality of products and to match the quality or quantity of bark or timber to market demand. The third aim is to obtain intermediate yields (before the final harvest) in order to increase overall financial return.

There are close relationship between thinning and important factors which influence the quality of bark, notably its thickness. Bark thickness is related to the diameter of trunk. If the management aim is to produce quality bark, heavy thinning is necessary. The first thinning should be carried out at an early stage, and the next must be on time in order to prevent the trees becoming suppressed. A high proportion of quality bark can then be obtained when clear felling. If the management aim is to sell timber, a light thinning should be used on medium-quality sites, leaving the density of the residual stand fairly high because the best-selling timber is straight with a small-end diameter of 8 cm and a large end of no more than 20 cm. If the stand is mainly for producing small-diameter timber, thinning can be delayed and the severity decreased, leaving the final stand density high. In such a regime is adopted, however, the bark thickness of the final crop is decreased and the bark becomes a by-product.

The general practice at present in South Africa is to produce a large quantity of ordinary quality bark by adjusting the thinning regime to get as much marketable timber as possible. The bark should be considered first, however, since the economic return obtained from bark is generally higher than that from timber by 50%.

Common thinning schedules in South Africa [34][35][37]

The methods of plantation establishment used in South Africa changed markedly after the 1970s.

Thinning practice also improved a lot. The thinning plan in common use now is as follows.

Naturally-regenerated and direct-seeded plantations

When the average height of the plantation is 0.2-0.3 m, an operation combining thinning of seedlings and weeding is undertaken. The trees are spaced to 0.6 m apart. The first selective thinning is carried out when the stand average height is 2 m, and results in trees 1.2 m apart, corresponding to about 3000 trees/ha. This thinning is mainly to remove diseased, deformed, suppressed and badly shaped trees. The second selective thinning is carried out when the stand average height is about 4 m; the density after thinning is about 2000 trees/ha. The last thinning is undertaken when the stand average height is 7 m, leaving 1500 trees/ha on medium-quality sites; 1600 /ha on better sites and 1200 /ha in poor conditions.

Planted stands

Two or more thinnings are common. When the initial density is 2400 trees/ha and two thinnings are planned, the first operation is carried out when the stand average height is about 4 m, decreasing density from 2400 to 2000/ha; the second, when trees are 7 m tall, reduces stocking to around 1500 /ha, or less on poorer soils. If a third thinning is used, it should be carried out before the stand is seven years old.

Management

Rotation and yield [2]

Rotation

Rotation length mainly depends on the characteristics of tree growth, site conditions and the market demand for wattle products. On good sites the rotation can be extended, and on poor sites shortened. The rotation was 8-10 yr before the 1950s, but is now 10-12 yr or more as bark is in oversupply.

Yield [13][24]

Historically bark has provided most of the income from black wattle plantations; timber has now become of greater importance in many places because bark is in oversupply and the demand for small timber is strong. In major producing regions - Natal and

Transkei provinces - and under good management, the typical yield from ten-twelve-year-old stands is shown in Table 4.2.

Harvesting [2]

Since both bark and timber of black wattle are useful and the bark is easy to strip when the moisture content is high, bark must be removed immediately after cutting.

Method and timing of bark stripping

Bark stripping in South Africa is undertaken with an axe. The method is generally to cut around the stem to sever the bark at a height of 1.3 m from ground, then to prise open the lower section of bark and pull it off downward as far as the root-collar. When the bark is removed the tree is felled. Remaining bark on the trunk is stripped and cut into lengths of 1.3 m. Harvested bark is collected for transport. In addition, any bark remaining on stumps must be stripped to prevent the sprouting of new branches.

Growth is vigorous in late spring, summer and early autumn when the moisture content of both the tree and soil are high; the bark is most easily stripped at this time.

Treatment of bark

The bark cannot be exposed to direct sunlight after stripping, so it must be quickly bundled and transported to the factory to prevent an undesirable change in colour. Bark awaiting transport should be stored in the shade or be covered by foliage and branches.

The fresh bark is usually sold in South Africa. It is dried for long-distance transport from plantations far from a factory in order to prevent deterioration and weight loss.

The bark is usually torn into strips 8 cm wide before drying. Two types of portable drying racks are used; both are simply made of wattle poles [2, p.341-2]. The drying frames are usually placed in the forest or in a shady location near the factory.

Kiln drying is often used in high-rainfall areas where natural drying is difficult. The common kilns are of two types, one made of brick and the other of lighter materials. The temperature in the kiln must be no more than 60°C, otherwise the bark will become black. The best results are obtained by keeping the temperature at 35°C and changing the air frequently.

Table 4.2 Plantation yield in two major productive regions

Region	Growth	Bark	Timber

	Height (m)	b.h.d (cm)	(t/ha)	(t/ha)	(m ³ /ha)
Natal	17.4	14.5	21.0	121.0	125.9
Transkei	14.4	13.4	16.6	74.8	74.9

Log processing and segregation

At age ten years the diameter of most stems is no more than 23 cm. The length of log is variable, depending on the intended use. Logs for mine props or pulp wood are usually 2.5 m long, and can be slightly crooked. Trees too large in diameter or too crooked are generally cut to 1.8 m lengths and sold as firewood.

Black wattle timber is difficult to saw after drying, so the freshly-felled trees are immediately delimbed, cut to log lengths, classified according to quality and transported to the side of highway.

Treatment of branch timber^[2]

In earlier times the branchwood remaining following felling wattle plantations was burnt in a broadcast burn. It is now treated by piling, firing or removing from the plantation.

The piling operation is as follows. Contour lines 20-30 m apart are marked with stakes before felling. On high-quality sites, the branches are piled tightly in order to check weeds and prevent wattle seedlings growing in the piles. The height of the branch pile when constructed is about 1.8 m and width at the base is no more than 4 m. The piles are discontinuous in order to give access throughout the stand for fire control or other operations. The ends of each pile are sloped to give stability and are compressed with the thick ends of large branches to prevent them being blown about. On sloping sites, the branches are piled between planting rows. On flat sites, the rows of piles alternate with access tracks. The time required for the branches to decay depends on the climate; it is usually 8-10 yr.

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Chapter 5

Black Wattle Plantations in South Africa: Protection

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Animal agencies

Both wild and domesticated animals damage wattle plantations by feeding and movement. Hares, buck, antelope, cattle and goats are responsible for most damage. Browsing is usually confined to removal of the leading shoot and the tips of the lateral branches of very young trees, causing a setback to growth and the formation of multiple leaders. Browsing by buck and hares causes severe damage to plantations established by transplanting, especially during drier

periods, resulting in the need for excessive blanking or even replanting. In the 1981-1982 planting season, almost 87% of 1000 hectares of newly planted wattle required blanking, due primarily to browsing by buck and hares. No completely effective control measures have been developed against such wild animals. Electric fences and various spray repellents may reduce browsing damage to some extent. It is preferable to avoid planting lands which are prone to attack by buck and hares, or to use line-sowing or line-burning methods of re-establishment, thus ensuring more adequate plant populations from which the final crop may be selected.

Insects pests

Hepburn^[40] listed 329 species of insects, spiders and mites recorded in wattle plantations in South Africa. Some 200 of these actually damage trees, but only 25 can be regarded as of economic importance. Subsequently, several other pest insects have been reported, including *Aphis craccivora* Koch and *A. gossypii* Glover, sucking on leaves of wattle and eucalypts and resulting in severe leaf distortion^[41], the fuller's rose beetle, *Asynonychus godmanii* Cortch, defoliating young wattles^[42], the bupestid borer, *Agrilus grandis* L.&G., larvae of which burrow just under the bark of trees^[43], and *Megalognatha granulicollis* Jac. reported as leaf-feeder of young wattle^[44].

Most of the insect pests recorded are leaf-feeders belonging to Lepidoptera, Coleoptera and Orthoptera, with important species in families of Psychidae, Lasiocampidae, Chrysomelidae and Scarabaeidae. Sap-feeders include aphids, scales, hoppers and bugs, of which the brown wattle mirid known as froghopper is responsible for most of the damage. Nearly 30 species involving shot-hole borers, buprestid beetles and longhorn beetles have been reported as borers attacking both felled and living wattles, especially young trees, but large scale outbreaks have not been observed for these species. Insects attacking root systems, mainly white grubs, termites and cutworms,

cause considerable damage to large plantations. Only three species are reported feeding on seeds or seed pods. *Lasioderma serricorne* (F.) has been found in black wattle seed imported from Australia.

Brief notes follow on the nature of damage and control of the most serious insect problems of wattle in South Africa.

The wattle bagworm, *Kotochalia junodi* (Heyl.)

The wattle bagworm is the most widespread and destructive pest insect of wattle crops in South Africa. It was first reported as a pest of wattles in 1899 and had caused great concern by 1912^[49]. Various indigenous acacias were the original hosts of the insect and migration from these to adjacent wattle plantations still takes place, but outbreaks now originate mainly from centres within the plantations themselves.

There is one generation a year. Defoliation by larvae feeding on leaves often results in considerable losses in growth and final bark yield, and difficulties in debarking will be encountered when plantations approaching harvest are infected. Bagworm infestations can be grouped into three main classes with seven degrees of severity in terms of defoliation (Ossowski^[45]):

- i. Light infestations (1-3 degrees): bagworms on a few trees, or on most trees but with slight damage;
- ii. Moderate infestations (4-5 degrees): all trees damaged; some trees completely defoliated;
- iii. Heavy infestations (6-7 degrees): most trees defoliated—virtually complete defoliation of the plantation.

The effect of infestations on growth and bark yield was evaluated in field trials by Sherry^[45]. He concluded that light infestations will generally not cause substantial losses in diameter growth and bark yield unless they are repeated over a number of growing seasons. Moderate and heavy infestations do result in marked losses in these two characters; these effects tend to disappear with the time unless there is heavy infestation in successive years, which is serious irrespective of the timing of the damage. Moderate and heavy infestations of the insect can reduce the final yield of fresh bark by 1.85-4.32 t/ha over a normal rotation of ten years.

Bagworm outbreaks periodically occur in wattle plantations. A cycle of five to seven years is 'normal'. The cycle consists of three stages, i.e. an initial stage of two years, the prodromal stage of two years and the

eruptive stage lasting from one to three years. However, the time needed for populations to reach an outbreak level varies sharply with different areas and plantations. Climatic conditions, food supply and natural enemies play important roles in population dynamics of the insect.

The larvae of the insect hatch in early spring and must feed on newly flushed leaves to survive. Late or early flushing of leaves will result in high mortality of larvae. Persistent rain and mists at this time will interrupt the feeding of young larvae which then perish from starvation. Insufficient food and natural enemies are mainly responsible for the collapse of populations after the eruptive stage. Bagworm infestations are more prevalent on marginal or submarginal sites where soil conditions and rainfall are less than optimum.

Spraying of chemical insecticides has been the major approach for preventing severe defoliation by bagworm, and more recently spraying has commonly been used to protect plantations approaching harvest from bagworm damage and consequent difficulties in debarking. Natural cryolite (sodium aluminium fluoride) and subsequently nendrin or chlorinated camphene had been used for bagworm control for many years. From the early 1980s, two synthetic pyrethroids have been registered to replace nendrin as the standard insecticide for wattle bagworm control at the recommended rate of 100 ml 20% cypermethrin e.c. or 200 ml 5% cyfluthrin e.c. in 30 l water per hectare.

Various groups of natural enemies such as parasitising insects, predatory spiders, birds and mammals as well as infective pathogens attack the bagworm^[49] and play some role in population dynamics, but these are usually incapable of preventing bagworm populations from attaining outbreak levels. Investigations on biological control of bagworm have emphasized the use of a nuclear polyhedral virus, *Borrelinavirus kotochaliae* Ossowski, which is common in bagworm populations and has a natural incidence ranging from 10% to 60%, even attaining 96%. Although studies on the use of the virus produced some promising results, many questions remain to be investigated, such as the optimum biotic and non-biotic conditions of infestation, the residual effectiveness and the cost of preparing the virus suspension. There has been a suggestion that the virus is not effective unless the bagworms are under some kind of stress. Few references have been found to virus studies in South Africa since the mid-1970s.

The brown wattle mirid, *Lygidolon laevigatum* Reut.

The brown mirid, widespread throughout wattle-growing areas in South Africa, sucks on growing

points of the leader and upper lateral branches, causing temporary cessation of apical growth and the production of numerous dwarf shoots, the typical froghopper damage called witches broom. There are several generations per year and the summer generation (November-December) appears responsible for the greatest amount of damage, although symptoms will not become apparent until the following February or March. The insect has a short life cycle of 4 - 6 weeks, and all stages of the life cycle may be found at any given time. The mirid favours feeding on young trees under 4 m high. Females feeding on young, succulent, undamaged trees contain significantly more eggs than those feeding on trees in poor condition. Insufficient rainfall and drought during spring and summer have marked effects on the growth of the insect population. Natural enemies are mainly parasites including *Euphorus praetor* Nix. and *E. nigricarpus* Szep. attacking nymphs, and *Telemomus* sp. and *Chaetostricha miridphage* Viggiani attacking eggs. The combined parasitism of the two nymph parasites generally ranges from 20% to 30% and can increase to 60% to 70% in plantations attacked by brown mirid for two successive years.

Because of the large overlap between generations, difficulties have been encountered in finding suitable insecticides with long residual effects for use against the insect, and there are no insecticides registered for brown mirid control. Some results have been achieved by aerial spraying twice at the nymph stage with 100 g active ingredient monocrotophos in 30 l water per ha at intervals of 3 weeks. Thinning in young stands with high populations of brown mirid should be postponed to permit selective removal of severely-damaged trees. Corrective pruning should be undertaken in plantations where thinning is not possible.

Batrachomorphus cedaranus (Naude) and *Anoplocnemis curvipes* F. occur often together with brown mirid and cause similar damage to wattles. Control measures recommended for brown mirid can be adopted in case of severe outbreaks.

Wattle chafers

Some 10 chafer species attack wattle over large areas. Adult beetles are leaf-feeders, but the larvae - so-called white grubs - are mainly responsible for damage attributed to chafers by feeding on roots. Common species include *Eulepida mashona* Arrow, *Hypopholis sommeri* Burm., *Monochelus calcaratus* Burm., *Schizonycha* sp., *Adoretus capicola* Burm. and *Anomala caffra* Burm. *H. sommeri*, the large wattle chafer, causes most of the damage and takes two years to complete one generation. The larvae, mostly found in the uppermost 50 mm of soil where the lateral roots occur, can cause high mortality in young

plantations and regeneration by destroying the root system.

Soil treatment is the major method of control of damage caused by white grubs. In nurseries, seedling beds can be treated by mixing lindane with the soil at the rate of 30 g of 0.6% dust per cubic metre of soil. The same insecticide can be applied over the seeds at the rate of 11 kg per hectare or in planting holes at the rate of 8-10 g per hole for line-sown or transplanted wattle plantations respectively. Control of adult beetles, if necessary, is usually achieved by spraying with contact insecticides.

Termites

Damage by *Macrotermes natalensis* Haviland, *Microtermes* sp. and *Hodotermes mossambicus* Hagen is a common and serious problem on wattles and eucalypts, and it has become more significant as large-scale plantations are established by transplanting on virgin land and use of dieldrin or aldrin is banned. Termites feed on taproots of young trees, resulting in high mortality and windthrow. Most damage is found on young wattle transplants and occurs mainly during the first year after planting, especially in the initial 3 months. The severity of termite damage may be exacerbated by drought after field planting. Replanting is often needed unless effective preventive measures are used before or at planting. Eucalypt cultivation encounters the same problem on lower situations in tropical and subtropical regions^[52].

Control of termites on wattle and eucalypt is achieved by mainly preventive measures including chemical destruction of termite colonies and application of insecticides to containerised seedlings or planting holes. The later method has been widely recommended and used with very persistent organochlorine insecticides- dieldrin, aldrin and chlordane. Field studies in *Eucalyptus grandis* plantations showed that treatment with dieldrin at planting significantly increased tree survival and mean height, and doubled the final timber yield, in comparison with untreated plots^[42,44]. Research for alternatives to dieldrin, which is no longer in use because of the environmental hazard which it poses, has found that carbosulfan - although non-persistent - when formulated as controlled release granules (CRG) has an effective period of one to three years depending on specification. Carbosulfan cannot be applied to potting soils and containerised seedlings because of its phytotoxicity, or placed at the bottom of planting holes because it is non-systemic. A comparable result is obtained by applying the insecticide mixed with soil around the taproot of transplants at field planting at the rate of 1 g a.i. per tree of 9.4% CRG^[39, 53].

Other important insects

Four lappet moth species, *Anadiasa punctifascia* Walk., *Braura truncata* Walk., *Gonometa postica* Walk. and *Pachypasa capensis* Aur., have been reported as common pests on wattles and cause defoliation every three to six years. There are one or two generations per year. Larvae of these species, except those of *G. postica*, usually congregate in clusters on stems in daytime and on leaves for feeding at night. Outbreaks can be controlled by spraying the larval clusters with contact insecticides.

The cutworms *Agrotis segetum* Schiff. and *Euxoa longidentifera* Hmps. are common pests of seedlings and very young trees throughout wattle-growing areas. The larvae live in the soil and move onto the ground at night for feeding by cutting seedling stems just above ground level. Control of the cutworms can be achieved by application of toxic baits in nurseries or spraying cypermethrin onto the soil surface at the rate of 125 ml 20% e.c. in 300 l water^[48].

Diseases

Studies on wattle diseases in South Africa have concentrated on the gummosis complex because of its high incidence and the significant economic losses it causes. Few references on other diseases are available, especially since the mid-1970s. The following is only an introduction to wattle diseases.

Physiological diseases

Dieback: Boron deficiency is known to cause disease in field crops in South Africa. It is reported that black wattle seedlings grown in a culture solution lacking boron and manganese exhibit 'silver leaf' symptoms. However, no disease condition due to deficiency of any minor element has been observed in plantations.

Boron deficiency is considered responsible for a dieback condition of wattle in Tanzania and Kenya, the diseased trees in both countries showing similar symptoms. The first symptom is a wilting and bending over of the leading shoot, accompanied by signs of moisture deficiency in the foliage. Soon thereafter, the leading shoot dries and turns brown, the younger leaves are shed, and discoloration appears in the inner phloem tissues nearest the wood and spreads rapidly downwards. Simultaneously, death of the inner bark tissues occurs in the branch axils, and necrosis may spread upwards to merge with the dead tissues above. Death of the tree may follow quite quickly. Overgrowth of dead or damaged tissues from adjacent areas which are still healthy may take place during the rainy season and, if this callus tissue develops around the stem, recovery may be complete.

If it does not, the tree will probably suffer a further attack in the following dry season. Dieback is usually

most severe in the second dry season in the life of the stand and little or no dieback occurs after the third year. The disease is generally less common in clean plantations than in those where there is much couch grass, and its effects are usually more marked on exposed than on sheltered sites.

It has been reported that soil dressings of up to 185 kg/ha of borax not only bring about a very marked reduction in the incidence of the disease but also stimulate growth of the wattle. As dieback is closely correlated with rainfall and appears only at irregular intervals in most areas, it is considered that the adoption of borax dressings as standard practice would be uneconomic. It is recommended, therefore, that plantations be left at a density of about 4900 trees per hectare until the end of their second dry season, after which they are thinned to a final density of 1483 trees per hectare, removing all affected trees in the process. In areas where this silvicultural policy fails to secure an adequate final stand, corrective pruning of affected trees accompanied by borax dressing at a rate of 34-45 kg/ha is recommended.

Leaf shedding: Very extensive leaf-shedding, causing the trees to become temporarily almost completely defoliated, sometimes occurs in plantations between one and four years of age. Well-managed stands which are above average in vigour are most commonly affected, and the condition develops quite rapidly, the foliage on apparently healthy trees taking on a golden - yellow colour and being shed, often within a period of little more than a fortnight.

Leaf shedding is apparently quite distinct from the normal shedding of older leaves from the proximal portions of branches in the lower part of the crown, which commonly takes place in trees of all ages in the late autumn and early winter. Leaf shedding occurs either during the spring, or in the late summer and early autumn, and appears to progress upwards from the base of the crown and outwards along the branches, with the youngest leaves only in the uppermost part of the crown and at the distal ends of most of the branches remaining unaffected.

This condition seems to be associated with sudden changes in available soil moisture. It mostly occurs in the spring following unusually heavy early spring rains or in the summer, usually coinciding with unseasonally dry periods. Therefore this leaf shedding may be caused by a physiological reaction to sudden changes in the water relations of the trees.

Leaf shedding is not regarded as a serious disease in South Africa because it occurs relatively infrequently and affected trees normally recover their foliage within a few months, but it probably causes an appreciable loss of increment in affected stands.

Pathogenic diseases

Most of the diseases reported on black wattle are associated with fungi. Roberts^[54] listed 67 fungal species occurring in plantations. Most are Basidiomycetes collected from dead material, the only exception being the following five species found on living trees: *Amauroderma rude* (Berk.) Cunn., *Corticium salmonicolor* Berk. & Br., *Hydnum henningsii* Bres. sensu lato, *Polystictus hirsutus* Fr. and *Schizophyllum commune* Fr. Two other Basidiomycetes, *Ganoderma lucidum* and *Goniophora arido* (Fr.) Karst., have been known to infect living wattles.

The only other fungi which have been reported attacking living black wattle in South Africa are members of the Fungi Imperfecti, of which the genus *Rhizoctonia* is concerned in two serious disease conditions.

Diseases of black wattle in which a fungal pathogen is involved may be grouped into three broad categories, namely wood-rot, wilt diseases and leaf diseases. However, these categories are not specific and individual trees may show symptoms characteristic of more than one of them. This makes it extremely difficult to determine the primary cause of the disease. Leaf diseases are not common and do not appear to cause serious damage to the tree.

Collar rot is really only one manifestation of wood rot diseases. The diseased trees show rotted heartwood, and blackened, rough and fissured bark at the stem base. There are sometimes no visible symptoms, and the presence of disease is not suspected until the tree is thrown by wind, revealing the complete rotting of the wood at the root collar, just above ground level.

A *Rhizoctonia* was most commonly associated with symptoms in early stages of the disease, but as the rot became more advanced this fungus was less frequently isolated than certain Hymenomycetes, of which *Amauroderma rude* (Berk.) G.H. Cunn. probably occurred most frequently in plantations. It seems possible that *Rhizoctonia* may have been responsible for the initial infection through the root system and for killing woody tissues subsequently colonized saprophytically by Hymenomycetes. This theory, if correct, would explain the cryptic form of collar-rot referred to above, in which no fructification appears, as being due to infection by *Rhizoctonia* alone with no subsequent colonization of the dead wood by Hymenomycetes^[55].

The symptoms of wood-rotting also appear on the upper stem of wattle. Some investigations found cases of stem wood-rot in living trees in which *Schizophyllum commune* Fr. was identified as the causal organism, having gained entrance through pruning wounds. Sherry has also observed this fungus, as well as *Amauroderma rude* and

Ganoderma lucidum Karst., fructifying on the stem of living wattles which did not at the time show the marked black-butt condition indicative of an advanced stage of wood-rot or gummosis disease, thereby suggesting that the primary infection had been due to these fungi.

One form of wilt, the most serious outbreak of which occurred in plantations in Natal between 1932 and 1935, was characterized by initial symptoms in the form of general chlorosis or slight withering of the foliage over the entire crown or by the sudden death of the foliage on one or more branches. These symptoms were followed, in a period varying from 5 to 15 days, by the death of the tree. The disease spread centrifugally, often killing quite large groups of trees.

Several fungal species and an unknown bacterium have been isolated from wood of withering trees. *Rhizoctonia lamellifera* Small is possibly the causal organism of the disease.

No serious outbreaks of the disease have occurred since 1935, although cases of individual trees suffering from a wilt disease of this type have been observed in plantations in many wattle-growing areas. This suggests that the disease has always been present in plantations, and some combination of predisposing factors may have been responsible for the epiphytotic outbreak in 1932.

Another form of wilt is characterized by reddening of the bark and sudden wilting of the leaves, followed rapidly by death of affected trees, without gumming. *Fusarium oxysporum* has been isolated from wood and bark on several occasions, but no symptoms have been induced by inoculation with the fungus. However, a root-rotting fungus of the genus *Fusarium* is suspected of causing the disease^[56, 57].

Several weakly-parasitic fungi, including *Pestalotia*, *Fusarium*, *Sphaeronema*, *Cytospora*, *Phomopsis* and *Rhizoctonia* have been reported to be associated with dieback in a two-year-old plantation 5-6 months after a severe hailstorm. The vessels in the wood had apparently been blocked with gum and hyphae, causing the dieback^[44].

The fungal genera *Phytophthora*, *Fusarium* and *Rhizoctonia* are probably associated with the damping-off of wattle seedlings. Used as seedbed sprays, cheshunt mixture and bordeaux mixture are equally effective in controlling damping-off. The application of diluted bordeaux mixture containing 0.5 g CuSO₄ per litre at the rate of 2.2 l/m² of seedbed area is recommended because the constituents of the fungicide are readily available, the treatment is the cheapest and it is simple to apply^[57].

No investigations have demonstrated any bacterial diseases in black wattle. Although a few bacterial

species have been isolated from diseased trees, inoculations of healthy trees with suspensions produced no disease reaction.

Tissue culture methods used in virus research have given indications that a virus is likely to cause blind pocket lesions, one form of the gummosis complex.

Gummosis complex

The disease with the highest incidence resulting in the most serious damage to wattle in South Africa must be the gummosis complex, which can be seen on trees of different ages in all wattle-growing areas. This disease has proved a puzzling phenomenon for many years because of the many forms in which it occurs, the only feature common to all being the exudation of gum. Now, through investigations into environmental conditions, silvicultural practices, physiology of host trees and etiology of the disease, it is known that gummosis in wattle is a complex of different diseases.

Many species of *Acacia* exude gum following mechanical damage and physiological or pathological stress. Pathological gumming in black wattle is clearly a defence reaction to the entrance of a pathogen into the bark. Penetration of the pathogen induces rapid death of host cells around the point of entry, thus totally preventing further advance of the pathogen. The phellogen over the dead area is less active than elsewhere, and in some cases it completely changes into cork. The tensions imposed on this weakened tissue by normal growth create the lesions through which gum exudes.

Apart from the exudation of gum from wounds following mechanical damage caused by adverse climatic agencies, boring insects and cultural operations, forms of gummosis attributable to pathological causes are listed below:

- i. Speckled lesions: A large number of small lesions appear on the bark of the stem and small drops of gum are exuded from each of these. If the tree recovers, small holes or minute cracks are left in the bark.
- ii. Soft blister lesions: Only a few blisters are found on a tree, and gum exudes when they rupture. The blisters are sometimes interconnected by long canals containing gum. When the lesions heal, the bark over them dries out but does not become discoloured.
- iii. Hard blister lesions: Only a few hard blisters are found on the stem of a tree. The bark over them is apparently healthy, but callus tissue and a little gum is found.

- iv. Blind pocket lesions: The stem bark is superficially healthy, but exhibits numerous vertically-elongated depressions. Beneath these, the bark is found to have proliferated into similarly-shaped depressions in the wood, in which very little gum is found.
- v. Mottled lesions: Patches of dark brown to black, dead or dying tissue appear - often on the green bark of young trees - with cracks within them, which exude gum copiously. These patches sometimes remain isolated, but occasionally spread and eventually cover the greater part of the stem.
- vi. Tongue lesions: This form consists of brown to black tongues of dead bark extending upwards from the base of the stem. Under favourable conditions copious gum is produced in advance of tissue death.

Mottled and tongue lesions are considered to be the initial stage of black-butt, the most serious disease in the gummosis complex and which can affect as many as 20%-70% of trees in mature wattle plantations in the summer rainfall region. The mottles occur mainly on trees one to four years of age. They usually appear initially on one side of the stem at heights of 18 to 120 cm above ground as roughly circular areas of dead or partially-dead bark, ranging from 0.8 to 9 cm in diameter. Cracks develop on their perimeter through which gum flows profusely during the summer rainy season. The gum varies in colour from pale to dark golden yellow except in rainy periods when it may be almost water-white. The disease spreads over the stem of affected trees through tongue-like extensions of the original mottles, which usually remain narrow and confined to one side of the stem, but sometimes broaden and occasionally encircle the stem, causing the death of the tree. The mottled tongues invariably extend upwards and develop at a rate of 18-55 cm per month during an 8-month growing season on 2-3-year-old trees, but only 9-19 cm per month on old trees. In trees three years old or less which are affected by mottled gummosis, healing may take place quite rapidly through callus formation at the perimeter of the depressed areas, resulting in the production of new phloem tissue beneath the dead layer, while lesions on older trees heal less readily. In severe cases of this condition, gummosis may also occur on branches and roots.

Diseased bark appears depressed and its moisture content is lowered at the time of harvesting, thus causing difficulty in stripping. Moreover, bark affected by gummosis disease does not find a ready market because of the belief that it contains less water-soluble extractives and that it has a deleterious

effect on the colour of the extract. Analysis of 27 pairs of diseased and healthy bark samples indicated that, as compared with healthy bark, bark showing black-butt had a lower percentage of tannin and non-tannins, an increase in both red and yellow colour units and a higher moisture content in the air-dry state^[59].

The first report on an investigation into the possibility of a pathogen being responsible for gummosis of black wattle in South Africa was published in 1914. However, not until the 1960s was some progress achieved, inoculations with gum from diseased trees and injections of extracts from diseased bark producing lesions typical of the gummosis disease. A few years later, inoculations with isolations from bark showing mottles or tongues induced typical disease symptoms. The successful re-isolation of the pathogen confirmed its role in the disease.

Neither fungal nor bacterial pathogens have been isolated from the blind pocket lesions. Studies of leaf extracts with the electron microscope showed that trees with blind pocket lesions contained particles of a size and shape similar to virus particles, whereas healthy trees did not. However, attempts to mechanically transmit the disease by the lesion method to *Cucurbita* and *Nicotiana* leaves failed, possible because of the high tannin content of the bark^[58]. Further studies were undertaken by tissue methods used in virus research; samples of the bark cambium of diseased trees were taken for sterile culture on Wolter and Skoog medium. Initially this produced a certain amount of callus tissue, but the callus soon developed brown patches with gum and died after periods of two to four weeks. It was also found that the higher the point on the stems of diseased trees from which the bark cambium was taken, the longer the callus tissue survived in culture. These would suggest that a virus is involved in the disease and that infection originates in the roots.

Pestalotia crassiuscula (Steg.) Guba was found in eight out of seventeen isolations from hard blister lesions^[58].

Reports by Zeijlemaker indicated that *Phytophthora nicotianae* var. *parasitica* (Dastur.) Waterhouse was responsible for the black-butt expressed as mottled or tongue lesions. He stated that both of the lesions contained the same fungal species of which *P. nicotianae* var. *parasitica* was the most abundant. Using these isolations, inoculations of healthy wattle trees with *P. nicotianae* var. *parasitica* or with mixtures including this fungus gave a significantly higher incidence of disease than the controls, whereas it was not the case with *Pestalotia*, *Fusarium* or *Rhizoctonia*. The pathogen has been successfully re-isolated from the diseased trees^[58, 60].

In two series of trials using isolates obtained from wattle, inoculations induced mottled lesions all over

the stem and the characteristic tongues which extended slowly up and down the stem respectively. The different symptoms induced by *P. nicotianae* var. *parasitica* was probably due to the effect of differing climatic conditions in inducing different modes of infection by the pathogen. Infection by zoospores of the pathogen may produce cracks and mottled lesions. Tongues, however, are probably the result of mycelial infection. The selected medium used since 1969 raised the recovery of *Phytophthora* to a much higher level.

Attempts to induce disease symptoms in seedlings of wattle were successful only when the tissues of the stem were damaged and when infection was made by zoospores. Two weeks after inoculation, symptoms were observed on infected plants as a blackening of stem tissue up to 1 cm away from the inoculation wound. Control plants and treated plants in which disease symptoms did not develop showed a slight, brownish discoloration of the tissues. Although the symptoms were obvious on trees with green bark, they are rarely observed under field conditions in trees younger than one year of age, probably because there are few wounds from mechanical damage or splitting of bark due to vigorous growth in very young seedlings. No disease was induced either by placing mycelial discs and zoospore suspensions in the soil in which seedlings were grown, or by wrapping mycelial discs around the bases of the seedling stems after these had been damaged by scraping with a scalpel.

P. nicotianae var. *parasitica* has the high optimum temperature of 32°C for vegetative growth. The mycelium is killed by prolonged exposure to temperatures below 4°C, and overwintering probably takes place by means of thick-walled spores. The onset of warm spring rains induces germination of resting spores, giving rise to sporangia in which zoospores are borne.

Under laboratory conditions, a mass release of zoospores takes place from the sporangia if temperature falls from the region of the optimum to about 4°C for 25 minutes and then returns to the original level. Such a temperature fluctuation often occurs between day and night during spring in the wattle-growing areas of Natal. In addition, the spring rains provide the water which is essential for the dispersion and germination of the motile zoospores. Therefore, the highest incidence of infection is likely to occur in plantations at this time. There are two compatible mating types of the pathogen. Both mating types are common and probably occur naturally in a 1:1 ratio; thus genetic material may be freely exchanged at sexual reproduction and new races of differing virulence to the host easily arise. In any breeding programme, therefore, selection for resistance to gummosis depending only on a specific type of hypersensitive reaction of the host plant is not recommended.

The incidence of gummosis of black wattle is obviously associated with the growth rate of trees and moisture supply. The larger, faster-growing, dominant and co-dominant trees are more frequently affected than sub-dominant and suppressed trees, and fast-growing trees on sites of high fertility usually show a higher incidence of the disease than trees on poor soils; the disease is also more common in high rainfall areas than in low, and the most severe manifestations of gummosis always occur during the summer rainy season. The fact that gummosis is rare or absent in so-called 'jungle' stands gives further support to the view that fast growth and ample moisture are prerequisites of the disease.

Fertilizing the soil, or reducing root competition in plantations and thereby making more growing space available, tends to increase the growth rate of the trees and by so doing may render them more susceptible to gummosis.

After afforestation of virgin land on which there were kraal sites, it has often been observed that trees planted on such sites suffered from gummosis so severely that the circular outline of the original kraal was indicated by the dead and diseased trees. Studies on application of superphosphate showed that gummosis incidence increased with fertilizing rates highly significantly^[47, 62] and the increase in growth and yield resulted from repeated application of fertilizer was usually accompanied by a significant increase in incidence of the gummosis complex^[63]. It has been also reported that application of nitrogen fertilizers to black wattle in South Africa cannot improve growth, but increases gummosis incidence significantly.

Results from two well-designed trace element experiments demonstrate that gummosis incidence, scored at harvesting, was significantly decreased by application of copper, boron and manganese^[64]. It was reported that fungicides containing copper and manganese induce the motility of *Phytophthora* zoospores^[65] and that growth of *P. nicotianae* var. *parasitica* was noticeably inhibited by concentrations of Mn of 100 ppm and higher. Several statistically-designed field trials have demonstrated a marked influence of stand density and thinning regime on the incidence of gummosis^[41,42,47,62,66]. The incidence is decreased with higher initial stand densities, properly delayed thinning and by the use of select seed. Disease incidence is increased by fertilizing.

The incidence of gummosis can thus be limited, without appreciably affecting quality and quantity of bark and timber, by cultural practices which prevent unduly rapid growth in plantations and by avoiding mechanical injury to the trees, especially at periods when conditions for fungal attack are at an optimum. Sometimes - depending on site conditions and initial

density of plantations - thinning may be best delayed. Weeding and pruning should be carried out in autumn or winter.

Gummosis can be prevented, to large extent, by painting the base of young trees with bordeaux mixture. When one-year-old trees were painted with this mixture up to 1.9 m from the ground monthly for a period of 15 months, 14% of trees contracted the disease in treated plots, cf. 35% in control plots. The effect of the bordeaux had persisted one year later. For effectively preventing the disease, painting should be repeated four times. This measure would be uneconomic in practice. Moreover, painting 3-4-year-old trees showed no beneficial effect, probably due to infection having occurred at an earlier stage.

The most successful control of gummosis has been by selecting and breeding trees resistant to the disease. In South African breeding programs for black wattle, started in the 1940s, particular emphasis has been placed on resistance to gummosis. Since improved seed was first produced in 1968, all progeny test results have confirmed that selection for resistance to gummosis has been very successful. The latest progeny trial tested 59 families from a total of six seed orchards with one commercial seedlot as control[63]. At one year of age, the mean disease incidence in trees from selected seed was 9%, while in those from the commercial source it was 17%. The corresponding results were 9% and 27% respectively at 6.5 years of age, with the lowest incidence being less than 4% for a few selected families. The difference in incidence between the various orchards was not significant.

Trees raised from selected seed may have a smaller diameter and height than those from commercial seed, but due to much lower gummosis incidence, better stem form, higher survival and better stripping characteristics, the final bark yield per hectare is not adversely affected.

Intensive cultivation will increase the growth of trees raised from select seed. Use of select seed instead of commercial seed in establishment of wattle plantations allows intensive cultivation, which improves the growth rate considerably, without fear of increasing disease.

There are six seed orchards of black wattle in South Africa at present; these yield 300 kg of select seed annually. If this amount of seed were to be used efficiently, the area established by transplants raised from select seed would account for one third of the total area re-established annually. Actually, however, it makes only up one tenth of the latter, mainly due to incorrect and wasteful practices in the nursery and in the field. To use the limited supplies of select seed most efficiently, concerted efforts should be made to improve nursery techniques and field planting.

Fire

Black wattle is not very inflammable, and the fire hazard in first-rotation crops of this species is very low because of the absence of ground cover. In regenerated stands, however, the ground cover is usually denser, and together with slash from the previous crop it provides sufficient fuel to increase the risk of fire. The period of maximum fire hazard coincides with the dry season and strong, dry prevailing winds. The fire risk is greatest from December to February in the winter rainfall region, from April to May in the continuous rainfall region, and from August to October in the summer rainfall region. Only a few small-scale, scattered, or rather larger but not extensive plantings of black wattle exist in the winter and continuous rainfall regions, and fire damage to them is relatively infrequent. More than 90% of the total area of commercial wattle plantations in South Africa is situated in the summer rainfall region, in which about three-quarters of the total annual precipitation is recorded from October to March. The ground vegetation in plantations consists mainly of perennial grasses and leaf-litter. Day temperatures are often quite high during winter when rainfall is normally at its lowest, these factors together with the prevalence of hot, dry northerly winds between August and October create peak hazard conditions at this time of the year.

Fires which escape from burning slash and natural grassland near wattle stands are responsible for most of the plantation fires. Such grassland in the summer rainfall region is usually burnt during the August - November period to provide spring grazing. As the risk of runaway fires is considerable, such burning should be well controlled. It is essential to avoid burning when environmental conditions are such as to introduce undue risk. Essential burning of slash after stands have been harvested should be undertaken in the late summer or early autumn. Slash burning during (the dry) winter or spring is extremely hazardous, since partially-decomposed organic matter in the surface soil may be ignited. Such material may smoulder for considerable periods unnoticed until it reaches dry fuels on the surface and break out again. Burning of grass for fire-protection purposes must be carried out after the beginning of winter and completed before the end of July. Burning of grassland for spring grazing can be done only after at least half an inch of rain has fallen on the area within a period of 24 hours, and must be completed within two or three days after such a fall of rain.

Early detection and speedy suppression action are factors of prime importance in the successful control of plantation fires with minimum loss. The former is best achieved by means of look-out towers and efficient telephone and short-wave radio communications, and the latter by organization of

trained fire-fighting teams equipped with basic fire-fighting tools and some form of transport.

Roads around and in plantations may be converted into major firebreaks by clearing breaks at least 4.5 m wide on either side in addition to clearing the actual road surface. Such cleared roads not only enable fire-fighting equipment to be conveyed rapidly to the site of a fire, but also prevent the spread of plantation fires.

Wattle foliage is easily killed by heat, and crowns of trees will sometimes be damaged by radiation from flames of a ground fire burning 9 - 12 m away from them. Trees up to three years of age, with stem bark still relatively thin, are also easily killed by heat of a ground fire. Trees older than this usually survive a light ground fire, but their growth will be set back by infection by wood-rotting fungi at the base of the stem. In plantations which are very grassy or infected with woody weeds, ground fires may generate heat sufficiently intense to kill large trees with relatively thick bark, and the ground fire may even develop into a crown fire. Trees eight or nine years of age, however, will usually have suppressed the ground vegetation completely. The brushpiles and most leaf-litter also decompose by this time, and thus severe ground fires are rare. However, such mature stands are likely to be invaded by crown fire from adjacent stands.

Fire-damaged wattle plantations, when less than five years old, are probably worth retaining only if survival is over 90% or, if over five years old, if survival is over 70%. Mature or immature plantations severely damaged by fire should be harvested immediately; any delay will reduce the market value of the timber because of its increasingly unattractive appearance.

Climatic agencies

Wind

Wind damage is generally limited to bent or broken trees. Where the degree of bending is small, the tree may straighten to some extent and damage will be confined to a slight crookedness of the stem. If the upper part of the stem is bent over at right angles, no such recovery takes place. The bark on the upper side of the stems of trees bent in this manner becomes sun-scorched and dies, thereby making subsequent stripping difficult, and the timber is of little use for anything but firewood.

Two alternative measures can be carried out after a wattle plantation is severely damaged. If relatively few trees are bent over at right angles, it is advisable to remove them in a thinning. If so many trees are damaged as to preclude their removal without reducing the stand to an undesirably low density, it is

wiser to clearfell. The loss involved in so doing will usually be less than that resulting from the reduced yield of bark and the poor quality of timber obtained at harvesting if the damaged stand is allowed to go on to maturity, especially when increased exploitation costs caused by difficulty in stripping and logging the malformed trees are taken into account.

Insolation

Young seedlings on western and northern aspects exposed to direct sunlight may be killed by insolation. Placed on the tree lines after sowing, a thin covering of dry branches with sufficient twigs remaining on them will provide shade adequate to protect newly-germinated seedlings from insolation. However, such sites should not be afforested to wattle, because they are exposed to maximum insolation, enjoy lower than average rainfall and have high evaporation rates, thus rendering establishment of wattle extremely difficult.

With the exception of that of the edge trees of a plantation, the bark of black wattle is particularly susceptible to damage by insolation. If the stems of trees inside plantations are exposed to direct sunlight, the bark on the western or northern side may be badly damaged or even killed. Apart from the loss of bark resulting from such damage, the trees are difficult to strip, and sale of their timber may be prejudiced by the presence of adherent dead bark. Felling of wattle stands should therefore always be from south to north or from east to west. If clearfelling cannot be completed during the stripping season, the bark of trees originally inside the stand will not be exposed to intense insolation.

Drought

When the soil moisture content falls below the critical level, as may readily occur where soils are shallow, wattle trees quickly show symptoms of water deficiency: pinnate leaves assume a closed position and appear silver-grey in colour. Thus, during dry periods, it is often possible to detect the presence of areas of shallow soil in plantations by the change in colour of the foliage of trees growing on them.

In areas where the annual rainfall is marginal for wattle growing occasional trees may die from drought in years in which the total precipitation is below average, and losses from this cause will naturally be greater on shallow or freely-drained soils and on hot, dry sites.

In areas with annual rainfall as low as 625 mm, wattle can survive and grow on deeper soils, but will be damaged by drought in dry years. Wattle plantations in areas where annual rainfall is less than 825 mm entail a risk of drought damage at least once in each rotation. Thus it is recommended that commercial plantations in the summer rainfall zone in South

Africa should be confined to areas where the annual average is 875 mm or more.

Hail

In the summer rainfall zone, thunderstorms accompanied by hail are fairly frequent during the rainy season. In the great majority of such storms, the hailstones are no more than a quarter of an inch in diameter and cause little damage to wattle trees unless they are driven by wind. In occasional storms some of the hailstones may be as large as half an inch in diameter, and these damage wattle even when not driven by wind. Storms carrying small stones driven by wind and those carrying larger stones- even if occurring infrequently- cause severe damage to plantations by breaking off shoot tips and leaves, and bruising or even stripping bark.

