A REVIEW OF SOME ASPECTS OF THE GERMINATION OF ACACIAS

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ABSTRACT: The morphology and anatomy of *Acacia* seeds are considered with special attention to the role of the strophiole in overcoming hard seededness. The variables which can influence germination, both in the laboratory and in the field, are discussed. These include the role of birds and animals in seed dispersal and germination, the part played by fire, and the effects of various seed coat treatments used to enhance germination. The majority of such treatments act on the strophiole and thus render the seed permeable. Treated seeds have been found to remain viable for periods of up to three years.

In a number of areas, notably the biochemical aspects of germination, little is known about Acacias and a plea is made for more systematic studies of important species. In particular, it is highly desirable that optimum treatment conditions be established for as many species as possible to provide much-needed practical information.

INTRODUCTION

Acacias form a large genus within the sub-family Mimosoideae of the Leguminosae family. They have a very wide distribution in tropical and sub-tropical areas of the world, notably Australia, Africa, Asia and the Americas. While the exact number of species is unknown, it is considered to exceed 1200 of which some 700 are found in Australia (Guinet & Vassal 1978). Additionally, a number of Australian species are widely used in many overseas countries, often for sand stabilisation and dune fixation e.g. South Africa (Ross 1975, Roux 1961), Cyprus (Raymond & Ward 1954), Libya (Messines 1952), Iran (Shaybany & Rouhani 1976), India (Venkataramany 1963), Argentina (Boelcke 1946) and Mediterranean France (de Ravel D'Esclapon 1962). They have adapted so well to these countries that in some areas they have become a considerable menace to the local flora (Control of Alien Vegetation Committee, c. 1960). Many products of economic importance are obtained from Acacias including timber for fuel, construction purposes and paper making, bark for tanning, gum arabic, perfume and cut flowers, while the foliage and seed pods are useful as top-feed for domestic and wild animals. In Australia, and to a lesser extent in South Africa and California, many species are grown as ornamental garden plants.

Consequently it might be expected that a good deal would be known about the germination of *Acacia* seeds. However, while extensive data exists for a few species, a number of fundamental aspects of the germination process have been ignored, and much of the available information is widely scattered and arises from many unconnected investigations. It is quite noticeable that most of this knowledge comes from overseas studies, these being necessary to provide data for large-scale plantings and for sand reclamation schemes [e.g. see Sherry (1971) for details of *A.mearnsii*].

In Australia, little effort has been made to farm Acacias commercially so perhaps the need for wider investigation has not existed. This became evident to us during evaluation of the effectiveness of microwave energy in breaking dormancy of *Acacia longifolia* (Cavanagh & Tran 1979). We found that relatively little was known about the mechanism of action of treatments applied to hasten germination; data on natural regeneration and softening were also very sparse and sometimes contradictory. This paper considers these points and attempts to present a summary of the present state of the knowledge in the general areas of seed characteristics and germination. Suggestions are also made concerning aspects about which more information is required.

SEED MORPHOLOGY AND ANATOMY

Acacia seeds are extremely variable in size, shape and weight, and even within a species marked differences can occur. Boelcke (1946) and Vassal (1963, 1971) studied the seeds of a total of 139 species

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and developed seed classifications based on such features as the type of funicle, the size and shape of the hilum and the strophiole* (trace rapheale), the form and dimensions of the seed and some aspects of internal morphology such as the presence or absence of albumen (endosperm). Gopal and Thapliyal (1971) developed a classification key for 35 species of forestry seeds of the family Mimosoideae which was based on observations of the external morpholgy, colour and dimensions. Twenty-three Acacias were covered, and the work is of value in that it includes photographs of all seeds described.