When hailstones are small to medium in size and are not driven by wind, damage will usually be confined to bruising of the bark on the upper part of the stem and breakage of succulent leading shoots, resulting in forks. In such cases, corrective pruning may be carried out in stands up to about two years of age. In stands older than this, such pruning is impractical because of the height of the trees, and the only treatment is to remove badly forked trees in a thinning if the stand density permits.

When hailstones are large or driven by winds, the bark on the stem and large numbers of shoot tips and leaves are broken. If stands less than one year of age are damaged in this manner, it may be good policy to clear the site and replant, especially if the damage occurs in spring when growing conditions are optimal. An alternative remedial treatment for young stands is to cut the severely damaged trees back to within two or three inches of the ground. Given favourable weather conditions, new shoots develop from adventitious buds near the root collar and grow rapidly; one shoot will usually outgrow the others to form a new single stem. If two or more shoots develop in competition with one another, corrective pruning must be undertaken at an early stage to allow the most vigorous and best-formed of these to develop. The trees should be cut back as soon as possible after being damaged in order to prevent nutrient reserves in the roots from being drawn upon for the repair of the injured tissues, thus leaving them available to sustain the development of new shoots. This method avoids the delay involved in clearing and replanting and is considerably less expensive, but it carries with it certain risk. If the cutting-back operation is followed by a period of dry, hot weather, many of the stumps will fail to shoot, and also some of the cut stumps may become infected by spores of wood-rotting fungi. This method cannot be attempted if the stems are more than an inch thick at their base, because it will not be possible to make clean cuts and

the bark may become detached from the wood, causing the stump to dry out and die.

When the thinner bark on the upper portion of stems is so battered by hail as to expose the wood, the damaged trees risk serious stem malformation. Corrective pruning is practicable when the trees are still small enough to enable the damaged portions to be reached with long-handled pruning shears. The most damaged portion of the stem is removed about 10 cm above a branch which is less damaged and best suited to form a new leader. Trees treated in this manner will always show a slight crook in the stem at the point of pruning, but the yield of straight timber at clearfelling will be much greater than if corrective pruning had not been carried out.

Hail damage in older plantations in which the trees are too tall for corrective pruning may vary from scarring of the bark to serious stem damage. Badly-scarred bark has a rough, corky appearance and frequently contains numerous gum pockets which usually cause it to be degraded when marketed. Stem deformation following hail, apart from reducing the value of the timber, is often accompanied by bark scorching as a result of the upper part of the stem being bent over so as to expose the bark to insolation. Thus the return from both bark and timber is reduced.

Snow

Black wattle is extremely susceptible to damage by snow. Light snowfalls can break branches and bend stems in young plantations, while heavy snowfalls may be quite devastating. In young plantations almost all trees are bent beyond the point at which they are able to assume an upright position again, with resultant bark and timber losses from sun scorch and stem malformation respectively. In older plantations, stem breakage is common, and the tangled mass of bent and broken trees makes clearance and salvage extremely difficult. As a result, it is impossible to remove all the bark from the trees and also a considerable volume of timber may be rendered unsaleable through shattering.

The severity of snow damage varies with age of tree and is affected by local topography. Damage in young plantations is generally more severe than that in older stands. Davison^[66] reported a heavy snowfall striking Natal and Transvaal in 1984. Trees up to two years old were prone to bend. Those of intermediate age showed an increasing tendency for the stem to break, while those six to eight years of age were affected mainly by broken boughs and crowns. Damage is usually less on level than on sloping ground, because the upper part of the crown of trees on sloping ground is not flanked by crowns of trees in the adjacent row below them on the slope. Similarly, trees on the edges of plantations along roads or open firebreaks will usually bend outwards. The most

serious snow damage to wattle plantations in South Africa occurred in 1905 and 1984 respectively. In the former case, in areas where heavy rains had preceded the blizzard, many trees were uprooted, but where this was not the case snow accumulating and freezing on the crowns caused extensive breakage of stems and branches. In the heavy snowfall in 1984, nearly 600 ha of plantations were badly damaged and 1768 ha moderately affected.

Frost

Cold injury to wattle plantations in South Africa is caused by either radiation frosts or extremely cold winds. In the former case, damage is usually confined to valleys or depressions in which cold air has accumulated, and may also occur at higher points where some obstruction has impeded the normal down-hill flow of cold air. Plantations may occasionally be damaged by radiation frosts at altitudes as low as 450 m, but frost injury of this type is commonest at altitudes above 1000 m. Damage by cold winds usually occurs on ridges on plateaux and is seldom encountered at altitudes below 1200 m.

In South Africa, black wattle will usually be killed by frost when minimum temperatures fall below -4°C . When wattle trees are subjected to a temperature below freezing point the younger and succulent tissues of the leading shoot and the distal ends of lateral branches are usually the first to be killed, while injury to the stem cambium may cause swellings near the base of the stem. When temperatures fall below the limit of tolerance of the trees, however, they are either killed outright or killed back to ground level. In the latter case, new growth from the root collar may eventually occlude the original frosted shoot, which will be found as a slender core of dead wood within the basal portion of the stem when the tree is felled.

In the case of radiation frosts, a zone of very cold air is formed over the surface of the ground and a reversal of the normal temperature inversion phenomenon occurs, resulting in the lowest night temperature being recorded not at the soil surface but some distance above it. It has been reported that, as a result of this phenomenon, young seedlings which are still in the prostrate or semi-prostrate stage of growth may escape injury from frost while other rather taller seedlings in the vicinity are killed. At higher altitudes, however, trees on level ground will normally not be killed by radiation frosts after they have attained a height of about 4 m in frost hollows or valleys. On the other hand, the level of cold air may rise to considerable heights, and 6-year-old trees about 12 m tall have been killed by frost in a valley bottom^[55]. The stem cambium of trees reaching certain heights may be killed by a thin stratum of extremely cold air frequently found just above tall, dense grass in plantations. Young wattle trees damaged in this manner will often show no sign of injury until, some

months later, the stem bends at the point of damage, causing the leader and crown to assume a horizontal position or even to drop to the extent of touching the ground. If the bark is cut away at the point of bending, the cambium layer will be found to be necrosed and dark in colour over a comparatively short length of the stem, but quite normal and healthy above and below this point, as are the phloem and woody tissues outside and inside the zone of dead cambium. It would seem that water movement and translocation are able to continue normally in the xylem and phloem respectively after the cambium has been killed, but that addition of new woody tissue ceases at this point on the stem. Consequently, with increasing height growth and crown development, bending takes place when the woody tissue at the point of injury is no longer able to withstand the stress involved. The intensity of radiation frosts is generally influenced by degree of compaction of the soil and the nature of the soil cover. Measurements during winter at heights of 2.5 and 45 cm above ground over different sites showed that the mean minimum night temperatures at both levels are the lowest over grass-covered soil, and successively higher over leaf-litter-covered bare soil, well-cultivated soil and unbroken, bare soil, and that mean minimum night temperature over all surfaces are higher at 45 than at 2.5 cm. Grass and leaf-litter serve as a barrier to heat absorption during the day and provide a poor surface for radiating heat at night, resulting in lower minimum night temperature over such ground than over bare soil. The latter absorbs a great deal of heat from the sun during the day and radiates this heat freely into the air during the night. Therefore successful establishment of wattle in cold areas is aided by maintaining a bare soil surface until seedlings are tall enough to escape frosting.

Any form of overhead cover which can inhibit the outward radiation from the soil surface during the night will tend to reduce the risk of frosting.

Experimental results indicate that retaining 250 large-crowned, evenly-distributed trees per ha at harvesting protects wattle regeneration against frost damage^[67].

Wattle establishment by seedlings, with their superior growth rate, has proved very advantageous in terms of frost resistance in cold areas. Some evidence of this was given by a trial on a site prone to frost. Trees were severely damaged by frost during the winter following planting, when the lowest recorded night temperature 8 cm above ground level was -9°C . Mean height of trees one month before the beginning of winter and severity of frost damage to the young trees are presented in Table 5.1. Most of the seedlings which suffered from frost were under 1.5 m high, while those over about 2 m were largely unaffected. Thus it seems that the height of the trees is a major factor influencing their susceptibility to frost^[41, 42, 68].

Table 5.1 Height and survival trees established by different techniques on a cold site

Method of re-establishment	Mean height (m)	Fraction of trees (%)		
		Killed outright	Killed back to ground level	Total
Seedling plants	1.29	7	28	35
Line-burning	0.57	10	69	79
Line-sowing	0.59	7	83	90

Damage due to cold wind is sporadic in nature and can be materially reduced by planting coniferous shelter-belts at right angles to the direction of the damaging wind. Such belts should consist of two rows of trees, spaced at least 6 m apart in either direction. Given the species used attain a height of at least 18 m, the belts should be sited about 140 m apart. In practice, however, it is wiser not to establish wattle plantations on sites liable to suffer injury from strong cold wind.

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Chapter 6

Black Wattle Plantations in South Africa: Genetics and Breeding

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Historical review

The first recorded work to develop superior strains of black wattle by selection was by Osborn in Natal, South Africa, in 1927. Seed collected from some 300 phenotypically-superior mother trees selected in commercial stands were sown in progeny trials in the four years 1927-1930. In reporting the results of the trials, Osborn (1931) stated that some progenies showed remarkable uniformity, several showing superior characters in respect of vigour, form and resistance to attack by froghopper. He also reported segregation for leaf colour in seedlings and described three recessive types in which chlorophyll was entirely or partly lacking. He was unable, however, to determine whether black wattle was predominantly cross- or self-fertilized.

Subsequently Philp decided to use the green wattle (*Acacia decurrens*) in the initial stages of genetic and breeding studies because of the much shorter period elapsing between fertilization and seed ripening than in *A. mearnsii*. On the basis of segregation for various leaf characters in green wattle, Philp and Sherry

(1946) concluded that this species was naturally cross-pollinated in plantations to the extent of between 85%

and 95%. On the assumption that the lethal and deleterious recessive seedling characters observed by Osborn(1931b) in natural progenies of black wattle differed from normal by being homozygous recessive for a single pair of genes in each case, they stated that Osborn's data indicated a natural out-crossing rate of between 80% and 94%, with a mean of 86%. On the evidence of counts of recessive characters made by themselves in six natural black wattle progenies, however, they expressed the view that the degree of natural out-crossing in black wattle might be as high as 98%.

Philp and Sherry (1949) reported successful crossing of green and black wattle, and stated that most of the characters in which the two species differed were quantitative and that those which were measured showed polygenic variation within each species. Although there might be oligogenic differences between them, the principal differences probably lay in their having different systems of polygenes. They considered also that the genetic evidence supported the view that black and green wattle were distinct species and not varieties of one species as was once thought^[1].

Provenance trials

Although species trials provide invaluable information for matching species to site, they do have limitations, especially with regard to species with a wide natural geographic distribution. Such species have evolved strains or races which are adapted to different geographic and climatic conditions. Trees of a certain species growing in one region may not be adapted to another region in which different populations of the same species grow. These different populations of trees form seed sources or 'provenances' of the one species. Hence provenance selection is one of the basic approaches to tree improvement.

Black wattle naturally occurs in south-eastern Australia between latitudes 34°S and 43°S, and at altitudes of 0 to 850 m. Some populations are adapted to coastal lowlands, whereas others grow successfully in cool highlands. The wide distribution of black wattle in a diverse environment provides great potential for selection.

Black wattle, in its natural habitat, occurs as an understorey species in eucalypt forests. This harmonious co-existence is absent from single-species plantations in South Africa, where imported black wattle populations are subjected to new climatic and silvicultural circumstances. Strong selection pressure is exerted by a changed ecological environment and repeated, and possibly intensive, artificial selection.

South African populations should thus be better than newly-imported seed from Australia because of selection over half century. The processes of selection, propagation and further selection indeed developed improved populations with uniform growth, high tannin yield and good stem form. Nevertheless, systematic exploration of provenances from throughout the natural range in Australia still has the potential to reveal provenances with high tannin content and resistance to factors such as cold.

In 1957, Sherry systematically collected seed from selected individuals throughout the natural range of black wattle. Parent trees with more than average vigour, free of damage by insects and disease, and with a well-developed stem in natural stands were selected and seed from each was sown separately. As results from a small number of families cannot reliably represent provenances as a whole, bulk samples was also made by mixing equal quantities of seeds from 10 to 20 individual trees within each population of interest.

Three large provenance trials of black wattle were established with the following results^[2, 15, 11].

Vigour

Height and diameter are commonly used as indexes of the vigour of black wattle. Although the two groups of provenances, Australian and local, did not differ significantly from each other, within each group there were large differences between families. As a result, it was expected that vigour would be highly improved by selecting the best families within the best provenances^[3].

Stem form

Stem form was recorded in five categories numbered 0 to 4. Trees having excellent form with straight stems free from forks were rated as 4, and those having poorest stem form were rated 0.

At 9 years of age the average rating for the whole trial was 45% with a range from 27% to 70%, and a mean of 37% for the commercial seedlot. Although there was no significant difference in stem form between the Australian and the local groups, or between these groups and the commercial seedlot, there were differences ($p=0.01$) within each group. In the local group, seven of the families were better ($p=0.05$) than the commercial seedlot, four of these being derived from parent trees selected from the best progeny in an earlier open-pollinated progeny trial. In the Australian group, only four families were better than commercial, two of these being from Tasmania. The heritability of family means (h^2_f) for stem form was 0.77^[3].

Bark biomass and tannin yield

Bark biomass and total tannin yield per acre are influenced by many factors.

The local families had significantly thicker bark ($p=0.01$), higher tannin content ($p=0.01$), and more bark per tree ($p=0.05$) than the Australian ones (Table 6.1). However, the incidence of gummosis at maturity was significantly lower ($p=0.01$) in Australian

families than in local ones. Although in the final yield of bark per unit area the lower incidence of gummosis and better survival in the Australian group may be some compensation for this, bark from the Australian families must be considered commercially inferior to that from local seedlots as bark thickness is a criterion of quality in grading, and low tannin content increases unit costs in the extraction process^[4].

Table 6.1 Summary of results of progeny trial at 9 years of age^[4]

Origin	Number of families	Height (ft)	Diameter (in.)	Bark thickness (mm)	Gummosis (%)	No. of trees stripped	Bark /tree (kg)	Bark /acre (kg)	Tannin (%)	Tannin /acre (kg)
Australia	19	54.7	5.7	4.56	27.2	22	20.82	7112	34.9	1290
Local	28	53.9	5.7	5.24	34.5	20	22.45	7011	38.0	1412
Commercial	1	51.8	5.0	4.85	33.4	15	22.59	5182	36.8	955
<i>A. silvestris</i>	1	56.7	5.4	3.46	12.4	19	16.24	4775	27.6	701
Whole trial	49	54.2	5.6	4.98	31.2	21	21.68	7011	36.6	1341

Table 6.2 Gummosis incidence at ages 3 and 8 years^[5]

Group	No. of families tested	No. of families with decrease in gummosis	No. of families with increase in gummosis
Australia	19	16	3
South Africa	28	6	11

Incidence of gummosis and its early prediction

From the point of view of selection, differences in gummosis between families and their ability to recover from this disorder must be considered. Australian families had, on the whole, a significantly higher ($p < 0.01$) incidence of gummosis in early life than the local group. However, with increasing age the disease incidence remained constant in the Australian group while increasing in the local group (Table 6.2).

As a result, an assessment of families based on a single early recording may be misleading, resulting in the wrong families or parents being selected for inclusion in the breeding program. Despite the element of uncertainty inevitable in early assessments, it is indeed possible to predict the incidence of gummosis at the time of felling from earlier observations, and such predictions are very necessary to speed up breeding programs^[5].

A trial to determine the reliability of early assessment was planted in 1959 and was assessed several times. The final records at 9 years of age were compared with recordings made at approximately 3.5, 5.5, 7.5 and 8.5 years of age. The correlation with the final incidence was highly significant in each case, and increased with age ($r = 0.50, 0.80, 0.96$ and 0.95 respectively). From the evidence available, a reliable assessment for gummosis should be possible at approximately 7.5 years of age and a reasonably good assessment at just over five years, or half rotation age. Any assessment of merit before half rotation age can be misleading^[3].

Resistance to frost

In order to test the frost resistance of seedlings raised from seed of black wattle collected in cold areas in

Table 6.3 Frost resistance of selected introductions^[6]

Australia, a trial was laid out in November 1961. The seedlot details are listed in Table 6.3. All seedlings were raised in paper pots and planted in a latin square design, each plot consisting of single row of five plants. Height was measured in April 1962, before any frosts had occurred, and the number of seedlings surviving were counted at the same time. Frost damage was scored at the end of June 1962, using a points system, and a frost damage index was derived by dividing the total points allocated per plot by the number of seedling surviving at the scoring in April - the lower the index value, the greater the frost resistance. The seedlings from a tree growing near Cooma, New South Wales, at an altitude of 884 m suffered markedly less frost damage than those from any other Australian locality. The seedlots from medium altitude (701-335 m) from Victoria were most damaged, with a mean index value of 4.05, twice that of the Cooma seedlot. Locally-collected commercial seed actually showed a slightly higher degree of frost resistance than any except the Cooma seedlot^[6].

Another frost resistance trial planted with nine Australian provenances and three South African seedlots in 1986 showed that resistance to frost was greater in provenances from cold regions than in those from coastal regions. The Lake George and Mittagong provenances, both collected from trees at altitudes over 700 m, were shown to be very frost resistant - 89% and 56% of the respective trees were still alive after heavy frosts. The coastal provenances - Batemans Bay, Stratford and Merimbula - were frosted most severely with survival of 14%, 23% and 24% respectively. Frost resistance of commercial seedlots was similar to that of coastal seedlots from Australia. The progeny from a seed orchard in South Africa, however, were somewhat more frost resistant (see Table 6.4)^[7].

No.	Seed source	Altitude (m)	Latitude (° 'S)	Mean height (inches)	Survival before frosting (%)	Frost damage index
1.	Near Cooma, New South Wales (1 parent)	880	36 16	33.5	86	1.69
2.	Bogong Village, Victoria (bulk)	700	36 43	37.0	86	3.92
3.	Omeo Highway, Victoria (bulk)	610	37 06	25.5	66	4.22
4.	Germantown, Ovens Valley, Victoria (bulk)	520	36 43	31.5	82	3.57
5.	Lal Lal, Victoria (bulk)	370	37 40	32.0	78	4.08
6.	Mount Nowa Nowa, Victoria (1 parent)	340	37 44	31.5	68	4.44
7.	Between Granbrook and Applawn, Tasmania (1 parent)	110	42 00	36.5	92	3.62
8.	Near Swansea, Tasmania (1 parent)	15	42 07	36.0	96	3.51
9.	Natal, South Africa (bulk commercial seed)	-	-	36.5	92	3.44
Standard error				2.0	3	0.18
Significant difference (p=0.05)				5.8	8	0.52
Significant difference (p=0.01)				7.7	11	0.69

Table 6.4 *Acacia mearnsii* provenance trial for frost resistance^[7p.2]

Provenance	Survival(%)
Lake George	89
Mittagong	56
Cann River	43
Seed Orchard	42
Omeo Highway	34
RSA Commercial	33
Bombala	32
Kyneton	29
Merimbula	24
Stratford	23
RSA Cape	17
Batmans Bay	14
Trial mean	39
S E	11
LSD _{0.05}	30

Progeny testing

Seedlings (families) from individual plus trees are raised for planting in large replicated trials at several locations. Assessment of growth of these offspring in the progeny test enables the breeding value of the plus trees to be calculated. This information is then used to remove the worst parents from the seed orchard, thus upgrading the quality of the seed obtained from the remaining better trees. Progeny testing was recognised as a major tool for tree breeding several decades ago.

Information from progeny tests is also used to estimate genetic parameters, e.g. to determine the amount of heritable variation among individuals, whether certain growth characteristics are genetically correlated, to test the stability of families over several locations (genotype x environment interaction), to estimate genetic gain and to determine the possibility of assessing important traits at an early age. This

information is useful in planning and developing the breeding program.

Progeny tests also serve as a source of selections for the next generation of plus trees. The families are ranked according to their performance with regard to the features under selection. The very best individuals from the best families will form the nucleus for the next generation seed production population, i.e. the next advanced-generation seed orchard. The offspring of this breeding population is again established in progeny tests to provide the source for the subsequent generation, and so on^[8].

During the 1950s and 1960s, a series of half- and full-sib progeny trials was established in South Africa for two purposes: first to estimate genetic parameters and second to provide superior seed for plantations. The results indicated that mass selection was efficient. Individual-tree heritabilities were estimated to be: tannin content 0.55, gummosis 0.29, bark thickness 0.22 and diameter 0.14.

Progeny trials of half- or full-sib families showed the great potential for selection. Height and bark tannin content increased by 12% and 8% at 3 years of age respectively, reflecting additive genetic effects.

In addition, trial results showed that early selection could be undertaken with confidence. In one of the trials, for bark thickness and tannin content, the correlation coefficients between 5.5 and 10 years of age were 0.88 and 0.92 respectively, compared with 0.77 for diameter between 3.5 and 10 years. This indicated that assessment at five years of age was reliable for plantations grown on a ten-year rotation^[6].

Mating designs used in progeny tests of black wattle

Open-pollinated mating

The easiest and least expensive means of creating a progeny population is to use open- or wind-pollinated offspring from selected parents. The method simply consists of collecting open-pollinated seed from the parent trees that are to be tested. Seed may be collected from parent trees growing in natural stands or plantations and also come from genetic tests, or from genotypes established in a seed orchard. [It is important, however, to know and take account of the nature of the male population when interpreting the results of the test.] This method has been widely employed for black wattle progeny testing since 1950 in South Africa.

Polycross (pollen mix) design

In a polycross design, each female parent is crossed with a mix of pollen from a number of male parents. Generally, a considerable number of pollens are included in the mix to ensure that female parents are pollinated by a representative sample of other parents. Several variations of polycross design have been proposed, one of which was used to test families in a seed orchard in South Africa. Seed was collected from individual trees of superior families in the seed orchard; equal quantities of seed from different individual trees within the same family were mixed to form a bulked family seedlot. Equal quantities of seed from those bulk families were then mixed to give a general bulk for the whole seed orchard. A total of $(n + 1)$ seedlots prepared from n families in the seed orchard will be included in a progeny test.

Tester or factorial design

This design is one in which members of one sex are crossed in all combinations with several members of the other sex. It allows a reasonable estimation of variance components and heritabilities. Specific combining ability can also be estimated for the actual crosses that are made. In 1965 a series of pollinations were made using this design. A total of 42 seed parents was divided into two groups because of differences between trees in date and duration of flowering. In one group, 24 trees used as seed parents were each cross-pollinated with three of the trees used as pollen parents, giving a total of 69 crosses of which 6 were reciprocals amongst the three pollen parents. In the second group which flowered somewhat later, 18 seed parents were cross-pollinated with three different pollen parents, giving a total of 54 cross-pollinations, again including 6 reciprocals between the three pollen parents^[9].

Full- or half-diallel design

The most comprehensive mating system available is the full diallel in which each parent is crossed to all others in every combination, including reciprocal crosses and selfs. The half-diallel is similar in design to full diallel, except that reciprocal crosses (and usually selfs) are not made and thus a total of $n(n-1)/2$ combinations are required for n parents tested. In 1966, a half-diallel design was carried out with 11 parent trees. Because of differences between individual trees in flowering time, the pollinations had to be made in two sets, the first containing 4 of the earlier flowering parents and the second containing 7 trees. Within each group, all the pollinations for a half-diallel were made. In all, 43 crosses were made for this trial^[9].

Single-pair mating

With this scheme, each parent is mated to one other member of the population; this creates the maximum number of unrelated families in each generation with a minimum number of crosses. Its use allows maintenance of a large effective population size. Since each parent is involved in only one cross, it is not possible to estimate general combining ability. However, specific combining ability can be estimated. This mating was often jointly employed with the other matings described above in breeding black wattle.

Testing clones of black wattle

Vegetative propagation

Most plants are propagated sexually through seed, but many can also be reproduced asexually through rooted cuttings, grafting, budding, air layering, and cell and tissue culture. Grafting and rooted cuttings are very commonly used in tree breeding programs. Although cuttings of *Acacia mearnsii* root only with difficulty, some experiments using hormones have shown promise, with best rooting of 83% - 92%^[10].

The greatest advantage of air-layering is that it may retain the mature characteristics of the branch used. The resulting plants flower freely after about a year or eighteen months and with suitable cross-pollination set seed well. The fact that flowering trees capable of setting seed can be obtained quickly confers a mobility on the genetic material which may do much to solve problems of isolation and intercrossing of selected strains. One serious limitation, especially from the point of view of tree selection, has been the difficulty in rooting airlayers on well-grown trees under normal plantation conditions. The lower branches, which have often been used for air layering, are weak so that the rate of successful propagation is reduced. In addition, the average life of layers seldom exceeds seven years. Thus considering the labour involved in making them and their relatively short

productive life, air layers are of doubtful value for the establishment of large-scale seed orchards^[11].

Clone tests can only provide information relevant to vegetative propagules; they cannot give genetic information applicable to sexual propagation, particularly in quantitative characters.

Clonal tests are simple: generally at least 30 ramets of each clone were propagated by air-layering or budding. Planting was at the final spacing of 1500 stems per hectare with three or four ten-tree single line plots of each clone. In other instances recommendations for commercial plantings were followed with an initial stocking of 2500 stems per hectare to be thinned to 1500, and the clones were planted in block or in single lines depending on numbers available. The sites were prepared cleanly, kept cultivated and free of competing weeds and grasses. Fertilizer was applied at planting at the rate of 30 g of superphosphate per cutting.

Under a uniform environment, differences in traits of economic importance between clones reflect differences in adaptation of the clones to the test environment. Ramets within a clone, however, should perform uniformly in a given microenvironment because they are genetically identical. In 1985, the results of a 12-year-old clone test were reported by ICFR^[12]. On the whole, the clones were only marginally better than improved seedling stock. Since these clones were planted there has been considerable technical progress in vegetative propagation and a better understanding of the important biological problems of rejuvenation. This is particularly relevant to wattle which is not an easy species to clone and which does not coppice readily. If these problems can be solved, clonal forestry with wattle could offer an attractive alternative to seedlings provided the clones are sufficiently high yielding to make the method cost effective.

Table 6.5 Differences between selfed and open-pollinated progenies

Family	Height (ft)			Basal area (sq ft)		
	Open pollination	Self pollination	Difference (%)	Open pollination	Self pollination	Difference (%)
S27/50	24.5	19.2	22	0.054	0.029	46
S28/50	22.3	16.9	24	0.039	0.021	47
S29/50	25.1	20.7	17	0.056	0.031	44
S31/50	23.9	15.6	35	0.054	0.023	59
S32/50	22.9	19.5	15	0.056	0.037	34
S33/50	25.9	19.1	26	0.073	0.040	45
S34/50	24.0	20.0	16	0.055	0.033	39
S38/50	23.1	8.6	63	0.059	0.008	86
Mean	24.0	17.5	27	0.056	0.028	50

Inbreeding of *S₁* lines

In some circumstances inbreeding is a useful breeding method. As selfed lines become more homozygous in each generation, they may display heterosis when crossed each other. Outcrossing may be arranged

Controlled crossing

Inbreeding

Selfing

A. mearnsii is generally open-pollinated, with the percentage of outcrossing between 24% and 100%. The selfed progeny is apparently inferior to outcrossed progeny in respect of vigour, disease resistance and fertility.

In an experiment made in South Africa (Table 6.5), progenies of family No. 50 from open pollination were much better than those from self-pollination, with increases of 27% and 50% for height and diameter respectively. Any desirable selfed line could be [potentially] used operationally by vegetative propagation.

The technique for selfing is simple, i.e., selection of plus trees, isolation of flowers by bagging and re-selection among the resulting progeny to constitute the next generation. Vigorous straight plus trees, free of disease and insects, were selected from five- or six-year-old plantations or experimental stands. Just before flowering, inflorescences of the selected trees were covered by bags. The resulting seeds of individual trees were collected and raised separately. Two or three years later, the whole process of selection, bagging and re-selection was repeated. If every step in the operation worked smoothly, a new generation was expected to be created within four or five years. As practical difficulties resulting from inbreeding depression will hinder further selfing, the method is usually used in breeding a first- or second-generation selfed line. Any selfs with desirable characters can then be vegetatively propagated and finally used as material in an advanced-generation breeding program.

between widely-separately geographical or otherwise distinctive lines. The seed from first- or second-generation outcrossing might be used in plantations. Selfing, however, may result in greater inbreeding depression with a detrimental effect on bark yield (Table 6.6)^[12 p.29].

Interspecific crossing

Hybrids may have the distinction that they may be an entity that does not occur in nature. Various acacia species have such desirable characters as quickly-maturing seed, and frost and pest resistance. If these desirable traits could be incorporated into hybrids with *Acacia mearnsii* having a high tannin content, the hybrid could extend the resources for the tannin industry. Unfortunately, so far, hybrids between *Acacia mearnsii* and related acacia species have only been available experimentally, and most seem unlikely to be useful in practice.

1) *A. mearnsii* x *A. decurrens*

Much work has been done with these two species because of the considerable potential for successful hybrids. Both *A. mearnsii* x *A. decurrens* and the reciprocal cross can be successfully made, with green wattle being the preferred seed parent because of the speedier ripening of seed.

There are two major programs to cross the two species. First, *A. mearnsii* x *A. decurrens* and reciprocal crosses are made to create F₁ hybrids. Selected F₁ are then backcrossed with one of parental species. The process of selection and backcrossing is

being repeated over several generations. By this means it might be possible to develop a strain of wattle which was predominantly black but which retained some of desirable characters of the green wattle parent. The second program is initially to develop F₁ hybrids, and those F₁ selected would be intercrossed. Finally, further selection and intercrossing would be carried out in successive generations^[1,13].

a) Variation of the hybrids

In hybrid families a number of chlorotic seedlings occurred as well as normal blue-green seedlings, the degree of chlorosis varying between seedlings from yellow-green to pale green. Morphological variation in respect of leaf tips, rachis, length of rachilla, numbers of pairs of pinnae and pinnules, pinnule length, rachis length, size and shape of small pinnal leaf, and distance between bipinnal leaves, was observed in hybrid seedlings.

Segregation for a number of recessive leaf characteristics in black wattle seedlings was more variable, and segregation rates of 15:1, 9:6:1, 1.5:1 or 1:1 even for the same character were observed in some cases^[11].

Table 6.6 Inbreeding depression of progenies resulting from different pollination systems^[12]

	No. of progenies	Height (m)		Diameter (cm)		Bark thickness (mm)	Survival (%)		Stem form (%) 5 years	Gummosis (%)		Bark yield (t/ha)
		2 years	11 years	5 years	11 years		5 years	11 years		1 year	5 years	
Outcross	10	8.5	17.0	11.9	14.3	4.2	71	71	69	12.8	8.7	27.0
Open pollinated	9	8.8	16.8	11.8	14.9	4.1	80	80	69	13.7	7.7	29.2
Half-sib crosses	5	8.1	16.4	11.1	13.0	4.1	68	65	71	9.8	7.4	20.8
Commercial	1	8.7	16.9	10.9	12.8	3.8	68	58	63	43.1	26.8	17.8
Mean		5.6	6.5	5.4	8.1	2.2	18.7	20.0	-	-	-	28.6
inbreeding depression												
% inbreeding depression for 10% increase in F.		4.5	5.2	4.4	6.5	1.8	15.0	16.0	-	-	-	22.9
Mean	25	8.5	16.8	11.6	13.8	4.1	73.0	72.0	69	13.8	8.9	25.0
SE		0.20	0.37	0.49	0.58	0.15	6.49	6.74	2.51	2.94	4.01	6.46

b) Seed-maturation period of hybrids

Seed of green wattle matures in 4-6 months, whereas black wattle does not ripen until 12-14 months later. The shorter seed-maturation period of green wattle is completely dominant in hybrids between the two species, irrespective of the direction in which the cross is made, and it appears to be controlled by two major genes.

The dominant green wattle genes for quick ripening lose expression as the black wattle genetic background is increased. The combination of late flowering and rapid seed-ripening causes maturation to take place at an unfavourable time of the year: time of flowering and maturation period of seed are functionally related.

c) Fertility of hybrids

There were significant differences in the fertility of hybrids produced by different pollination systems. When crosses were made between green and black wattle using green as the seed parent, the F_1 hybrids had a rather high degree of sterility both on selfing and on backcrossing to green wattle, but they were considerably more fertile when backcrossed to black wattle (Table 6.7). It would seem that when black wattle is the seed parent, the F_1 hybrids are more sterile than the opposite cross. The basis of the difference observed may lie, however, in the characteristics of the particular trees used in the cross^[14].

2) Black and silver wattle hybrids
(*A. mearnsii* x *A. dealbata*)

The hybrid seedlings were all uniform in appearance, the first leaf being pale cream with a faint green tinge, and died without producing second leaves. This

suggested that discolour in the first leaf was fatal to the seedling.

3) *A. mearnsii* x *A. baileyana*

A. mearnsii was generally used as seed parent because of common infertility in *A. baileyana*. *A. baileyana* appears to be very resistant to damage by frost or cold winds and is, therefore, a possible source of cold tolerance. It is a very glaucous species having striking grey-green leaves, and there is a suggestion that the glaucous character may be concerned with cold resistance. F_1 hybrids showed a range of chlorotic types in the seedling stage very similar to that occurring in green and black hybrids. The leaf characters in the F_2 were approximately intermediate between the parents, while the presumed F_2 showed that a wide range of recombination. The F_2 hybrids had only a slight trace of glaucousness while in the F_2 , although the character was more pronounced in some trees, the full expression was not recovered. It was noticeable that the F_2 trees while showing the highest degree of glaucousness were closest to *A. baileyana* in leaf form and plant habit^[15].

4) *A. mearnsii* x *A. irrorata*

Scabrousness, or roughness of the surface of young shoots and the lower surface of the rachis and rachillae, is typical of *A. irrorata*, whereas *A. mearnsii* is smooth to the touch. The F_1 between these species was very much closer to *A. mearnsii* than to *A. irrorata* in the expression of this character. The F_2 families from these hybrids were, rather surprisingly, more scabrous than the F_1 parents. Most of the F_2 trees were approximately midway between the parent species in scabrousness, but considerable variation occurred. No trees as smooth as *A. mearnsii* were found, while none as scabrous as *A. irrorata* occurred. It seems that the inheritance of scabrousness is controlled by polygenes.

Table 6.7 Black and green wattle hybrids - seed set following different pollinations^[14]

Black x green hybrids	Selfed			x Green wattle			x Black wattle		
	No. of pods	No. of seeds	Mean per pod	No. of pods	No. of seeds	Mean per pod	No. of pods	No. of seeds	Mean per pod
H1/54/39	126(6)*	36	0.28	8(1)	0	0.00	8(1)	2	0.25
H2/54/6	51(7)	1	0.02	-	-	-	-	-	-
H3/54/20	4(16)	2	0.12	11(2)	1	0.09	52(2)	15	0.29
H3/54/30	0(3)	0	0.00	0(1)	0	0.00	1(3)	0	0.00
H3/54/51	0(3)	0	0.00	0(2)	0	0.00	0(3)	0	0.00
H3/54/55	27(5)	7	0.26	5(2)	1	0.20	21(1)	6	0.29
H3/54/39	140(10)	39	0.28	-	-	-	-	-	-
	360(38)	85	0.21	24(8)	2	0.08	82(10)	23	0.28
Green x black hybrids	612(35)	497	0.81	17(3)	25	1.47	236(9)	957	4.05

*Figures in brackets give the number of inflorescences.

A. irrorata had a mean number of 8.9 pairs of pinnae per leaf and of 1.2 glands per leaf compared with 14.7 and 23.5 respectively for *A. mearnsii*. In F_1 trees, the number of pairs of pinnae was approximately midway between the two species. In the F_2 trees, the range of variation extended from *A. irrorata* to *A. mearnsii*[6].

Biology of pollination

Pollination mechanism and fertility

Pollination for black wattle is mainly effected by insects, especially bees collecting nectar. Although black wattle is an insect-pollinated species, wind also plays a role.

The effect of isolating inflorescences from large insects, particularly bees, but not from wind-carried pollen, was assessed in 1958. A framework of aluminium wire (2.2 mm diameter) covered with nylon gauze with a mesh of 2.7 x 2.3 mm proved satisfactory. The extent to which the nylon gauze prevented free passage of pollinia was first tested. During the flowering season, cages were put on inflorescences on each of two species trees, one black wattle and the other *A. irrorata*. Near each cage, a comparable inflorescence was left for open-pollination. In addition, several inflorescence on each tested tree were covered with cellophane bags. Pod counts were made some time later, and the numbers occurring following different treatments are given in the Table 6.8.

From these preliminary tests, it would seem that the exclusion of large insects forms a fairly effective barrier to cross-pollination[16].

The number of pods matured per inflorescence during November and December 1960, and mean of number

of seeds per pod following different treatments from the experiment described above, are given in Table 6.9.

Grouping the four trees, the number of pods per inflorescence from open pollination was significantly higher ($p < 0.01$) than from either caged or selfed treatments, but there was no significant difference between the latter two[17].

Pollen dispersal

The distance of pollen dispersal by wind has great significance when choosing locations for seed orchards. There were no significant differences in pollen density between a point 730 m away from the edge of a plantation and the edge in moderately windy conditions.

The assessment method used is described below: Open fields bordering the eastern edge of a plantation were selected as a site having only one source of pollen and little likelihood of lateral contamination. A line of slides extending 800 yards (730 m) was placed in an approximately central position and at right angles to the plantation, i.e., running in an easterly direction. A second line of slides, starting from the same point as the first, extended 600 yards (550 m) in a southeasterly direction, i.e., at an angle of 45° to the plantation edge. In both cases, slides were positioned at 100-yard intervals. There were four slides in each position, facing north, east, south and west in the first line and north-east, south-east, south-west and north-west in the second. Slides were coated with glycerine jelly and on each slide, a rectangle, 2.75 inches square in area, in which the pollinia were counted, was marked. Over a 24 hours exposure with a wind force estimated at Beaufort Scale 2-3, slides facing south and west in the first line had a

Table 6.8 Pods formed following open-pollination, caging and bagging[16]

	<i>A. mearnsii</i>			<i>A. irrorata</i>		
	No. of inflorescences	No. of pods	Mean	No. of inflorescences	No. of pods	Mean
Open-pollination	4	71	17.75	4	102	25.50
Caged	4	1	0.25	4	9	2.25
Bagged	8	15	1.87	3	0	0.00

Table 6.9 Mean number of pods per inflorescence and seeds per pod following open-pollination, caging and selfing[17]

Tree number	Open-pollinated		Caged		Selfed	
	No. of pods	Seeds per pod	No. of pods	Seeds per pod	No. of pods	Seeds per pod
9	8.8	4.7	5.8	3.2	1.0	2.9
49	23.8	5.8	0.0	0.0	1.3	2.8
60	14.0	6.2	6.8	6.5	2.4	1.7
71	76.0	6.2	11.5	4.5	20.3	1.3
Mean	30.6	5.7	6.0	3.6	6.2	2.2

significantly higher catch of pollinia than those facing north and east, the number being 22, 19, 7 and 12

respectively. There was no difference in the catch at different positions. In the second line of slides, those

facing south-east and south-west had a higher catch than those facing north-east and north-west. Again there was no difference between the positions [18].

Establishment of seed orchards

Selection of plus trees

Phenotypically superior trees were selected in plantations over 5 years old or in existing experimental stands. The criteria used for initial selection were stem form and freedom from gummosis, care being taken that the vigour of the trees selected was not less than the average for the stand in which they occurred. (The traits for final evaluation include bark characters of economic importance, such as bark thickness and tannin content. Trees which fail to reach a certain standard in respect of these characters will be discarded.) Seed of each tree selected was collected separately, or branches were air-layered, to provide the initial material for the tree breeding program.

Designs of seed orchards

Completely randomization

The complete randomization of all the available ramets of all clones, or of family plots [to be thinned to one tree each] of all families, between all the available planting position on the site is the simplest of all designs. Care should be taken to ensure that no two ramets of the same clone or two individual tree of the same family are planted in adjacent positions within rows or columns, or where they will occur in adjacent diagonal positions. This design was employed in the first seed orchard for black wattle in South Africa in 1965.

Each plot consists of a single tree, so that the offspring of all parent trees are thoroughly intermingled. The initial stocking was 600 trees per acre. It was planned to cull, over a period of years, trees showing undesirable characteristics such as heavy gummosis, poor growth and crooked stems. The complete randomization was expected to lead to a fairly even distribution of the trees remaining when culling finished. These trees could then be used as a source of seed or for further breeding. Each tree in the layout was numbered and recorded so that the proportion eliminated from each family could be balanced [19].

Systematic arrangement

The method involved simply running the clones or families consecutively by numbers down a row and repeating the process in each succeeding row, but always re-starting the process at a point offset from that used in the preceding row. The design fits any orchard size or shape, maximizes the separation of ramets of a clone or individual trees of a family, and maintains even representation of clones or families and the optimum scatter after any number of systematic thinnings. The method was used in establishing several seed orchards of black wattle with three-tree plots and twice thinning to single-tree plots before collecting seed [3].

Hedgerow design

The basis of the design was to encourage the type of growth typical of trees growing along plantations edges, by planting at a close spacing within widely separated lines to give a hedgerow effect. Since the orientation of such hedgerows could be important, one was laid out in a north-south direction and two others, 68 m apart, in an east-west direction making the whole orchard approximately F-shaped. Each hedgerow consisted of two rows of trees 4 m apart with 2 m between trees in each row. A systematic arrangement of families from selected trees, with one tree per plot, was used in each hedgerow [20]. Although the seed orchard area in the F-shape design is larger than that in the others, the quality of seed in the former design is more uniform (Table 6.10). Progeny of the F-shaped seed orchard showed significant differences for incidence of gummosis, bark biomass and survival rate from the commercial control (Table 6.11).

Genetic gain from seed orchards

Two half- or full-sib progeny trials, planted in 1965 and 1968 respectively, were converted into seedling seed orchards (SSOs) by selective thinning and maintaining superior trees within superior families. *Acacia mearnsii* can propagate a new generation within five years because of its rapid growth and early flowering. By 1973, the third generation seed orchard had been established and, for plantation establishment, seed from the first generation orchard was replaced by seed from the second generation orchard. Several traits of major economic importance - tannin content, incidence of gummosis, stem form and survival rate - were significantly improved by this progression. No significant differences for vigour and bark thickness, however, were not found between 'commercial' and seed orchard stock.

Table 6.10 Results of open-pollinated progenies in three hedgerows of the hedgerow seed orchard^[20]

Hedge	Height (m)	Diameter (cm)	Gummosis at 5 years (%)	Bark thickness (mm)	Tannin (%)	Bark yield (t/ha)	Stand (%)
1	15.10	13.20	16.72	4.22	39.12	21.87	71.32
2	15.50	13.83	15.62	4.19	38.55	22.61	77.33
3	16.03	13.43	12.69	4.00	38.50	21.39	70.84
Bulk	15.18	12.28	14.75	4.04	38.59	20.42	70.85
Mean	15.55	13.38	14.94	4.11	38.69	21.57	72.58
LSD _{0.05}	0.47	0.92	8.61	0.51	1.33	4.17	12.46

Table 6.11 Differences between progeny of hedgerow seed orchard and commercial control^[20]

	Height (m)	DBH (cm)	Gummosis (%)	Bark thickness (mm)	Tannin (%)	Bark yield (t/ha)	Stand (%)
Commercial	14.30	12.13	40.19	3.75	38.40	9.44	38.88
Mean of experiment	15.22	12.92	18.11	4.01	38.28	19.07	67.73
LSD _{0.05}	1.21	1.77	16.80	0.52	2.63	7.31	23.21

During 1978, a trial was planted with seed from six seed orchards and one commercial seedlot to determine the extent of improvement achieved. The results at 6.5 years are presented in Table 6.12.

Differences for gummosis incidence and stem form between the commercial seedlot and seed orchards were significant. Some important economic characters, however, - growth, tannin content, bark thickness and stocking survival - were only slightly better in progenies from seed orchards than in those from commercial stands, but significant differences in growth (mainly diameter) were found between the six

seed orchards. The fact that the incidence of gummosis in all seed orchard progenies was highly significantly lower than in the commercial control is evidence of success in selection against gummosis. The selection of clones for the fourth orchard (SO-4) does not seem to have been very successful as some of them seem to rank at the bottom end of the range for some characters described. The sixth seed orchard (SO-6), which is a second generation orchard, has succeeded in reducing the incidence of gummosis and in raising the tannin content in its progeny. Although not outstanding in this trial it is still better than the commercial control^[20,21].

Table 6.12 Progenies from six seed orchards at 6.5 years of age

Origin	No. of families	Height 1 year (m)	Diameter (cm)	Gummosis (%)		Bark thickness (mm)	Tannin (%)	Stem form (%)	Stand % of Nominal
				1 year	6.5 year				
SO-1 *	1	4.07	9.19	4.24	5.26	3.79	38.30	74.15	75.0
SO-2	1	4.45	10.20	9.98	15.97	3.60	38.40	69.79	77.8
SO-3	1	4.17	10.03	10.58	9.71	4.13	39.90	70.83	80.6
SO-4	15	4.46	9.62	10.20	8.62	3.86	38.55	72.20	78.4
SO-5A	12	4.47	10.55	9.73	10.52	4.02	39.21	70.13	84.1
SO-5B	17	4.40	10.35	8.80	9.02	4.00	39.46	66.85	83.9
SO-6	12	4.52	9.72	7.48	6.85	3.97	39.51	67.53	79.3
Commercial	1	4.40	9.24	16.93	27.00	3.77	37.25	60.53	77.8
Mean	60	4.56	10.03	9.18	8.75	3.95	39.12	69.11	81.5
SE		0.19	0.45	3.54	4.23	0.15	0.87	3.13	1.78

*: SO-1, single-tree plots with 12 half-sib progenies from trees selected in 1965.

SO-2, single-tree plots with 12 specific cross progenies in 1968.

SO-3, F type hedgerow design with 6 controlled-cross progenies in 1971.

SO-4, 30 - 50-tree plots with 14 clones derived mainly from controlled crosses in 1971.

SO-5A, three-tree plots with 24 controlled crosses from 19 families in 1972.

SO-5B, three-tree plots with 25 controlled crosses from 18 families in 1973.

SO-6, three-tree plots with 11 open-pollinated families in the SO-2 orchard in 1971.

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Chapter 7

Plantation Practices in Zimbabwe, Kenya and Tanzania

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Introduction

The earliest and largest commercial stands of *Acacia mearnsii* (black wattle) are in the Republic of South Africa. Shortly after the development of the tannin industry in South Africa neighboring African countries became interested in duplicating the South African success. Many of these countries had developing wattle industries and needed tannins for leather manufacture but they were also interested in developing rural export industries. The species was tested in field trials in a number of African countries (Sherry 1971) but today the most successful plantations are in Zimbabwe, Kenya and Tanzania. These three countries have suffered the ups and downs of world market trends for tannin, with the maintenance of Zimbabwean and Kenyan plantations being somewhat neglected during their wars of independence. Today the main controller of the industry in East Africa is the British multi-national trading giant Lonrho (London and Rhodesian Mining and Land Company).

The aim of this chapter is to provide an overview the industry in Zimbabwe, Kenya and Tanzania and cover early introductions, climates, soils, nursery practices, planting, tending, protection, harvesting practices and yields, utilization and research needs. It should be noted that it is difficult to obtain accurate statistics on the industry in East Africa because of the commercial nature of the activities. The conclusion draws the chapter together by outlining past development patterns and future development trends in the industry in East Africa and seeks to find relevance in their experience to the situation in China.

Zimbabwe

Early introduction of black wattle to Zimbabwe

The first introduction of black wattle into Zimbabwe is generally believed to have been made at Cecil Rhodes's Estates at Nyanga in the Eastern Highlands and at Matopos near Bulawayo in 1902 (Sherry 1971). At about the same time, attempts were made to establish the species near the outskirts of Harare (Anon. 1956). By 1923 commercial plantations of black wattle amounted to 110 ha (Sim 1927) and, during the period 1929-34, some bark was exported from the Nyanga district. However low prices and difficulties of transport militated against the success of the venture (Anon. 1956).

The Rhodesian Wattle Company Limited was formed in 1945 at a time when vegetable tannins were in

extremely short supply following World War II. As a result large-scale establishment of black wattle started in 1946 and, by 1962, the area of commercial plantation had reached 26 000 ha, all of it in the Eastern Highlands (Fig. 7.1). Attracted by the booming industry, a number of private growers in the Eastern Highlands started to plant black wattle with the help and encouragement of the Rhodesian Wattle Company Limited (now The Wattle Company Limited) but the area established never amounted to more than a small fraction of the estate of The Wattle Company.

All plantations of *A. mearnsii* in Zimbabwe were established with seed provided initially from South Africa and subsequently from the abundant local supplies. The Australian origins of Zimbabwean plantations, however, remain obscure. Other Australian species of *Acacia* have been tried in Zimbabwe for commercial tannin production, notably green wattle, *A. decurrens*, and silver wattle, *A. dealbata*, but they both produce excessively red-coloured tannin extract that is not readily accepted by tanners.

In the latter part of the 1960s the wattle industry world-wide began to decline due to the impact of synthetic tannins and leather substitutes, and this led to a major reduction in the plantation area committed to black wattle. Most of the Wattle Company's holdings in the north of the Eastern Highlands were converted to pine and eucalypt and some of the wattle plantations in the south of the Eastern Highlands have given way to coffee and other crops. Today, the total area of commercial black wattle in Zimbabwe is about 14 000 ha, and all but about 400 ha is owned by The Wattle Company Limited (a Lonrho subsidiary). The company has also diversified into other commercial areas such as cattle raising.

Climatic zones and soils

Black wattle plantations occur mainly in the frost-free areas of the Eastern Highlands where the mean annual rainfall exceeds 1000 mm. Within this zone the altitude ranges from 700 m to more than 2500 m but the higher, cooler regions are the most suitable. About 84% of the plantation area lies at altitudes of 1500-1800 m, where mean temperatures of the hottest months are 20-24°C and mountain mists are frequent. The remaining 16% of the planted area is near the southern extremity of the Eastern Highlands at altitudes of 1100-1250 m with mean hot-month temperatures of 25-26°C. Mean annual temperatures are 15-17°C at the higher altitudes and 18-20°C at the lower.

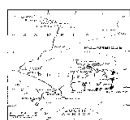


Fig. 7.1 Location of black wattle prunings in Rhodesia (now Zimbabwe) (Sherry 1971).

Soils of the principal wattle-growing areas are derived from granite, quartzite and dolerite, with textures varying from sand to clay loam. The highest yields of wattle bark are obtained from deep, well-drained soils irrespective of the parent rock.

Nursery practice

The first crops of black wattle in Zimbabwe were established by direct field sowing in ploughed and harrowed land, but 90% of the current re-establishment is hand-planted with container stock raised from local select seed or imported orchard seed.

Seed is sown in mid-August for field planting in December, or sooner if the main rains arrive early. All seed is given 'hot water' treatment before sowing. The standard technique is to boil the water and allow it to stand for five minutes before immersing the seed; when the water has cooled the seed is removed and sown directly into soil-filled polythene sleeves. Fertilizers are not used in the nursery unless sowing is late, in which case single superphosphate (18.5% P₂O₅) is applied when the seedlings are at least 5 cm tall. In some nurseries the filled sleeves are sterilized with methyl bromide a few days before sowing, but this is not universal practice. Generally, two seeds are sown per sleeve, but when seed orchard seed imported from South Africa is used (and this accounts for 35% of all planting) sowing is reduced to one seed per sleeve.

Some of the lower-altitude nurseries are troubled by white grub (*Lepidiota mashona* Arrow) which can be controlled by applications of insecticide to the soil. Few other serious problems occur in the nursery. There may be occasional damage by grasshoppers and cutworms, and some damping-off may occur in unseasonably wet weather, or from over-watering.

Seedlings spend 3-4 months in the nursery. During this period an important operation is root-pruning. It is essential to confine the roots to the container either by drawing a taut steel wire below the sleeves or by lifting the plants individually and trimming the roots. Seedlings may also be shoot-pruned to the ideal planting size of 15-20 cm if planting is delayed.

Planting

Soil preparation on sites being re-established is done manually by digging 20 x 20 x 20 cm planting holes spaced at 2.7 m between rows and 1.5 m within rows (2469 plants/ha). All planting is done in summer and each plant is given 50 g single superphosphate applied in a circle around it, about 20 cm away from the stem. Fertilizers are only applied on sites known to have

poor fertility. The polythene sleeves are always slit open and removed before planting. Site preparation on virgin land includes deep ripping, ploughing, and discing prior to pitting. Ten percent of current re-establishment is by direct field regeneration. This is achieved by stacking the slash at the required between-row spacing after clear-felling and bark-stripping, burning it, and then thinning out the seedlings that germinate from the abundant seed lying on the forest floor. The profuse regeneration after burning can be a major problem.

Cutworms are a serious problem after planting or natural regeneration and control is effected by placing a small quantity of insecticide bait around each plant, or along the seeding hedgerow in areas of natural regeneration.

Tending

Black wattle is intolerant of weed competition and the plantations must be kept free of weeds until the canopy closes at 12-18 months after re-establishment. Herbicides are expensive locally and therefore all weeding is done by hoe - immediately prior to planting, in autumn at the end of the first growing season, and finally just prior to the following growing season. The most troublesome weed is the grass *Eragrostis acraea*, which is not only a major competitor for moisture but is believed to also produce exudates that inhibit wattle growth.

Naturally-regenerated stands are 'lined out' (reduced to clearly defined rows) and then thinned to the same within-row spacing as the planted stands. This usually starts with 'two-foot spacing' (3000 stems/ha) when the wattle is 60 cm tall, then 'four-foot spacing' at 1.8 m height, followed by reduction to 2000 stems/ha at 4 m and finally to 1500-1700 stems/ha at 7 m; the final stocking depends on site, with the best sites carrying the highest numbers of trees.

Planted stands are thinned to 2000 stems/ha when stand average height has reached 4 m, and to 1500 or 1700 stems/ha when the average height reaches 7 m.

Protection

Three insect pests are of economic importance in black wattle in Zimbabwe. These are the wattle mirid or froghopper (*Lygidolan laevigatum* Reuter), the white grub (*Lepidiota mashona*) and the cutworm. The wattle mirid, a sap sucker, is currently the major insect pest and severe infestations in young wattle, which it favours, usually result in deformed growth and a consequent loss of up to a season's growth. It attacks the growing parts of the leading shoot and upper branches, causing a stunting of apical growth and the production of numerous dwarf shoots to give the trees a 'witches broom' appearance. The mirid is controlled by aerial spraying. Damaged trees usually

require corrective pruning to a single leader after new apical growth begins.

At the lower end of the latitudinal range of commercial black wattle plantations in Zimbabwe, gummosis (the exudation of gum from the base and roots of a tree) may be attributable to pathological causes or to physiological stress. No pathogens have been identified so far, and the fact that gummosis is confined to plantations established at altitudes lower than 1250 m suggests that the problem may be a reaction to physiological stress.

Frost is the most serious type of climatic damage and periodic severe frosts have caused widespread injury, especially along watercourses where trees up to 4 m tall may be killed outright (Anon. 1956). Wind and hail occasionally cause damage.

Harvesting and yields

Black wattle stands are felled at about 10 years. A prefelling thinning or cleaning may be done about 18 months before the end of the rotation. The object of this is to remove diseased and non-strippable trees to facilitate the main felling operation. It is usually necessary in naturally regenerated stands but may be omitted in those planted with nursery seedlings. This late cleaning operation does reduce competition but has little effect on the yield of the final crop.

Felling is done by axe or bowsaw during the time of the year when the bark is most easily stripped from the trees. This occurs when the sap is rising and this occurs during the warm, wet, summer months. In practice no felling is done between mid-August and mid-November, which is quite convenient because nursery and land preparation operations are in full swing during that period.

At clearfelling, the trees will have breast-height diameters of 15-20 cm, with heights up to 18-22 m on the best sites. The felled trees are de-branched and the bark is stripped as far up the stem as possible. The stripped bark is then cut into lengths of 1.2 m and tied in 50 kg bundles for transport to the tannin extraction factory. Bark should be as fresh as possible for delivery to the factory; any delays can result in oxidation and excessively red-coloured extract, or the formation of undesirable fungal mould.

Bark left in the plantation after the 'factory season' has ended is usually dried for use as stick bark. This involves careful drying of the bark in well-aerated strips to minimize mould growth. The main advantage of 'stick' bark is that it allows the factory to better regulate incoming bark for tannin extraction in that the factory needs to spread out the extraction workload and maintain a more stable workforce.

The wattle brushwood is no longer stacked on the stump lines after felling, but in windrows every fourth

row apart with the timber lying separated between the windrows for later recovery to satisfy orders for poles.

Yields of wattle bark in naturally-regenerated stands have been affected by past management, particularly the enforced neglect during the war years of 1972-79. Yields of 16 t/ha (range 8-26 t/ha) have been realized from such stands. These figures are low, but with the improved silviculture in recent years planted stands should yield about 22 t/ha, and exceed 30 t/ha on the best sites.

As a result of the distortion in age-class distribution, wattle has had to be felled at 7 to 9 years in recent seasons. Recovery of extract has consequently been low (31%) but it is expected that this yield will increase in coming years when the better-managed stands are harvested, as the age class distribution evens out, and the optimum age of 10 years at felling is achieved.

Yields of wattle timber amount to 4-4.5 t of air-dry timber for every tonne of bark recovered, i.e. 64-72 t/ha from the naturally-regenerated stands with the expectation of 80-120 t/ha in the future.

Utilization

Black wattle is grown in Zimbabwe primarily for its bark extract. All other products are secondary but the considerable amount of timber that is produced is utilized wherever possible.

Ten percent of Zimbabwe's annual production of extract is marketed locally and the balance is exported. The excellent quality and light colour of Zimbabwean extract makes the product readily acceptable on world markets.

The general stem form of wattle trees is not good (except for trees of seed orchard origin), which limits timber utilization from the plantation to short, light posts, mine timber (approx. 3 m lengths of good form) and sawn fencing droppers. Reject mining timber is also sold locally as pulpwood for making cardboard and packaging material. At one time the larger-diameter timber was used for the production of very durable woodblock (parquetry) flooring but market demand for this type of flooring is no longer significant. There is also a large market for firewood in nearby Mutare township. Currently the only other outlet for wattle timber in Zimbabwe, apart from poles, is charcoal. The quality of wattle charcoal is excellent but there is little tradition of charcoal usage in the country and production is well below annual capacity. This product does, however, have great sales potential as a domestic fuel in Zimbabwe.

Wattle timber makes good mine props, and some exports of this product have occurred in recent years.

The greater proportion, by far, of the timber produced by Zimbabwe's black wattle plantations cannot be marketed economically and is burnt during land preparation for the following rotation. This situation could change dramatically if a proposed chemical pulp mill is established, or when transport and shipping routes through the Mozambican port of Beira are re-opened. Wattle plantations could then become the most important source of the hardwood component of the raw material for the proposed pulp mill, or of chips or roundwood for direct export. Black wattle could, in the future, be grown as much for its timber as for its bark.

Research needs

No formal research has been conducted on black wattle in Zimbabwe. The industry has relied largely on the Institute for Commercial Forestry Research (formerly the Wattle Research Institute) in South Africa for advice on silvicultural matters and for the provision of improved seed. The possibility that the future of black wattle in Zimbabwe lies more in its wood than in its bark suggests that the question of formal research in this country be reviewed. Rangewide provenance testing to identify the best seed sources for Zimbabwe, in terms of volume production, stem form and bark tannin content would be the most important starting point for a research program. This should lead to the creation of one or more breeding populations for local conditions and end-products, and the establishment of silvicultural management trials along the lines of those already laid down in pines and eucalypts.

Kenya

Early introduction and plantation development

Black wattle was first introduced into Kenya around 1900 through seed imported from South Africa. By 1910 it had gained recognition as a valuable crop in Kenya for the production of vegetable tannin. In 1912 steps were taken to ensure the purity of species grown and tannin yields by citing both *A. dealbata* and *A. decurrens* as undesirable plantation species. By about 1970 there were some 60 000 ha of wattle plantations established (Sherry 1971) in Kenya but accurate estimates today of plantations established are difficult to make because of the large number of scattered small holdings.

There are two main centres of wattle plantations in Kenya. These are located on the moist fertile highlands either side of the dry Rift Valley (see Fig. 7.2). The largest area of plantations is located near Eldoret on the Uasin Gishu (or western plateau) where today EATEC (East Africa Tannin Extract Company - a subsidiary of Lonrho) has its centre. The

second centre is located near Thika (outside Nairobi in Central Province) on the Aberdare Range. This area has historically consisted of a large number of small holdings owned by private growers. Little development of industrial plantations has been undertaken in this area.



A tannin extract plant was first established near Eldoret in 1930 and the present Eldoret tannin factory (EATEC) was established in 1952. The Thika tannin factory was established in 1978 mainly to take advantage of a large leather industry nearby. Some private growers in Central Province (Thika area) are bypassing the local factory and selling 'stick' bark direct to India and Pakistan through Asian export companies because of the low prices offered for their bark by EATEC. Extract production in Kenya has declined from about 23 000 t/annum (containing 60% tans) in 1953 to about 10 000 t in 1985.

An appreciation of the major political and social changes in Kenya is fundamental to understanding the current wattle industry. Between 1947-63 the Tannin Extract Company at Eldoret had many private suppliers who provided over 50% of the bark. These suppliers were mostly foreigners and after Independence these plantations were sold to local people who maintained production until the 1966-67 world recession on tannin markets. During the recession the company was reluctant to purchase bark from local growers who responded by replacing wattle stands with more profitable crops such as wheat and maize. Another factor which has led to the reduction of area under wattle on private farms are concerns about the weediness of wattle and its competitive ability over neighbouring crop plants. This led to a further fragmentation of existing wattle stands. Today most farmers grow wattle as a firewood for domestic cooking rather than for bark.

The EATEC plantations based around Eldoret consist of 7500 ha of wattle plantations (producing about 6000 t of extract in 1984) with age classes spread over 9 years. The plantations are harvested at a rate of 600-700 ha per year and the tannin factory has a capacity of about 10 000 t of extract per annum. The Eldoret factory also receives bark from private growers who control numerous small stands of black wattle (from 0.1-0.2 ha) near Turbo. In 1985

Fig. 7.2 Location of the two main centres of wattle plantations in Kenya (Sherry 1971).

a further 4500 t of tannin was produced at the Thika tannery mainly supplied by private wattle growers in the area. Because of low bark prices and poor transport arrangements, the company has sought to establish wattle plantations near Thika on 10 000 ha of its own land to reduce its dependence on privately-grown wattle.

Socio-economic difficulties have had a large bearing on the tannin industry in Kenya. The main trend at present is for EATEC to secure its own plantings and reduce its dependence on private growers. This will ensure continuing supplies of high quality tannin at low prices (because of the highly mechanised nature of the operation). EATEC has also sought to diversify its investments away from tannin production on wattle lands to include farm produce (e.g. maize, wheat), cattle raising, mushroom production and a wide range of wood products (e.g. for poles, charcoal and firewood; but surprisingly, not for pulpwood, in spite of the fact that there is a nearby pulpmill) to ensure a financial safeguard in case of a future world recession in tannin prices.

These developments have acted against the interests of the small private grower. It has been vigorously argued by some that these growers should form a growers cooperative to market their product.

Climates and soils

Acacia mearnsii is grown in Kenya at high altitudes from 2000-2800 m asl mainly on deep volcanic soils quite close to the equator. Annual rainfall ranges from 1200-3200 mm per annum and temperature data for two representative stations (Eldoret, Molo) are given in Table 7.1. The main rains occur between April and September with the remainder of the year being relatively dry. Temperature records reflect a fairly equitable climate over the year.

Soils over much of the western plateau where *A. mearnsii* is grown are derived from Tertiary phonolitic lava flows with volcanic tuffs and breccias additional at some sites. Soils are typically ferruginous clays and clay loams with little or no free silica present due to the unsaturated nature of the parent rock. These soils show a higher content of exchangeable bases and lower acidity (Kenyan soils about pH 5.5) than wattle soils in South Africa (Schonau 1973). They also often have high magnesium content (Sherry 1971).

Most soils are deep, except where they are underlain by a murram pan (an impervious lateritic layer), which may influence site quality. Soils are often deficient in phosphate. In some areas soils derived from granites (gneiss) are usually inherently more fertile than those derived from the phonolitic lava flows. These granite soils are deep, well-drained and have remarkably uniform texture and colour.

Nursery

A major feature of Kenyan wattle growing is the lack of seedling nurseries as regeneration is direct from seed. A move to use improved seed from seed orchards will require use of nurseries in the future. It

is not currently clear whether Kenyan growers have access to improved seed from South African seed orchards as is the case for Zimbabwe.

Planting

The method of establishment involves either direct seeding on newly-ploughed ground (not sown to wattle before) or natural regeneration on freshly harvested wattle fields.

In the first method about 5 kg of wattle seed per hectare is required. Seed is taken from routine plantations 6-10 years old and pretreated by removing a drum of boiling water from the fire then placing the wattle seed into the water for 15 minutes. Seed is then removed, washed and sun dried.

Seed is either sown in rows using an agricultural seeding implement drawn by tractor or sown directly into pits. In the first method wheat and wattle are sown at the same time in a kind of agroforestry system. The wattle seed drill lines are spaced 3 m apart. Wheat is planted only once, and then harvested, without further intercropping. One year after sowing, harrowing with a Rome plough is used twice to suppress weed growth.

In the pit planting system four seeds are hand planted (at a depth of about 3 cm) into pits spaced at 0.9 m along rows and 3 m between rows with no intercropping. Thinning to 3 plants per pit is done when plants are 15 cm tall and later to one plant per pit when plants are 30 cm tall. With both methods final crop spacing is 1.8 x 3 m with an average of 1700 trees/ha.

Table 7.1 Temperature data for Eldoret and Molo (°C)

	Eldoret			Molo		
	Mean	Mean daily max.	Mean daily min.	Mean	Mean daily max.	Mean daily min.
January	16.9	24.9	8.9	14.1	21.8	6.3
February	17.3	25.7	8.9	14.1	22.4	5.9
March	17.9	25.8	9.9	14.8	22.5	7.1
April	17.7	24.4	11.1	14.7	20.9	8.5
May	16.9	23.3	10.4	14.3	20.3	9.2
June	15.7	22.4	9.1	13.2	10.4	7.0
July	15.3	21.2	9.5	12.6	18.4	6.8
August	15.5	21.5	9.4	12.9	18.6	7.1
September	15.9	22.9	8.9	13.3	20.1	6.4
October	16.6	23.5	9.7	13.7	20.9	6.7
November	16.9	23.6	10.1	13.7	19.9	7.4
December	16.7	23.7	9.7	13.8	20.3	7.6
Year	16.6	23.6	9.6	13.7	20.4	7.1

The regeneration system is the most common method employed in Kenyan wattle stands. It relies on seed stored in the soil and stimulated to germinate by burning. Tree crowns and branches remaining after the harvesting of bark and wood are piled up over each row of cut stumps and burnt on a sunny, windless day (in about May-June). Fire control equipment and personnel are usually on hand to prevent fire escapes. About a week after the burn, during the first rains, wattle seedlings start to emerge from the ground. The burning technique not only serves to stimulate seed germination but the stacking of trash is an erosion control measure, while burning suppresses weed growth long enough to allow a dense crop of young seedlings to become established.

Tendings

In the year after the treatment for natural regeneration, deep Rome ploughing is conducted to suppress weed growth. The main weeds are couch grass (*Digitaria scalarum*) and kikuyu grass (*Pennisetum clandestinum*). Both have a suppressive effect on wattle growth. Maize is planted between the rows and is fertilized. This added cultivation and fertilizing between rows can reduce the wattle rotation from 9-10 years to 8-9 years.

After 1.5 years the strip of wattle seedlings resulting from the burn is thinned manually to a single row so as to avoid large seedlings on the outside edges of the strip and stunted suppressed seedlings on the inside of the strip. At 2.5 years of age trees are thinned to 0.9 m spacing, with tall and vigorous trees being left to grow on. The thinnings at this stage are used for stakes for building traditional Kenyan mud houses and for fence droppers. After 4-5 years trees are thinned to 2 m and left until final harvest. Thinnings at this stage can be used for fencing droppers and stakes, and green bark is harvested from bigger trees.

Sub-soiling by means of a Caterpillar D4 bulldozer and a single, hydraulically operated, big chisel is performed in the advanced age of the plantation. The aim of this operation is to capture all available water for added growth and to enable easier stripping of the green bark at harvest. The increased soil moisture decreases the proportion of non-tans but increases the fibre content of the bark. Fertilizing practices have not been well documented.

Protection

Generally the cultivation of wattles in Kenya is trouble free but sometimes plantations have to be sprayed to control insect attack. Hail damage can occur and is localised in narrow belts but causes serious damage to plantations on occasions.

Sherry (1971) listed about 80 different species of insect found in wattle plantations in Kenya of which

only 25 could be considered to be of economic importance. The most serious is perhaps the weevil (*Nematocerus perditor*) which severs the hypocotyl of the seedling soon after germination. Nematodes cause damage on occasions and attacked seedlings may show chlorosis and have unthrifty growth.

One of the most serious diseases is a die-back disease or wilting which is most severe in the second year of growth and is associated with drought conditions and overstocking of young trees.

There is a strong relationship between soil moisture and wattle die-back (Elmer et al. 1963a) and boron is a major nutrient deficiency, particularly in areas where trees suffer seasonal moisture stress. Sodium borate at 36.5% borax is applied at 70 kg/ha on such deficient soils. Comprehensive testing of black wattle soils in Kenya is described by Elmer et al. (1963b) in work associated with sugar beet trials.

Harvesting and yields

The harvest

Trees are normally harvested at age 8 to 10 years using power-saws, axes and machetes. Most of the lower section of the tree is stripped before felling to avoid damage to the bark. Remaining bark is stripped immediately after felling. Stripping is done by cutting circular rings up the trunk (after felling) at intervals of 1 to 1.2 m. Bark is taken to 10 m up the tree for 8-year-old trees and to 15 m for 10-year-old trees. Tannin yield declines with tree height (especially in the green crown region).

Once the bark is stripped the bark sections are then slit into narrow longitudinal strips 5 cm wide and 1-1.2 m long and arranged in stacks for drying (usually laid on wattle poles above ground in the field) with the inner surface of the bark facing downwards. This arrangement reduces oxidation and leaching of tannins during drying. About 3-4 weeks of drying in the field is needed to reduce the moisture content to about 12% and care is taken to avoid mould damage during drying operations. The dried bark is called 'stick' bark.

It is well recognised that green bark produces a higher quantity and quality of tannin than 'stick' bark but problems in transport of bark during the cutting season and mill capacity mean that it is more sensible to spread the mill, transport and personnel work loads over a longer time period by using the flexibility of the stick bark method. Green bark is preferred by the mill.

Yields

Schönau (1973) found that general height growth behaviour in Kenya is not very different to that in South Africa. Mean stand height at age 10 years over

a range of site qualities ranges from about 12 to 20 m. In general mean stand height growth reflects site quality.

Bark yields are on average about 20 t of green bark per hectare and 3 t of green bark will produce about 1 t of extract. Data on wood yields are not available.

Utilization

Tannin

Kenya has a rapidly expanding leather industry and hence an increasing need for tannin, but over 90% of the tannin output of EATEC is exported, mainly to India and Pakistan (Patel pers. comm.).

Wood products

Wood products depend very much on the size of the wood harvested. At final harvest roundwood is separated into three classes e.g.-

- straight and medium-sized poles
- general firewood lots
- heavy and thin lots

Wood in Class A is taken to the Wattle Preservation Plant where it is preserved with creosote and sold as fencing posts, power-line poles, building poles, or as poles for cattle yards. Wood in Class B is used to fuel factory boilers. Wood in Class C is taken to the EATEC Charcoal Production Unit. Remaining wood and branches are stacked over the cut stumps ready for burning.

Charcoal

Harvesting 8 t of green bark per hectare will yield about 40 t of firewood and each tonne of firewood will produce about 10-12 bags of charcoal. EATEC uses brick kilns for charcoal production and each of these kilns has a capacity of 60 t of firewood. Charcoal is removed after 2 weeks of burning. Charcoal is used for domestic cooking in towns and cities (e.g. Nairobi) and is also exported to Uganda for use in a cement factory. EATEC produces about 10 000 t of charcoal annually (Midgley 1983).

Mushrooms

A major and unique initiative of EATEC is the production of mushrooms (*Agaricus bisporus*)-Eldoret has an ideal climate for growing mushrooms. A pilot plant was established in 1976 and commercial operations commenced in 1979. Annual yield of mushrooms is 336 t. Mushrooms are utilized in the local hotel and restaurant industries and canned mushrooms are exported to Europe (mainly West Germany).

Mushroom production consists of two main phases. In the first phase manure, wheat straw and molasses are added and the mixture composted in anaerobic and aerobic conditions. In the second phase the compost is pasteurised in one huge chamber (unlike in Europe where this is done on a tray basis) through the addition of steam. Mushroom spores are then added and the material (compost plus spores) removed in polythene bags to the cropping houses. In the cropping houses wattle bark (after extraction), paper waste and red soil (murrum) is used as casing material for the culture of mushrooms.

Mushrooms from Kenya compete strongly with mushrooms produced in China. Low world prices, mainly influenced by the heavily subsidised mushrooms produced in China, have affected production. Because of economies of scale and the need to use specialist staff to carefully monitor production to avoid diseases, production of mushrooms in Kenya is not likely to develop as a cottage industry despite initial efforts in this regard.

Research needs

During the 1950s and 60s EATEC had access to notable researchers who published some of their less commercially-sensitive results on soil properties and silvicultural treatments in scientific journals such as the East Africa Agricultural and Forestry Journal. During the 1970s and early 1980s this publication stopped and has only recently been recommenced.

There is concern amongst some staff at EATEC that tannin yields per hectare have progressively declined in recent years. One factor could be the poor genetic quality of the seed being used. The use of superior seed orchard seed may improve this situation.

Tanzania

Early introduction and development

A. mearnsii was first introduced during the colonial period in about 1908 (Kessy 1986) although Sherry (1971) believed that earlier introductions were possible. Today's plantations are divided into two main geographic locations. The largest and best organized are located in the Southern Highlands near Njombe (see Fig. 7.3) where in the early 1950s the Colonial Development Corporation (now the



Fig. 7.3 Location of the main centres of wattle cultivation in Tanzania (Sherry 1971).

Commonwealth Development Corporation) established about 12 000 ha of plantations. Sherry (1971) and Voll (1980) documented the history of this development in some detail. The second centre is in northern Tanzania near Lushoto in the Usambara Mountains and here the bulk of the plantings are controlled by small private growers. At West Usambara a total of 4586 ha was established in the 1950s (Kessy 1986). Today there are two tannin extract factories in Tanzania. One, the Giraffe Extract Company Ltd, is located in northern Tanzania near Lushoto and is controlled by the Government-owned Tanzania Nood Industry Corporation. The second factory, known as the Tanganyika Wattle Extract Company Ltd, is controlled by the Commonwealth Development Corporation and is located near Njombe in southern Tanzania.

In 1986 the Giraffe Extract Company was in serious financial difficulties in that it operated at a financial loss from 1978-82 (Rihiyo and Rowero 1986). The quantity of extract produced was reduced from about 2500 t in 1973 to about 550 t in 1982 (the extract factory has a capacity to produce 4000 t per annum). This productivity downturn was the result of the Giraffe Extract Company's reliance upon bark supplies from many small local private growers whose holdings rarely reach 2 ha in size. This region of Tanzania has a high population density and many other cash crops like tea, cardamom, coffee, vegetables and fruits are preferred to wattle because

they are more profitable than tannin production. Most local farmers prefer to maintain wattle for sale as firewood rather than cultivate wattle intensively for bark sales. This meant that the factory had to rely on a nearby small Government plantation of 350 ha which had the advantage of reliable supplies and higher tannin/non-tannin ratios (about 3:1) compared with private bark (2:1) because of poorer silvicultural maintenance of the latter. The mill couldn't remain operational for long periods as stick bark wasn't being supplied by local farmers (Kihoyo and Kowero 1986). Kihoyo and Kowero (1986) argue that as wattle tannin extract is the major forestry product foreign exchange earner in Tanzania, steps should be taken to improve factory productivity by having larger company-controlled plantations producing higher-yielding tannin bark, thus reducing factory costs and increasing yields.

The Tanganyika Wattle Extract Company Ltd in the Southern Highlands was initiated by the British Colonial Development Corporation in 1948 at the request of the Tanganyika Government and the aim was to establish about 12 000 ha of wattle near Njombe, to construct an extract factory and encourage the local people (Wabena) to grow and sell wattle to it. The project suffered many difficulties e.g. isolation, lack of a rail link initially and strong competition from synthetic tannins world-wide in the 1950s. EATEC was involved in the project from 1957-59 and the factory is now controlled by the Commonwealth Development Corporation (CDC). Under the CDC the project diversified into wheat and maize and in 1968 the Corporation began paying dividends to its shareholders (Voll 1980).

Little has been published on the silviculture and tannin extraction operations of the Tanganyika Wattle Extract Company Ltd. Sherry (1971) stated that the factory mainly uses green bark (similar to the Zimbabwe situation) and around 1970 was producing 7000 t annually of high quality tannin extract (over 63% tans). At that time over 60 000 t of timber was produced annually by the company, with 13 000 tonnes being utilized for fuel for the extract factory and the remainder being burnt in the plantations prior to regenerating them. The situation in the Usambaras is very different with most wood being used by the villagers in this more densely populated region.

Climate and soils

The species is grown between 1200 and 2150 m elevation asl, with an annual rainfall of 1100-1300 mm. Rainfall patterns in each of the two main centres are quite different. In the Usambaras most rain (85%) falls between May and November with equable temperatures and no frosts. In the Southern Highlands over 90% of the rain occurs between December and April. Morning mists during the first half of the dry season assist in reducing evaporation. Nevertheless

soil moisture shortage becomes a critical factor towards the end of the dry period. Frost occurs in the valley bottoms during June and July but trees rarely suffer damage as plant growth during the dry season has virtually stopped (Sherry 1971).

Soils in the Southern Highlands are mainly derived from granite and granite gneiss (Sherry 1971). One serious problem in this area is the loss of surface soil over large areas due to soil erosion resulting from the adverse effects of past deforestation, shifting cultivation and overgrazing by livestock owned by local people. In the Njombe area Sherry (1971) details three soil types as being suitable for wattle:

- normal plateau soil which consists of ferruginous loam with high sesquioxide content;
- the previous soil type with a covering of volcanic dust; and
- a chocolate-coloured loam.

In northern Tanzania near Lushoto black wattle is grown on fertile volcanic soils in competition with a wide range of other cash crops.

Nursery

As in Kenya, nurseries are not used in Tanzania.

Plantings and tending

Direct sowing of seed in the field has been employed to establish plantations of *A. mearnsii*. The rate of sowing has been 1.2-2.4 kg/ha. Pretreatment of seed by boiling water gives faster and more uniform germination. Prior to sowing it is essential to undertake complete cultivation of the ground. The seed is sown at a spacing of 1.8 m. Clean weeding is essential for the first year because young plants are highly sensitive to weed competition. Major weeds are Mexican marigold (*Tagetes* sp.) and bramble (*Rubus* sp.) although couch grass (*Cynodon* sp.) and nutgrass (Cyperaceae) are the most difficult weed species to control.

After clear felling it is possible to achieve natural regeneration for the second and subsequent generations. Trials have been carried out in Tanzania to find the best methods of encouraging natural regeneration. Plantation establishment methods have drawn on South African experience. Methods tried in Tanzania include strip burning of leaf litter, burning slash spread over the whole plot and the taungya system. These methods have given equally satisfactory establishment.

Protection

Acacia mearnsii is susceptible to attack by *Loranthus*, termites and *Icerya purchasi*. During 1984 a total of 290 ha of wattle plantations at Malibwi in Lushoto district were attacked by an insect suspected to be a species of *Plusia* (Lepidoptera).

During the 1950s attempts were made to introduce *Rodolia cardinalis* from South Africa to control *Icerya purchasi* by biological means. Records show that the predator has successfully established itself in the country. At the same time an unidentified local predator suspected to be a Coccinellid contributed to the population control of *Icerya purchasi*.

A recent outbreak of *Plusia* spp. at Malibwi acacia plantations was effectively controlled by several parasites including an unidentified insect belonging to the family Eulophidae which was parasitising eggs of *Plusia*. Other controlling parasites included *Theronia* spp., *Lurida* spp., *Apanteles* spp. and *Metopius* spp. There have been several insect outbreaks on *A. mearnsii* in Tanzania and biological control methods have been used to check the pest populations.

In 1954 the Colonial Development Corporation reported a disease outbreak on *A. mearnsii* plantations at Njombe in the southern highlands. The trees were noted to die back from the top and this was attributed to boron deficiency. Some of the earliest work on boron deficiency and the relationship of this element to wattle wilt was conducted in Tanzania (Sherry 1971). This kind of dieback has recently been encountered also in other plantations at Sao Hill including *Pinus patula*, *P. elliottii* and *Eucalyptus saligna/grandis*.

Harvesting and yields

Thinning is usually undertaken after 1 year to leave plants spaced at 2.4 x 2.4 m. The plants are then not thinned again until clear felling at 8 to 12 years. Early height growth of about 2.4 m/annum has been achieved on good sites with an average yield of 50 t of fuelwood and 6 t of dry bark on an 8-year rotation.

Conclusion

Overall the wattle industry is not particularly profitable in East Africa although the industry is viable in Zimbabwe, Kenya and perhaps Tanzania. The lack of a charcoal and paper pulp market in Zimbabwe makes the industry mainly reliant on bark production while in Kenya an active program to diversify farming interests to cattle, wheat, mushrooms, charcoal, preserved posts and poles has secured a more viable portfolio of marketable products which should enable EATEC to withstand temporary market fluctuations in tannin extract prices. The situation in Tanzania is not very encouraging

(particularly for the Government-controlled factory in the Northern Highlands) and the industry needs revitalizing in order to get back on a more secure footing. In all three countries the ability of tannin extracts to earn foreign exchange is highly appreciated. About 90% of the tannin produced in each country is exported.

The industry in East Africa has relied on research and technological development in South Africa which has mainly been conducted by the Wattle Research Institute of Pietermaritzburg, Natal Province, RSA (now called the Institute for Commercial Forestry Research). In the 1950s and early 1960s both Kenya and Tanzania had active silvicultural research programs but these have declined. In recent years staff from the WRI visited Kenya and Zimbabwe (and perhaps Tanzania) to advise on silvicultural matters. In Zimbabwe seed from seed orchards in South Africa is now used for establishment of 35% of the new stands. The recent mushroom project in Kenya was assisted by FAO advisers.

In Kenya and Tanzania increasing population pressure, particularly in the more fertile lands where wattle is cultivated, has led to a reduction in average farm sizes and a very fragmented ownership of private wattle stands. Silvicultural control has virtually ceased, leading to poor quality bark and less interest now than formerly in selling bark for tannin. This situation particularly applies to the small wattle holders in the Central Province of Kenya (near Thika) and the Northern Highlands of Tanzania.

A rise in tannin prices world-wide could see a renewed interest by growers as operational but under-utilized tannin mills are located nearby.

The East African experience points to the importance of several factors in this industry which will be important for the future development of black wattle in China. The main points are-

- The price of tannin extract is subject to significant fluctuations. The product is valuable for tanning leather and for adhesives. Other alternatives for vegetable tannin have various disadvantages, for example environmental pollution, and this should result in a continuing demand for black wattle extract.
- Integrated operations, in which the spent bark and wood are used, improve overall returns and buffer the effects of fluctuations in the price of tannin.
- Adequate volumes of high-quality bark, which permit extract factories to work efficiently at or near full capacity, contribute significantly to overall viability.
- A high standard of silviculture and harvesting practice is very important. The requisite standards of operation are most easily attained where they can be effectively supervised by skilled staff. If the trees are grown privately on small farms, effective extension and an attractive price structure will be needed to maintain quality and ensure steady supply.
- An effective research capacity is needed to manage problems of pests, diseases and nutrition and to improve the crop through breeding.

Acknowledgments

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The section on Zimbabwe was extracted from a paper published in ACIAR Proceedings No. 10 (1986) by Luyt, Mullin and Gwaze (1986). Mr Luyt works for The Wattle Company Limited, Mutare, while Messrs Mullin and Gwaze are employed at the Forest Research Centre, Harare, Zimbabwe.

The section on Kenya was largely extracted from an unpublished paper titled 'Wattle (*Acacia mearnsii*) cultivation and tannin industry in Kenya' by Prof. F. Owino (now at the International Council for Research into Agroforestry, Nairobi).

The section on Tanzania relied heavily on a recent paper prepared by B.S. Kessy of the Forest Division, Ministry of Natural Resources and Tourism, Dar Es Salaam, Tanzania.

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Chapter 8

Black Wattle Silviculture in Brazil

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Introduction

Black wattle seed was first brought to Brazil in 1928 from South Africa. The species now makes up large plantations in Rio Grande do Sul.

The tree provides raw material for a variety of economic and industrial activities. It is also of environmental value as through symbiosis it is able to add nitrogen to the soil, and it can quickly provide forest cover as it propagates easily and grows rapidly.

The cultivation of black wattle is very different from that of other plantation trees because it is traditionally grown by small farmers, giving them an alternative income and providing fuelwood for the domestic market.

This account describes the current silviculture of black wattle in Brazil. We also assess the potential to increase the productivity of the species.

Position and location of black wattle forestry

Geographic distribution

Cultivation commenced in Estrela, in the area of Vale do Rio Taquari, and later centered in the Vale do Rio Cal where the tanneries were located. Production then extended to other areas within a range of about 300 km, limited as follows:

Latitude	:	28°30'S	-	31°00'S
Longitude	:	50°30'W	-	52°30'W
Altitude	:	50 m	-	1000 m

Topography, soil and climate

The topography of the area of cultivation ranges from flat to very irregular as the altitude varies widely in the region.

The region has soils derived from Mesozoic and Paleozoic volcanic and sedimentary formations, mainly from Serra Geral. The species is well adapted to the sands and sandy clays in the area of cultivation. It does not grow in hydromorphic [waterlogged] soil.

The climate is sub-tropical or Cfa according to the Koeppen classification. The maximum temperature is higher than 22°C, while the minimum varies from 3° to 18°C. The average annual precipitation varies from 1190 mm to 2470 mm. The ideal climate for black wattle is within these limits. It does not tolerate intense frost or long periods of dry weather, especially in the first year of the plantation.

The social and economic importance of the species

The social and economic importance of wattle cultivation in southern Brazil reflects a close association between the farmers and the processing industry. The possibility of combining farming with profitable cultivation of black wattle is an important factor in preventing massive migration from rural areas to the cities.

The black wattle plantations are situated in a region of high energy consumption for domestic and industrial purposes. The great use of wood has caused environmental problems through heavy cutting of native forests, but this pressure has now eased because of the extensive cultivation of wattle.

Some 40 000 families have benefited either directly or indirectly from the results and alternatives originating from plantations of black wattle.