It is possible from Vassal's 1971 data to estimate the thickness of the seed coat if other dimensions of the seed are known. Though there is some evidence that seed coat thickness can influence the response of the seed to various treatments, this point has received little attention. It might well prove a fruitful study and perhaps explain widely differing germination results between various species for similar severities of treatment. In general, the *Acacia* seed coat is considerably thicker than in many of the small seeded legumes such as alfalfa, clover etc. Table 1 gives typical thicknesses for several species determined on cross-sections of the seed. Though differences would almost certainly be observed with other batches, it is interesting to note that the seed coat of the desert species *A. aneura* is one of the thinnest. According to Murray et al (1978), the density of the coat is considerably greater than that of the embryo — for *A. longifolia* and *A. sophorae* they found that between 33.7 and 43.1% of the seed mass was concentrated in the coat.

Vassal's data also enables the seed to be classified by shape. The influence of seed shape on response to treatment is another area in which little research appears to have been carried out. With impaction or percussion treatments, for example, the evidence from the work of Barton (1947) is inconclusive but appears to indicate that disc-shaped seeds respond more favourably than do spherical seeds.

Directly related to the problem of enhancing germination is the structure of the seed coat and the features or characteristics which are responsible for impermeability. The anatomy of the *Acacia* seed coat has received spasmodic attention over the years though only a few species have been examined in detail. General studies have been made by Boelcke (1946), Ishizaki *et al*. (1976), Maisel (1909) and Vassal (1971). These indicate that the structure is similar to that of other Leguminosae, with a cuticle and sub-cuticular layer, a layer of palisade or Malpighian cells and a third layer which Vassal calls a 'tegmen'. The more comprehensive work of Hoffmann and Kummerow (1962) on *A. caven* and of Robbertse (1973, 1974) on *A. grandicornuta* and several other African Acacias reveals further information about the palisade cells, the 'tegmen' and the region around the hilum. An additional feature of the palisade cells, the light line, is clearly shown in Fig. 1, adapted from Robbertse (1974). This optical effect is characteristic of many legume species and at one time was thought to contribute to impermeability. The 'tegmen' generally consists of a row of osteosclereid (or 'hour glass') cells underlain by mesophyll tissue. In *A. caven* (Hoffmann & Kummerow 1962) and several African species (Vassal 1975), the osteosclereid cells are absent and the palisade cells overlie the mesophyll tissue directly. It seems from the work of Vassal (1973) that the hour glass cells are variable in their distribution in the coat though their presence appears to play no part in the germination process. Likewise, while albumen (endosperm) has been found in the seeds of a number of species and has been used in seed classification schemes (Boelcke 1946, Vassal 1968, 1971), the layer is usually very thin, ranging from a trace to 0.4 mm. It does not appear to play a significant role in germination.

When treatments are applied to *Acacia* seeds to induce germination, it is usually considered that these soften or damage the seed coat and thus allow general water penetration. The detailed microscopy work of Robbertse (1973, 1974) calls this concept into question. He paid particular attention to the area around the hilum. Our Pl. 21 is a scanning electron micrograph of this region and shows the relationship of the three

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*The recent review of Rolston (1978) again raises the question of the 'correct' usage of the word strophiole. Following the work of Hamly (1932), the strophiole has generally been accepted as referring to a specific area of elongated epidermal cells in certain members of the Papilionate subfamily, though *Acacia* seeds have previously been claimed to possess a strophiole e.g. Preece (1971b), Winkworth (1973) for *A. aneura*. While it is possibly not the most appropriate term, in the absence of a suitable alternative I have used it to designate a small, raised area of the *Acacia* seed coat close to hilum but on the side opposite the micropyle (Pl. 21). It is variable in size, shape and colour (Vassal 1971) and a section through the strophiole reveals that the epidermal cells here are considerably *shorter* than elsewhere in the coat (Pl. 22).

Many species within the sub-families Mimosoideae and Caesalipinoideae possess this structural feature and it is unfortunate that there is no generally agreed term which can be used to describe it. In the literature, the following words have been applied: 'plage sub-hilare' (Pitot 1936), 'marca rapheale' (Boelcke 1946), 'trace rapheale' (Vassal 1963, 1971), 'lens' (Brown & Booysen 1969, Gopal & Thapliyal 1971) and 'rapheole' (Robbertse 1973, 1974).

It is thus highly desirable that in the future some attempt be made to standardize terminology applied to leguminous seeds.