Utilisation

Black wattle plantations provide raw material for the following industries:

Bark:	Tannin extract
Wood:	Cellulose; plywood; grain drying; tobacco drying; bakeries; pottery factories and other domestic uses (firewood)

Expansion and extent of cultivation

Following the first commercial plantation in 1930, cultivation expanded rapidly once the efficiency of tannin production became clear and the tanneries settled down in the 1940s. The total area now planted is 120 000 ha. The major companies which process

the bark (Tanac and Seta) are promoting planting through programs addressed mainly to small farmers.

The bark processing capacity of the tannin industries, including direct consumption by some of the tanneries, is around 220 000 tons per year. Assuming an average rotation length of 6.5 years, the demand for bark corresponds to the yield from 18 000 ha per year. The tannin extract industry is responsible for 40% of this production. The remaining 60% is provided by third parties (small farmers).

The tannin extract industry

Sixty percent of the national tannin extract production is used for the domestic leather industry and other purposes like effluent treatment, adhesives, ceramics, drilling muds, rubber and agricultural pesticides.

Silvicultural practices

Biology

The scientific name of black wattle is *Acacia mearnsii* (Wild). It is a legume with a rounded crown. The leaves are bipinnate, with 12 to 21 pairs of pinnae.

The inflorescence consists of several globular flower heads, borne in axillary racemes of pale creamy colour. Floret formation begins in the 3rd year and a few seeds are produced in the 4th year. Good seed production commences in the 5th year.

Propagation

Black wattle propagation occurs via outcrossed seed. Cross pollination is effected through the action of wind and insects (bees), although the flowers are self-fertile.

Flowering extends from September to October (spring), and the seed mature the following year in November and December fourteen months after flowering.

Seeds are plentiful and may be collected from either the trees or from ant nests. Most of the seed available comes from ant nests. The seed is carried by ants to the nest where the white aril is eaten, leaving the seed itself still viable. Each nest supplies up to 3 kg of seed.

Seed is collected directly from trees in seed production areas (SPA) chosen and managed by Tanac. The branches of the trees are shaken and the legumes fall to canvas spread on the ground and from which they are collected.

The amount of seed produced per tree in commercial forest is still to be determined. The average quantity collected in a 10-year-old SPA is 0.7 kg per tree. One kg of seed of any origin contains an average of 65 000

seeds. The germination capacity varies from 85 to 90%. The seed requires only cleaning before storage at ambient temperature and low humidity.

The seed has an impermeable integument. Immersion in boiling water for 5 to 10 minutes just before sowing will break dormancy.

Raising seedlings

The demand for black wattle seedlings for plantation establishment is met principally by local nurseries. Private companies have their own nurseries associated with their plantation programs. There are basically three methods of raising seedlings-

Clod nursery

Most seedlings on the market are raised by this traditional method. Seedlings are grown directly on a sandy-silt soil. The seed is sown in small furrows that allow the bed to be cut into clods with sides of 4 cm having 3 to 4 seeds in each. The clod about each seedling is retained intact, as far as possible, during lifting and transport.

Wood veneer tubes

This is the method adopted by industry and certain specialist nurserymen. The seedlings are cultivated in veneer tubes on a clay substrate with added nutrients (NPK). Seedlings are transplanted from germination boxes or seedbeds into the tubes.

Plastic sleeves and pots

This is a new method which has been adopted by industry to improve productivity and plant quality by increasing uniformity. The seedlings are raised in a suspended frame with an organic substrate and added micro-nutrients. One or two seeds are sown in each tube. When the seedlings reach 3 cm high they are selectively thinned to one plant per sleeve. To achieve rapid and uniform development it is necessary to apply liquid fertilizer.

Nursery operations begin in February and end in September. The production cycle lasts from 60 to 100 days according to climatic conditions in the particular year. As the species is leguminous, the Tanac Group has selected rhizobia cultures for routine inoculation of the seed. Among phytosanitary treatments of the growing media, methyl bromide is important.

Seedlings are transported to the planting site in boxes with high sides which enable boxes to be stacked without damaging the seedlings. The companies use shelving systems in vehicles, thereby avoiding contact

between the boxes, and cover the load with canvas to avoid desiccation by wind whilst in transit.

Plantation establishment

The establishment season commences in April and continues until the end of September when temperature and humidity are favourable for rapid growth.

Because of its characteristic hardiness and tolerance of harsh conditions, black wattle can be established by direct sowing of the seed in the field as well as by seedlings. A third method of establishment may be used in areas previously cropped with black wattle. Burning the site promotes germination of seed stored in the soil. After some months a selective thinning will leave 2000 to 2500 trees/ha. This method is not always successful.

The planting of seedlings is widely used and preferred as it has clear advantages such as more uniform spacing and fewer weeds and pests. The alternative of direct seeding suits mechanization and may reduce costs. However, its use is restricted in some areas by the presence of weeds and pests, and difficult terrain. The mechanization of planting itself is well developed but is confined to suitable terrain. Mechanization has become popular because of the lack of labour in certain areas, together with the need to establish large areas of plantation each year. The Tanac Group pioneered plantation mechanization by developing a planting/fertilizing machine.

Site preparation

Before any clearing or ploughing, an ant extermination program is essential. There are now fast and efficient methods to attack the ants - for example, with 'Microbaitrack' or 'Baitrack'. This entails leaving out plastic packages soaked with an attractant and a small quantity of insecticide. This method is not often used by small agro-farmers, who mostly search for and destroy the ant colonies.

The next step in the process is soil preparation and ploughing. In virgin areas this may be done along planned rows, the spacing of which depends on whether the intention is to work with a single crop or not. In previously-cultivated areas the preparation is undertaken between stumps, enabling interplanting of other crops.

The companies use subsoiling to improve impermeable soil, enabling better drainage and facilitating root development. This practice also reduces erosion.

Planting espacement

The espacement used by companies varies from 3.0 m x 1.33 m to 3.0 m x 1.66 m, corresponding to

densities of 2500 to 2100 trees/ha respectively. Concern about uniform espacement increases once operations are mechanized.

The forests of small agro-farmers have diverse and even irregular espacement, typically with 2500 to 3000 trees/ha. Stem diameter is not important in plantations grown for fuel.

Fertilization

Fertilizer is used only in the first year of the plantation. An initial dose is applied at root level during planting, followed some months later by a tailored dose of NPK (5-30-15).

The purpose of applying fertilizer is to provide seedlings with an initial boost so that they can out-grow competing ground flora and understory shrubs, and to ensure uniform growth. The dosage varies but averages 80 g per planting hole. The formula used has a high phosphorus content as this has been proven to be most effective. In general the soils used for wattle plantations have a low content of soluble phosphorus, an element of major importance for legumes.

Cultural practices

In order to create a successful plantation it is essential to apply appropriate stand treatments from the time of establishment.

Initially the competition from grass and shrubs (and sometimes natural regeneration) is very low. Their effect as they develop may be kept to a minimum by:

Weeding This is done beneath the crown, or in any case in a circle with a minimum diameter of 30 cm. This practice is important on sites with lots of weeds. It is usually done in spring (from September to December) in the first month after planting.

Thinning The desired density is attained by removing excess seedlings.

Cultivation This treatment is used on sites with regular espacement and can be realized in two ways. In areas previously planted a special machine is used. In virgin areas, strips are harrowed between rows. This is done in the summer (December to March) of the year of planting.

Clearing This operation is undertaken one year after planting, either manually or, if conditions permit (trees in rows, and sufficient space between rows), mechanically. There is limited use of selective herbicides.

Damage and disease

Since black wattle was introduced to Brazil, termite beetles (twig girdlers, *Oncideres* sp.) have caused considerable damage in plantations. The greatest

incidence of this damage is in the largest concentration of plantations, and is a consequence of poor and ineffective methods of extermination. The State Government became concerned by the damage and laid down a specific law to address the problem. That law (Law number 2869 of 25 June 1956 approved on 19 February 1957) obliges every plantation manager to collect and burn the branches cut by the termite beetles.

The life cycle of the insects has four different stages: egg, larva, pupa and adult insect.

The damage is caused by the adult insects when they cut the branches to lay their eggs during the September to January period, and for this reason the control program should follow immediately.

The most abundant species are *Oncideres impluviata* (German 1824) and *Oncideres degeani* (Thomas 1968).

Other pests which have appeared within the last few years have had rare though harmful effects on the plantations. A leaf-cutting caterpillar of the Geometridae family and cachonilias are examples.

One of the causes of mortality of black wattle is gummosis. In this case there is a cellular reorganization which disrupts translocation and stimulates production of a gum-like substance. Gummosis appears in trees from the third year onwards, initially causing degrade in bark and continuing until it kills the tree. Gummosis appears principally in injured trees. The reason for this phenomenon is still not completely understood.

Harvesting

The rotation is short, with trees maturing for harvest from age seven years. As a consequence of the demand for both bark and timber and the economic needs of the farmers, however, harvesting starts in the sixth year.

The trees are cut close to the ground without regard to variation in diameter in the stand.

Because of the preference for family labour, machinery is rarely used in this process. The operation commences by defining the front of the swath to be cut to a width equivalent to 6 rows of plantation. To maximize the yield, the bark is stripped downwards from a height of one metre, permitting harvest to ground level. The felling is usually done with power-saws in order to direct the trees towards the front cut. Next, the trimmed branches are stacked in piles beside the main operation.

The wood is marked in lengths for further processing. Each log is stripped individually of its bark with the aid of a chainsaw. Finally the bark is sorted into 20

kg bundles, graded and stacked. Transport to the roadside is by animal carts.

Tanning industries which have their own forests have flexible cutting plans which allow them to alter the portion of their needs which they meet from their own forests, depending on the quantity of bark offered by small farmers.

The bark becomes available on the market between March and August.

The average yield of a 7-year-old forest is:

- Timber: 175 st*/ha (first grade)
18 st/ha (second grade)
- Fresh bark: 15 750 kg/ha
- Number of harvested trees: 1300 trees/ha

(*st = stere = 1 x 1 x 1 metre of stacked wood)

Research on black wattle

Since the introduction of black wattle to Brazil, several studies have pursued higher bark and tannin yield. Since 1983 the Tanac Group has had an agreement with EMBRAPA to seek better silvicultural practices. Some outstanding projects are:

Development of seed production areas. Choice of superior stands from which seed of high quality may be gathered.

Provenance/progeny tests of newly-imported seed. The goals are to determine the origin of seed originally brought from Australia, to identify the best-adapted provenances and to select families which offer the greatest potential genetic gain if used in seed orchards.

Progeny test in Montenegro. The aim is to evaluate genotypes of black wattle selected from commercial plantations and thus to determine the genetic variation in the population and establish a basis for better seed production.

Formation of a black wattle base population. The goal is to maintain diversity in the black wattle population in order to be able to supply material of a recognized quality for future seed production programs.

Micro-propagation of black wattle (culture in vitro). The aim is to reduce the length of the generation interval and thus speed progress in breeding.

Reaction of black wattle to applied phosphorus, potassium and calcium. The objective is to determine minimum essential quantities of fertilizer and ascertain the optimum application, and to assess the effects fertilization on gummosis resistance.

Influence of thinning and rotation length on production of timber and tannin. To evaluate the influence of thinning and rotation length on the yield of timber and tannin per unit area, and tannin quality, as well as the movement of nutrients through the harvesting of timber, bark and residues.

Forest inventory

Because of the extent of black wattle plantings the State government is unaware of the exact magnitude of the plantation area and its likely production. The Tanac Group is about to conclude a survey of the better-quality plantations in order to plan future industrial strategy. The inventory is being done with the help of the Landsat images and field inspections by company technical staff.

Chapter 9

Development of Black Wattle (*Acacia mearnsii* De Wild.) Plantations In China

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Introduction

Black wattle seeds were first brought into China by overseas Chinese and planted tentatively in coastal areas in Guangxi, Guandong and Fujian provinces in the early fifties. During the following two decades, black wattle seed was imported by the Chinese government from Australia, Indonesia, Holland, Japan, Kenya, Algeria, France etc. These seeds were

experimentally planted in many widely-distributed sites in 10 provinces in subtropical southern China. Although the results of these trial plantations varied considerably, owing to differences in site factors, quality of seed and level of management, they did help us to realize the possibility of developing black wattle plantations in China and provided a good basis for choosing most the suitable areas and best locations for subsequent development.

Abstractor's remarks

This is an English abstract of Chapter 5 of the book entitled *Black Wattle and its Utilisation* sponsored by ACIAR, edited by Ho Chin Ko and A.G. Brown and published in Chinese by the Chinese Forestry Publishing House in 1991 in Beijing. The original 33-page Chinese text includes 5 figures, 11 photographs, 11 tables and 27 references. The selected figures and tables accompanying this abstract have been renumbered.

The tannin extract industries in China need a high quality raw material, like black wattle bark, to replace inferior materials, so that the quality of their products

and the overall economic status of this industry can be significantly improved. New black wattle plantations, especially those in Fujian province, have been

planned and managed as a source of raw material, in accordance with industrial development, to provide superior raw material to the factories on a sustained basis. In the eighties, many measures including financial support, personnel training, special administrative arrangements and organization of research were undertaken by the government to speed up development of black wattle plantations. Furthermore, this work has been greatly assisted by international cooperation. The joint efforts of Chinese and Australian scientists, working on cooperative projects, have yielded research results on both silviculture and utilization of black wattle. New provenances and modern techniques and have been increasingly introduced to China.

Locations, extent and seed sources

Locations

The following are the main four areas for black wattle growth in China-

- (1) coastal areas of Zhejiang, Fujian and Guangdong provinces;
- (2) eastern and south-eastern parts of the Sichuan basin within 300-500 m above the sea level;
- (3) mountainous region of the southern ridge on the north of the Tropic of Cancer;
- (4) hilly areas in the valleys in Yunnan, Guanzhi and Guizhou provinces.

Other newly developed areas include three gorges along the Yantze River in the western part of Hubei province; the eastern Guizhou Plateau and the valley in western Hunan; lowlands in the central part of Yunnan Plateau and a belt along the Jinsha River.

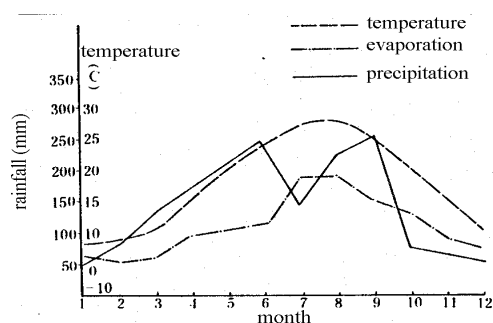


Fig. 9.2 Distribution of temperature and humidity of Wei Zhou city in the Zhe Jiang province.

The distribution of black wattle plantations in China is illustrated in Figure 9.1, and temperature, rainfall and evaporation throughout the year at representative locations are shown in Figures 9.2, 9.3, 9.4 and 9.5. The climate at centers of black wattle growth in China and abroad are compared in Table 9.1.

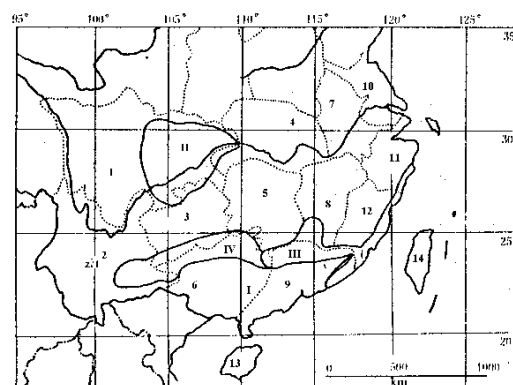


Fig. 9.1 Distribution of black wattle plantations in China. I. Coastal areas of Zhejiang, Fujian and Guangdong provinces. II. Sichuan basin area. III. Mountainous region of the southern ridge. IV. Valleys in Yunnan, Guanzhi and Guizhou provinces. (1) Sichuan (2) Yunnan (3) Guizhou (4) Hubei (5) Hunan (6) Guangxi (7) Anhui (8) Jiangxi (9) Guangdong (10) (11) Zhejiang (12) Fujian (13) Hainan (14) Taiwan.

Extent

A survey of black wattle plantations in China in 1987 revealed that the total area of plantations was 10 433 ha. Their extent has greatly expanded since that time, especially in Fujian province.

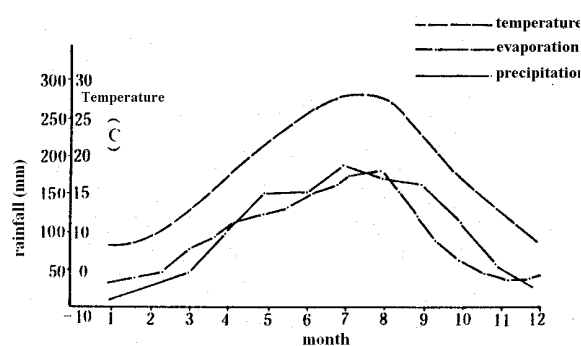
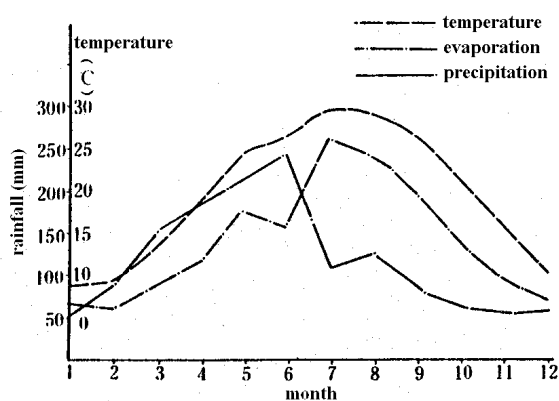
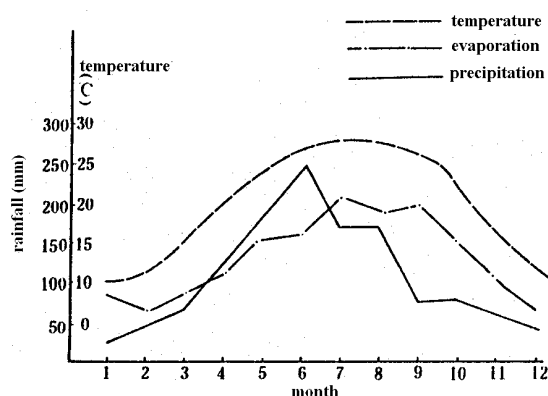


Fig. 9.3 Distribution of temperature and humidity of Da county in Sichuan province.

Table 9.1 Comparisons of climatic factors at centres of black wattle growth in China and abroad

Location	Longitude	Latitude	Elevation (m)	Mean annual temperature (°C)	Mean temperature of coldest month (°C)	Absolute minimum temperature (°C)	Mean annual rainfall (mm)	Mean annual evaporation (mm)	Mean annual relative humidity (%)	Years of observation
New South Wales, Australia	151° 42'E	30° 10'S	640	15.6	5.1	-8	870		72	34
Natal, South Africa	29° 25'E	30 32'S	1305	15	9.2	-7.8	728		76	
Fukuoka, Japan	130° 23'E	33° 35'N		16	4	-6	1675		82	9
Tongjiang, Sichuan province	107° 14'E	31° 56'N	507	16.7	5.5	-6.2	1129	1116	76	19
Da county, Sichuan province	107° 28'E	31° 16'N	380	17.3	6.1	-4.7	1192	1128	79	19
Wenzhou, Zhejiang province	120° 41'E	28° 01'N	3	12.9	12	-5	1698	1345	81	20
Yishan, Guangxi province	108° 52'E	24° 29'N	151	20.1	10.2	-2.9	1292	1596	79	15
Zhanjiang, Guangdong province	110° 24'E	21° 13'N	26	23	15.6	2.8	1440		80	20
Ganzhou, Jiangxi province	114° 50'E	25° 25'N	124	19.5	8	4.2	1440	1666	75	10
Nanjing, Fujian province	117° 22'E	24° 31'N	23	21.2	12.6	-2.0	1698		78	15
Baise, Guangxi province	106° 22' E	23° 55'N	138	22.2	13.4	-2.0	1692	1937	76	20

**Fig. 9.4** Distribution of temperature and humidity of Ganzhou city in Jiangxi province.**Fig. 9.5** Distribution of temperature and humidity of Yishan country in Sichuan province.

Seed sources; tree types and forest categories

Black wattle seed was initially imported to China from many countries. That from Holland and France was 'commercial' seed. Seed of the second and third generations in China since have been collected. Land races ('new provenances') such as Wenzhou, Ganzhou, Tongjiang, Yunnan and Zhangzhou have formed with their own characteristics owing to different founding populations and ecological conditions. This seed has been used to establish new plantations, although some may be contaminated or degenerate.

Black wattle trees grown in China can be classified into 4 types according to the shape of the stem and canopy, and arrangement of branches.

Black wattle plantations in China consist of the following categories:

- (1) Industrial plantations, mainly for bark and wood.
- (2) Environmental plantations, mainly for conservation of soil and water.
- (3) Energy plantations grown on short rotations, mainly for fuelwood used in the countryside.

Planting technology and subsequent management

Seeds and seedlings

Trial plantings and comparisons of provenances from different countries and various parts of China have been carried out in Zhangzhou, Nanping, Ganzhou, Da-county etc. for some years, but most seed used so far is descended from that imported in earlier years. Great care must be taken in seed procurement-

1. Choosing mother trees for seed collection: Trees selected must be fast growing, cold resistant, straight, with evenly arranged branches, healthy and no mechanical injury. Any seed orchards must be carefully constituted and well managed.
2. Time of collection: Black wattle seed ripens at different times in different places because of the climate: for instance, it is 1-10 June in Fujian, 11-20 June in Zhejiang and late June to early July in Sichuan.
3. Treatment and storage of seed: The pods from the trees are dried and stirred in the sun until the pods open and release the seed. Usually 10 kg of seed can be obtained from 100 kg of pods; each kilogram of seed usually contains more than sixty thousand seeds. Seed must be carefully stored if not used promptly. Seed can be refrigerated or stored in a dry, ventilated place. Damage

from high humidity, mould, rats and insects should be avoided. Viability can usually be maintained for at least 2-3 years.

4. Tests: The seed must be examined before use. Good seed is black and lustrous without extraneous material, disease or insect damage. Purity should not be less than 97% and viability should be over 70%. The weight of 1000 seeds should be not less than 14 g.

Nursery practice

Seeds are usually treated before use with boiling water, or water at 80°C if the wax layer on the seed coat is thin, to accelerate germination. Other methods of treatment, like sand papering or stimulation by sulphuric acid, are occasionally used.

Spring sowing is ordinarily undertaken between February and March, and autumn sowing between September and October.

The quantity of seeds to be sown in each mu (1/15 ha) is usually 2.5-3.5 kg for raising seedlings to be transplanted to containers, 1.5-2.0 kg for direct sowing and 1-2 seeds in each vessel.

The quality and quantity of resulting seedlings depend on nursery practice. Criteria set by Fujian province are given (Table 9.2). The quality of seedlings will affect early growth (Table 9.3).

Table 9.2 Quality and quantity of seedlings of *Acacia mearnsii* De Wild. at age 5 months obtained from different nursery practices.

Nursery practice	Criteria of quality						Yield
	Grade I		Grade II		Grade III		
	Ground diameter (cm)	Height of seedling (cm)	Ground diameter (cm)	Height of seedling (cm)	Ground diameter (cm)	Height of seedling (cm)	
Seedlings from bags	0.4	30	0.3	20	0.2	15	
	0.5	40	0.4	30	0.3	20	
Bare-root seedlings	0.5	35	0.4	25	0.3	20	3.5-4
	0.6	50	0.5	35	0.4	25	10000 seedlings / mu*

* 1 mu = 1/15 ha

Table 9.3 Early growth of seedlings of different quality

Class of seedlings	Survival (%)	Record after planting (13 May 1983)		Record after one year growth (20 April 1984)		Increment of growth			
		Height of seedlings (cm)	Ground diameter (cm)	Height of seedlings (cm)	Ground diameter (cm)	Height of seedlings (cm)	Ratio (%)	Ground diameter (cm)	Ratio (%)
Superior seedlings	92	22.7	0.36	250	3.83	227	166	3.47	212
Ordinary seedlings	96	17.8	0.36	225	2.90	207	151	2.54	155
Low quality seedlings	81	10.3	0.26	147	1.90	137	100	100	1.64

Planting

Site selection

Good growth depends on correctly matching the planting site with the trees to be planted. The most desirable conditions for planting black wattle in China are: yearly average temperature 15-20°C; average temperature in January 5°C; absolute minimum temperature not less than -5°C; frost-free period more than 280 days; yearly rainfall 1000-1500 mm; and soil depth more than 50 cm. Following systematic assessment of black wattle plantations in Fujian province, Zhang Qing Hua et al. proposed a classification of site conditions which accorded the following order of importance to the main factors affecting growth-

1. Soil texture
2. Position of slope
3. Depth of top soil
4. Shape of slope
5. Organic matter content of the soil.

Land preparation

Land preparation includes the clearing of forest and ploughing the soil. Clearing is usually done by collecting, heaping and burning any grass, shrubs or woody residues. Land can be prepared in different ways-

1. Flat land preparation

2. Strip preparation
3. Trench-type preparation
4. Preparation of individual planting sites.

This preparation is preferably carried out preferably 3 months before planting, usually in October to December in the year prior to planting.

Planting techniques

Establishment can be accomplished by seedlings or by direct sowing. It is usually carried out in China in spring (March-April) or autumn (September-October). Spacing is determined by many relevant factors such as site index, age of trees and intensity of management. The principle of 'denser first and thinner later on' is often used. Ordinarily 200-240 trees/mu are used on grade I or II sites and 300 trees/mu on grade III sites in industrial plantations, and 800-1000 trees/mu in energy or environmental plantings. (Energy plantations can be harvested every 2-3 years to maximise the yield of biomass, the coppice shoots being mainly used for fuelwood.)

Black wattle trees may grow faster in mixed-species stands than in pure forest.

Pruning and measures to improve wind stability are sometimes necessary. Denser forests are more resistant to strong winds.

Fertilization

Black wattle trees are capable of utilizing atmospheric nitrogen and are sensitive to the availability of phosphorus. The basic fertilizers used for black wattle plantations are mainly organic, phosphatic or composites. The dosage is 3-5 kg of organic fertilizer or 100 g of phosphate and 50 g of composite fertilizer for each pit. Sometimes 2-4 kg/mu of boron fertilizer is needed if dieback is evident.

50 g N-fertilizer is added to each pit after planting, followed by composite manure or 50-100 g of NPK mixture (1:3:1) applied later on. A small amount of lime may be used if the soil is highly acidic.

Studies of fertilisation in Changtai county of Fujian province and Ouhai county of Zhejiang province showed that the growth of height and diameter at breast height of black wattle treated with N+P (1:2) was 63% and 92% greater respectively than those of the control.

The first application of fertilizer is usually in between May and June and the second between September and October.

Tending of young plantations

Tending requirements differ with different types of land preparation.

Pest control

The Chinese edition of this book describes the nature and management of 10 common diseases and 10 species of insects most harmful to black wattle in China.

Thinning

Thinning, an important operation, is can be carried out once or twice depending on rotation length. The time and intensity of thinning are determined by the purpose of management, initial spacing and status of growth of the trees.

Harvesting

The age of trees at harvest in industrial black wattle plantations should be that at which maximum quantity of total biomass and technically satisfactory bark as well as economic benefit can be obtained within the shortest possible rotation.

Lin Jie identified the ages of biological, technical and economic maturity of black wattle plantations under different site conditions in the Zhangzhou area of Fujian province after extensive assessments of a series of sample plots. He recommended an 8-year rotation.

The scale of black wattle bark production at present is rather small as the tannin extract industry near

plantations, which could routinely use a large amount of black wattle bark, has not been fully developed.

Black wattle plantations for purposes other than tannin

(1) *Energy plantations*

Black wattle, owing to its fast growth, coppicing ability when young and the high calorific value of its wood, is an ideal source of fuel for people living in the countryside. This is especially true in China where fuelwood is scarce in many locations where black wattle can grow.

The silviculture and management of energy plantations are in many respects different from those of industrial plantations. 'Commercial' seed, bare-rooted seedlings from field nurseries, close spacing and short rotations (2-3 years) are usually employed to obtain a maximum quantity of biomass as quickly as possible. Thus sites with deep friable soil and good drainage, and intensive management including fertilization, are usually required.

Various forestry research organisations have shown that much biomass and great economic benefit can be derived from high density, short-rotation energy plantations of black wattle.

(2) *Environmental plantations*

Black wattle is also a superior species for environmental plantations, especially those for soil and water conservation in appropriate areas. It can grow easily on poor sites; protect the soil and water efficiently and improve the soil properties including fertility to a certain extent. These attributes result from such characteristic features of the species as wide adaptability; vigorous foliage development and fast growth; capacity to fix atmospheric nitrogen; large crown and well developed, horizontally oriented root system.

Since environmental plantations are usually established on poor sites with serious soil erosion, the land is ordinarily prepared in contour strips 1 m wide, 30 cm deep and 2 m apart. The outer side of the strip is slightly raised so that water will be retained and erosion reduced. 'Commercial' seed and bare-rooted seedlings can be used. Close planting, usually 600-1500 trees/mu, using two rows in a strip and triangular arrangement, is adopted. Adequate fertilizer to improve site conditions and accelerate tree growth is applied.

The advantages of black wattle as a species for soil and water conservation are obvious. The HeTian Conservation Station of Chang-Ting district and other workers of Fujian province report that the above-ground biomass of black wattle trees 33 months old was 3.6 - 8.2 times as much as that of the main local

species they used to use, at the same age. The coefficient of surface runoff fell from 0.54 on bare land to 0.07 in the black wattle plantation; the amount of erosion per square kilometre per year was 8358 t

less; the number of microorganisms and the organic matter content of the soil were substantially increased and the microclimate and hydrology in the plantations were markedly improved.

Chapter 10

Wood Properties and Uses

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Anatomy and general properties

The fibre length in five 16-year-old trees of *Acacia mearnsii* (syn. *A. mollissima*) was 0.88 mm (Hannah *et al.* 1977). The fibre length of the wood from trees of unspecified age and grown in India varied between 0.52 to 1.16 mm with an average of 0.70 mm; the fibre diameter varied from 0.0091 to 0.0212 mm with an average value of 0.0142 mm (Bhat and Virmani 1953). The vessels are moderately numerous with about 6-8 per mm², or 13 vessels/1000 fibres (Hannah *et al.* 1977). The vessels are chiefly as radial multiples of up to 4 in an oblique arrangement and may be visible to the naked eye. The rays are inconspicuous and more narrow than the vessels. The parenchyma may be absent or sometimes small amounts may be found surrounding the vessels in a wing-like confluent shape. The growth rings are indistinct. Tension wood can be present and is recognised by its darker appearance and by the inner gelatinous layer in the fibre lumen.

The sapwood is pale straw coloured and the heartwood light brown with reddish markings, hard and tough, fine textured but cross or interlocked grain is common. The dominant stems in the commercial plantations in South Africa on ten-year rotations seldom exceed 23 cm diameter, but most trees are

relatively straight. Small-sized knots can sometimes cause problems in utilisation.

The average surface area of heartwood measured on cross-sections from random logs from 9-, 10- and 12-year old trees increased with increase in diameter. In logs 2-7.4 cm diameter the area was 31%, 7.4-9.9 cm diameter 39.5%, 9.9-12.4 cm diameter 47% and 12.4-15.0 cm diameter 48%. Several trees were sampled along their length and showed a reduction of percentage heartwood with height in individual trees, a large variation between individual trees of similar age and a considerable variation within each diameter-class (Roux *et al.* 1976).

Chemical properties

The proximate chemical analysis of *A. mearnsii* (syn. *A. mollissima*) wood grown in Madras State, India was reported to be ash 0.36%, cold water solubility 1.61%, hot water solubility 3.28%, 1% sodium hydroxide solubility 15.9%, 10% potassium hydroxide solubility 28.5%, ether solubility 0.16%, alcohol-benzene solubility 0.60%, pentosans 20.3%, lignin 21.2%, cellulose (Cross and Bevan) 63.9%, all on a dry weight basis (Bhat and Virmani 1953). The Klason lignin content of extracted black wattle wood

from 16-year-old trees was 18.1% (Hannah *et al.* 1977).

The sapwood contained sucrose, glucose, fructose, and (+)-pinitol (Saayman and Roux 1965). Starch can also be present.

The materials extracted from the wood of 16-year-old black wattle trees were 3.3% with alcohol:benzene, 18.1 with 1% sodium hydroxide, and 4.2% with hot water (Hannah *et al.* 1977).

A. mearnsii heartwood contains about 8% extractives. In trees about 8 years old, the extractives are mainly flavonoids with low concentrations of tannins. The proportion of tannins increases with increasing age and the change appears to correlate with the progressive darkening of the wood with age (Roux *et al.* 1976). With the limited number of trees examined, the age of the tree does not appear to have much influence on the amount of extractives. Also, the butt and top sections contained a higher percentage of extractives than the middle section of the tree. The extractives yield 8% resorcinol on fusion with alkali (Roux *et al.* 1976).

The heartwood extractives contain (-)-fisetinidol, (+)-fustin, fisetin, 3-O-methyl fisetin, (-)-butin and butein (Roux *et al.* 1976), (the formulae are depicted in Chapter 12). However the predominant monomeric polyphenol is (+)-mollisacacidin, the (+)-7,3',4'-trihydroxy-(2R:3S:4R)-2,3-*trans*-flavan-3,4-*trans*-diol) also known as (+)-leucofisetinidin. Also present are small amounts of its *trans-cis* and *cis-cis* isomers (Drewes and Ilsley 1969a).

Mollisacacidin is considered to be the precursor of the dimers and tannins in *A. mearnsii* heartwood. The dimers isolated are composed of two 4,6-linked *trans-trans:trans-trans* leucofisetinidin moieties, as well as the *trans-cis:trans-trans* and *trans-trans:trans-cis* isomers (Drewes *et al.* 1967) (see Chapter 12). These molecules as well as their polymers are unique in that the 3,4-diol function is in the terminal group (Roux 1972).

As well as the above three biflavanoids of differing stereochemistry, a triflavanoid has been isolated (Drewes *et al.* 1967; Drewes and Roux 1968; Roux *et al.* 1976) consisting of a mixture of diastereoisomers and/or rotamers. The molecular mass of species in the tannin mixture ranges up to 3000.

The unusually dioxan-linked biflavanoids have been isolated from the heartwood of *A. mearnsii* (Drewes and Ilsley 1969b; Young *et al.* 1983; see Chapter 12).

The “non-tannins” present in the heartwood include (-)-pipecolic acid (0.04%) and (-)-4-hydroxypipecolic acid (0.05%), very small amounts of amino acids, (+)-pinitol, and a ‘steroid’ alcohol (Saayman and Roux 1965).

Physical and mechanical properties

Despite its widespread planting, the wood of *A. mearnsii* has received relatively little attention to increase its use for solid wood purposes. As physical and mechanical properties of wood can vary according to the genetic and growth characteristics of the tree, published data may differ from those of individual trees.

Density and shrinkage

Air-dry density varies considerably from 550 to 750 kg/m³, and basic density 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).

Shrinkage of green wood to wood with 12% moisture content is within the ranges of 3.1% to 4.0% in the radial direction and 5.6% to 7.0% in the tangential direction (Bolza and Keating 1972; Bootle 1983).

Mechanical properties

The mechanical properties of black wattle wood reported for both green (undried) wood, and for dry wood (at 12.5% moisture content, and with data given in brackets) are as follows. For wood from trees grown in Australia, the data were,

- (a) static bending, stress at limit of proportionality 32.1 MPa, * modulus of rupture 58-89 (124-139) MPa, modulus of elasticity 7.7-10 (18) MPa x 10³,
- (b) compression parallel to the grain, stress at limit of proportionality 23.8 (35.1) MPa, maximum crushing strength 32-46 (41-59) MPa, modulus of elasticity 12.3 (14.3) MPa x 10³,
- (c) maximum shear strength, on radial face 10.4 (12.2-19.9) MPa and on tangential face 12.0 (15.7-21.1) MPa,
- (d) impact, (Izod) radial 28.8 (25.9) Izod tangential 29.5 (23.7) N.m, toughness value radial 40.45 (35.7), toughness value tangential 39.5 (40.1) N.m,
- (e) cleavage 66.8 N/mm,
- (f) hardness, radial 6895 (6316) N, tangential 6494 (7074), end 5694 (8853) N (Sakata *et al.* 1959; Bolza and Kloot 1963; Bootle 1983).

* 1 Megapascal = 1 N/mm² = 145 lbf/in² = 10.2 kgf/cm²; toughness N.m - in.lb x 0.113; Izod N.m. = ft. lb. x 1.36; cleavage N/mm = lb./in. x 0.175; hardness N = lb x 4.44822.

For green wood from trees grown in Africa, the minimum standard test values for green wood (values for wood with 12.5% moisture content in brackets) were modulus of rupture 62 (93.7) MPa, modulus of elasticity 10.7 (12.4) MPa $\times 10^3$, maximum crushing strength 31 (53.4) MPa and maximum shear strength 9.1 (15.0) MPa (Bolza and Keating 1972).

Conversion and preservation

Sawing

The small diameter and variable quality of black wattle logs require grade sawing. Sherry (1971) reported that the considerable losses in the conversion of logs to parquet blocks made their price uncompetitive despite their good properties.

Drying

The recommended kiln drying schedules for green 25 mm thick boards of *A. mearnsii* are-

Moisture content of board (%)	Dry bulb temperature (°C)	Wet bulb depression (°C)
Green	50	5
60	50	8
40	55	10
35	55	15
30	60	20
25	65	20
20	70	20
15 to final	70	20

The kiln drying time from green to 12% moisture content would be 6-7 days. A high humidity treatment (70°C dry bulb temperature with 5°C wet bulb depression) is recommended at the end of the kiln drying for the relief of drying stresses (Campbell 1980).

Sherry (1971) reports that the difficulties in drying the wood without losses from checking and splitting have hindered its use for furniture and other uses. However the choice of particular drying schedules, such as the above, could reduce the extent of these defects.

Preservation

The sapwood is lyctus susceptible but absorbs preservatives readily. The heartwood is of medium durability and susceptible to termite attack. No data are available on the penetrability of heartwood to neutral preservative fluids but it is expected to be low.

Uses

Solid wood products

The hard, tough timber is moderately easy to work but with a tendency to become rough at knots; it polishes well. Preboring is necessary before nailing in order to avoid splits. Black wattle wood has been used for a range of products - light or parquet (heavy) flooring, structural timber, furniture, joinery, tool handles, toys, boxes and crates and agricultural equipment (Bolza and Keating 1972).

Roundwood

Logs have been used in South Africa for posts, poles and mine timbers. During April 1983 to April 1984, over 3 million m³ of roundwood mining timber was used in South Africa and of this amount 9% was black wattle logs. It was used in the form of mats or slabs (Saunders 1985).

Pulp, paper and board products

Satisfactory hardboard has been prepared from pulp prepared with an Asplund defibrator (Sherry 1971); and black wattle wood has been used with eucalypts for the production of particle board (Sherry 1971).

In early studies, satisfactory papers were made from mixtures of black wattle and bamboo kraft pulps (Bhat and Virmani 1953). The kraft pulping and papermaking properties of the *Acacia* species are suitable for a wide range of paper and paperboard products such as linerboards, bag and wrapping papers, white boards and writing and printing papers (Logan 1987). Plantation-grown *A. mearnsii* wood is currently being used commercially in South Africa as a component of a wood furnish for kraft and soda-anthraquinone pulp production and in Japan for kraft pulps. The wood from 16-year-old trees has been kraft pulped readily with moderate amounts of alkali to Kappa numbers in the bleachable range and with high yields of pulp. In one study, when pulped by the kraft process to a Kappa number of about 20, a relatively high yield of 330 kg of oven-dry pulp/m³ of green wood (47% moisture content) was obtained (Hannah *et al.* 1977). This corresponded to a yield of 57.9% pulp, comparing very favourably with yields of pulp under similar conditions of 49.6-53.6% for *Eucalyptus nitens*, *E. fastigata* and *E. regnans*. In another study, the screened pulp was 52.4% based on oven-dried *A. mearnsii* from 10- year-old trees (Logan 1987).

Paper handsheets prepared from laboratory kraft pulps exhibited very good strength properties. The level of tearing strength (9.6-8.4 mN.m²/g) was particularly satisfactory for an unbleached hardwood pulp on beating (at 4000 revs) and generally the bonding properties of the pulps attained high levels on beating (with burst index between 3.2-7.0 kPa.m²/g and

tensile index at 88 N.m/g) (Hannah *et al.* 1977; Logan 1987). Handsheet bulk (1.38-1.59 cm³/g) is sufficiently high to indicate favourable conditions for the production of printing papers. Other recorded data on beaten pulps (at 4000 revs PFI) are 250-432 freeness (CSF), tensile index 88 N.m/g, breaking length 6.1 km, air resistance 2 s/100 ml, and scattering coefficient 329 cm²/g (Hannah *et al.* 1977; Logan 1987). Pulps from *A. mangium* and *A. decurrens* have been readily bleached to high brightness levels (Logan 1987) and it would be expected that *A. mearnsii* would behave in the same way. Accordingly the bleached pulp properties would be suitable for a variety of end products such as writing and printing papers (Logan 1987). Wood chips and bark of *A. mearnsii* have been bleached by the DCEHD sequence. The bark had little effect on pulp brightness and no bark specks were evident after the final dioxide stages (Hannah *et al.* 1977).

Sherry (1971) reported that in about 1917, papers were made in South Africa from the soda and sulphite pulps of black wattle wood, but the low strengths were attributed to the short fibres (0.8-1.1 mm). However at that time satisfactory soda pulps were made from extracted wattle bark with its longer fibre length (1.0 to 2.2 mm with an average of 1.7 mm). The pulp bleached readily and a paper of satisfactory strength and quality was prepared.

Pulping methods other than kraft were applied to 10-year-old *A. auriculiformis*, which has wood properties similar to those of *A. mearnsii*, by Logan (1977). Two conditions of neutral sulphite semichemical pulping (NSSC) were tried. Yields were the same or higher than those of kraft pulp with properties similar to or higher than those of unbleached hardwood kraft pulp. Accordingly the pulps could be used in the manufacture of corrugating medium where crush resistance is required or in liner board. Because of its relatively high density the wood would probably be unsuitable for groundwood from impregnated billets (GIB), for cold soda semichemical (CSSC) pulp, refiner mechanical pulp (RMP) and chemithermo-mechanical pulp (CTMP).

Black wattle wood has been used in the production of rayon pulp (Sherry 1971).

Fuelwood and charcoal

The wood has been widely used for fuel for which it is highly regarded. Yields of 25-35% charcoal have been obtained (Sherry 1971) which has been used for several purposes including the production of producer-gas in Brazil for mobile vehicles.

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Chapter 11

Bark Properties

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Anatomy and general properties

Thickness

The basal bark from mature trees of *Acacia mearnsii* is usually more than 1.3 cm thick.

There is a strong correlation between stem diameter and bark thickness of black wattle although temperature and soil moisture can influence bark thickness. Sherry (1971) examined a large number of trees that ranged in age from 2 to 15 years and were from stands of different densities and site conditions. These gave correlation coefficients of 0.84 and 0.83 between undried and dried thickness respectively and breast height diameter. With another group of trees of the same age but grown under a wide range of different silvicultural treatments a correlation coefficient greater than 0.90 was obtained. Bark thickness tends to increase in thickness with increasing age and with decreasing stand density.

As bark thickness varies irregularly around the circumference of the stem at any given level, thickness determinations are taken as the mean of at least four samples from points equally spaced around the stem. Thickness decreases more or less regularly with increasing height from ground level. The mean bark thickness at a point above ground level equal to one-quarter of the total height of the tree represents a close

approximation to the weighted bark thickness of the tree (Sherry 1971).