TABLE 1

THICKNESS OF SEED COATS OF TYPICAL *Acacia* SPECIES

| SPECIES	THICKNESS μm	SPECIES	THICKNESS μm
A.accola	170 – 180	A.mearnsii	180 – 200
A.aneura	120 – 135	A.melanoxylon	190 – 200
A.baileyana	125 – 135	A.normalis	175 – 200
A.botrycephala	170 – 180	A.pravissima	150 – 170
A.brachybotrya	260 – 300	A.pycnantha	180 – 190
A.buxifolia	140 – 160	A.saligna	190
A.calamifolia	150 – 170	A.suaveolens	180
A.cyclops	240 – 260	A.triptera	105
A.implexa	125 – 140	A.victoriae	> 430
A.longifolia	150 – 160		
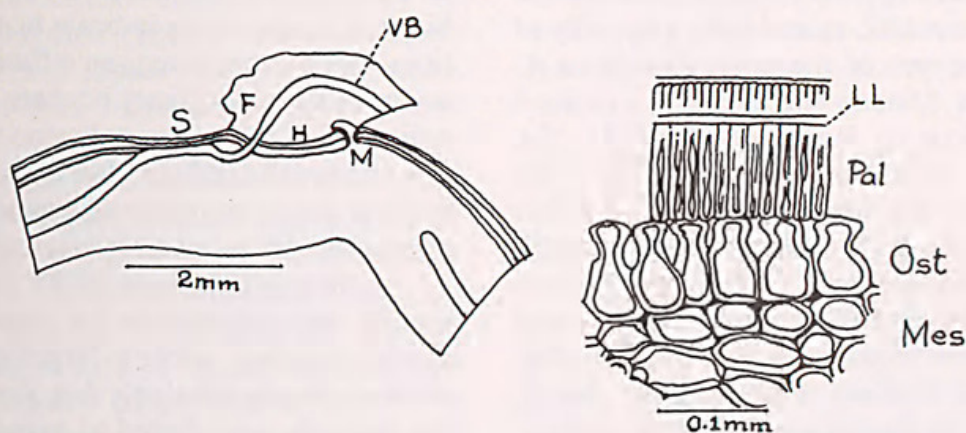
Fig. 1 — Anatomy of the seed coat of *A. grandicornuta*. (Modified from Robbertse (1974), used with permission). F = funicle; H = hilum; LL = light line; Mes = mesophyll cells; M = micropyle; Ost = osteosclereid cells; Pal = palisade or Malpighian cells; S = strophiole; VB = vascular bundle.
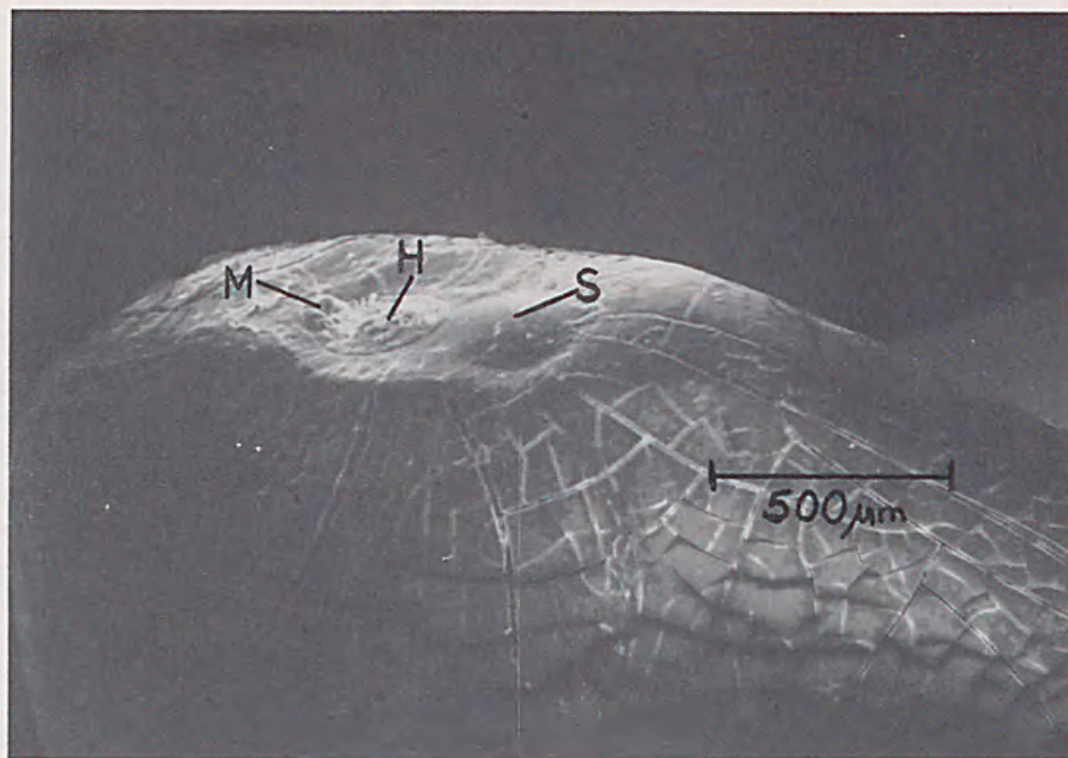
PLATE 21