Trees grown at relatively high altitudes and subjected to low winter temperatures generally have much thicker bark than trees of the same diameter and age grown at lower altitudes (Sherry 1971). However the thickness of the bark taken from the clear boles of four, 6-year-old *A. mearnsii* (syn. *A. decurrens* var. *mollissima*) grown in Tottori, Japan and killed by frost was between 4.5 to 5.5 mm (Sakata *et al.* 1959). Trees growing in deep moist soils in the valleys usually have thinner bark than trees of comparable diameter growing higher up the slopes in the same stand (Sherry 1971).

Average undried bark weights from plantation-grown trees in South Africa range from 13.6 to 22.7 kg with yields of between 18 830 to 22 595 kg/ha (Sherry 1971). If the tree age at stripping is allowed to increase, greater yields of bark can be obtained but over 15 years age the difficulty to remove the bark increases considerably.

Structural elements and location of tannin

The term 'bark' as commonly used in industry comprises all the tissues lying outside the cambium. The histology of the bark of black wattle (and to a limited extent green and silver wattle) has been described in detail by Luckhoff (1943, see also Sidey 1953).

By far the greater part of the thickness of mature bark is due to the phloem. In mature bark the original epidermis has been shed so that the outer surface is a thin cork layer or phellem containing dead cells with thick suberised walls arranged in very regular rows. Immediately inside this layer is a meristematic layer - the phellogen or cork cambium. The outside of the phellogen produces new cork cells and the inside the secondary cortex (Fig. 11.1). The latter contains a number of layers of cells which contain chlorophyll and are rich in protoplasmic content. Separating this secondary cortex from the phloem is the pericycle consisting of two or three layers of cells with thick lignified walls. The pericycle stains strongly with safranin. The phloem comprises three distinct types of cells: the sieve tubes with their companion cells, fibres (sometimes defined as bast, or bark, fibres), medullary rays and parenchyma. The sieve tubes and companion cells are functional only in the young or secondary phloem close to the cambium. They are arranged in regular radial groups between the bast fibre bundles. As the phloem increases in thickness, the outer layers of these tubes and cells are compressed and crushed so that they appear as dark conspicuous bands in the outer layers of a cross-section of the bark. The numerous fibres occur in oval bundles arranged in regular concentric rings (Fig. 11.1), each bundle being surrounded by a sheath of collenchyma cells which not only provide additional support but contain living protoplasts, such as chloroplasts, and can contain tannins. The fibre bundles are largest and most numerous a short distance from the wood and generally become smaller and thin out towards the pericycle. The fibre length ranges from 1.0 to 2.2 mm, with an average of 1.7 mm. Some barks (collected in parts of southern Natal and Cape Province) are less fibrous than those from Transvaal.) The rest of the phloem tissue consists of thin-walled parenchyma cells. Running radially through the phloem from the cambium are the medullary rays which are composed of three to five rows of rectangular parenchyma and are clearly defined.

The tannin in wattle bark is always most abundant in the phloem parenchyma cells. In tannin-rich barks these cells are full. The tannin is concentrated either in the outer parenchyma tissue adjacent to the pericycle or in the fibrous region. In some cases the tannin cells are in patterns; in other cases they are irregularly distributed. Tannin rarely occurs in the

sieve tubes and companion cells and never in the pericycle (Luckhoff 1943).

Variability of bark

Young bark is green and smooth becoming reddish-brown and rough in about two years. With increasing age, the bark at the base of the tree takes on an increasingly greyish tinge. When it is ready for harvesting at about nine years of age small white flecks about 2 cm in diameter are commonly present on the bark (Sherry 1971).

Occasionally instead of the normal smooth appearance of the bark, the older trees can have a corky bark at the base of the stem and this is a feature which appears to be genetically controlled (Sherry 1971). Also a few trees may have a sharply tapering stem with a spongy brittle bark that is difficult to remove from the grooves or depressions in the wood of the stem.

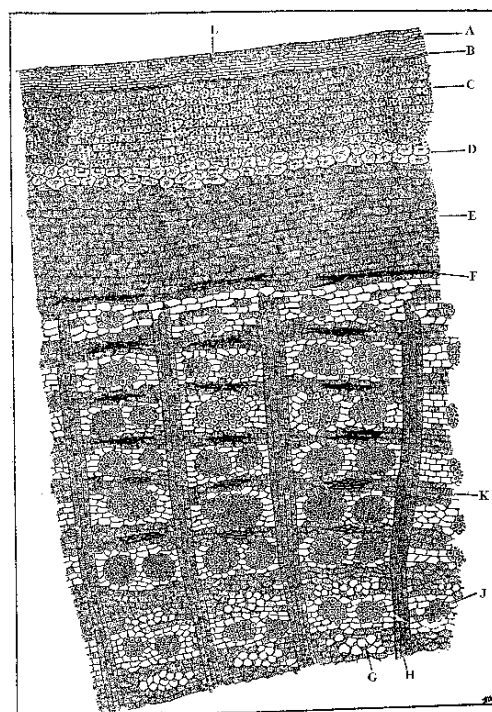


Fig. 11.1 Cross-section of black wattle bark from Eastern Transvaal (Stippling in cells indicates tannin precipitate.) (A) Layer of cork cells. (B) Cork cambium. (C) Cortical parenchyma cells containing chlorophyll and tannin precipitate. (D) Pericycle. (E) Main phloem parenchyma tissue in which majority of tannin cells occur. Width drawn disproportionately should be wider than shown. (F) Strip of compressed, functionless sieve-tubes and companion cells. (G) Normal sieve-tubes and companion cells. (H) Medullary ray. (J) Bast fibre bundle. (K) Phloem parenchyma cells. (L) Lenticel (Luckhoff 1943).

Chemical composition of bark

Introduction

The high reactivity of the condensed tannins and the ready solubility in cold water of many of them assist their use in many aspects. Wattle bark extract is perhaps more suitable for wide application than any other condensed tannin because of the high hydroxylation and suitable range of molecular mass of its components. The similar quebracho extract (from *Schinopsis* spp.), with its lower degree of hydroxylation, has a lower solubility and requires sulphitation to improve its use. Mangrove and pine bark tannins are more highly condensed than wattle bark tannins probably due to the higher reactivity of the phloroglucinol moiety of the flavan-3,4-diol precursors. Viscosity of concentrated extracts is important in some applications and the carbohydrates which are the main components of the non-tannin fraction of wattle bark extracts (Saayman and Roux 1965) not only enhance the solubility of tannins but also act as hydrogen-bond breakers and thus reduce viscosity at high concentrations.

Extractives

Methods of analysis

Since ancient times, aqueous extracts of certain plants grown in different countries have been used for the conversion of animal skins and hides into leather. The term 'tannin' was introduced by Sequin in 1796 (see White 1958) to denote those substances responsible for leather formation and subsequently these were found to be of a polyphenolic nature. However only some of the polyphenolic compounds in vegetable-tannin extracts can form leather. The simpler, smaller-molecular-weight polyphenols and those containing only low proportions of phenolic groups do not tan and a minimum molecular weight of about 500 appears essential. True affinity effects of polyflavanoids for collagen develops from the triflavanoid level ($m \sim 800$) and thereafter increases rapidly with increasing mass (Roux 1955a, 1958). Also when the molecular weight exceeds 3000 the penetration of the collagen fibrils in the hide is poor and inadequate tanning action occurs. The average molecular weight of methanol-soluble tannins is 1200-1300 (Roux 1955a).

The most direct method to assess the quality of a tannin extract for the manufacture of leather is to mix it with pulverised hide of known reactivity and to determine the amount of reactive material removed from the extract. However tannin extracts are used for other purposes besides leather production and other methods of analysis would be more appropriate for these applications.

The standards for determining the extractives, tannin and non-tannin content of vegetable tissues vary between different countries. Because of the empirical nature of the determination, the details of the various official methods require to be closely followed. The methods require a predetermined amount of ground sample (a minimum of 30 g for duplicate analysis) to be extracted in a specified type of extractor with cold and then hot water during a fixed period of time. The 2 litres of extract obtained must contain tannin within certain limits (such as 8.0 ± 0.5 g). Aliquots of this extract are used to determine total solids, total solubles and tannin materials. The latter determination involves shaking the aliquot with a specified amount of an approved hide powder that has been freshly moistened and reacted with a chrome alum solution of specified strength. After shaking for a specified period, the mixture is filtered and the weighed evaporated aliquot defined as non-tannins. The tannin matter absorbed by hide powder is defined as the difference between the percentages of total solubles and non-tannins in the extract. The analyses take 4-5 days. Even with adherence to specified conditions, analyses carried out by different analysts can vary, and with the Official Methods of the English Society of Leather Trades' Chemists variations within 3.0% of total tannin content of the sample are acceptable.

A faster method utilising smaller samples is needed to monitor biological practices aimed to obtain maximum tannin yields. The rapid spectrophotometric methods developed by Roux (1952, 1957a, 1957b, 1957c) produce results showing a close relationship with those determined by the hide powder method. There are some disadvantages (Gordon-Gray 1957) with these methods and results may vary with changing composition of the raw material.

Other uses of tannin rely mainly on the amount and nature of the phenolic components present in the extract. In particular, condensed tannins react with formaldehyde (which does not react quantitatively with hydrolysable tannins). A direct method for the determination of those polyphenols in *A. mearnsii* bark which can form the basis of adhesives (and also tan hides) is the reaction with formaldehyde. In 1952 Bayfield *et al.* soaked and boiled *Pinus radiata* bark with water for long periods after which an aliquot of the extract was refluxed with formaldehyde and hydrochloric acid for 30 minutes and the polyphenol-formaldehyde precipitate was removed and dried. A regression equation $y = 0.7593x - 3.45$ was determined (with a 10% standard error of ± 0.05) when 'x' represented the percentage of polyphenol formaldehyde precipitate and 'y' represented tannin content as determined by the Official Methods of the Society of Leather Trades' Chemists (such as Anon 1965). Later Wissing (1955) studied the similar 1905 method of Stiasny and found that comparable results

are obtained only when the reaction is carried on solutions of the same concentration of tanning material and within a narrow pH range in the acid region. The yield of precipitate from a model compound catechin under different conditions varied between 108%-116% (Hillis and Urbach 1959a,b; Zheng and Yazaki 1987). It is not possible to calculate the absolute amount of reactive polyphenols in an extract as the pure compounds are not available for analysis. However the method enables rapid reproducible estimations (within 1%) to be made under controlled conditions. Zheng and Yazaki (1987) developed a method in which ground *A. mearnsii* bark (1.5 g) was refluxed with water for 15 minutes, the hot mixture filtered, the residue again refluxed and washed and the filtrates freeze-dried. Dried samples dissolved in water and heated under reflux with formaldehyde and hydrochloric acid for 30 minutes yielded a precipitate which could be filtered, washed and dried. The procedure enables five samples of bark (and 10 samples of the dried extracts) to be analysed daily to give closely reproducible results.

Tannin content and variations in amount

In the early surveys of the tannin content of a large number of Australian acacias the highest contents were found in the barks of black wattle and golden wattle (*A. pycnantha*) (Coghill 1927). The attractiveness of the richness of the bark of the latter (tannin content about 40%) is diminished by the small size of the tree. Some of the trees sampled as black wattle at that time may have been other species with a superficial resemblance to *A. mearnsii* (and its synonyms) and not recognized at that early stage; these could have been responsible for some of the low contents reported. It should be noted also that early data were often expressed as a percentage of bark of 12% moisture content whereas data in this chapter are expressed on the more usual moisture-free basis. Early surveys reported the tannin content (as determined by the International Association Leather Trades Chemists (I.A.L.T.C.) method) in the bark samples as between 22.0%-50.3% (with a significant majority containing more than 36%) and a non-tannin content between 8.7%-11.8% (Coghill 1927). The bark of black wattle grown outside Australia, and analysed by the I.A.L.T.C. and other methods contained between 30.9% and 53.2% tannin and 8.2% and 12.7% non-tannins and again a large majority of the samples contained more than 36% tannin. In a later survey of barks from trees of different ages in different localities of the eastern states of Australia, Coghill (1927) found the tannin content of bark to range between 24.2% and 48.7% and non-tannins between 6.2% and 13.3%.

In South Africa, the analyses of bulked core-samples taken from every bundle of bark harvested from 378 plots containing trees 7 to 13 years of age showed

averages of 29.1% to 41.8% with a mean of 36.8% (Sherry 1971). However tannin contents as high as 53% have been recorded for a whole-tree sample and values between 44% and 48% are not uncommon (Sherry 1971).

An early (1928) interest in New South Wales in the improvement of the quality of black wattle (syn. *A. mollissima*) later led to the plan to establish a seed production stand of four high tannin (55.1%-57.4%) producing provenances ('strains') collected from trees of unknown age in that State. At the completion of the last set of trials it was concluded (Humphreys and Johnstone 1957) that insufficient seed samples had been taken to establish differences between the provenances.

A survey was undertaken of the extractives and tannin contents of 94 bark samples collected in 1987 from 20 provenances of *A. mearnsii* in eastern Australia. The extractives yields ranged from less than 40% to more than 70% with an average of 55.3%. Although the value of the survey was reduced by inability to determine the age of the trees and to define the effects of various environmental conditions it was evident the Victorian and Tasmanian samples contained more (and the Victorian less variable) amounts of extractives and tannin than those from other States. The maximum amount of extractives (63.8% to 71.7%) were obtained from the combined samples from trees sampled in the four best provenances which were found in Tasmania and Victoria (these two States had an overall average of 62.2%). The corresponding values for the four best provenances in New South Wales were 56.2% to 58.2% and with an overall state average of 51.2%. The average yield of extractives from all Tasmanian and Victorian samples was above that of all the bark samples analyzed; all samples from other regions were lower (Yazaki and Zheng 1987).

The amount of polyphenols (estimated as polyflavanoids) in the bark from the four best Tasmanian and Victorian provenances were 56.2% to 65.5% and the overall average of 54.9%. When attention is directed to the four best trees, these were again in Tasmanian and Victorian provenances with 65.5%-71.7% extractives and 60.9%-65.5% polyflavanoids. In addition, the Victorian bark samples had the highest proportion of polyflavanoids to unreactive material (Yazaki and Zheng 1987).

Possible causes for variation in tannin contents

Several factors can affect the tannin content of the bark sample and ultimately the yield per hectare and must be considered when selecting parent trees for the provision of future crops.

Luckhoff (1943) noted considerable differences in the anatomical distribution of tannin in the bark collected from different regions of South Africa. Some of the

differences may be under genetic control. The tannin (as detected by a 2.5% potassium dichromate stain) in the bark collected from trees in the south-eastern Transvaal was mainly in the parenchyma of the cortex, outer phloem and medullary rays. These cells were generally filled with tannin. The fibre bundles and associated parenchyma rarely contained tannin.

In bark affected by gummosis, the tannin gradually disappears and the surrounding unaffected regions also lack tannin. Irregular pockets of completely tannin-free cells were frequently found in the outer phloem of gummosis or some other injury (Luckhoff 1943; Siey 1953). Considerable variation existed in both the tannin content and the distribution of tannin in the phloem at different heights in the same tree. At 1.5 m height tannin was abundant in the outer parenchyma tissue but much less in the inner fibrous region. At 3.6 m height it was sparse or absent in these regions but abundant in the ray cells. At 7.6 m it was very largely in the outer parenchyma tissues.

Further north in the north-eastern Transvaal the distribution of tannin in the bark was similar although the barks were thinner. On the other hand, bark collected in other regions of South Africa (to the south of Transvaal and to the west) which contained lower amounts of tannin an entirely different distribution of tannin was observed. In those regions most of the tannin occurred in the inner phloem parenchyma surrounding the fibre bundles closer to the wood. The cortical parenchyma were almost devoid of tannin and only the outermost rows of cells in the outer phloem parenchyma and adjacent to the pericycle contained tannin. Sherry (1971) considered these differences in tannin distribution could be associated with soil types and winter frosts and cold.

The yield of extractives relative to bark thickness, tree diameter and tree diameter over height were clearly higher (6%-14%) for the Tasmanian and Victorian samples than the others mentioned above. In contrast to the South African studies no close relationship was found between extractives and tannin content with bark thickness, tree diameter and tree height (Humphreys and Johnstone 1957). This may be due to the selection of the best trees on the variable Australian sites and to small sample size.

Bark thickness can vary, being thinner on the top of the tree and branches; it also varies with age and vigour of the tree. Sherry (1971) quotes the earlier work of Williams and of Taylor reporting the direct relationship between thickness and tannin content and his own correlation coefficients of 0.780 and 0.755 between percentage tannin content and the thickness of undried and dried bark respectively. The percentage tannin content of the bark decreases with increasing height above ground (with a corresponding increase in non-tannin content), and whereas 27.4% tannin was found in the bark of the lower branches of

nine-year old trees only 6.7% was found in the twigs of trees of the same age (Sherry 1971). As would be expected the degree of taper in the stem of the tree can influence the thickness of bark at breast height. Beard (1957) found that ten-year-old trees in Natal (South Africa) of the same breast height diameter as those in the south-eastern Transvaal may yield identical weights of undried bark although the ratio of bark thickness to tree diameter is greater in the Transvaal than in Natal. This is due to the greater degree of taper of the trees in Natal and because they are 40% taller. These trees also yield 30% more timber. When the yields of undried bark range from 20 to 21.5 tons/ha the ratio of timber/bark yields is about 4.1 and this increases when bark yields per hectare increase (Sherry 1971).

In an early study of plantations of black wattle in New South Wales (Australia) (Humphreys and Johnstone 1957), it was found there was a very marked increase in tannin content during the first four years of growth. After this age was reached there was a slower increase up to the end of the trial at 10 years. All four provenances showed highly significant differences between the means of the four different ages (between 2.75 to 10.08 years) as expressed in the regression equation $y = 21.35 + 16.18 \log x$, where y = tannin content %, x = age in years. The authors recommend that bark collected from trees about five years of age should give sufficient data to evaluate tannin inheritance. Studies in South Africa also showed a steady annual increase of 36.1% to 39.4% tannin content in trees from four to eight years of age when grown on the one site (Sherry 1971). The age of naturally grown trees is difficult to determine owing to the indistinct nature of the growth rings in this species. Stem diameter may give some indication of age and the stem diameter of plantation-grown trees has been shown to be strongly correlated with bark thickness.

The site of a plantation appears to have an effect on tannin content. Barks from 'moist' sites are usually thinner and shrink more than the barks from 'dry' sites, and as expected from previous comments have lower tannin contents. The means of tannin content of trees grown in stand densities of 1500, 1375 and 1250 trees/ha with ages 7, 9, 11 years were respectively 37.3%, 37.0% and 35.5% for rainfalls of 933, 996 and 1209 mm (Sherry 1971). Low winter temperatures may produce thicker barks and hence higher tannin contents. This suggestion has been made (Sherry 1971) to explain the higher tannin contents - namely a mean of 45.1% - of bark from a range of sizes of 11-year trees collected in northern Natal (South Africa) when compared with the tannin contents - namely a mean of 42.7% - of bark collected from comparably sized trees grown on similar soils in the midlands of Natal.

Diseased bark - due to gummosis, or 'black-butt' - can have a lower tannin content than healthy bark and yield a darker colored extract (Sherry 1971).

In order to maintain the highest possible standard in the quality of wattle bark and extracts, strong emphasis has been placed on the exclusion of diseased bark and of green bark from the uppermost 2-4 m (7-14 ft) of mature (8 or more years of age) trees. The latter represents about 5% of the total weight of bark. It was found (Gordon-Gray and Jones 1959-60) that there was no difference in tannin content with change from green to grey bark taken at the same height. On the other hand, the tannin contents and the tannin/non-tannin ratios in the barks at the tops of the trees were significantly lower (tannin 34.5%, tannin/non-tannin ratio 2.09) than at the base (44.8%, 3.2 respectively). However the influence of the small proportion of the bark available from the top of the tree on the extract composition of all the bark was relatively slight. The black-butt disease of bark caused a considerable (17%) loss in tannin content and a significant increase in colour in red and yellow units.

There are few reported studies on the variation of extractives and tannin contents in the bark of *A. mearnsii* grown in extract-producing countries outside South Africa. Workers in Kenya found the total extractives content was lower but the tannin-nontannin ratio was higher when the soil moisture increased. Also with an increase in tree diameter, both the tannin/non-tannin ratio and the extractives content improved, and, as expected from other work, the higher the point on the stem from which the sample was taken these properties declined (Sherry 1971). The Kenyan investigators recommended that the rotation age should slightly exceed 10 years and the stand density at final thinning should not exceed 1500 trees/ha to ensure development of large-diameter trees. The tannin content of bark from the Indian region of Nilgiris ranged from 42.8% to 37.2% with tannin/non-tannin ratios of 3.58-2.88. The Indian workers claimed the tannin content was highest from December to March (the driest period) and 2%-3% lower during the rest of the year (Sherry 1971). The bark of the large areas of *A. mearnsii* grown in Rio Grande do Sul, Brazil is generally inferior to that grown in South Africa, with the average thickness of bark from trees about 13 cm diam. being about two-thirds of that from trees of the same age and diameter grown in Natal. In addition the average tannin content was 28.6% and the tannin/non-tannin ratio 2.16 (Sherry 1971). The tannin content of the bark of *A. mearnsii* grown in Chiba prefecture (Japan) and Taiwan varied from 22% to 29% (Shibamoto *et al.* 1950).

In addition to the variations in tannin content due to sampling procedures as mentioned above, loss in tannin can occur due to inadequate drying and storage of the bark. In most countries the early stages of

development of production was marred by inadequate precautions in drying the bark resulting in mould growth, lower tannin yields and discolouration of the extract. This deterioration is avoided when the bark is extracted within 2-3 days or the bark is spread to dry as quickly as possible out of direct sunlight which can cause darkening of the cambial side of the bark.

Non-tannins

The extractives of black wattle bark which are not retained by hide powder contain predominantly sugars, gums and smaller amounts of polyphenols with molecular weight below 500 and several nitrogen-containing compounds. Sucrose is the only sugar in aqueous extracts of fresh bark and it hydrolyses to glucose and fructose on storage. (+)-Pinitol is also present (Saayman and Roux 1965). The gums are large molecular units (of about 1880 equivalent weight) yielding on hydrolysis arabinose (46%), galactose (38%), rhamnose (8%) and glucuronic acid (8%) (Roux 1952). The gums within the bark and the natural exudate (due to injury or other causes) appear to have the same composition.

The exudate gum from *A. mearnsii* contains residues of D-galactose, L-arabinose, L-rhamnose, and D-glucuronic acid (in part, as the 4-methyl ether), in the approximate molar ratio of 9:6:2:3. Partial hydrolysis with acid affords mixtures of neutral and acidic oligosaccharides including 6-0-(β -D-glucopyranosyl-uronic acid)-D-galactose, 6-0-(4-0-methyl- β -D-glucopyranosyl-uronic acid)-D-galactose, 3- and 6-0- β -D-galactopyranosyl-D-galactose, and 3-0- β -L-arabinopyranosyl-L-arabinose (Aspinall *et al.* 1968; Churms *et al.* 1978). A structure has been proposed for the gum collected from a tree growing in Jamaica. When compared with the gum from trees growing in South Africa (Charlson *et al.* 1955; Kaplan and Stephen 1967; Churms *et al.* 1978) there were no apparent differences in the nature of the sugar residues or in the linkages between them.

The gum of *A. mearnsii* is polydisperse, of high molecular weight (over half has $M_w > 500,000$) and limited solubility in water (Churms *et al.* 1978). The gum swells considerably in water to form a semi-colloidal gel which can block the space in the collagen structure of skins to interfere with the diffusion or penetration of tannins. The gum probably has other effects in other applications as it has been found that when gum arabic, or glucose, were added to phenol-resorcinol-formaldehyde resins, severe losses in glue bond quality resulted (Pizzi 1983).

The gums show a complex behaviour at different concentrations. At intermediate concentrations, a colloidal suspension can form and at high dilutions this suspension can dissolve. In concentrated aqueous solutions, the tannins can solubilize the gums (Roux 1955a). It is very probable that condensed tannins

form strong complexes with starch and other polysaccharides, which when in solution will increase viscosity (Rahman and Richards 1988).

Nitrogen-containing compounds constitute about 3% of the dry extract from 5-6-year-old bark. The compounds identified include the imino acids L(-)-pipecolic acid, trans-4-hydroxy-L(-)-pipecolic acid and L(-)-proline. Also present were the amino acids α -alanine, arginine, aspartic acid, glutamic acid and serine. The petroleum-soluble fraction of the bark (0.22% on bark weight) consists of at least 6 components, among which a long-chain β -diketone and a 'steroid' alcohol predominate (Saayman and Roux 1965).

The low molecular weight polyphenols are present in only about 3% of the total polyphenols (Drewes and Roux 1963). They form a complex mixture and provide the basis of understanding of the composition of black wattle tannins (see Chapter 12). The fluorescent polyphenols in this mixture can be used to distinguish black wattle bark from green wattle (*A. decurrens*) and silver wattle (*A. dealbata*) barks.

Structural components of bark

No information on the chemical composition of the structural components (usually expressed as fibre or insoluble material) is available. Variations in the amount of cellulose and hemicelluloses and nature of the hemicelluloses could influence the choice of extraction procedures. It is probable that the procyanidin polymers of pine bark can form strong complexes with cellulose and hemicelluloses (as well as starch) (Rahman and Richards 1988). Similar reactions probably occur when black wattle bark is boiled with water.

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Chapter 12

Tannin Chemistry

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Definition of tannin

Vegetable tannins have been defined as '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) (see also Roux 1955b). However the term tannin has been applied to a range of plant polyphenols which may not have tanning properties. Plant anatomists describe secondary components in plant cells which form different colours with certain stains as 'tannins', although there is no information as to whether they have tanning properties. In recent years, vegetable tannins have been used for purposes other than the conversion of hides and skins into leather, but the now inappropriate name is still used for convenience. It would be preferable if the term 'plant polyphenols' were used.

Definition of condensed and hydrolyzable tannins

Condensed tannins

The major portion of condensed tannins consists of proanthocyanidins, or those substances isolated from plants that form anthocyanidins, and a brilliant red colour, when heated with hydrochloric acid; at the same time a dark brown precipitate is formed. Their molecular weight ranges from about 500 to over 20,000 and they are relatively unstable and darken in sunlight and heat.

Hydrolyzable tannins

These are polyesters based on gallic acid and/or hexahydroxydiphenic acid and their derivatives and esterified most commonly with glucose. They range in size from simple mono-esters such as β -D-glucogallin to complex polyesters with D-glucose and molecular weights up to 3000. They were formerly of great importance probably owing to their availability in a number of local resources, their lower 'astringency' and production of softer leathers, their paler colours and colour stability. They have been replaced by condensed tannins in a number of

situations as the latter are available in larger quantities of uniform quality and tannage with them can be modified to produce a leather similar to that given by hydrolyzable tannins. Because of their sensitivity to hydrolysis, the activation of the benzene ring caused by the vicinal trihydroxy substituents being much less than the activation towards electrophilic attack of the meta-hydroxyl groups in condensed tannins, the carboxyl (ester group) function, and steric hindrance of the residual nucleophilic centres, the enlargement of uses for hydrolyzable tannins is limited.

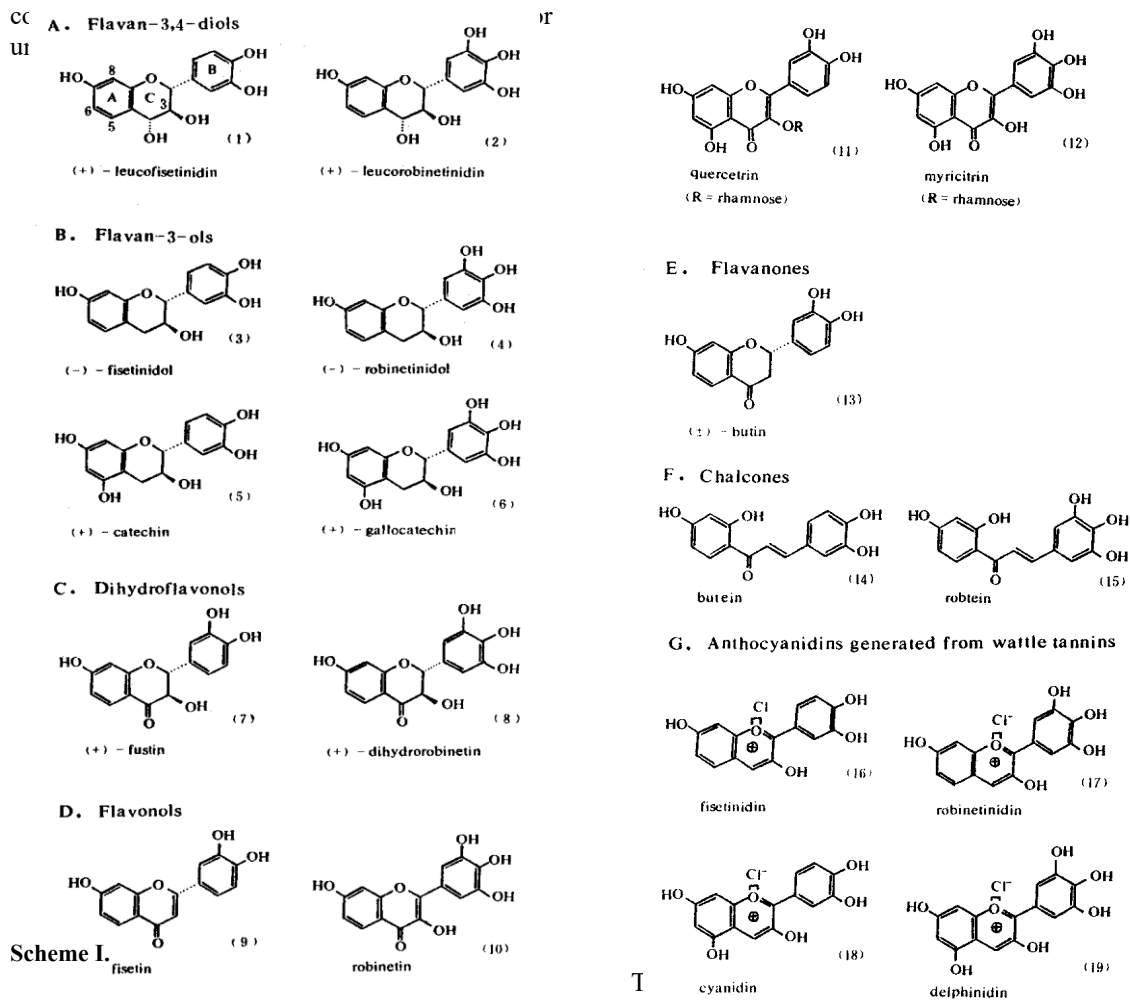
Biosynthesis

The biosynthesis of plant polyphenols from glucose in the plant commences when the metabolic products passes through the shikimic acid pathway. Components of this pathway progress to form gallic acid which gives rise to numerous derivatives and the hydrolyzable tannins. Through various stages the shikimic acid pathway gives rise to p-coumarylquinic acid which combines with acetate units from the tricarboxylic acid (TCA) cycle to give rise to C₆-C₃-C₆

Condensed tannins

Monomeric polyphenols

The phenolic non-tannins of black wattle bark contain flavan-3,4-diols (leucoanthocyanidins), flavan-3-ols (catechins), dihydroflavonols (flavanonols), flavanones, flavanones and chalcones (Roux *et al.* 1975). Collectively they represent a relatively low percentage of the phenolic fraction. Two of the flavan-3-ols, namely (+)-catechin (5) and (+)-gallocatechin (6, see Scheme I from Roux *et al.* 1975), which possess a phloroglucinol A ring are found in a wide range of plant tissues. On the other hand the other phenolic non-tannins (see Scheme I) lack the C5 hydroxyl (i.e. possess a resorcinol A ring) which is a characteristic of flavonoids found in many of the Leguminosae (such as *Acacia* spp.) and some of the Anacardiaceae (such as *Schinopsis* spp.). They are strongly yellow fluorescent in ultra-violet light, and are less reactive than their counterparts possessing the C5 hydroxyl.



Scheme I.

T
tl
Scheme I), (-)-fisetinidinol (3), (+)-fustin (7) fisetin (9), (-)-butin (13), butein (14) (Roux *et al.* 1961; Roux

and Paulus 1961a), and 3 methoxy-fisetin (Drewes and Ilsley 1968). In addition the heartwood contains the bi-, tri- and oligo-meric flavanoids based on (+)-leucofisetinidin (1) (Roux and Paulus 1961b, 1962, see 'Polymers' below) all of which possess potential chromogenic properties and are possibly largely responsible for the pink colour of the heartwood. In addition two pyranones and a pyrone have been isolated in very small amounts. These compounds are 3,8,9-trihydroxy- and 3,9,10-trihydroxy-6H-dibenzo [*b,d*] pyran-6-ones (20) and (21) and (2'S,3'R)-9-(5',6'-dihydroxy-2'-hydroxy-methyl-2', 3' - dihydrobenzo [*b*] furan-3-yloxy)-6H-dibenzo [*b,d*] pyran-6-one (22). Compound 22 possesses chromogenic capability and compounds 20, 21 belong to a class of metabolites known for their cytotoxicity (Young *et al.* 1983).

Catechins, flavan-3,4-diols and anthocyanidins

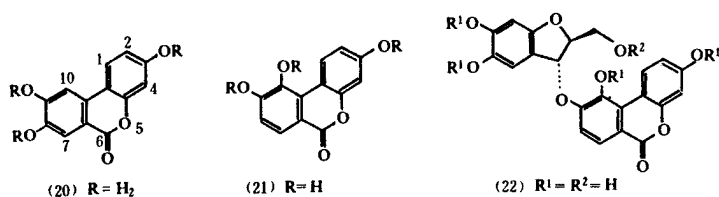
(+)-Catechin (5), (+)-gallocatechin (6) and (-)-robinetinidol (4) predominate among the monomeric polyphenols in black wattle bark. The catechins (flavan-3-ols) and leucoanthocyanins (flavan-3,4-diols) are the basic units of condensed tannins. (+)-Catechin and (+)-gallocatechin, and their 3-epimers namely (-)-epicatechin and (-)-epigallocatechin were the first to be isolated and studied to provide an understanding of the polymeric condensed tannins. In addition to the (+) or (-) direction of rotation, there is the unassociated different configuration (R = right, S = left) around chiral centres. Also, the substituents on the heterocyclic ring (ring C) can be in the *trans*- or in the *cis*- position. Thus, the complete definitions are (+)-catechin [(2R:3S)-2,3-*trans*-flavan-3,3',4',5,7-

pentaol], and (-)-epicatechin [(2R,3R)-2,3-*cis*-flavan-3,3',4',5,7-pentaol] (see 23).

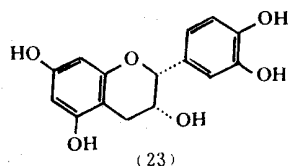
(+)-Catechin and (+)-gallocatechin are strongly nucleophilic substances and (-)-fisetinidol and (-)-robinetinidol are less strong. The flavan-3,4-diols are potential electrophilic compounds. The other flavonoids all possess a 4-carbonyl function which not only prevents substitution at this position but also deactivates their respective resorcinol A-rings towards electrophilic attack.

The catechins do not produce a red colour when heated with hydrochloric acid as do the flavan-3,4-diols of which (+)-leucofisetinidin (1) (or (+)-mollisacacidin [(2R:3S:4R)-2,3-*trans*-3,4-*trans*-flavan-3,3', 4',7-tetraol], and the corresponding (+)-leucorobinetinidin (2) (Drewes and Roux 1964) have been found in black wattle bark in lower concentrations. Later the (+)-(2R:3S:4S)-2,3-*trans*-3,4-*cis* (24) and the (+)-(2S:3S:4S)-2,3-*cis*-3,4-*cis* (25) isomers along with (+)-mollisacacidin were isolated from the heartwood of *A. mearnsii* (Drewes and Ilsley 1969a).

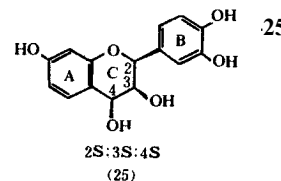
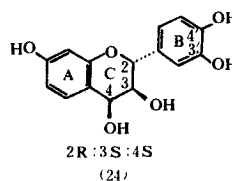
The flavan-3,4-diols are much less stable than the flavan-3-ols and have been shown to be the major units of condensed tannins. These compounds and their oligomers occur free and unglycosylated. The flavan-3,4-diols which lack the C5 hydroxyl are the more stable members of this class and were the first to be isolated from *Acacia* and related genera and characterised, mainly by Roux and co-workers. Flavan-3,4-diols are grouped with leucoanthocyanidins or proanthocyanidins which give a strong red colour when heated with hydrochloric acid. The yield of the corresponding anthocyanidin increases significantly when heated with alcoholic



Formulae 20-22



Formula 23



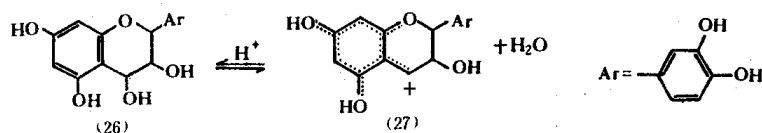
hydrochloric acid, such as butanol hydrochloric acid, so that these substances can be estimated (Swain and Hillis 1959). The anthocyanidins (16-19) have been isolated from black wattle bark and wood after heating with

hydrochloric acid. In this review leucoanthocyanidin is used as a generic term for flavan-3,4-diols and proanthocyanidins for the various dimers and higher oligomers.

Di-, tri-, and oligo-meric flavan-3,4-diols - Creasy and Swain (1965) and Geissman *et al.* (1965,1966) drew attention to the extremely reactive 4-position in 3,4 diols such as (26).

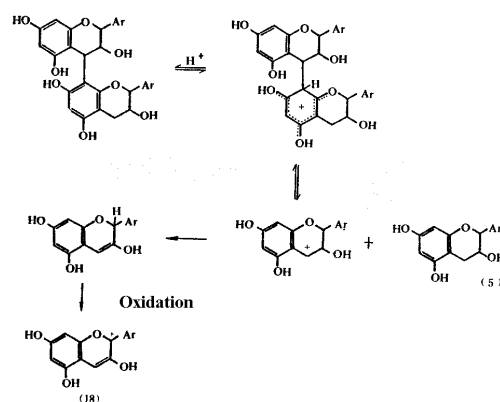
This is evident when it is observed that the carbonium ion formation (which they expressed as (27)), or the 4-carbocation, is enhanced by resonance stabilisation of the three phloroglucinol oxygen stems. They proposed that electrophilic substitution of this form into the highly active and nucleophilic phloroglucinol ring of a similar molecule would be expected to occur readily and the reaction would be reversible. The reversibility of this reaction under acidic conditions was represented as in Scheme II.

The facile acid-catalysed cleavage of the interflavanoid bond of procyanidins is important in many reactions and uses of condensed tannins. The cleavage of the C(4)-C(8) interflavanoid bond (see 28) occurs more rapidly than in the C(4)-C(6) linked isomers under mild acid conditions, and also the carbocations generated can be captured by phenols (including flavanoids as nucleophiles). This lability of the interflavanoid bond to cleavage can affect the constitution of condensed tannins during their extraction and concentration and the behaviour of derived products during their use.



Formulae 26-27

obtained when the water content in the solvent is kept at about 6% v/v. The yield of anthocyanidin from polymers was found to be dependent not only on the mole fraction of the proanthocyanidin but also the length of time the polymer preparation had been stored.



The absence of a C5 hydroxyl in the flavan-3,4-diols and most of the flavan-3-ols of the extractives of the *Acacia* tree species (and some other species of the Leguminosae and Anacardiaceae) has lowered the reactivity of these molecules and the lability to cleavage of the interflavanoid C-C bond and reduced the experimental difficulties of their study. With this advantage Roux and co-workers (e.g. Roux 1972;

The high reactivity of the carbocation forms of the flavan-3,4-diols, amplified by the presence of the C5 hydroxyl on the A ring, leads to rapid self-condensation, or to condensation with nucleophilic (+)-catechins and (-)-epicatechins, resulting in oligomers and polymers. This would be responsible for the absence or near-absence of monomeric leucocyanidins and leucodelphinidins in plant tissues (Creasy and Swain 1965).

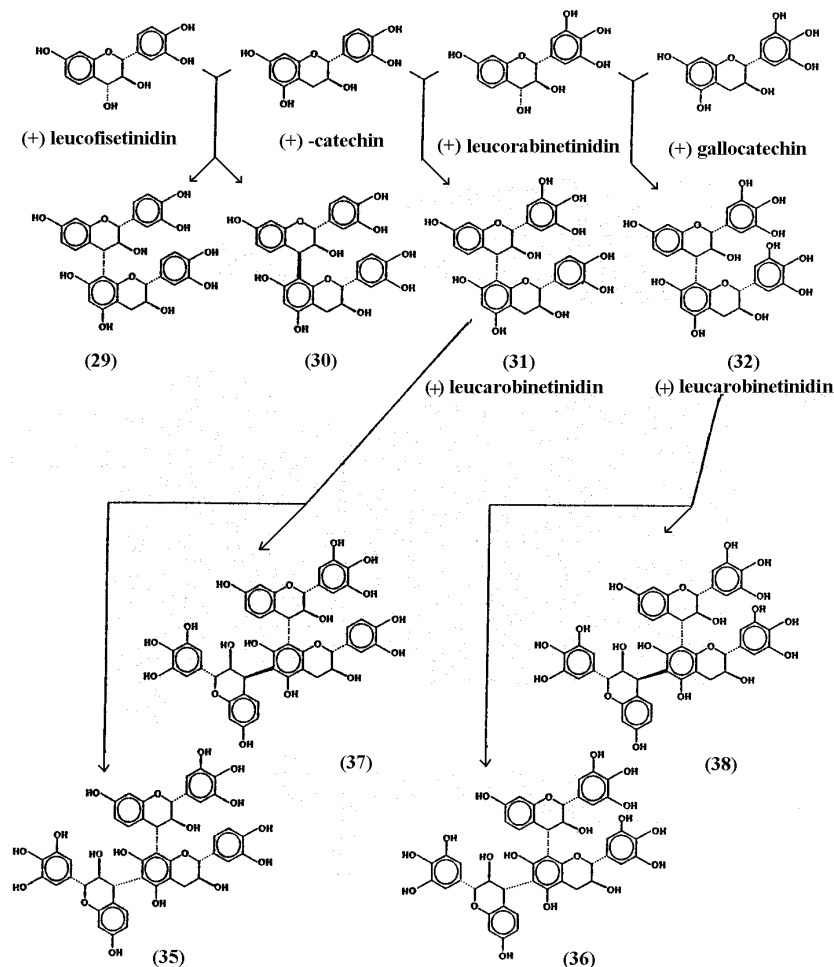
Heating aqueous solutions of condensed tannins leads predominantly to the formation of 'phlobaphenes' or 'tanners' reds' and then to insoluble condensates. When condensed tannins are heated with acid in alcoholic conditions much larger amounts of anthocyanidins are formed. The latter conditions lead to the development of the method of estimation for proanthocyanidins by Swain and Hillis (1959) using n-butanol-concentrated hydrochloric acid (95:5 v/v). Recent studies (Porter *et al.* 1986) have shown the hydrolysis of proanthocyanidins to anthocyanidins (e.g. 18) occurs by an autoxidation following acid-catalyzed cleavage of the interflavanoid bonds (Scheme II). To obtain consistent yields of anthocyanidins, trace amounts of iron (III) salts (or other transitional metal ions) must be present to catalyse the autoxidation. Also the maximum yield is

Roux and Ferreira 1982) have laid the basis of the structure of condensed tannins and in particular those of black wattle tannin. Even so the sensitivity of the components of tannin to experimental conditions alone render their separation difficult. Also as the size of the oligomers and polymers increases, their study becomes extremely complex. 'The combined

function of the abnormal complexity of the gradational range of oligomers of increasing mass and affinity for substrates, which typify most extracts rich in tannins, and the consequent problem of their isolation and purification, the high chirality (at the 2,3, and 4 position of the heterocyclic C ring) of tannin oligomers, the need to contend with the

phenomenon of dynamic rotational isomerism about interflavanoid bonds in the ^1H n.m.r. spectral interpretation of their derivatives, the lack of precise knowledge regarding the points of bonding at nucleophilic centres⁷ (Roux and Ferreira 1982) led to another approach. Roux and his school decided,

because of the disadvantages of the degradative approach to tannin polymers, that more definitive results would be obtained from the synthesis, under very mild conditions, of di-, tri- and tetra-mers (itself a difficult task) to enable unambiguous proof of both structure and absolute configuration.