Scanning electron micrograph of the hilum region of *A. suaveolens*. S = strophiole; H = hilum; M = micropyle.

important features, the hilum, the micropyle and the strophiole (Vassal's 'trace rapheale', Robbertse's rapheole'). The vascular bundle enters the seed via the funicle at the hilum, penetrates deeply into the inner layers of the seed coat and then bends upwards coming close to the surface at the strophiole (Fig. 1). Newman (1934) illustrates this very clearly with his photomicrographs of *A. baileyana* while Corner (1951) confirms that in many legume seeds, the vascular bundle takes a characteristic bend around or through the 'lens' (strophiole). Under low power magnification, the strophiole appears as a small, raised area generally of the same colour as the rest of the coat, though in *A. farnesiana* and several African species, it is a distinct white spot. According to Robbertse (1974), the palisade cells of the seed coat continue across the hilum, and in the area of the strophiole they are shorter and more poorly developed (Pl. 22). This is in marked contrast to the strophiole in many other legumes where the palisade cells are much longer than elsewhere and are bowed and in a state of considerable tension (Aitkens 1939, Hagon & Ballard 1970, Hamly 1932, Zimmermann 1936). On the basis of laboratory experiments and from field observations Robbertse concluded that the strophiole was the area of the seed coat most likely to suffer damage in the soil, or to be attacked by micro-organisms, and that it was probably responsible for overcoming hard seededness in Acacias. Subsequent work has shown that 'pricking'

the strophiole with a scalpel or needle allows rapid germination of *Acacia* seed (V. N. Tran, pers. comm.)

The nature of the seed coat impermeability in Acacias appears to have been little investigated. By excising the seed coats, Kao (1971) and Kaul and Manohar (1966) have shown that dormancy is associated only with the seed coat and not the embryo. For the species examined, *A. confusa* and *A. senegal* respectively, rapid and nearly complete germination followed immersion in water. Kao further claimed that he detected no inhibitor in the seed coat; additionally, his results appear to indicate that the seed coat functions as a barrier to oxygen diffusion. Though secondary or embryo dormancy has been invoked as an explanation of decreased germination rates following storage (Aveyard 1968) or after nicking as compared with boiling water treatment (Clemens et al. 1977), there appears to be no experimental proof of this.