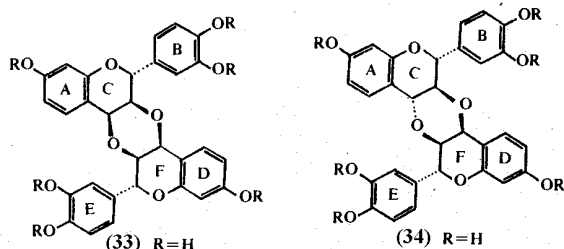


Scheme III. Hypothetical condensation scheme for wattle bark tannins (*Acacia mearnsii*) (Roux and Ferreira 1982)

The starting point of Roux and co-workers was the identification of the bonding positions at either C-6 or C-8 of the presumed 'terminal' (+)-catechin (5) unit which serves as the initial nucleophile in most tannins under consideration. The 7-hydroxyl in the A ring, at a meta-position to the heterocyclic oxygen group, creates strong nucleophilic centres at the 6- and 8-positions of flavan-3,4-diols and flavan-3-ols. The C-5 hydroxyl amplifies the nucleophilic character. When (+)-catechin (5) was coupled with (+)-leucofisetinidin (1) only a small portion of the 4,6-dimer was formed; the rest were 4,8-dimers. The metabolites in wattle bark are presumably based on two nucleophilic species [(+)-catechin (5) and (+)-gallo catechin (6)] and two electrophilic species [(+)-2,3-*trans*-3,4-*trans*-leucorobinetinidin (2) and the corresponding-leucofisetinidin (1)] (Roux and Ferreira 1982). The corresponding four [4,8]-linked biflavonoids have been isolated from black wattle bark extract, namely 2,3-*trans*-3,4-*trans*:2',3'-*trans*-(+)-fisetinidin(+)-catechin (29) and its 3,4-*cis* isomer (30) (the major biflavonoid in wattle bark), 2,3-*trans*-3,4-*trans*:2',3'-*trans*-(+)-robinetinidin(+)-catechin (31) and the corresponding (-)-robinetinidin(+)-gallo catechin (32) (Botha *et al.* 1978b, 1981; Viviers *et al.* 1983a,b). The absolute configuration of the [4,8]-linked biflavonoids is 2R,3S,4S:2R,3S and the [4,6] linked biflavonoid is 2R,3S,4R:2R,3S (Botha *et al.* 1978a) (see Scheme III).

When the C5 deoxyflavans were reacted together, substitution at the strongly nucleophilic centres was highly sensitive to steric factors and reaction occurred preferentially at the least hindered site of C6 to give [4,6] linkages (Botha *et al.* 1978a,b).

The biflavonoids with their relatively low mass and good solubility in water do not exhibit tanning properties. They are regarded as precursors of the tri- and oligo-meric forms which eventually become the polymers of tannins.



Formulae 33-34

Before further discussion of the various C-C linked forms of flavan-3,4-diols, attention is drawn to the small amounts of two novel doubly ether-linked ('dioxane type') biflavonoids isolated from the heartwood of the black wattle (Drewes and Ilsley 1969b; Young *et al.* 1983). They are structurally symmetrical profisetinidins with a 2R,3S,4S:2'R,3'S,4'S-(2,3-*trans*-3,4-*cis*:2',3'-*trans*-3',4'-*cis* relative stereo

chemistry (33) and the stereochemically asymmetrical 2R,3S,4R:2'R,3'S,4'S-(2,3-*trans*-3,4-*trans*:2',3'-*trans* 3',4'-*cis* diastereoisomer (34).

The triflavanoids present in wattle bark are based on the condensation of (+)-leucorobinetinidin (2) with 2,3-*trans*-3,4-*trans*:2'3'-*trans* (-)-robinetinidinol-(+)-catechin (31) and the corresponding (-)-robinetinidinol-(+)-gallo catechin (32) (Scheme III). This condensation results in the [4,6:4,8] 'angular' triflavanoids of 2R,3S:2R',3S':2R'',3S''(2,3-*trans*-3,4-*trans*:2',3'*trans*:2'',3''-*trans*-3'',4''-*trans*)-bi[(-)-robinetinidinol]-(+)-catechin (35) and the -bi[(-)-robinetinidinol]-(+)-gallo catechin (36) and their respective 3'',4''-*cis* diastereoisomers (37, 38) (Scheme III) (Roux and Ferreira 1982).

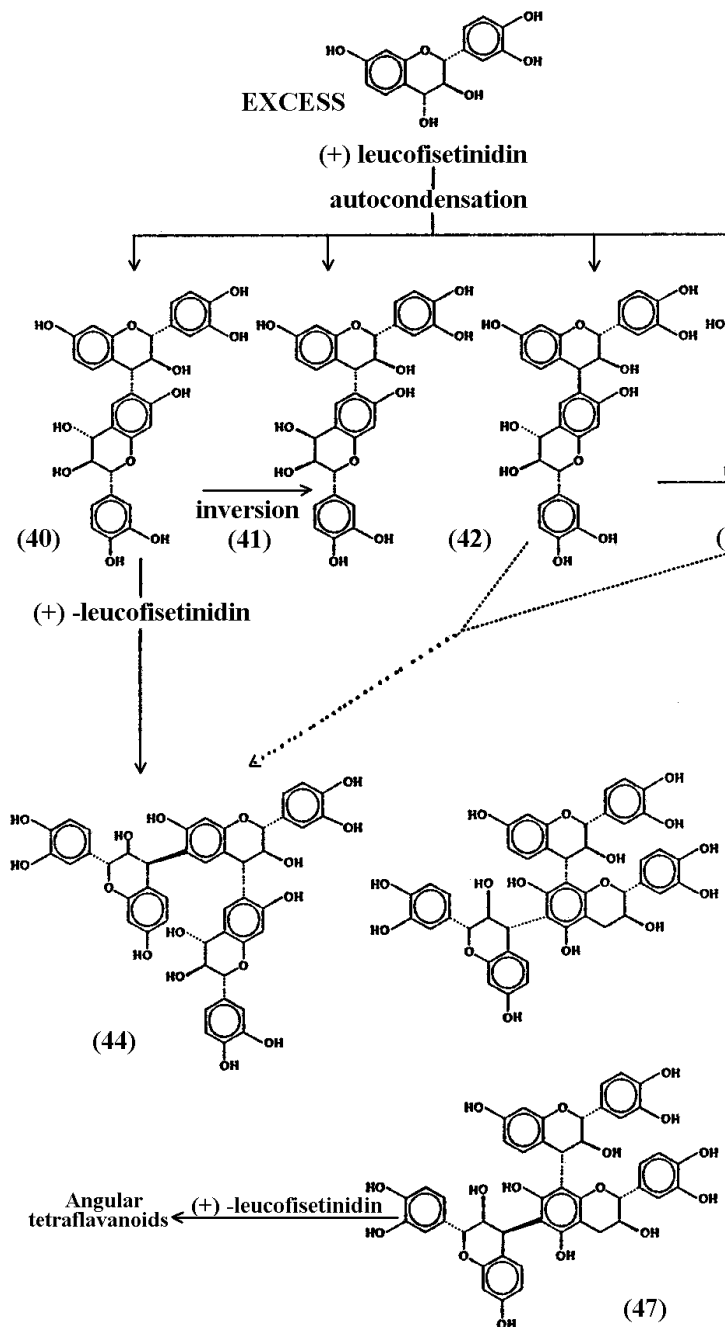
The C-6 position of the (+)-catechin unit of the biflavonoids is the dominant reactive nucleophilic centre in triflavanoid synthesis. Although there is a considerable degree of overall steric hindrance it is largely overcome by the reactivity of the C-6 position, and (+)-catechin and (+)-gallo catechin apparently initiate further condensation (Drewes *et al.* 1967b). Accordingly the angular triflavanoids are the likely intermediates in the further elaboration of condensed tannins to higher oligomeric forms (Botha *et al.* 1982).

The triflavanoids of the closely related quebracho wood tannins are 2S,3R-(2,3-*trans*)-leucofisetinidins that are 'angular' or 'branched' linked to 2R,3S-catechin (39) (Viviers *et al.* 1983a,b).

The gradational sequence of oligomeric phenolic units of increasing mass in black wattle bark extract is populated at the triflavanoid level by prorobinetinidins (Scheme III), whereas both profisetinidins (Scheme III) and the predominant prorobinetinidins (Scheme III) constitute the associated biflavonoids. The overall excess of prorobinetinidins in the extract apparently correlates with the more rapid rate of formation of bi- and triflavanoid prorobinetinidins than of their profisetinidin analogues during condensations (Viviers *et al.* 1983a,b). It has been proposed this is due to the change in the charges over the B-ring, due to the pyrogallol function, leading to higher condensation rates for leucorobinetinidin (Viviers *et al.* 1983a,b). In the presence of excess of (+)-catechin, condensation does not proceed significantly beyond the [4,8]-biflavonoid level. With excess of the flavan-3,4-diols both [4,8]-bi- and [4,6:4,8]-tri-flavanoids result in sequence. Steric factors operating in the nucleophilic C-8 and C-6 positions can dominate the sequential nature of condensation (Viviers *et al.* 1983a,b).

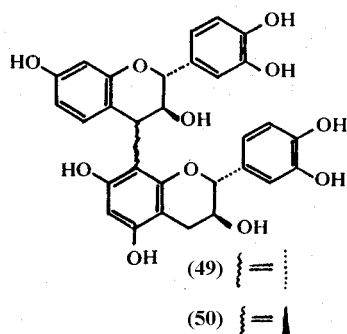
The tannin precursors in the heartwood of *A. mearnsii* are more complex than those listed above from bark. The heartwood is chemically unique in that it contains a preponderance of the flavan-3,4-diol, (+)-

mollisacacidin (also called (+)-leucofisetinidin) (1), but also the absence of free (+)-catechin which serves as a powerful nucleophile in initiating bi- and tri-flavanoid formation. Present are four biflavonoids with terminal 3,4-diol function (40-43 Scheme IV) (Drewes *et al.* 1967a). The two biflavonoids with the upper 2,3*trans*-3,4-*cis*-flavanyl units (42, 43 Scheme IV) predominate in the heartwood extract and have the absolute configuration of 2R,3S,4S:2'R,3'S,4'R and 2R,3S,4S:2'R,3'S,4'S respectively (Viviers *et al.* 1982). The 'linear' triflavanoid has the absolute configuration of 2R,3S,4S:2'R,3'S,4'R:2''R,3''S,4''R [4,6:4,6]-2,3-*trans*-3,4-*cis*:2',3'-*trans*-3',4'-*trans*:2'',3''-*trans*-3'',4''-*trans*-bi-[-fisetinidinol]-(+)-mollisacacidin (44, Scheme IV) and four 'angular' [4,6:4,8]-triflavanoids (45-48, Scheme IV) each with a centrally incorporated (+)-catechin unit (Roux and Ferreira 1982; Viviers *et al.* 1982).



Scheme IV. Wattle wood: *Acacia mearnsii* (Rowe and Ferreira 1982)

Only four of the possible stereoisomers of tetraflavanoids have been found in the heartwood of *A. mearnsii*, together with all four possible 'angular' triflavanoids and free (+)-mollisacacidin. The tetraflavanoids were shown to be [4,6]-substitutions of (+)-mollisacacidin (1) on both units of a [4,8]-(-)-fisetinidol-(+)-catechin (49, 50) (Young *et al.* 1985) and with the absolute configurations of (4R,4'R,4"S)-I and (4R,4'S,4"R)-I where I is formulae (49) and (4S,4'R,4"S)-I and (4S,4'S,4"R)-I where I is (50).



Formulae 49-50

Polymers

As indicated in the previous section the triflavanoids in wattle bark extract are predominantly pyrogallol based (see also Steynberg *et al.* 1986). Self condensation of the units continues until polymers containing 5 or more units are formed to give the average molecular weight of 3000 (or number average mass of 1250) (Roux *et al.* 1975). Increased polymerisation leads to molecular sizes, perhaps up to molecular weights of 7000 or about 20 flavan units, that are less suitable for penetrating hides during leather manufacture. Also, large polymers have higher viscosities which reduce their suitability for adhesive preparation and use, particularly when this involves a spraying operation.

Black wattle tannins have relatively high solubility and low viscosity. Nevertheless, in aqueous solutions some polymers appear to associate into conglomerates of large size (Yazaki and Hillis 1977, 1980; Czochanska *et al.* 1980). These associations can limit the crosslinking of polymers in reactions with formaldehyde and similar reagents. Fortunately the presence of phenol, urea and polymethylol phenols helps to disperse the aggregates (Roux *et al.* 1975).

Viscosity can be controlled in extract manufacture by eliminating bark with a significant gum content which probably forms an association with the polymers (e.g. Rahman and Richards 1988). Also the selection of the extraction procedure or temperature can influence viscosity. Pressure leaching at high temperature gives

a more viscous extract than the open-vat, counter-current process (Sherry 1971).

Reactivity

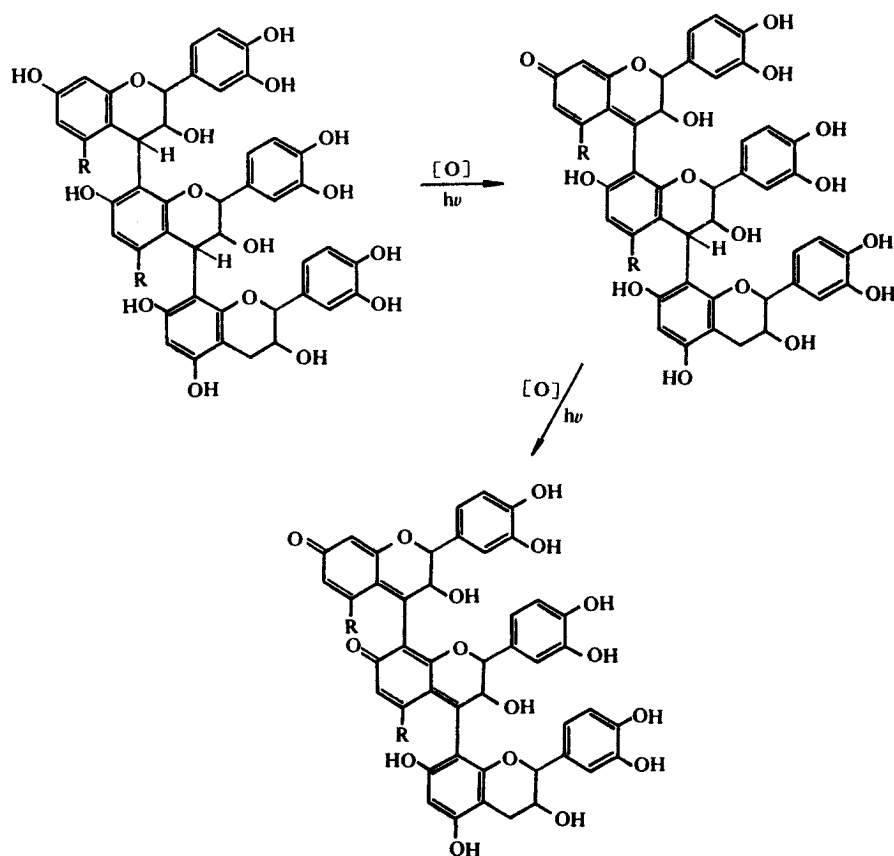
Oxidation and reddening

Wattle tannin extracts are stable as spray-dried powders of low (ca. 4-5%) moisture content. Changes occur under other conditions.

All phenols and particularly those containing vicinal hydroxyl groupings, such as pyrogallol or robinetinidins, undergo oxidation and darkening in solution, and in the presence of moisture and oxidase enzymes found in plant tissues. Oxidation proceeds slowly at pH 2.5 but increases rapidly at pH 3.5-4.6 and particularly under alkaline conditions. Oxidation in solution is completely inhibited by the presence of low concentrations of compounds that have a higher oxidative potential than the catechol or pyrogallol moieties of tannins e.g. by sodium bisulphite or sulphur dioxide (Roux *et al.* 1975).

Leathers prepared with condensed tannins redden when exposed to sunlight although the effect is not severe with black wattle bark tannins. It was suggested (Hillis 1954) that the proanthocyanidins in most condensed tannins are responsible and later Roux and Drewes (1965) determined the structural factors responsible. With monomeric leucoanthocyanidins the presence of a C-7 hydroxyl is mainly responsible with a strong activating effect of the 4-hydroxyl. The shade of reddening is affected by the degree of substitution in the B ring, with the 3',4',5'-trihydroxy grouping contributing the most intense colour. The C4-*axial* hydroxyl arrangement is the most sensitive for the loss of water in sunlight and on heating. In addition leucoanthocyanidins with a phloroglucinol A ring redden far more rapidly in response to light and heat than their resorcinol analogues. These data explain why extracts of *A. pycnantha* bark redden more than those of *A. dealbata* which in turn redden more than *A. decurrens* and this species more than *A. mearnsii*. The first two species contain higher proportions of leucoanthocyanidins with a phloroglucinol A ring than do *A. decurrens* and in turn *A. mearnsii*. Thus although *A. dealbata* is reputedly more frost resistant, and *A. decurrens* has a more vigorous growth than *A. mearnsii* they give extracts of inferior quality for tanning.

An unduly lengthy retention of wattle bark extract at elevated temperatures during the final vacuum



Scheme V. The postulated route of photochemical reddening (Roux *et al.* 1975)

to yield a more active compound that is more readily available for reaction with formaldehyde.

Reaction with acid or alkali

Roux *et al.* (1975) suggested that, in addition to the formation of anthocyanidins and catechin, mineral acid treatment of condensed tannins also results in hydrolysis of the heterocyclic ring. The p-hydroxybenzyl carbonium ions (52) formed condense randomly and

evaporation of the extract leads to a relatively rapid deterioration of the colour and an increase of the red components. These changes would largely involve the polymers in the extract. Roux *et al.* (1975) proposed that after the initial oxidation of an A ring in flavan-3,4-diols and their polymers to a quinone methide (Scheme V), the mechanism repeats itself and forms conjugated quinone methide chromophores. This colour could be reduced or inhibited by rupture of the heterocyclic ring with bisulphite but the tanning properties are affected.

Reaction with bisulphite

Reaction with sodium bisulphite or sulphite is used to solubilize lignins and some of the slightly soluble condensed tannins (e.g. quebracho), as well as reducing the viscosity of the polymers of condensed tannins. There are no reports of the studies of these reactions with wattle tannin which is readily water soluble. By analogy with (+)-catechin (Sears *et al.* 1972, Yazaki and Hillis 1980), it is probable that if the reaction was undertaken cleavage would occur within the heterocyclic ring to form a soluble propan-2-ol-1-sulphonate (51). The presence of sulphonate groups and the ring-opened flavanoid units may interfere with some properties such as high moisture resistance or waterproofness of adhesives.

On the other hand as suggested by Roux *et al.* (1975), the sulphonic groups may be replaced by strong alkali

nucleophilic centres on other tannin units to form 'tanners reds' or 'phlobaphenes'. These terms and 'phlobatannins' have long been associated with the insoluble phenolic fractions formed during tanning with condensed tannins. Alcoholic acid conditions favour anthocyanidin formation.

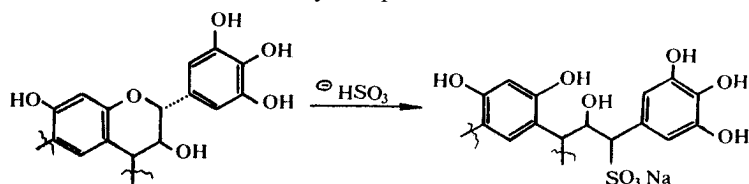
Care must be taken when using wattle tannin in alkaline solutions. Whereas reactivity towards formaldehyde of the B ring in flavanoids can be increased by raising the pH to 10 (Hillis and Urbach 1959a), the vicinal trihydroxy grouping in that ring of wattle bark prorobinetinidin polymers would readily oxidise to form quinones and then polymers. In addition, if cleavage occurs in the pyran ring, then rearrangement could result with the formation of a derivative of catechinic acid (Sears *et al.* 1975); this

reaction would remove some of the reactive positions required for cross-linkages. Also as pointed out by Steynberg *et al.* (1986) oxidative conditions should be avoided during activation of wattle tannins via ring-isomerisation as the pyrogallol moieties are involved in facile condensation reactions with nucleophilic centres. Accordingly, the possibilities of these reactions must be recognised when using wattle tannin adhesives in alkaline conditions.

Phlobatannins may also be formed by treatment of the condensed tannins with sodium bicarbonate-sodium carbonate buffer (pH 10) at 50°C for a few hours (Steenkamp *et al.* 1985; Steynberg *et al.* 1986). These

treatments induce ring isomerization in the biflavonoid units. From the study of the model compound [4,8]-2,3-*trans*-3,4-*trans*-(*-*)fisetinidol-2,3-*trans*-(*+*)-catechin (53), known to be present in wattle bark extract, Steynberg *et al.* (1986) found there was a 'liberation' of the nucleophilic A-ring and concomitant involvement of a functional group of the (*+*)-catechin moiety (Scheme VI). Coupling occurs preferentially at C-6 (ring D).

The apparent conformational stability of the new groups of compounds and also the relative planarity of the central 'core' after dual isomerization lead to the postulation (Steenkamp *et al.* 1985) that these factors contribute to reduced solubility in aqueous media and

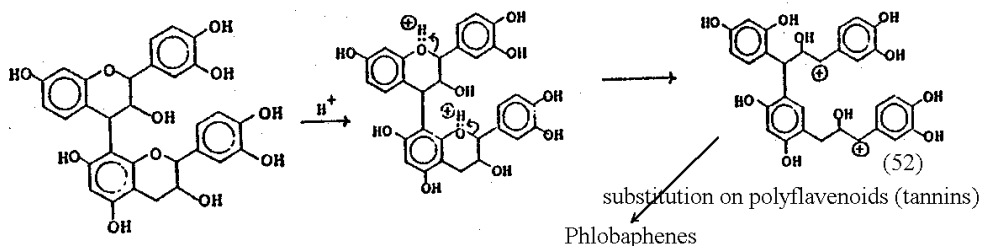


thus enhancement of their affinity for collagen substrates. Of particular importance for wood adhesive formation is the prediction (Steynberg *et al.* 1986) that bifunctionality of the ring-isomerised

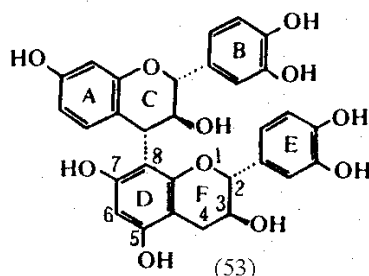
Formula 51

products towards formaldehyde is ensured by potent nucleophilicity at both C-5 (ring A) and C-6 or C-10 (ring D).

Of further importance in adhesive formation is the parallel isomerisations of the robinetinidol homologues of (53), as these are the major components of wattle bark extracts (Steynberg *et al.* 1986). Their isomerisations with sodium bicarbonate-carbonate buffer (pH 10) proceeds to completion under much milder conditions than the fisetinidol homologue. This facile ring-opening and isomerisation has been attributed to the enhanced ionization and electron release from the pyrogallol moiety compared with the catechol B ring. This 'liberation' of reactive nucleophilic resorcinol units provides the basis for the development of 'warm-set' (Pizzi and Daling 1980) and 'cold-set' wood adhesives (Pizzi *et al.* (1988). The addition or use of resorcinol in hot or cold set adhesives adds significantly to the cost of the finished adhesive and any process which decreases the amount of 'free' resorcinol needed in an adhesive system is economically important.



Formula 52



Formula 53



Scheme VI. Phlobatannins formed from a fisetinidol-catechin under mild alkaline conditions (Steynberg *et al.* 1986)

Reaction with formaldehyde

Formaldehyde reacts much more quickly with the strongly nucleophilic phloroglucinol, either as a compound or a moiety in the flavanoids of pine bark, than with resorcinol as a compound or a moiety as in wattle bark tannin. This rate of reaction, known as gelation time in adhesives manufacture, is important in commercial use, and can be influenced by molecular weight and pH with the minimum rate at about pH 3.5. Studies have been made of the reaction of (+)-catechin with formaldehyde over a wide range of temperatures and pH conditions (Hillis and Urbach 1959a,b; Kiatgrajai *et al.* 1982). They showed that substitution occurred at either the C-6 or the C-8 positions leading to the formation of linear polymers. The rate of condensation was approximately 60 times faster than the rate of polymerisation of phenol in reactions with formaldehyde (Kiatgrajai *et al.* 1982). Increasingly alkaline conditions lead to more rapid reactions and at high pH values the pyrogallol and catechol B rings also react.

The reaction of condensed tannins with formaldehyde may be catalyzed by limited addition of divalent metal ions, the most useful being zinc (Hillis and Urbach 1959a,b) and lead acetates (Pizzi 1978), resulting in adhesives with shorter curing times, lower pressing

temperatures and improved strength (Pizzi 1979; Pizzi and Cameron 1981). Some adhesives based on wattle tannin use prepolymers carrying reactive methylol functions rather than reacting the tannin directly with formaldehyde (Pizzi 1983). The prepolymers involving *ortho*- or *para*-hydroxybenzyl alcohols will react predominantly first at the remaining and less hindered C-6 positions of the A rings of the prorobinetinidins of the wattle tannin. These compounds provide an improved link between the large tannin molecules.

Formation of complexes

Polyphenols possessing vicinal-trihydroxy (pyrogallol type) and -dihydroxy (catechol type) moieties form complexes with metals, notably iron. This property of both condensed and hydrolysable tannins has been long used to inhibit corrosion in exposed iron articles or boilers for steam generation (Knowles and White 1958) and a 'Mimosa wash primer' has been developed for use before painting (Seavell 1978). The reaction between acidified 'Mimosa', or black wattle, extract and iron results solely in the formation of iron tannate involving chelation with the vicinal -OH groups of the tannin structure. The presence of residual rust hastens the reaction and serves to hold the iron (III) tannate as an adherent layer (Seavell

1978). The iron-tannates formed through complexing with bright or rust-less steel are less adherent and do not have the same strength as the original metallic iron. Consequently the erosion of tools cutting materials containing condensed and hydrolysable tannins occurs much more rapidly than those free from tannins (Hillis and MacKenzie 1964; MacKenzie and Hillis 1965). The complexing of tannins with other metal ions has been used for mineral beneficiation (White 1958; Roux *et al.* 1980), and for modifying the physical properties of aqueous clay or cement suspensions (White 1958).

Wattle tannins, ethanolamine and formaldehyde have been condensed in acidic aqueous media to form the salt of a secondary amine. The ionised product neutralises the electrical charges on clay particles in aqueous suspension while simultaneously causing their complete precipitation. The product has been found to be an excellent clarification agent for muddy water (Roux *et al.* 1980).

Hydrolyzable tannins

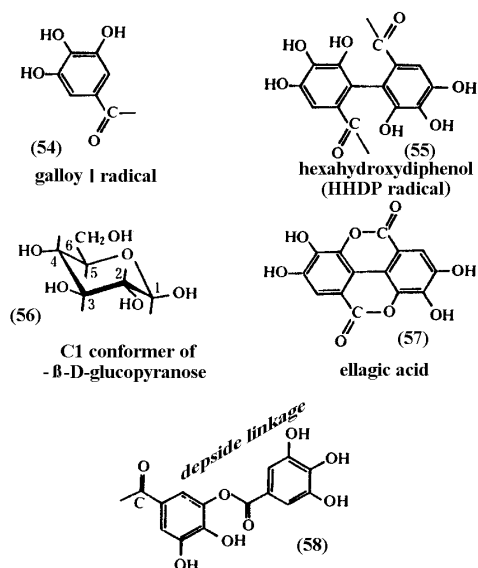
Derivatives of gallic acid

As previously stated hydrolyzable tannins are polyesters based on gallic acid (as the galloyl radical (54)) and/or hexahydroxydiphenic acid (as the radical (55)) and their derivatives and esterified most commonly with glucose (56). They range from the very simple esters such as β -D-glucogallin, a member of the gallotannins, to complex polyesters with D-glucose. A common feature of gallic acid metabolism in many plants is the oxidative coupling of appropriately orientated galloyl ester groups in a particular metabolite to give derivatives of hexahydroxydiphenoyl esters. These are usually

referred to generically as ellagitannins, even when a galloyl ester may be present in the molecule, as on acid hydrolysis the hexahydroxydiphenic acid rapidly forms the insoluble ellagic acid (57).

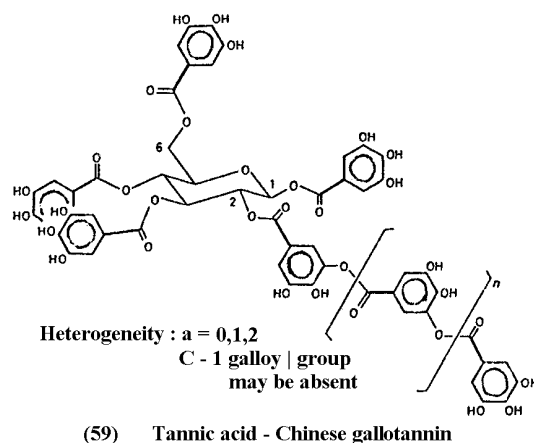
In addition to the substitution of between one and five galloyl substituents on different positions of the different forms of glucose, intramolecular oxidative coupling of galloyl ester groups can occur to produce 'dimers' and 'trimers' (e.g. Haslam 1987). Depside linkages (58) can also link additional galloyl ester groups to β -pentagalloyl-D-glucose resulting in compounds commonly known as tannic acids (e.g. 59). These acids are obtained from the galls on the leaves of *Rhus semiazata* and from the leaves of other *Rhus* species, but it is possible that isolational methods may have ruptured the depside linkages in the original gallotannin so that a range of 'tannic acids' may exist.

Hydrolysable tannins of commercial importance are obtained from the fruit of *Terminalia chebula*, acorn cups of *Quercus valonea* or *Q. macrolepis*, pods of different *Caesalpinia* species and from the wood of *Castanea valonea* and *C. dentata* and some *Quercus* species. Often when tissues are rich in proanthocyanidins, the synthesis of gallic acid and its derivatives is minimal. On the other hand, the pathways to both the condensed and hydrolysable types of tannin can converge as shown by the isolation of a partial 3-O-galloyl prodelphinidin from the bark of *Myrica esculenta* and a mixture of partial 3-O-galloyl derivatives of prodelphinidin and proanthocyanidin in *Phyllanthus emblica* bark (Zhao *et al.* 1987).



Formulae 53-58

Formula 59



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Since the above account was prepared in 1989 there has been further significant work on the chemistry of wattle tannins. The papers below provide an entry to recent literature-

- Bonnet, S.L., Steynberg, J.P., Bezuidenhout, B.C.B., Saunders, C.M. and Ferreira, D. 1996. Structure and synthesis of phylobatannins related to the (4-beta,6-4-alpha,8)-bis-fisetinidol-catechin profisetinidin triflavanoid. *Phytochemistry* 43, 215-228.
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triflavanoids. *Phytochemistry* 43, 253-263.

CHAPTER 13 MISSING ON DISK GET FROM PETER

Chapter 14

Uses of Wattle Extract: Tanning Agent in Leather Manufacture

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Introduction

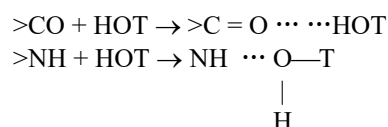
Black wattle extract is regarded by leather manufacturers as a vegetable tannin of excellent quality and versatility, being suitable for preparing a wide range of leathers.

Tannin action and physico-chemical properties of black wattle extract

Tanning action

Tanning is the action between tannin and pelt collagen to form leather, during which the poly-hydroxyl groups in tannin molecules react with functional groups on the polypeptide chain, such as -NHCO-, -OH.NH₂ and terminal COOH groups.

During tannage, tannin particles diffuse into the pelts under the influence of concentration gradients. They are deposited on collagen fibers and chemically bound. Among the three possible forms of bond - hydrogen, ionic and covalent - the hydrogen bond seems to be predominant, such as:



The mechanism of vegetable tannage can be summarized as crosslinking by multiple hydrogen bonds of hydroxyl groups of tannins with functional groups of collagens.

Physico-chemical properties**Solubility**

The solubility of black wattle extract in water, methanol, ethanol and acetone is 93.6%, 87.6%, 84.4% and 35.4% respectively. A water-organic solvent mixture enhances its solubility, e.g., 96% in MeOH-H₂O (1:1) or EtOH-H₂O (1:1), 97.2 % in acetone-H₂O (1:1).

The density of aqueous solution increases as the concentration increases, as shown in Table 14.1.

Buffering capacity

Black wattle extract has a low buffering index at 0.66, which is attributed to the small content of weak acid salts.

Viscosity, specific heat, thermoconductivity

As listed in Table 14.2, viscosity of black wattle extract solution increases with respect to increased concentration, and increases rapidly above 25% concentration, due to the presence of structural viscosity.

Colloid particle size

A colloidal tannin particle with molecular weight 1000 has a radius of 1 nm, or 2.14 nm with MW 30000.

Tannage properties

Specifications on tannage properties of black wattle extract are listed in Table 14.3.

Table 14.1 Relationship of concentration and density of black wattle extract solution

Concentration (g/L)	Density at a temperature of- (°C)					
	30	40	50	60	70	80
20	1.003	1.001	0.998	-	-	-
40	1.001	1.009	1.004	-	-	-
60	1.018	1.011	1.010	1.003	-	-
80	1.030	1.024	1.019	1.014	1.010	1.005
100	1.033	1.031	1.026	1.021	1.021	1.012
120	1.041	1.038	1.034	1.030	1.025	1.022
140	1.048	1.045	1.041	1.036	1.032	1.027
160	1.055	1.052	1.048	1.043	1.039	1.034
200	1.070	1.066	1.061	1.057	1.055	1.049
300	1.160	1.102	1.098	1.099	1.089	1.084

Table 14.2 Viscosity, specific heat and thermo-conductivity of black wattle extract ^[1]

Concentration (%)	Viscosity (cP)	Specific heat (cal/(g.°C))	Thermoconductivity (Kx10 ⁻⁴) (cal/(cm ² .s.K))
10	1.600	1.0184	7.597
12	1.900	0.9670	7.597
16	2.589	0.9294	7.464
20	4.257	0.9066	6.990
25	4.561	0.9056	6.990
30	15.36	0.7586	6.760
35	31.74	0.7354	6.760
40	63	0.7250	6.700
45	195	0.7233	6.560
50	546	0.7039	6.560
55	574	0.6796	6.560
60	1599	0.6698	5.809
65	10480	0.5947	5.809
70	-	0.4905	5.809

Note: cP=10⁻³ Pa.s; cal=4.187 J

Table 14.3 Specifications on tannage properties of black wattle extract

Specifications	South African ^[2]	Chinese
Tannin (%)		72
Tannin / non-tannin	>3	5
Astringency	Medium	Medium
-acid (meq)*	95	-
-salt (meq)*	55	-
Sugar (% sucrose)	8	-
Buffering index	-	0.92
Penetration rate (days)	11	10 (5.5 m/m)
Absorption value (%)	-	46.4
Combining value (%)	Fast combined 97 Loosely combined 74 Totally combined 171	31.1
Salting-out value(%)	-	Coarsely dispersed 4.56 Moderately dispersed 26.37 Finely dispersed 40.79 Very finely dispersed 27.91
Degree of tannage (%)	57.4	-
Loss during tanning period (%)	3	-
Colloid particle size (nm)	0.7 (average)	-

*pH 4.8, 150°Bkr

Appraisal of utility

As a tanning agent, black wattle extract is appraised by leather manufacturers as follows:

1. Versatile, being suitable for both heavy and light leather of good quality.
2. It has high combining value, with little precipitation or loss of tannin during tannage.
3. Penetration and combination are rapid, giving a high degree of tannage and a high yield of leather.
4. The leather produced is light in color and bleachable, and can be suitably finished by various pigments.

Tanning methods

Pit tannage

The old traditional pit tannage has been gradually replaced by advanced methods because of the very long tannage period and laborious operation of the former. In pit tannage, pelts are processed in a battery of pits with extract liquor of different concentration in a countercurrent system.

The sequences of tannage is: hanging tannage, soaking tannage, hot tannage and de-tannage.

Concentrations of tanning liquors are: 6-30° Bkr in hanging tannage, 25-70° Bkr in soaking tannage, and up to 100° Bkr in hot tannage (40°C).

Pit-drum combination tannage

After hanging and soaking tannage, leathers are transferred into a drum and subjected in turn to: drum tannage, dry tannage, hot tannage and de-tannage. In the drum, leather is tanned by 80° Bkr liquor for 1-3 days. For dry tannage, powdered extract is added to the drum, together with an auxiliary tanning agent (e.g. NF) and tanned for 1-2 h while rotating.

Effluent-free rapid tannage

Effluent-free rapid tannage has been developed since the 1960s. It offers a significant improvement for heavy leather tannage by reducing the tanning period to 3 days.

Pelts are pretreated or de-watered by the acid-sodium sulfate, acid- de-acid or acid-ammonium sulfate process. The pretreated pelt is then pre-tanned by different processes, such as the Liritan process (South Africa) or C-RFP (Italy), using sodium hexametaphosphate / sulfuric acid or sodium bisulfite / formic acid / syntan respectively. Finally, high quality tannin extract, such as black wattle extract, is used. This extract has the advantages of cold solubility, rapid penetration, good combining ability, low salt content, good chemical stability and reduced precipitation.

Tanning in practice

Heavy leather tannage

Five practical examples of heavy leather tannage are described in the Chinese edition of this book.

Light skin and light leather tannage with black wattle extract

Four examples are described in the Chinese edition of this book.

References

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Chapter 15

Uses of Wattle Extract: Tannin Based Adhesives

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Abstract

Studies on the possibilities of wattle tannin being used as adhesives for wood bonding were initiated by Dalton at CSIRO, Australia, in the late 1940s and then the fundamental research was carried out by scientists at CSIRO to establish the basic principles for the use of wattle tannin as adhesives for reconstituted wood products. The production technology for wattle tannin based adhesives was initially established and commercialized in Australia. This chapter describes the specific characteristics of wattle tannin and its derived adhesives, compared with synthetic phenolic adhesives and also with those from other tannins such as radiata and mangrove. The original and basic formulations of wattle tannin adhesives and also the commercial formulations, which have been used in the reconstituted wood industry, are given. Furthermore, it is emphasized that wood moisture content is a critical factor affecting gluebond quality and a closely controlled wood moisture content should be chosen so that an optimum gluebond moisture content will be obtained at pressing to produce high quality wood bonding. In addition to adhesives formulation, the gluing technology suitable for individual wood species should be developed and established in order to maximize the use of wattle tannin as adhesives.

Introduction

The use of tannin as both a condensing agent and a reactant in the phenol-formaldehyde reaction was first suggested by McCoy in his patent as early as seventy years ago (McCoy 1918). However, consideration was given to studying the possibilities of tannins being used as adhesives for wood bonding in the late 1940s. Dalton in Australia reported extensive work on the tannins extracted from six species including a wattle (mimosa), three eucalypts and two conifers (Dalton 1950). His work showed that the tannins would react with formaldehyde to form resins and that wattle tannin with formaldehyde could be used with hot pressing to produce water-resistant bonds which were superior to those of urea formaldehyde adhesives. Dalton carried out further work on viscosity control and reported that sulphite-treated mimosa tannin adhesives provided good joint strengths (Dalton 1953). The results of the 6-hour boil tests on these plywood samples were superior to those made with urea-formaldehyde, but inferior to those with commercial phenolic adhesives.

No further work was done on tannins in Australia until the early sixties when, at the Division of Forest Products, CSIRO, tannin adhesives blended with synthetic fortifying resins were evaluated. These wattle tannin adhesives gave very favourable indications that low density wood species could be bonded even without fortifier. Plomley (1959) reported the effect of soluble salts on gelation of wattle tannin adhesives. Various salts were shown to be capable of reducing gelation times and for example, improvement in bonding quality was obtained using a 5 per cent addition of magnesium acetate. He also developed unfortified wattle tannins which showed promising results in laboratory and commercial trials of particleboard bonding. Further work on wattle tannin adhesives carried out by Plomley established that commercial wattle tannin adhesives produced a strong waterproof bond with veneers of a number of species (Plomley 1966). In Australia phenol-formaldehyde (PF) fortified tannin adhesives have been in continuous use for plywood since 1966, and for particleboard since 1968. In the early years they were made on site using a liquid wattle tannin extract imported from South Africa.

Wattle tannin adhesives have been commercially produced and used in South Africa for many years. Consistency in producing particleboard adhesives was established in 1971, and the industrial application and export of exterior-grade particleboard adhesives commenced in 1972 and 1973 respectively. Furthermore, plywood adhesives fortified with phenolic resins were commercialized in 1973-1974 followed by those with urea-formaldehyde in 1976-

1977. Finally, 'honeymoon' fast-setting adhesives for fingerjoints were developed in 1982-1983.

It is interesting to note that the basic and fundamental research on wattle tannin adhesives and the early commercialisation were carried out in Australia, where important *Acacia* species are indigenous whereas today the production of these wattle tannin adhesives is done mainly in South Africa, where *Acacia* plantation had been established. This is largely due to the availability of wattle tannin from tannin extraction plants established in South Africa because sufficient amounts of wattle bark are available and labour costs render such operations competitive.

Wattle tannin has been commercially produced by extracting bark of various *Acacia* species and the typical wattle tannin is the extract from bark of black wattle (*Acacia mearnsii*). The major components of wattle tannin belong to 'condensed tannin' which consists of flavanoid units (mainly flavan-3-ols) and has been condensed to varying degrees. The distinctive flavan-3-ol units of wattle tannin are (-)-fisetinidol and (-)-robinetinidol which consist of resorcinol for A ring and catechol and pyrogallol for B ring (Roux and Maihs 1960; Drewes and Roux 1963). Formaldehyde reacts with these flavanoids to produce insoluble polymers through methylene bridge linkages to reactive positions of mainly the A rings of the polyflavanoid molecules. This is the fundamental reaction for wattle tannin adhesives.

A comprehensive book (Pizzi 1983) covering tannin-based wood adhesives was recently published in which more detailed information can be found. This chapter concerns mainly the most essential topics in relation to wattle tannin adhesives.

Characteristics of wattle tannin adhesives

Reactivity with formaldehyde

One of the most significant characteristics for wattle tannin is the reactive sites and the rate at which wattle tannin reacts with formaldehyde. The reactive sites of flavanoid units have been examined by selective bromination using units of the phloroglucinol and resorcinol series (Roux *et al.* 1975). Tetra-O-methylcatechin, which is a model for radiata tannin, is brominated preferentially at the 8-position. Only when this position is filled does bromination start at the 6-position, while the B ring is unreactive. However, tri-O-methyl fisetinidol, which is a model for wattle tannin, the bromination sequence for the A ring is changed to 6 > 8 and again the B ring is unreactive.

Although wattle tannin reacts with formaldehyde in either acidic or alkaline condition, weakly alkaline conditions have been used for the reactions in industrial application. Increasing alkaline conditions

leads to more activation of the phenol as nucleophile, and the nucleophilic centres on the A rings of flavanoid units tend to be more reactive than those on the B rings.

The reactivity of wattle tannin toward formaldehyde can be estimated by determining gelation time (Plomley 1966). The gelation time - pH curve revealed that the maximum gelation time was found at approximately pH 3.5 which is natural pH of wattle tannin, indicating that wattle tannin is the most stable at the natural pH. When the gelation times of wattle, mangrove and radiata tannins were compared at pH 6.0, the wattle tannin takes more than 4 times longer to gel than the mangrove tannin and about 20 times longer than the radiata tannin (Fig. 15.1). This indicates that the wattle tannin shows a lower degree of reactivity toward formaldehyde than mangrove or radiata tannin.

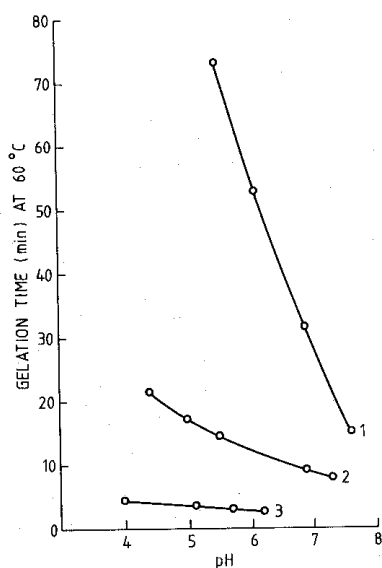


Fig. 15.1 Comparison of gelation times of wattle, mangrove and radiata tannin solutions at 60°C. 1. Wattle; 2. Mangrove; 3. Radiata.

Gelation time

Gelation time can be measured from the time taken for a tannin solution to gel after the addition of the hardener or catalyst and at a particular temperature and pH. Gelation time can be used as an indication of the 'usable life' of an adhesive which is in practice approximately half of the gelation time. Since the gelation is in principle based on the polymerization reaction of reactive components in the adhesive, the gelation time is dependent on the type and amount of hardener or catalyst, the pH and the temperature. The gelation times of wattle tannin solution relating to these variables have been thoroughly examined (Plomley 1966). The minimum requirement of

formaldehyde for commercial adhesives made from wattle tannin was between 6% and 8% based on tannin solids, while a minimum of 4% formaldehyde was required for mangrove tannin and 6% for radiata tannin obtained from cold aqueous extraction of radiata pine bark. The addition of soluble inorganic salts markedly decreases the gelation time of formaldehyde-wattle tannin (Plomley 1959). However, short gelation times can affect application in an industrial situation.

Viscosity

Viscosity is frequently mentioned as a problem in the preparation of adhesives. The viscosity of aqueous wattle tannin solution is affected by the solids concentration, the proportion of high molecular weight polyflavanoids, the amount of gelatinous gums, the temperature and the pH.

The viscosity of wattle tannin increases markedly when the solids concentration exceeds 45% (Fig. 15.2). The effect of pH on viscosity was very different for different tannins. For example, the viscosity curve for mangrove tannin shows a marked peak between pH 8 and 10 and a tendency to decrease at high pH, while that of the wattle tannin solution increases appreciably with rise in pH, particularly after pH 9.3 (Fig. 15.3).

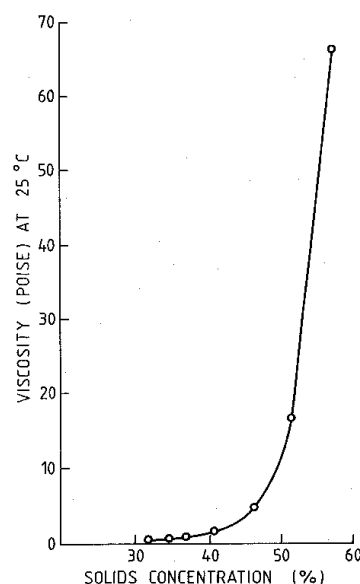


Fig. 15.2 Relation between solids concentration and viscosity of wattle tannin solutions.

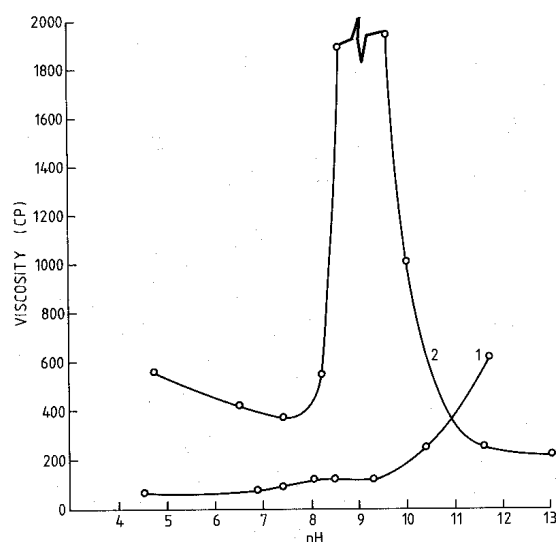


Fig. 15.3 Effect of pH on viscosity of wattle and mangrove tannin solutions at 25°C. 1. Wattle; 2. Mangrove.

The molecular weight range and proportion of high molecular weight polyflavanoids have profound effects on the viscosity. The polymeric fraction of radiata tannin with a molecular size greater than 106 has been found to be the major cause of excessive viscosity of radiata tannin (Yazaki and Hillis 1980). On the other hand, results from ultrafiltration of wattle tannin prepared in China revealed that the proportion of high molecular weight polyflavanoids was extremely small (less than 5%) and the viscosity of the Chinese wattle tannin may be very similar to that of commercial wattle tannin from South Africa (Zheng *et al.* 1988). Furthermore, it has been reputed that high molecular gums present in wattle tannin (Roux 1952) increase the viscosity.

High viscosity may prevent the utilization of polyflavanoid extracts in adhesives within certain pH ranges. Viscosity can be reduced by lowering the solids concentration, by adding phenol and urea to break up aggregates, by hydrolyzing the gums with alkali or acid (Pizzi 1978a) or by heating with sodium sulphite or bisulphite. The sulphitation method has been used successfully with a number of bark extracts (Dalton 1953).

Heating with sodium bisulphite has been used for some time to improve the solubility and to reduce the viscosity of wattle tannin. The O-C₂ linkage in the pyran ring of flavan-3-ol is readily ruptured, presumably with the formation of a sulphite but the reactivity of the A ring may still remain.

Wood moisture content

Wood moisture content is a critical factor affecting glue bond quality. A closely controlled wood moisture content should be chosen so that glueline moisture content will reach a suitable gluing moisture content and then not decrease appreciably over a longer period. This will give flexibility in assembly time, particularly in manufacturing plywoods. For example, the use of a very dry veneer will result in a very rapid initial decrease in glueline moisture content followed by a sustained and continuing decrease. This will result in extremely narrow assembly time conditions which give little flexibility. Conversely, high veneer moisture contents require extremely long assembly time because the rate of the decreasing moisture content in the glueline is extremely low and when hot pressed, it will result in a 'washout' situation which loses most of the resin from the glueline.

Glueline moisture content is a moisture content reading made with a resistance-type moisture meter calibrated for Douglas fir. It is not necessarily the actual glueline moisture content. In taking a reading needle electrodes are pressed from the surface of the panel into gluelines.

For plywood adhesives, it is considered desirable to produce a controlled penetration of the adhesive into wood substrate prior to final curing. Insufficient penetration will result in reduced specific or chemical adhesion at the glue/wood interface and loss of mechanical adhesion. On the other hand, excess penetration has been found to be undesirable as the resin from the glueline penetrates into the wood substrate so far that the glueline loses continuity of reactive components between the glueline and the wood substrate. The remaining glueline is often composed only of the adhesive fillers resulting in poor glueline cohesion. An underpenetrated glueline usually exhibits a hard flaky appearance, whereas an overpenetrated glueline is sandy to touch, this being the remaining fillers without resin.

Since the range of molecular sizes of wattle tannin is much wider compared with that of a synthetic phenolic resin, some of these fractions with lower molecular weight tend to diffuse relatively rapidly into the wood substrate during assembly and pressing conditions so that only high molecular weight fractions of the wattle tannin remains in the glueline which needs more moisture to flow. Therefore, it is widely recognized that higher moisture contents are necessary when using tannin adhesives than in the case with synthetic phenolic adhesives.

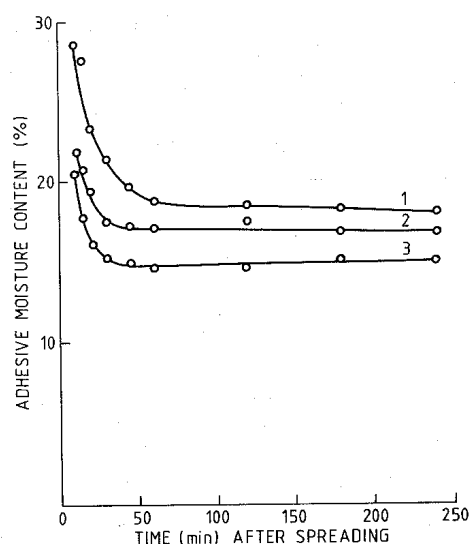
The rate of moisture absorption from phenol-formaldehyde and wattle tannin adhesives by wood at different moisture content and the influence of glue moisture content at hot pressing on bond strength were studied (Plomley and Pankevicius 1977). Phenol-formaldehyde and wattle tannin adhesives containing 20% of walnut shell flour filler (glue solids contents 50.7% and 55.2%, respectively) were spread on coachwood veneers at two moisture contents 3% and 9%. The moisture changes are shown in Figure 15.4. There is an initial period of relatively rapid loss of moisture followed by a stage of slow or virtually no change in moisture content. There are important

differences in the behaviour of wattle tannin adhesives and the phenolic resin. The tannin adhesives lost moisture more rapidly than phenolic resin although its initial soluble solids concentration was higher, and the moisture content reached in 4 hours by the wattle tannin adhesives on veneers at both 9% and 3% moisture content was lower than for phenolic resin on veneer at 3% moisture content. Wattle tannin and phenolic adhesives also differed in the minimum moisture content required for bonding (Fig. 15.5). For wattle tannin adhesives, at a glue moisture content below 17% the failing load decreased rapidly to zero at about 14.8% moisture content, whereas for phenolic adhesives, there was no significant decrease in failing

load down to 14.7%.

Fig. 15.4 Influence of veneer moisture content on the moisture content of phenol- and wattle tannin-formaldehyde adhesives after spreading. 1. Phenol-formaldehyde; veneer mc 3%, 2. Tannin-formaldehyde; veneer mc 9%, 3. Tannin-formaldehyde; veneer mc 3%.

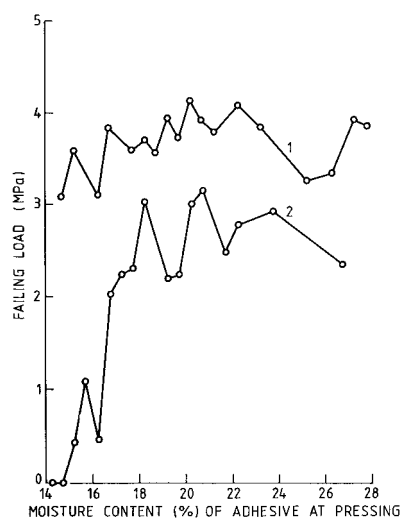
With the veneer that had been conditioned to 9% moisture content the glue moisture content of the wattle tannin adhesive reached the critical level of 17% in about 50 minutes whereas for the 3% veneer the same glue moisture content was reached in about 20 minutes (see Fig. 15.4). Therefore, it would be necessary to use veneer at a moisture content above 9% or to increase the moisture available from the glue by increasing the glue spread for longer assembly times. On the other hand, for the phenolic



adhesive the critical moisture content for bonding is below 14.7%, but the glue moisture content on 3% veneer did not decrease below 18% in 4 hours. Hence an assembly time of at least 4 hours could be used.

Fig. 15.5 Relationship between adhesive moisture content at hot pressing and failing load of 2-ply coachwood shear test specimens. 1. Phenol-formaldehyde, 2. Wattle tannin-formaldehyde.

The influence of mat moisture content at pressing on physical and mechanical properties of particleboards bonded with phenol-formaldehyde, wattle tannin-formaldehyde and wattle tannin-formaldehyde blended with emulsified phenolic resin in the ratio of 20% phenolic resin to 80% wattle tannin adhesive (fortified wattle tannin adhesive) was investigated and modulus of rupture (MOR) after pressure soaking and internal bond (IB) were determined (Plomley and Collins 1977). On MOR results the optimum moisture content for phenol-formaldehyde bonded boards was lower (about 18%) than for wattle tannin-formaldehyde boards (about 21%) and fortified wattle tannin adhesive boards (about 24%), while the MOR for phenol-formaldehyde and fortified wattle tannin adhesive bonded boards at mat moisture contents less than 25% were approximately equal or higher than for



wattle tannin-formaldehyde (Fig. 15.6).

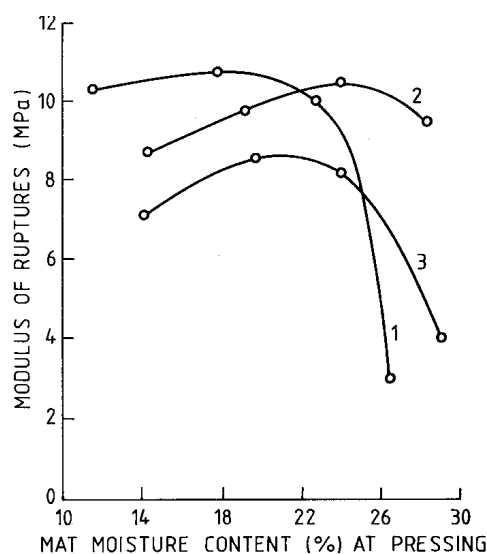
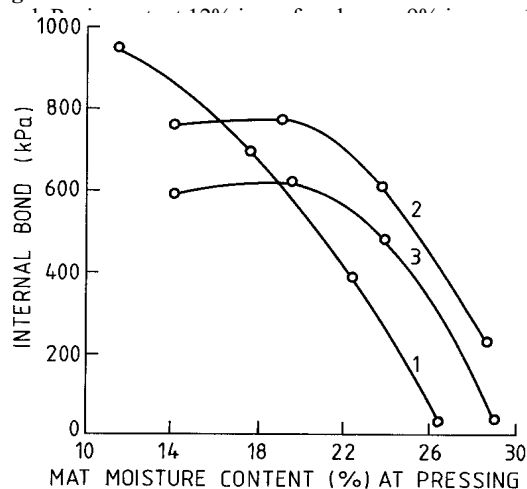


Fig. 15.6 Influence of mat moisture content on modulus of rupture after pressure soaking. Resin content 12% in surface layers, 9% in core. 1. Phenol-formaldehyde; 2. Fortified tannin-formaldehyde; 3. Tannin formaldehyde.

The results of IB tests also showed the strong influence of mat moisture content (Fig. 15.7). There was a marked difference between the results for phenol-formaldehyde and those for the wattle tannin adhesives. The maximum value for boards bonded with phenol-formaldehyde was higher than for the wattle tannin adhesives and was found at the lowest moisture content 11%, while the IB for the fortified wattle tannin adhesive was higher than for the wattle tannin-formaldehyde at all moisture levels and the optimum moisture content for the tannin adhesives was in the range of 14% to 20%.

Fig. 15.7 Influence of mat moisture content on internal



use.

In 1953 Dalton reported that when the aqueous wattle tannin solution was heated with sodium sulphite, the resultant viscosities enabled spreading by mechanical roller spreaders. The sulphited tannin solution mixed with paraformaldehyde and filler gave good joint

strengths but wood failures were low compared with commercial phenol- and urea-formaldehyde adhesives.

After some exploratory tests at CSIRO, Division of Forest Products, Australia, the following basic formulation was developed by Plomley (1966).

Ingredient	Parts by weight
Wattle extract (tannin)	100
Water	113
Sodium hydroxide	0.9
Wood flour	10 to 12.5
Paraformaldehyde	8

The glue constituents were mixed in the order shown. The wattle extract was soaked for about 2 hours, or more conveniently overnight, in all the water except for a small portion reserved for dissolving the sodium hydroxide. The extract was then brought into solution by heating to about 60°C, cooled, and the sodium hydroxide was added, followed by the wood flour and paraformaldehyde.

Although wattle tannin is ultimately the most important ingredient contributing to the integrity of the reconstituted wood products such as plywood, particleboard and laminated timber, filler, extenders and water are critical in the gluing process; they help to ensure that the optimum glue line moisture content is obtained at the right time i.e. hot pressing time.

Typical fillers include wood flour and nut shell flour which is added to the adhesive mix to control penetration of the resin into the wood substrate and thus reduce the likelihood of failure either as 'washout' or 'dry out'. Typical extenders include wheat flour, maize flour, starch and dextrins. Extenders impart 'tack' to spread veneers to ensure adequate grip out of the cold press.

The hot-press exterior type adhesive formulations developed by Plomley for wood bonding are based on relatively simple mixtures of aqueous solutions of wattle tannin with formaldehyde in the form of paraformaldehyde as a crosslinking agent. Control of curing time and usable life of the adhesive is obtained by control of pH together with the use of paraformaldehyde as the source of formaldehyde. The adhesive pH selected for a formulation is that which will give a short curing time and at the same time will provide a sufficiently long usable life at ambient temperature. Wattle tannin formaldehyde adhesives have been formulated for wood bonding over a pH range of 6.7 to 8.0. The hot press curing time and the usable life of the adhesive at ambient temperature decrease with increasing pH.

With a view to improving bond quality, it was found that the bond quality of tannin adhesives could be improved by incorporation of small proportions of a synthetic resin ('fortifying resin'). The quantity of

resin needed to achieve a required result depends on the adhesive properties of the tannin-formaldehyde compound, the kind of fortifying resin, and the wood being bonded. Generally, the wood density is an important factor in determining the amount of fortifying resin required. In general, higher fortification is needed for higher density species.

An effective phenol-formaldehyde resin was developed as a fortifying resin but it was too slow curing. Commercial resorcinol-formaldehyde resins were found to be compatible with wattle tannin formulations but were too costly for use. Finally, a resorcinol-phenol-formaldehyde resin was developed, which was fully compatible with tannin-formaldehyde adhesives at the required pH and was sufficiently reactive and economical (Plomley 1966). Successful factory trials of wattle tannin adhesives for plywood were conducted in 1961 and 1962. A plywood adhesive formulation is as follows:

Ingredient	Parts by weight
Wattle tannin	90 (oven dry weight)
Water	113
Sodium hydroxide	0.9
Fortifying resin	10 (oven dry weight)
Wood flour	10
Walnut shell flour	10
Paraformaldehyde	15

The pH of the formulation is about 7 and the usable life is approximately 4 hours. The proportion of fortifying resin in the above formulation gives a satisfactory bond with a wide range of Australian veneer species. Some low-density species can be bonded with unfortified adhesives but close factory control is essential because reduction in the proportion of fortifying resin results in a decrease in the working life of the adhesive. The pH of the adhesive can be varied according to the hot-press curing time and pot life required. Slight changes in formulation result in lower viscosities, providing control of gluing, assembly and pressing conditions. This helps to control glue penetration and yet gives good flow in hot pressing so that improved bonding can be obtained.

Wood adhesives

Wattle tannin adhesives for wood can produce the highest quality bonding, 'A Bond', which is fully weather resistant (72-hour boil resistant) and equivalent to the British Standards WBP specification, while melamine fortified urea-, urea- and extended urea-formaldehyde adhesives provide 'B Bond' partially weather resistant (6-hour boil resistant), 'C Bond' warm water resistant (interior glue) and 'D Bond' cold water resistant (interior glue), respectively. Phenol-formaldehyde, resorcinol-formaldehyde, and resorcinol-phenol-formaldehyde adhesives are most common in the 'A Bond' category.

Adhesives for wood fall into two general types, cold-setting and thermosetting adhesives. Cold-setting adhesives are 'adhesives that set without the application of heat or that set at a temperature below 20°C'. However, the cold-setting adhesives include adhesives that set in the temperature range from 20°C to 30°C (room-temperature-setting adhesives). On the other hand, thermo-setting adhesives are 'adhesives that set only with the application of heat, usually at or above 100°C'. The word 'setting' is generally defined as the process by which adhesive and/or cohesive strength is developed by chemical or physical action, for example, polymerization, oxidation, gelation, hydration, cooling or evaporation of volatile constituents. Wattle tannin adhesives for wood can obtain bonding strength developed by condensation polymerization reaction of wattle tannin with formaldehyde or its related compounds. Therefore, wattle tannin adhesives are formaldehyde-based adhesives.

Cold-setting adhesives

The first cold-setting formulation for wattle tannin was outlined by Dalton (1950). It was found that because of the rapidity with which the resins gel, only mild conditions can be used if they are to be kept for even a short period in a liquid state. A resin was prepared by heating an alcohol soluble fraction of wattle tannin with formaldehyde in aqueous alcohol. The adhesive was prepared from this resin by adding paraformaldehyde, alkali to control the setting rate and filler. The shelf-life of the resin was only 15 days at 25°C and several weeks at 10°C.

Resin

Ingredient	Parts by weight
Alcohol soluble fraction of wattle tannin (A.S.F.; 45% resin solution)	54
Glycerol (40% A.S.F.)	20
38% Formalin	10.6
Water	10
Alcohol	17

These constituents were mixed and heated at 60°C for 15 minutes.

Adhesive

Ingredient	Parts by weight
Resin	10
10N NaOH (9% A.S.F.)	1
Mixed, cooled and added:	
Paraformaldehyde (12% A.S.F.)	0.55
Walnut shell flour (20% A.S.F.)	0.9

Specimens were prepared by gluing two slips of mountain ash (*Eucalyptus regnans*). The slips were conditioned at 25°C to 10% moisture content before gluing. After spreading the adhesive, the slips were allowed to dry for five minutes before assembly (open assembly time). After assembly the specimens were stood further for five minutes (closed assembly time) before pressing in spring-loaded gluing boxes for 20 hours at 20–23°C and 1.4 MPa (Dalton 1950).

Compared with commercial resorcinol-formaldehyde and urea-formaldehyde adhesives, the wattle tannin adhesives requires a short assembly time, and have a short pot life, and their bond strengths are lower except that, in resistance to boiling water, the wattle tannin adhesive is far superior to the urea-formaldehyde adhesive. The use of alcohol for the fractionation of wattle tannin and for the viscosity control and the limitations of the conditions for the preparation of resin prevented the commercial application of this formulation.

Finger-joint adhesives

Normal adhesives for finger-joints, based on phenol-resorcinol-formaldehyde, require a long duration to set at lower temperatures. The 'honeymoon' system for this application was first described by Kreibich (1974). The system consists of two components A and B. The component A consists of a slow-reacting resin with a reactive hardener and the component B consists of a reactive resin with a slow-reacting hardener. Apply component A on the fingers of the one side of the joint and component B on the fingers of the other side of the joint. Press the joints together

and leave to cure at room temperature for approximately 30 minutes.

Wattle tannin has a similar reactivity with formaldehyde to that of resorcinol because the A ring substitution pattern of the principal components of the wattle tannin is the same as resorcinol. Successful formulations have been developed in South Africa (Pizzi *et al.* 1980). Typical examples of adhesive systems are as follows:

System	Component A	Component B
1	Wattle cold set	Amino phenol resin
2	Wattle cold set	Wattle cold set at high pH
3	Wattle cold set	Wattle bark extract solution

These components are prepared as follow:

Wattle cold set

Ingredient	Parts by weight
Novolac I	100
Paraformaldehyde	10 to 15
Coconut shell flour (200 mesh)	5
Wood flour (200 mesh)	5
pH (adjusted with NaOH solution)	7.45 to 7.55
Viscosity (cp)	2,500
Pot life	2.5 hours at 25°C

Amino phenol resin

Ingredient	Parts by weight
Novolac II	42
Wattle bark extract solution (55% solids)	100
pH (adjusted with NaOH solution)	9
Viscosity (cp)	3,500

Wattle cold set at high pH

Ingredient	Parts by weight
Novolac I	100
pH (adjusted with NaOH solution)	11.4
Viscosity (cp)	2,500

Wattle bark extract solution

Ingredient	Parts by weight
Wattle bark extract (50 to 55% solids)	100
Fungicide	0.05
Defoamer	0.2
pH (adjusted with NaOH solution)	12.6
Viscosity (cp)	3,200

Novolac I

Ingredient	Parts by weight
Wattle bark extract	38.4
Defoamer	0.1
Water	44
Methanol	34
Paraformaldehyde	2.3
Heat at 90°-92°C for 120 minutes and add	
Resorcinol	18
NaOH	8

The NaOH is added slowly. Heat at the same temperature for 120 minutes. Evaporate the methanol to obtain a mixture of water and methanol which has a ratio of 80:20. Cool down and store.

Novolac II

Ingredient	Parts by weight
Phenol	25.6
Water	7.8
Methanol	6.8
Paraformaldehyde	10.4
NaOH	4.5

Bring mixture to reflux within 30 minutes and reflux at 82 to 83°C for 150 minutes. Add

m-Amino phenol 16.3

and reflux for 120 minutes. Cool down and store.

It is essential to decide which of these systems is best suited to the particular application.

Thermosetting adhesives***Particleboard adhesives***

Exterior-grade particleboard is the oldest field of application of wattle tannin adhesives and 100% of all exterior grade particleboard is produced using wattle tannin adhesives in South Africa (Scharfetter and Pizzi 1981). One of the biggest disadvantages in use of wattle tannin for producing particleboards is relatively high viscosities of the wattle tannin solutions, and particularly those containing more than 45% solids. The most common process to decrease the high viscosity consists of a series of acid and alkaline treatments of the wattle tannin which hydrolyzes high molecular weight carbohydrates (gums) or the addition of hydrogen bonding breakers such as phenol (Pizzi 1978a). The following are examples of these formulations.

Resin

Ingredient	Parts by weight	
Formulation	I	II
Wattle tannin	100	100
Water	100	100
Defoamer	0.5	0.5
Maleic anhydride	3	-
Phenyl maleate	3	-
Sodium hydroxide	5.5	5.5
Glacial acetic acid	0.5	1.2
Acetic anhydride	-	0.4
Phenol	-	2

The above resins I and II (100 parts) are blended with paraformaldehyde (8 parts), wax emulsion (15 parts) and 25% pentachlorophenol sodium salt solution (11 parts) to give adhesives I-I and II-I (Pizzi 1978a).

In some formulations, fortifying resins can be added to wattle tannin solutions to improve the quality of particleboards. Boards which had been bonded with wattle tannin at a level of 12% of extract on the weight of wood particles sustained immersion in boiling water for 72 hours. A particleboard formulation for air application is as follows:

Ingredient	Parts by weight
Wattle tannin	95
Water	138
Sodium hydroxide	1.6
Fortifying resin	5 (oven dry weight)
Paraformaldehyde	15
Viscosity (cp)	150-200 (25°C)

Typical pressing conditions are: temperature 160°C and pressure 14 kg/cm². Boards of about 700 kg/m³ density with 14% of tannin solids in the surface layers and 10% in the core comply with the mechanical property requirements for Flooring Grade particleboard (AS 0115-1968). Thickness increase after VPS (vacuum/pressure soaking) treatment is less than 12% (Plomley 1976).

Bivalent metallic ions have an accelerating effect on the reaction of wattle tannin with formaldehyde so that better curing in shorter times and improved strength are obtained (Pizzi 1979a). Furthermore, the use of those metallic ion catalysts such as zinc acetate in wattle tannin adhesives produces better board properties at lower pressing temperatures without any lengthening of the pressing time of the board and appears to offer the possibility of reduction of resin solids (Pizzi and Cameron 1981).

The basic adhesive formulation consisted of modified wattle tannin solutions, which are acid and alkali treated wattle tannin such as Resins I and II described above, paraformaldehyde, zinc acetate and wax emulsion (Mobilcer ED 80/63). The optimum temperature of pressing at 2% zinc acetate addition is approximately 130°C instead of 170°C and the percentage of resin solids can be decreased by approximately 1% from 10% to 9%.

A comparatively new adhesive formulation called a universal formulation for exterior-grade particleboard has been developed (Pizzi 1981). The adhesive glue mix consists only of a mix of wattle tannin solution to which has been added paraformaldehyde and 4,4'-diphenylmethane diisocyanate (commercial MDI). The wattle tannin solution, paraformaldehyde and MDI can be mixed a short time before spraying onto the wood chips, or sprayed onto the chips by separate applications. The proportion of wattle tannin solids to MDI is 70:30 on the basis of weight. The adhesive formulation consisted of 44% aqueous wattle tannin solution (175 parts), paraformaldehyde (11 parts), MDI (33 parts), wax emulsion (22 parts) and water (135 parts). The pressing conditions to produce 600 x 600 x 12 mm boards were as follows: Moisture content; core 18%, surface 22%, maximum pressure 25 kg/cm², pressing time 7.5 minutes and pressing temperature 170°C.

The high quality bonding obtained is possibly due to the fact that MDI may cross-link with the phenolic and alcoholic hydroxyl groups of polyflavanoids, sugars and gums present in the wattle tannin and increase the cross-linking obtained by the reaction of the wattle tannin with formaldehyde.

Urea-formaldehyde adhesives are known for the production of interior particleboard which is not boil proof or weather resistant. Wattle tannin adhesives can be used in the manufacture of the interior particleboard. A mixture of 55% aqueous wattle tannin solution (100 parts), defoamer (0.3 parts) and sodium hydroxide (15 parts) was heated at 90°C for 3 hours under continuous stirring and then cooled. Based on this reacted mixture, an adhesive can be formulated as follows:

Ingredient	Parts by weight
Reacted mixture of wattle tannin	100
Sodium pentachlorophenate	0.1
Wax emulsion	20
Hexamethylenetetramine	12

The pH should be adjusted to between 7.8 and 8.2 with either 30% aqueous sodium hydroxide solution or glacial acetic acid and the viscosity is adjusted to between 100 and 300 cp by the addition of water. Wood chips are loaded with the above adhesive at 5 to 8% on the dry weight basis and pressed at 130°C for

4.5 minutes to give interior-grade particleboards (Pizzi 1979b).

However, since the price of urea-formaldehyde adhesives is still very competitive, the use of wattle tannin adhesives for interior particleboard has not been emphasized yet.

Plywood adhesives

Several formulations for wattle tannin adhesives have been developed for bonding wood veneers to produce plywoods. For interior-grade plywood an unfortified wattle tannin-formaldehyde resin similar to that used for particleboard can be used. However, in order to keep the adhesives in the glueline, 10-25% of fillers such as wood flour or coconut shell flour are required for the formulation. On the other hand, for exterior-grade plywood, which is 72 hours boil proof and fully weather resistant, it is necessary to fortify the wattle tannin-formaldehyde resin with synthetic resins such as urea-formaldehyde, a phenol-formaldehyde or phenol-resorcinol-formaldehyde resins.

For interior-grade plywood, the following formulation can be used (Saayman and Oatley 1976).

Ingredient	Parts by weight
Wattle tannin	100
Water	100
Sodium hydroxide	1.15
Coconut shell flour (200 mesh)	10-15
Paraformaldehyde	10

The adhesive was applied to wood veneers (150 to 200 g/m² for hardwood, 200 to 250 g/m² for softwood) of 4 to 10% moisture contents. After 15 to 60 minutes of open assembly time and cold pressing 9 kg/cm² for 5 to 10 minutes, the veneers were pressed at a pressure of 12 kg/cm² and at 120 to 140°C for 5 minutes basic, plus 1 minute per mm to furthest glueline.

The characteristic of wattle tannin adhesives is the need to fortify the tannin. The lack of strength of unfortified tannin-formaldehyde adhesives is due to low cross-linking as a result of immobilization of the tannin-formaldehyde network, caused by the initial formation of methylene bridges. Further methylene bridge formation is prevented by the distance involved. Longer cross-linking agents are necessary to bridge these distances, to increase cross-linking so that bonding strength can be increased. Phenolic- and urea-formaldehyde resins have been used for this purpose.

Plomley (1966) formulated a simple Novolac to be fortified to wattle tannin solution which, with paraformaldehyde, was successfully used in the production of exterior-grade plywood. Based on this, a fortifier which was produced from a phenolic

fraction of coal tar acids was also developed (Pizzi 1978b).

Tar acids can be obtained as a by-product of Lurgi-type coal gasification in Fisher-Tropsch processes producing light hydrocarbons from coal, or as a gasification by-product of the production of coke in the steel industry. The tar acid fraction can be considered as composed of 80% phenol readily usable to form resins when reacted with formaldehyde. The tar acids are considerably cheaper than commercial and technical-grade phenol and are commercially available in considerable quantity. Therefore, their use as a substitute for phenol in the production of fortifiers has great advantages from an economic point of view.

Tar acids and phenol fortifiers were prepared as follows:

Tar acids fortifier

Ingredient	Parts by weight
Tar acids fraction	42.0
Formaldehyde (40% solution)	28.6
NaOH (40% solution)	2.3
Resorcinol	15.6
Tar acids fraction	25.2

Phenol fortifier

Ingredient	Parts by weight
Pheno 1	33.4
Formaldehyde (40% solution)	28.6
NaOH (40% solution)	2.3
Resorcinol	15.6
Phenol	20.1

The tar acids are mixed with formaldehyde and the sodium hydroxide is added. The mixture is refluxed for 45 minutes, then resorcinol is added to the mixture immediately followed by the second lot of tar acids and the mixture is refluxed further for 30 minutes. The fortifier prepared with phenol is prepared in the same way by substituting the tar acids with phenol.

Pizzi made the following adhesive formulations.

Ingredient	Parts by weight
Wattle tannin (55% solution)	350.0
Tar acid fortifier	22.7
Phenol fortifier	-
Defoamer	0.5
NaOH (45% solution)	4.3
Water	57.0
Coconut shell flour	45.0
Paraformaldehyde	30.0

Plywood panels (60 x 60 cm) of Okoumé (golan) were prepared using the following conditions: Glue spread 180 g/m², veneer thickness 1.2 mm, veneer moisture content 6%, pre-pressing 5 kg/cm² for 10 minutes, and pressing 16 kg/cm² at 125°C for 5 minutes. The panels were knife-tested according to British Standard (BS 1088:1957) for marine grade plywood. The results of these tests showed an excellent glue bond quality (Pizzi 1978b).

Although urea-formaldehyde adhesives are not boil and weather proof, when small amounts (10-20%) of a urea-formaldehyde resin are added to an aqueous solution of wattle tannin, a reaction takes place immediately at room temperature giving a soft jelly-like mass (wattle tannin/urea-formaldehyde copolymer) which is easily dissolved by fast stirring and the addition of small amounts of water. Addition of formaldehyde cures the wattle tannin/urea-formaldehyde copolymer giving a resin that is fully weather resistant (Pizzi 1977, 1979c; Pizzi and Scharfetter 1978). Different types of urea-formaldehyde resins have been available, e.g. mole ratio of 1:1.4 to 1:3.8. If free formaldehyde exists too much in the resin, the pot life of the fortified wattle tannin adhesive will be shortened because of the strong reactivity of wattle tannin with formaldehyde.

Premature adhesive gelling and consequent immobility were the major problems encountered with wattle tannin adhesives at pH higher than 6.

However, these problems are largely overcome by fortifying the wattle tannin with urea-formaldehyde resins which are used in the pH range 4.5 - 5.2. The following formulations have been commercially used for exterior-grade plywood:

Ingredient	Parts by weight
Sulphited wattle tannin	36.4
Wattle tannin	-
Water	41.22
Defoamer	0.15
Fungicide (25% Na P.C.P.)	0.40
Urea-formaldehyde fortifier (63% solids, molar ratio 1:1.4)	6.78
Coconut shell flour	6.75
Water	4.19
Paraformaldehyde	4.10
Viscosity (cp)	2,300

Prepare the wattle tannin aqueous solution in a stainless steel or plastic container, add defoamer and fungicide with continuous stirring and leave overnight. Add the urea-formaldehyde resin slowly to the wattle tannin aqueous solution prepared. The mixture will become very viscous but with continuous stirring viscosity will decrease. Add fillers and paraformaldehyde and adjust the viscosity with extra water. The adhesives are usually used at pH of 4.8 to 5.1. The adhesive is ready for use and has a pot life

of approximately 5 hours. The sulphited wattle tannin can be prepared by adding 5% (based on wattle tannin solids) sodium sulphite to the wattle tannin aqueous solution and heating at 80°C to 90°C for at least 8 hours. Cool down to 25°C and add the other components as described above. The unsulphited wattle tannin adhesive is recommended for veneers with a higher moisture content. When softwoods are glued, the sulphited adhesive is recommended.

When viscosity causes problems, a small amount of acrylic emulsion can be added to improve flow and spreadability of the adhesive without changing the viscosity. The basic adhesives were fortified wattle tannin adhesives with urea-formaldehyde resin (BASF Kaurit 285, 64% solids). Revacryl 272, 275, 277, 6014, 6016 and 6020 from Revertex Co. Ltd (South Africa) were examined as acrylic emulsions. The laboratory plywood results revealed that an increase in the amount of acrylic emulsion in the glue mix causes a decrease in the water resistance of the cured tannin adhesives and the optimum amount of acrylic emulsion would be a 1% to 3% range of resin solids. Furthermore, Revacryl 275, which is a chemically inert and less expensive acrylic polymer, was found to be preferable for wattle tannin adhesives (Pizzi *et al.* 1981a).

As mentioned in the section of particleboard adhesives, the addition of a small amount of a bivalent metallic salt to the wattle tannin adhesives accelerates gelling of the adhesives so that shorter pressing time can be applied without appreciable shortening of the pot life. One of the most effective bivalent metallic salts was zinc acetate. The adhesive was formulated by mixing the following components:

Ingredient	Parts by weight
Wattle tannin (57.7% solids)	130
Urea-formaldehyde resin (Kaurit K285, BASF)	12
Zinc acetate (hydrated)	3
Coconut shell flour (200 mesh)	14
Paraformaldehyde	9
Water	25

A small amount of extra water was added to obtain an initial adhesive viscosity of 2.5-5.5 Pa.s at 22°C. Three-ply panels (9 mm thick, pine) were prepared from veneers (moisture content 5%-6%) loaded with the adhesive (230 g/m² single glueline) by pressing at 1.6 MPa and 125°C. The results from plywood tests revealed that the presence of the metal ion is capable of shortening the pressing time by 1 to 1.5 minutes or between 20 and 30% of the original value and also at the same time of increasing bond strength (Pizzi, 1979a).

Glulam adhesives

The development of thermosetting adhesives based on wattle tannin for laminating timber has been considerably slower than that for particleboard and plywood. This is mostly due to the lower technical sophistication of the factories producing gluelam, particularly relating to the effective heating of the glueline.

The results of some laboratory tests of wattle tannin adhesives using radio-frequency heating to cure the adhesive were first reported by Plomley *et al.* (1973). Assemblies of five pieces of radiata pine (610 mm long x 50 mm wide x 21 mm thick) were bonded with adhesives based on commercial wattle tannin with addition of phenol-resorcinol-formaldehyde resin. The glue spread was 340-365 g/m² single glueline and pressed at 1.30 MPa. Cure was effected at power input of 7 kW for 32 seconds or 6 kW for 38 to 42 seconds. In a study of the effect of rate of cure on bonding, assemblies of six pieces of radiata pine (914 mm x 90 mm x 26 mm) were bonded with a wattle tannin-phenol-resorcinol-formaldehyde formulation. The assemblies were cured for 2.0, 2.5 and 3.0 minutes at a pressure of 1.03 MPa and a total power input of 10.7 kW min. The results indicated that this gluing system had shown considerable potential as a low-cost substitutes for resorcinol-formaldehyde adhesives (Plomley and Collins 1975).

The first industrial curing chambers were installed at a glulam plant in South Africa, 1979. The dimensions of the curing chambers are 14.4 m long x 2.95 m wide x 1.85 m high. Fans circulate air, and temperature and relative humidity are closely controlled. The performance of the TRU (Wattle tannin-Resorcinol-Urea)-link adhesive was comparable with that of cold-set resorcinol adhesives of the highest quality. Proper curing of the TRU-link wattle tannin adhesive was obtained under the conditions of a glueline temperature 70°C, a temperature of the air of 90°C, a relative humidity of 85% and an air circulation of 1.5 m/s. These conditions can only be obtained in the curing chambers. The TRU-link wattle tannin adhesive contains only 15% resorcinol whereas cold-setting adhesives contain approximately 20% resorcinol. Results from further experiments indicate that a formulation containing 10% resorcinol provides satisfactory bonds at glueline temperature of 45°C. Curing at lower temperatures requires less energy, no humidity control, and insulation requirements are reduced, so that with tannins the cost of a curing chamber would be much lower (Pizzi *et al.* 1981b).

Corrugated cardboard adhesives

Starch-based adhesives had been used extensively in the paper-to-paper bonding for producing general-purpose corrugated boards since two-component starch systems were introduced by Stein Hall and Co. Inc. in 1934. In order to produce water-resistant

bonds in corrugated boards, it became necessary to fortify basic starch adhesives with small amounts of water-resistant resins or resorcinol. Based on the experience relating to the use of wattle tannin as wood adhesives, it was possible to predict the use of wattle tannin in starch based adhesive formulations for corrugated boards.

Initial investigations on the use of wattle tannin in starch corrugating adhesives were carried out at the Division of Forest Products, CSIRO, in 1968. When an alternative material to resorcinol was urgently needed in 1969, the project was extended to include some studies designed to establish reasons for the poor performance of water-resistant starch adhesives. The two-component commercial starch mixture, containing pre-gelatinized carrier and native starch, was suspended in water. Tannin powder was added and mixed thoroughly. Formalin (40% formaldehyde) was added in the proportion of 1 part to 4 parts of tannin. Gelatinization of the carrier portion of the adhesive was achieved by the addition of 1M sodium hydroxide. The adhesive was applied to sheets of corrugated medium which were then lightly pressed onto the filler side of sheets of jute liner. These were oven cured at 105°C for 3 minutes and then allowed to stand overnight but in the later study the oven curing was replaced by hot pressing with a domestic flat iron for curing the adhesives (McKenzie and Yuritta 1972).

Further research and developments in the field of fortified starch adhesives with wattle tannin were carried out in South Africa (Saayman and Brown 1977). However, the use of an unfortified wattle tannin adhesive for corrugated cardboard gave poor and inconsistent dry and wet strengths. Custers *et al.* (1979) reported that wattle tannin adhesives fortified with urea-formaldehyde resins can be used in place of the more expensive waterproof reagents such as resorcinol, and moisture resistant paper bonds of high quality are produced.

The formulae which have been developed for the manufacture of water resistant corrugated cardboard are based on the addition of spray-dried wattle tannin, urea-formaldehyde resin and formaldehyde to a typical Stein-Hall starch formula of 20-22% starch content. A typical starch corrugating mix is shown below:

Primary tank (carrier portion)

Ingredient	Parts by weight
Water (cold)	300
Starch	75
NaOH	17
premixed	
Water	15

Heat to 70°-72°C and hold for 10 minutes. Add further cold water (300 parts) and mix for 5 minutes. Drop into the secondary tank over a period of 20 minutes.

Secondary tank (slurry portion)

Ingredient	Parts by weight
Water (cold)	1450
Starch	525
Borax	13

After dropping the contents of the primary tank into the secondary tank, the following components of the waterproofing resin are added in random order.

Ingredient	Parts by weight
Spray-dried wattle tannin	25 (4% of starch mass)
Urea-formaldehyde resin (65% solids)	5
Formaldehyde (37% HCHO)	8

BASF K 285 urea-formaldehyde resin was used in the experiment but any suitable alternative liquid urea-formaldehyde resin or resins in powder can also be used, although appropriate adjustments to the quantity added are necessary if the solids content is different.

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Chapter 16

Uses of Wattle Extracts : Anticorrosion of Metals

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Summary

This chapter discusses the uses of *Acacia mearnsii* tannins in preventing the corrosion of metals. They are twofold, and are confined almost solely to protecting iron (mild steel and cast iron).

In the treatment of water cooling systems tannins are usually added with sodium phosphate and often with anti-freeze chemicals in the case of motor vehicle radiators. In Australia, approximately 150 tonnes per year of chestnut, quebracho and mimosa (*A. mearnsii*) tannins are imported for all water usages and the preference is for the first two.

Boiler water systems are treated by blends of tannins, soda ash and sodium phosphate. Tannins protect by reducing the dissolved oxygen, making an iron tannate protective film and by sequestering calcium salts enabling them to precipitate and be removed rather than deposited on heat transfer surfaces. Boiler waters at pressures above 1380 k Pa are seldom treated with tannins. The prevention mechanism is discussed and possible markets in the Peoples Republic of China are mentioned.

Tannins are used in conversion coatings on lightly rusted steel and usually with an acid, e.g. phosphoric acid, at pH 2.5.

Areas of unruled steel surface react to produce ferrous tannate which is bound into the light rust as a protective primer which can prevent further rusting of steel for up to 12 weeks. Researchers have used *A. mearnsii* tannin on corrosion test panels exposed for up to four years. Recent development is in the field of improved co-polymer coatings with tannins, iron tannate as a pigment and tannate wax coatings. Mimosa tannin seems to be preferred.

Introduction

Tannin extracts of all types react with iron salts to produce blue-black iron tannin complexes known simply as iron tannate.

Even Pliny the Elder in the first century noted the reaction (Pliny before 79AD). Well-preserved iron objects have been excavated in Great Britain at archaeological sites where tannins were or had been present (Knowles and White 1958).

For a hundred years tannins have been used in formulations for feed water to prevent corrosion of the internal steel and copper surfaces of low-pressure steam boilers (Brannt and Wahl 1886) and for about forty years in industrial and automotive water cooling systems. However, in the western world at least, that tannins might be a useful component in paints used to protect steel was not considered until fifty years ago (Knowles and White 1958). The advantages (or disadvantages) of using *A. mearnsii* tannin extract instead of, for example, quebracho or chestnut extract were not closely compared until 1976. Since then the chemistry and application of 'mimosa tannin' for the treatment of rusted steel has been given much attention because of support given by the African Territories Wattle Industry Fund Ltd (Seavell 1978; Ross and Francis 1978; Morris et al. 1987).

In this section 'water soluble tannin' or 'tannin extract' refers equally to tannins derived from all hardwoods including *A. mearnsii* or even pure tannic acid, unless distinctions are made.

Tannins in water treatment

Cooling systems

If tannins are added to the water of circulated cooling systems they may not be as effective alone as inorganic corrosion inhibitors such as phosphate or chromate, but often they are favoured because they are safer. Lower-than-recommended concentrations do not cause pitting corrosion and an increased general attack.

Blended tannins which contain sodium carbonate, phosphate and/or nitrite in water used up to 80-90°C, reduce the corrosion of steel by lessening the attack by dissolved oxygen, and produce a protective film on the metal surface and reduce the scaling of precipitated hardness salts like calcium carbonate. They are said to distort the crystal structure and make a fluid sludge easily removed by filtering the cooling circuit (Evans 1961).

Such tannin blends were used in diesel locomotive cooling systems in the United Kingdom. This is not

the case in Australia where sodium chromate-sodium phosphate blends are used in locomotives in Victoria, Queensland and at the Broken Hill Propriety Company (B.H.P.) at Whyalla, South Australia. Sodium nitrite is used in the rest (Beatty 1988).

Motor vehicle radiator cooling systems are treated traditionally with anti-freeze (triethylene glycol) and blended inhibitors. In the colder Australian south-eastern States anti-freeze is important but even though town waters are not saline (Cl- <30 mg per l) inhibitors are needed in case the polyhydric alcohols oxidise to corrosive organic acids. In the remainder, the salinity is much higher (Cl- > 100 mg per l) and has been one cause of the severe corrosion of the aluminium alloys in motor vehicle engine components in Australia. Sodium nitrite inhibitor may be discontinued because it can be reduced to ammonia which attacks aluminium and can cause pitting (Hyde and Ritchie 1981). Blends of tannins and sodium phosphate now used are satisfactory. In one product, *A. mearnsii* tannin extract is effective as a minor constituent of a blend with chestnut and quebracho. The particular water treatment company considers that *A. mearnsii* tannin is difficult to handle because of its fineness compared with the other two. Two important disadvantages (Ings 1976) are that the films on surfaces may reduce heat transfer and tannins may be degraded by some organic biocides and organic growth.

An ideal combination for uniform protection of steel cooling systems and for stopping corrosion pitting is seldom less than 0.5% but has to be determined in each type of cooling water by research and development.

Steam boiler systems

Steam locomotive boilers and stationary boilers have been treated by dosing tanning extracts into the feed waters in conjunction with alkalis since about 1865. In these early days a typical formulation for a 7.5 kw boiler needed 1 kg of quebracho tannin and 1.3 kg of mixed lime, potash and soda fed intermittently with the feed water (Brannt and Wall 1886).

Tannin treatment has been specified for locomotive boilers having copper tubes, fire boxes or staybolts. For an all-steel system the addition of sodium carbonate or sodium hydroxide to keep the alkalinity above pH 10 is desirable to allow the protective Fe₃O₄ magnetite layer to repair itself. However, this high alkalinity and dissolved oxygen is harmful to copper, so the role of tannins added to the mixture is to de-oxygenate the water so as to lessen the harmful formation of cupric oxide which is not a protective film at high pH. (Refer to Nathan 1973 for quantitative information). A typical dose of

quebracho of 35 to 50 mg per l of feed water has been suggested (Hamer et al. 1961). To control calcium phosphate 150 mg per l of tannin has been recommended for pressures of 2200 k Pa and 200 mg per l for carbonate scale with suspended solids in the boiler water of about 400 mg per l (Betz 1962).

The use of tannins is restricted generally to boilers operating under 1380 k Pa (200 p.s.i.) and are considered to be unstable at high temperatures, but they are being partly displaced by polyelectrolytes and ethylene-diamine tetra acetic acid (EDTA) (Potter 1988). The brown colour of tannin-treated boiler water can interfere with analyses when the detection of a colour change is important.

Although it has been shown experimentally that tannins are stable to 2760 k Pa and possibly higher (Streatfield 1962), boiler chemists are reluctant to add tannins, but prefer hydrazine as they aim for zero solids and oxygen in feed water for high-pressure stationary boilers.

Mechanism of corrosion protection of immersed steel by tannins

As mentioned earlier, tannins act in three ways:

- To reduce dissolved oxygen and so lessen general and pitting attack,
- To produce a protective film on the metal surface, and
- To change the nucleation of dissolved salts so that they precipitate as a sludge and not as a scale. This is easily blown down in a boiler, or filtered out in a cooling system which uses raw water make-up.

Different tannins act in different ways. For example the capacity at 25°C to absorb oxygen in solution at pH 12 varies. Chestnut and quebracho are 1.7 and 1.3 times faster respectively than *A. mearnsii* tannin (Knowles and White 1958). At boiler temperatures the capacities might be quite different and a good blend could be found only by experiment.

Tannin blending for water treatment became more than an art when water chemists distinguished between the two groups of tannins and decided that condensed tannins functioned to sequester scale-forming calcium salts and prevent their deposition, and that hydrolyzable tannins combined with the iron oxide film on steel in boiler waters to form a blue-black protective iron tannate complex which contained gamma Fe_2O_3 . This stifled further attack. However, in alkaline water either group removed oxygen by oxidation at the catechol or pyrogallol groups (Knowles and White 1958).

Parkins and Pearce (1963) showed that the corrosion rate for mild steel at 21°C in 1% w/v solutions varied in four different tannin solutions in distilled water; pH adjusted by sodium carbonate to a range of 6 to 10. After exposing immersed test plates for 100 days the corrosion rate in sodium carbonate alone was reduced to only 0.23 times in *A. mearnsii* tannin; 0.40 in quebracho; 0.11 in valonea; and 0.33 times in myrabalsm tannin 1% solutions at pH 9.0-9.3. The authors concluded by experimental electrochemical measurements that tannins function anodically, that is, they prevent the solution of iron (the formation of Fe^{2+} ions) by a protective film of mixed tannates, ferrous and ferric iron, but the exact form of iron tannate was not established.

More recently Rosenberg (1987) studied solutions of pure gallic acid which, like tannic acid in the broadest sense, absorb oxygen and form metal complexes with iron. He concluded that the iron surface was passivated by oxygen on the metal surface or by the enhancement of the rate of oxidation of Fe II to Fe III, in spite of the antioxidant tannin-like properties. His work is continuing and may pin-point the mechanism precisely.

More evidence such as this is needed for a definite conclusion to be made, but it is highly likely that *A. mearnsii* tannin extract behaves as an (electrochemically) 'safe' anodic inhibitor for steel, and requires an existing iron oxide film on steel to make a satisfactory protective tannate film.

Future for tannins in water treatment

All tannins have to be imported into Australia. The exact usage in the water treatment industry is not known.

Imports of 'Wattle bark extracts' were 2830 t in 1985/86 and 5480 t in 1986/87, almost exclusively for the tanning industry and adhesive production. A postal survey of 25 water-treatment and coating companies in Australia (Moresby 1988) was not complete because 10 were reluctant to disclose approximate usages. Maximum stated usages were 100 t. An annual average usage of 150 t for all tannins in the water-treatment industry is realistic, with about 50 t per annum being for imported *A. mearnsii* tannin. At average unit cost the total value would be \$A100 000 for all tannins used for water treatment.

In Australia, there is likely to be a continuing market for beneficial tannin alkalibends for low-pressure steam boiler water treatment for stationary and locomotive boilers. In the Peoples Republic of China, which has a declining but still substantial steam locomotive fleet, this market for tannins must be large. Australia's few preserved operating steam locomotives number only 20. Four are known to use tannin/alkali/phosphate/polyelectrolyte treatment.

Tannin does not seem to be favoured for cooling systems in diesel locomotives.

In communities with corrosive town water having an electrical conductivity above 200 $\mu\text{S}/\text{cm}$ and a chloride content more than 30 mg per 1 Cl^- , a blend of *A. mearnsii* tannin and sodium phosphate (and glycol anti-freeze in frost-prone districts) would be desirable for all water-cooled internal combustion engines, and essential for any constructed of aluminium alloy. This is probably the largest potential market in the Peoples Republic of China. It is certainly a developing one in Australia in all but the south-eastern States where city waters have conductivity less than 200 $\mu\text{S}/\text{cm}$.

Tannins in protective coatings

In the 1950s at the Paint Research Association, Teddington, United Kingdom scientists showed that tannins incorporated into surface coatings painted onto steel gave it improved resistance to atmospheric corrosion (Knowles and White 1958). These authors reviewed existing knowledge and laid the foundation for comparing hydrolysable and condensed tannins for their suitability to form an iron-tannin complex in acidic aqueous solutions suitable for wash primers for firmly-attached lightly rusted steel. Its first big application was apparently the temporary protection of the cast-iron roof of Big Ben (clock tower) at the Houses of Parliament, London, before repainting.

Shreir (1964) described the synergistic effect of phosphoric acid and tannins which produced conversion coatings together on steel which were more resistant than those formed by the individual compounds alone. Commercial conversion coatings were on the Australasian market a year earlier as pretreatment primers containing tannin (Emery 1963).

An advance was made in 1978 by Ross and Francis (q.v.) who investigated the fundamental aspects of the tannin-on-steel protection layer. They used an aqueous solution of *A. mearnsii* tannin, with the pH adjusted to 2 with phosphoric acid, plus a wetting agent. This was brushed on rusted steel test panels (loose rust removed), and then exposed outdoors in severe environments. They found that the clean steel needed some rust to make the wash primer more adherent for better protection. Also a double coating was an advantage. Scanning electron microscopy, electron probe analysis and infra-red spectrophotometry helped them to determine that tannin on steel formed a crazed outer layer of ferric tannate with about half of the original light rust impregnated and the rest left unaffected. Magnetite was detected but did not necessarily contribute to the anticorrosion properties of the conversion coating. Failure of the coating was caused by moisture reacting with existing rust, causing the tannin coating to blister and rust to burst through.

This important research was taken a step further by Seavell (1978) who after four years of field trials and working concurrently with Ross and Francis was able to quantify further the characteristics of *A. mearnsii* tannin as a short-term protective coating.

The reader is recommended to obtain and study the details in these important papers. Seavell's steel exposure panels pretreated with mimosa wash primer and later painted with conventional primers and undercoats are depicted at all stages of his thorough assessment. He concluded that the primer can serve best as a short-term protective coating between surface preparation and subsequent painting; and as a special pretreatment when paint is to be applied in a humid atmosphere. Short-term protection out-of-doors was effective for 6-12 weeks, or longer if panels were protected from the weather.

Subsequent years have seen painting costs increase because of the high labour cost required to prepare steel surfaces to near "white" specification. Any coating, like a tannin based primer, which can be applied successfully to lightly rusted steel could reduce preparation costs.

Formulations of vinyl acrylic co-polymers and *A. mearnsii* water-thinned tannate primers became available in the mid-1980s. Progress results from an assessment by the Paint Research Association were reported recently (Morris et al. 1987).

A wire-brushed surface treated with a mimosa tannin-vinyl acrylic pretreatment primer overcoated with a zinc phosphate epoxyester resisted corrosion as long as a better-prepared surface (requiring more expensive labour) coated with only the latter coat. The economics of these tannin-based pretreatments are greatly affected by the cost of mimosa tannin which is the most expensive component of the coating by far (Seavell 1988).

Formulations of tannin-based conversion coatings require tannins of 85-95% purity which are completely soluble in ethanol; an additional acid - usually phosphoric - and a catalyst to control the speed of chelation of iron atoms and sometimes an organic cross-linking agent are also added. In five patent examples (Ranney 1976) acids used were oxalic, maleic, malonic, phthalic or (acidic) ferric chloride. Glycol and isopropanol were extra additions and catalysts were polysulphoric or amino acids. In most cases tannins formed 15% w/w of the total formulation and were not specified individually.

Mechanism of corrosion protection of surface steel

A rational explanation of the mechanism of the role of *A. mearnsii* tannin and iron, which should be read in detail, was given by Ross and Francis (1978) and Seavell (1978).

The tannin reacts with the ferric Fe^{3+} ion and not directly with iron or rust. With some of the bare metal (iron) exposed, attack by moisture and phosphoric acid -or (I assume) alternate acids in a formulation - forms ferrous (Fe^{2+}) ions which are readily oxidised to Fe^{3+} absorbed by tannin-wetted rust, where this reaction prevents further anodic reactions by stifling the metal surface with an insoluble product.

This tannate is 'physically bonded to the rust which is therefore, covered with a blue-black tannate and appears to have been converted to tannate'. As far as the writer is aware, this explanation has not been disputed in ten years.

Future for wattle extracts in protective coatings

Historically Australia was one of the first countries to manufacture conversion coatings based on tannins and phosphoric acid (Emery 1963). Tannin extract from eucalypts was used in Emery's development work, but now all tannins are imported into the country.

Three or four other coating manufacturers formulate and market industrial coatings containing tannin to increase the life of paint primer/undercoat/top coat systems; they feature the advantages of them as being non-toxic, non-flammable and permitting application in all weather by spray, brushes or rollers. Several of them are complex formulations with plastic emulsions. It was not possible to establish the Australian market with any accuracy nor the usage of tannins in coatings.

Tannin technology outside Australia is progressing quickly. The use of iron tannate as a pigment would have great advantages, being non-toxic and possessing anticorrosion properties. Tannin-containing wax coatings too are a possibility. These products are being developed in the United Kingdom and information about them is expected to appear in the literature early in 1989 (Seavell 1988).

There would seem to be a large opening for the use of *A. mearnsii* tannin in the formulation of conversion coatings for lightly rusted steel in the Peoples Republic of China. It is an expensive raw material in the western world; the chemistry behind the action on steel has been adequately explained; and the preparation and formulation of coatings could be done safely by unskilled people.

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Chapter 17

Other Uses of Wattle Extract

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Conditioning agent for drilling mud

Tannin is used as conditioning agent to contribute necessary technical properties to drilling mud. Hydration of tannin's hydrophilic groups can weaken or break down the network formed by clay particles and liberate free water. This enhances the fluidity of mud and decreases its shear strength and viscosity. The organic agent, absorbed on the surface of clay particles, enhances hydration and results in the formation of a thick cake on the well wall and reduced water loss.

Kr 6D is a commercial mud fluidizing agent made of black wattle extract which has been satisfactorily used in wells to 1820 m depth, under not-too-salty conditions. Kr 6D is a chelated product prepared by reacting chromium salt with calcium bisulfite-treated black wattle extract. The Cr^{+++} ion contributes resistance against salt, calcium and heat, while solubility depends on the degree of bisulfite treatment.

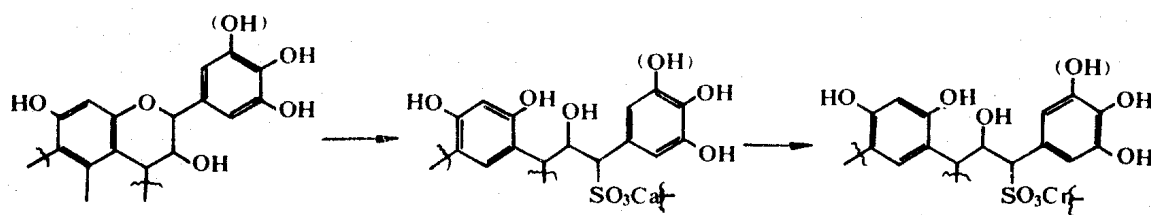


Fig. 17.1 Preparation of mud fluidising agent from wattle extract

Calcite depressant in ore flotation

Production of fluorides requires refined fluorite ore (CaF_2 not less than 92-93%, CaCO_3 not higher than 2-3%). During flotation of fluorite ore, tannin can be absorbed on the surface of calcite particles at a particular pH through bonding between tannin's -OH group and Ca^{++} , to increase the hydrophilic properties of calcite and deposit calcite particles.

In 1975 it was reported that 100 t per month of black wattle extract was used in South Africa for fluorite ore flotation, consuming 746 kg extract per ton of ore (CaF_2 20-25%).

Flocculant in water treatment

Colloidal tannin particles in aqueous solution are negatively charged. Reaction of black wattle tannin with ethanolamine and formaldehyde in acid medium introduces the positively-charged methylamino-group into the tannin molecule. This modified tannin, commercially named Floccotan, is able to neutralize the negative charge of suspended colloidal particles, such as clay and organic matter, in water, and results in coagulation of these suspensions to obtain purified water for municipal water supplies. The chemical structure of Floccotan is illustrated in Fig. 17.2.

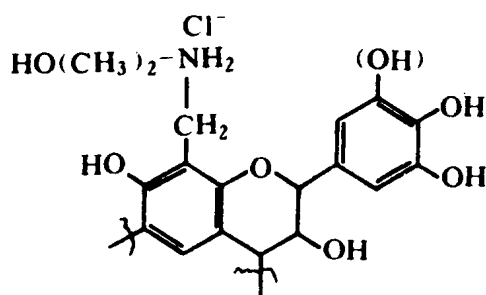


Fig. 17.2 Chemical structure of Floccotan

Fig. 17.3 Wattle extract reacts with paraformaldehyde to give tannin-formaldehyde resin

Floccotan exists as a salt having very good water solubility, and is able to rapidly coagulate clay and suspended matter in water. The treated water contains no residual tannin salt. The addition of 6.8 ppm of modified tannin to river water reduced the turbidity from 17 to 8, and the APHA index from 50 to <1, compared with the results of an addition of 1 ppm alum of 14 and 20 respectively.

Tannin can remove metallic ions from water by forming insoluble chelates with bi- and trivalent metallic ions through complexation. Waste water containing Cr, Zn, Ni and Cd ions can be clarified by treating with 50-2500 g per g of metal at 0-100°C and pH 2-3.

Ion-exchange resin

Condensed tannin can be used to prepare cation exchange resin. Preparation of the resin is briefly as follows:

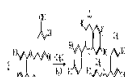
Black wattle tannin reacts with paraformaldehyde in alkaline conditions to form unmodified tannin-formaldehyde resin (Fig. 17.3).

Etherification of tannin-formaldehyde resin with chloroacetic acid in alkaline medium introduces a carboxylic acid group into the molecule (Fig 17.4).

Tannin-formaldehyde resin reacts with sodium bisulfite which introduces a sulfonate group into the molecule (Fig. 17.5)

Introduction of a relatively strong acidic group, such as a carboxylic or sulfonyl group, into the resin extends the utility of this resin in neutral and acidic media.

The exchange capacity (mmol H/g resin) of different tannin-formaldehyde resins are: unmodified 6.0, bisulfitized 6.2, sulfonized (by fuming with sulfuric acid) 7.4, etherified 6.0.



Tannin-formaldehyde resin

Fig. 17.4 Etherification of tannin-formaldehyde resin.



Fig. 17.5 Tannin-formaldehyde resin

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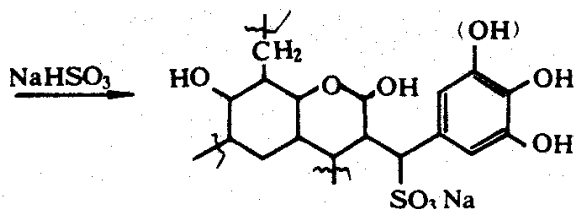
Tannin-formaldehyde resin

S wood

Black wattle extract can be used to prepare polyurethane-type coatings for wood, having hardness, brilliance, abrasion resistance and weather resistance comparable to commercial polyurethane coatings.

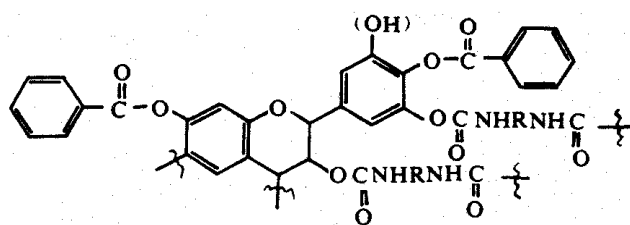
Partially benzoylated (or benzylated) tannin derivatives are used to react with diisocyanate in anhydrous solvent to form coating material with the structure shown in Fig. 17.6.

For example, 10 g of spray-dried black wattle extract is dissolved in 100 ml water, and 12.5 ml benzoyl chloride is added, followed by adding 24 ml 20% (w/v) KOH solution and allowing reaction for 40 min.



under stirring. After filtration, washing and drying, 16 g of light-brown precipitate is obtained. This benzoylated tannin is dissolved in cyclohexanone / butanone / acetone / ethyl acetate / turpentine (3:3:2:1:2, or 7:7:5:1:4) to form a solution which is blended with diisocyanate Desmodur L. before being applied to the wood surface. The pot life of the preparation is ca. 2 h. The coating film retained its brilliance and hardness for 2.25 years in an outdoor test.

In addition, black wattle extract can be used as chemical grouting agent, an additive to prevent boiler scale, a gas adsorption agent, a color fixing agent, etc. Further effective and diverse applications of black wattle extract are likely to be recognised in the future.



To another flavanyl unit

Fig. 17.6 Structure of a surface coating derived from wattle extract

Chapter 17

Other Uses of Wattle Extract

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Conditioning agent for drilling mud

Tannin is used as conditioning agent to contribute necessary technical properties to drilling mud. Hydration of tannin's hydrophilic groups can weaken or break down the network formed by clay particles and liberate free water. This enhances the fluidity of mud and decreases its shear strength and viscosity. The organic agent, absorbed on the surface of clay particles, enhances hydration and results in the formation of a thick cake on the well wall and reduced water loss.

Kr 6D is a commercial mud fluidizing agent made of black wattle extract which has been satisfactorily used in wells to 1820 m depth, under not-too-salty conditions. Kr 6D is a chelated product prepared by reacting chromium salt with calcium bisulfite-treated black wattle extract. The Cr^{+++} ion contributes resistance against salt, calcium and heat, while solubility depends on the degree of bisulfite treatment.

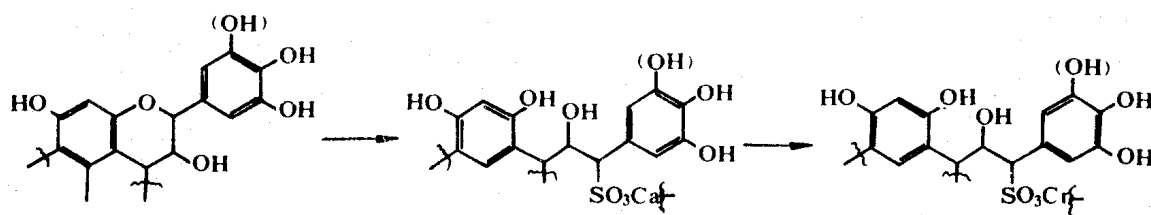


Fig. 17.1 Preparation of mud fluidising agent from wattle extract

Calcite depressant in ore flotation

Production of fluorides requires refined fluorite ore (CaF_2 not less than 92-93%, CaCO_3 not higher than 2-3%). During flotation of fluorite ore, tannin can be absorbed on the surface of calcite particles at a particular pH through bonding between tannin's -OH group and Ca^{++} , to increase the hydrophilic properties of calcite and deposit calcite particles.

In 1975 it was reported that 100 t per month of black wattle extract was used in South Africa for fluorite ore flotation, consuming 746 kg extract per ton of ore (CaF_2 20-25%).

Flocculant in water treatment

Colloidal tannin particles in aqueous solution are negatively charged. Reaction of black wattle tannin with ethanolamine and formaldehyde in acid medium introduces the positively-charged methylamino-group into the tannin molecule. This modified tannin, commercially named Floccotan, is able to neutralize the negative charge of suspended colloidal particles, such as clay and organic matter, in water, and results in coagulation of these suspensions to obtain purified water for municipal water supplies. The chemical structure of Floccotan is illustrated in Fig. 17.2.

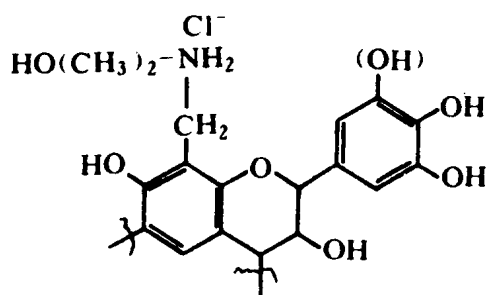


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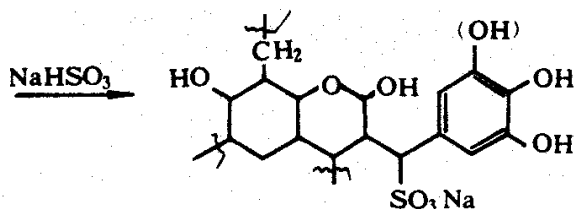
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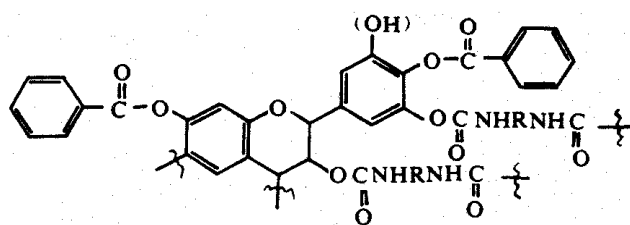
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To another flavanyl unit

Fig. 17.6 Structure of a surface coating derived from wattle extract

Chapter 18

Research on and Prospects of Black Wattle (*Acacia mearnsii* De Wild.) in China

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Abstracted and translated by Ho Chin Ko

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Research

Overview

Research on black wattle has developed concurrently with the expansion of plantations of the species in China. It started with observations of black wattle growth and comparisons of silvicultural techniques at different locations by local forestry organisations. A research project entitled 'Breeding and Cultivation Technology of Black Wattle' was officially approved by the Ministry of Forestry in 1981. A co-operative research program on black wattle between China and Australia commenced in 1984. This was, and still is, organised and supported by the Australian Center for International Agricultural Research (ACIAR) and the Chinese Academy of Forestry (CAF), and

implemented by related research organisations in both countries. At the same time research on black wattle has also been carried out by local forestry research institutes and colleges. As a result, the scope of black wattle research has been broadened, and many results have been obtained and applied. On the other hand, from a production point of view, black wattle research in China is still far from adequate. In this chapter, the author attempts for the first time to summarise and review past research on black wattle, much of which is unpublished.

The main organisations undertaking research on black wattle, and their research fields, are listed below:

Abstracter's remarks

This is the English abstract of Chapter 10 of the book entitled *Black Wattle and its Utilisation*, sponsored by ACIAR, edited by Ho Chin Ko and A.G. Brown and published in Chinese by the Chinese Forestry Publishing House in Beijing in 1991. The original 47-page Chinese text of this chapter includes 13 figures, 40 tables and references. It can be obtained, on request, from the author at the above address.

Research Institute of Subtropical Forestry, CAF (Fuyang, Zhejiang)

- Biological and ecological studies, assessment and classification of sites
- Silvicultural technology
- Provenance trials and tree breeding
- Pests, diseases and their control

Research Institute of Chemical Processing and Utilisation of Forest Products, CAF (Nanjing, Jiangsu)

- Tannin analysis and heat value determination
- Technology of production and utilisation of tannin extracts and tannin adhesives
- Technology of pulping and activated carbon manufacture from wood

Forestry Research Institute of Ganzhou Area (Ganzhou, Jiangxi)

- Tests of introduced species; provenance trials
- Silvicultural technology
- Short-rotation energy forests

Zhejiang Provincial Institute of Subtropical Crops (Wenzhou, Zhejiang)

- Forestry studies on black wattle

Research Institute of Forestry, CAF (Beijing)

- Introduction of exotic species

Research Institute of Wood Technology, CAF (Beijing)

- Properties of wood

Forestry Research Institutes of Guizhou, Guangdong, Yunnan, Sichuan and Fujian Provinces and related areas

- Field trials of introduced species
- Properties and utilisation of introduced species

Forestry College of Fujian Province (Nanping, Fujian)

- Silviculture and management
- Pest and disease control

- Properties and utilisation

Southern Central Forestry College (Zhuzhou, Hunan)

- Best harvesting age

Nanjing Forestry University (Nanjing, Jiangsu)

- Sulfate pulping of black wattle wood

Forestry research

Provenance trials

The use of provenances optimum for local conditions is one of the most important steps which can be taken to ensure the technical and economic success of black wattle plantations.

The black wattle seed imported and used in China for the first plantations was of commercial grade and uncertain pedigree. Poor seed quality may be responsible for unsatisfactory growth and early flowering of trees in some areas. Attempts have been made by some forestry research organisations to select seed of better quality from second- or third-generation descendants of the initial introductions, with certain results. Ganzhou Forestry Research Institute planted and assessed 12 provenances, and selected 4 for further use. Zunji Forestry Institute in Guizhou Province tested and compared 9 provenances in the early eighties, and identified some which were cold tolerant.

The Research Institute of Subtropical Forestry, in co-operation with the CSIRO Division of Forestry and many forestry organisations in China, has carried out extensive trials since 1986 on 30 provenances (23 from Australia, 2 from South Africa, 5 from China) in 7 locations in China (3 in Fujian, 2 in Jiangxi, 1 in Guanxi and 1 in Zhejiang). In addition, because of large differences between individual trees within the better provenances, family selection is also going on. Several experimental forests were established in Fujian, Jiangxi and Yunnan Provinces for this purpose and 187 families (including 175 from CSIRO) of 25 provenances are being tested. Results obtained so far are important and interesting. Pronounced differences in productivity are evident among provenances, of which 5 look most promising. The 10 best families in the progeny trials have been identified.

To complement these trials, the Research Institute of Chemical Processing and Utilisation of Forest Products, CAF, has undertaken tannin analyses. It has also successfully sought more rapid methods of tannin analysis which could replace the traditional hide powder method and cope with the large number analyses required by forestry experiments.

Studies of management systems

The feasibility and technology of growing black wattle on short rotations have been studied over some time by several institutes, especially in Ganzhou. Experimental results have shown that the biomass of trees grows rapidly in early life. The average annual growth in height and diameter of trees and their yield of bark and wood were much higher in a 2- or 3-year-old forest than in a 9-year-old one. The former produces 170-270% more bark and 200% more fuelwood than the latter. Short-rotation low forest of black wattle, which is capable of providing fuelwood and quickly changing ecological conditions, can suit severe conditions like those in Ganzhou where the soil is poor, trees grow slowly when older, production of timber is difficult, damage by insects and disease is common, cold injury occurs periodically and fuelwood is scarce.

The Research Institute of Subtropical Forestry also carried out experiments on short-rotation, dense plantations of black wattle in Wenzhou and Changtai in 1982-1984. High yields of biomass were obtained and appropriate spacings were recommended.

Technologies for highly productive normal plantations were targets of research by a number of organisations. Many plans and suggestions have arisen from the research results. Typical yields of solid timber, fuelwood, and bark from forests 2.5-4.5 years old were reported by the institutes listed above.

Rotation length

Lin Xuilan pointed out after extensive research that the growth of black wattle was initially fast but slowed after age 7. The growth of bark peaked at age 6.5 years and that of wood at 7.3 years. She concluded that maximum economic return would come from plantations harvested at age 7 when good yields of high quality wood and bark would be obtained.

Lin Jie determined the time of quantitative, technological and economic maturity of black wattle grown under different site conditions in the Zhangzhou area, and recommended 8 years as the best general age for logging.

It was stressed that the growth of black wattle could be affected by many factors such as site conditions and silvicultural practice, and hence the optimum age for harvesting will inevitably vary.

Yield tables

Tables of the standing volume of wood, weight and volume of bark, weight of biomass and site index of black wattle were compiled by Lin Jie and others from data obtained from detailed assessment of 333 sample trees and 133 sample plots in the Zhangzhou

area of Fujian province. Tables for the rapid estimation of bark yield were also compiled.

Factors affecting bark yield

Relationship between bark production and site conditions were examined, mainly in Fujian province. Lin Jin Ji pointed out that the thickness and weight of black wattle bark fell progressively up the stem of the tree, while the ratio of weight of bark to wood increased. The weight of bark on branches is 15-24% of the total. He suggested that soil type, aspect, depth of surface soil and the shape of slope are critical in site selection. An equation for predicting bark yield under various site conditions in Fujian province was developed by Huang Wen Luan. The significance of each site factor was quantitatively assessed and, to assist site selection, the factors were classified into 3 categories based on their impact on bark yield. A very detailed yield table for fresh bark from 8-year-old black wattle grown on different sites was given by Zhang Qing Hua.

The value of black wattle as an energy source

The value of black wattle as fuelwood was tested in Changsha of Hunan province. Nine species, namely *Pinus elliottii* Engelm., *Pinus massoniana* Lamb, *Quercus alba* L., *Lithocarpus glabra* Rend., *Acacia mearnsii* De Wild., *Alnus cremastogyne* Burk., *Robinia pseudoacacia* L., *Schima confertiflora* Merr. and *Nyssa sinensis* Oliv. were compared. Black wattle (*A. mearnsii*) was considered best because of its higher growth rate and calorific value.

The Forestry Research Institute of Ganzhou reported that an intensively managed 3-year-old low forest of black wattle produced 96 t/ha of biomass. Annual production of oven-dry wood was 24 t/ha. The wood produced by 1 mu (1/15 ha) of black wattle provided sufficient fuel for a family of five people. After cutting, 93% of the stumps sprouted. The calorific value of wood, bark and extracted bark residue under different conditions was also determined.

Black wattle for soil conservation and dune stabilisation

There is clear evidence of the value of black wattle as a species for soil conservation. Experiments carried out in Chang Ting and Lian Cheng of Fujian Province indicated that black wattle grew much better than any other species previously introduced to this area and was also superior in many respects as far as soil conservation was concerned. It was suggested that this species, if properly planted and managed, could alleviate soil erosion in this part of China.

Experimental black wattle plantations on sands along the coastline in Chang-Le County of Fujian Province

also grew well and had strongly-developed root systems, but were susceptible to high winds.

Nutrition of seedlings and young stands

Chen Xiang Xin studied the nutritional requirement of black wattle seedlings, using 12 different combinations of nutrients. He concluded that N and P were the most important elements affecting height, collar diameter and biomass of seedlings. Other factors including K, B, Mo and Zn and other trace elements were of minor significance. N and P interacted, and therefore must be applied in an appropriate ratio.

Lin Yong Ming investigated 2-year-old black wattle stands in Yong Jia, Wenzhou and Ou Hai districts of Zhejiang Province and pointed out that malnutrition could cause early flowering.

Research on properties and utilisation of products from black wattle

Properties of wood and bark

Sun Cheng-Zhi et al. of the Research Institute of Chemical Processing and Utilisation of Forest Products carried out microscopic anatomical and ultrastructural studies on black wattle wood and bark. Detailed descriptions of structures and electron micrographs were given. Fibre morphology and chemical composition of the wood have been examined by the pulping section of Nanjing Forestry University. Physical and mechanical properties were investigated and reported by the Research Institute of Wood Technology, CAF, and Lin Xui-lan et al. of Fujian Forestry College. It was concluded that the physical and mechanical properties of the wood of black wattle peaked at age seven.

Variation of bark thickness and tannin content

Deng Yu Fang studied the relationship between the thickness of black wattle bark and age of the tree in samples from five districts in Guangxi and Hunan Provinces. Bark thickness increased rapidly with the age of the tree during the first 7 years of growth and then slowed.

Lin Xui-lan et al. analysed black wattle bark samples of different ages grown in five districts of Fujian Province and concluded that, under ordinary conditions, the tannin content of bark increased rapidly with tree age in the first 7-8 years of growth.

Data provided by the Zhejiang Provincial Institute of Subtropical Crops showed that the tannin content in bark from different parts of the tree varied markedly.

Li Bing-Ju found obvious differences in tannin content of black wattle bark from sites prepared in

different ways, but less obvious variation between differently spaced 2-year-old trees.

Properties of tannin extractives

Viscosity and other characteristics of aqueous solutions of tannin extractives from black wattle bark were assessed by Zheng Guang-Cheng and Lin Yun-Lou. The results, which have been published in detail, provide data important for the engineering design of production plants.

In a cooperative project between China and Australia, Y. Yazaki, Zheng Guang-Cheng et al. used an ultrafiltration method to investigate the molecular distribution of black wattle tannin extractives produced by Yishan (Guangxi Province) tannin factory, South Africa and the Nanjing laboratory of CAF. Their condensation with formaldehyde was also studied. Eighty-four percent of the material had molecular weights lower than 105, and more than 90% of the fraction with molecular weight between 104-105 condensed with formaldehyde. Knowledge of the molecular distribution of tannin extract is important to research on tannin adhesives; ultrafiltration can be used to purify the extract.

Production and utilisation of black wattle tannin extracts

A pilot plant using a new continuous extraction device and designed by the Research Institute of Chemical Processing and Utilisation of Forest Products was built in the Ganzhou area of Jiangxi Province. Preliminary operational tests have given good results with short-rotation black wattle bark.

Experiments on plywood production using tannin adhesives made from locally-produced black wattle tannin extracts were carried out by Zhao Lin-Wu et al. with good results.

Chemical composition of foliage

Deng Yu-Fang analysed the foliage of black wattle grown in five districts in Guangxi and Hunan Provinces and concluded that, beside other factors, the content of sugars, protein, P₂O₅ and K increased with the age of trees until maximum values were reached at age 7 or 8 years.

According to a report from Guizhou Province, young leaves of black wattle contain 15% crude protein which can be used as cattle feed. Furthermore, each tonne of fresh foliage is equivalent to the combined effect of 42.4 kg (NH₄)₂SO₄, 7.8 kg Ca-super phosphate and 8.5 kg K₂SO₄.

Mushroom cultivation

Many experiments on cultivation of edible fungi on sawdust of black wattle were carried out in Fujian and

Zhejiang Provinces with good results. Wang Yu-Ying and Lin Xui-Lan showed that in many respects wood of black wattle is superior for cultivation of mushrooms to that of the usually-preferred *Quercus* species. Many kinds of edible fungi including *Lentinus edodes* CR-04, *Auricularia polytricha* 781, *Flammulina velutipes* 8123, *Pleurotus sajor-caju* PF-1 and *Hericium erinaceus* H-8 grew satisfactorily on media based on black wattle wood.

Other research

Zhuang Wen-Shan et al. studied the structural characteristics of lignin in wood and bark of black wattle. Li Cui-Shong investigated chemical methods of nutritional diagnosis of black wattle low forests. Pu Mingong et al. studied tanning using locally-made black wattle bark extracts and compared these with imported products. Nanjing Forestry University undertook laboratory-scale pulping studies of black wattle. Many others worked on identification and prevention of diseases and insects affecting black wattle plantations.

Benefits and prospects

Benefits

Black wattle is a multipurpose, versatile species with considerable economic value and broad social and ecological effects. Its bark and the extract of the bark is a high quality tanning material and source of wood adhesives. The wood can be used for pulp and paper, activated carbon and composite boards, beside traditional purposes of fuel, railway sleepers, mine timber and building material in rural areas. Owing to its rapid growth, adaptability and ability to coppice, black wattle has been considered a superior species for energy forests and soil conservation in many countries. It is also used for farm shelterbelts. The tree can fix atmospheric nitrogen and its leaves, which are rich in nitrogen, are good green manure. Branches and other residues yield potassium fertiliser when burned. All these contribute to the improvement of soil quality and make the alternation of agricultural crops and trees attractive.

Importance of black wattle trees to China

The benefits of black wattle, described above, are especially important to China for the following reasons:

- The tannin extract industry in China must innovate and upgrade its products. The quality and quantity of tannin in the raw material are the main factors influencing the quality, yield, utility and marketing of the product. The Chinese tannin extract industry, which has grown rapidly, now has both a fairly large

capacity and adequate technical skill.

Difficulties in production and marketing are common, however, because of the relatively low quality and irregular supply of raw material, most of which is gathered from natural-occurring sources scattered over a large area. As a result, a large amount of high quality tannin, usually black wattle tannin extract, has to be imported.

- The large Chinese population creates a correspondingly extensive domestic market for tannin extract and consequent opportunity to develop black wattle plantations. The most appropriate way to improve the basic situation of the tannin extract industry and obtain the desirable supply of high quality tannin extract at a competitive cost is to establish sufficient area of well-managed black wattle plantation to provide a sustained supply of superior raw material to support an efficient integrated industry.
- Acute shortages of fuelwood occur in some deforested areas in southern provinces. These have made life difficult for rural people, and have also been environmentally damaging. Black wattle plantations, especially when planted densely and grown on short rotations, can alleviate these pressing problems in many places.
- Serious soil erosion and other environmental degradation exist in many mountainous areas in China. Experiments show that this can be effectively combated, at least in some areas, by establishing black wattle plantations.

Assessment and realisation of economic benefits

Long experience in South Africa and Brazil has clearly shown that integrated enterprises which combine black wattle plantations and the production and marketing of tannin extract can be financially successful. The feasibility of establishing similar enterprises in China has been assessed in Guangxi, Guizhou, Jiangxi and Fujian Provinces. These studies, although taking different approaches, reached the common conclusion that such ventures might also be highly profitable in China. One example of these studies entailed a systematic assessment of profitability of black wattle plantations in Zhangzhou area of Fujian Province; the conclusion supports the development of such plantations.

The prospect of economic benefit is a driving force for further development of black wattle plantations. Explicit steps can be taken to optimise returns. Superior provenances or otherwise genetically-superior stock and scientific management of the

plantation must be used to maximise the quality and quantity of products per unit area. In addition, new uses of tannin extract and wood, increasing the output of high value products and raising the contribution from wood to overall return, must be pursued. Priority should be given to the following:

- Using black wattle extract for producing wood adhesives.
- Using black wattle wood for pulp and paper, and cellulose derivatives.
- Using black wattle wood as raw material for making activated carbon.

- Using sawdust of black wattle wood as substrate for cultivation of edible fungi.
- Using black wattle for environmental amelioration.

Prospects

There are many reasons why China should develop black wattle plantations. The natural and social environments are favourable. Much knowledge has been accumulated through research and practice over recent years. Development is proceeding rapidly in some areas, and the benefits will soon be evident. With well-informed and careful management, the prospects are bright.

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