Rees (1911) and White (1908) considered the cuticle was responsible for impermeability in small seeded legumes, while in larger seeds, where the cuticle tended to be relatively thin, they thought that part of the palisade contributed to restriction of water entry. Ballard (1973) subsequently showed that the waxy cuticle in legumes was water permeable. With *Trifolium subterranean* L.C.V. Geraldton he found the palisade cells to be impermeable, or only slowly permeable, to a considerable depth below the light line. The detailed anatomical studies of Hamly (1932)
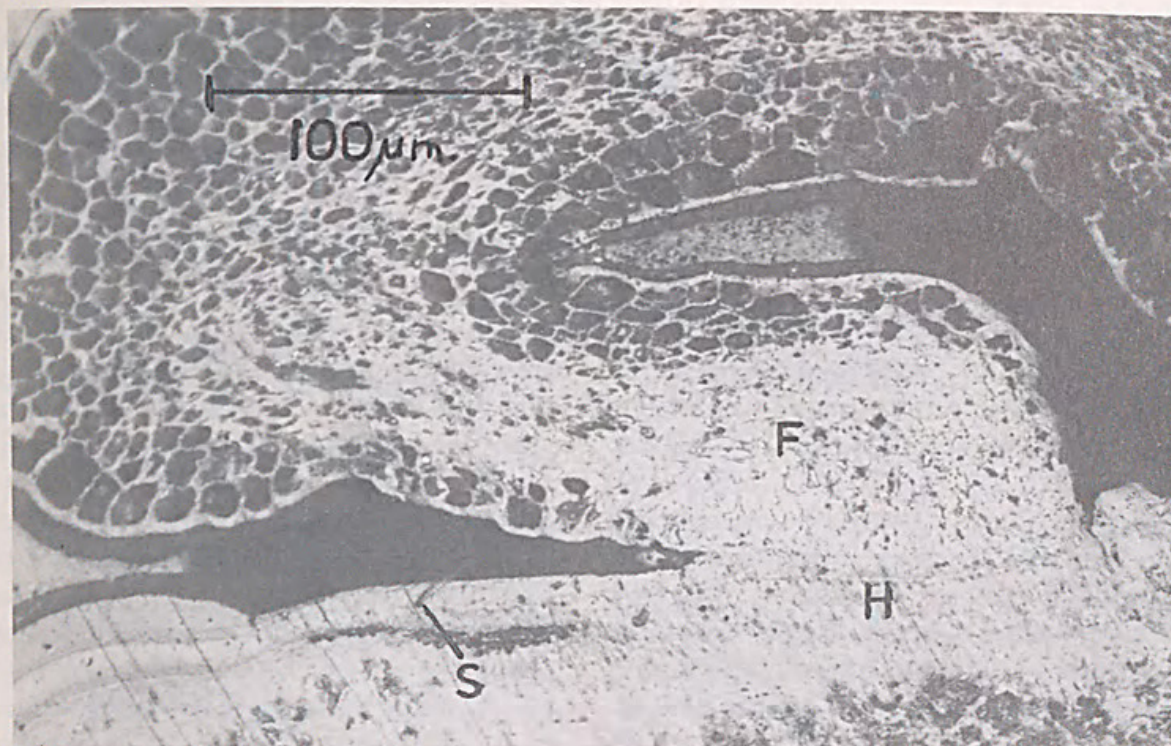
PLATE 22

Longitudinal section through the hilum and strophiole of *A. suaveolens*. F = funicle;
H = hilum; S = strophiole.

	Normal Coat	At Strophiole
Length of Malpighian Cells:	70 μm	40 μm
Distance to light line:	45 μm	20-22 μm

on *Melilotus alba* established that the suberin matrix in which the caps of the palisade cells were embedded was responsible for impermeability. No similar studies exist for Acacias though several lines of evidence indicate that the situation here may be somewhat different.

Firstly, a number of species are known to germinate freely without the need for pretreatment, e.g. many dehiscent African species (Lamprey *et al.* 1974), *A. argryodendron* (Pedley 1978), *A. cambagei* (Hall *et al.* 1975 a), *A. harpophylla* (Coaldrake 1971, Hall *et al.* 1975 b, Johnson 1964), *A. peuce* (Hall *et al.* 1975 c)

Secondly, it has been established that some species contain a high proportion of soft seeds if picked 'green' i.e. before the pods have dried. These include *A. mollisima* (now *A. mearnsii*) (Isikawa 1960), *A. senegal* (Kaul & Manohar 1966) and *A. aneura* (Everist 1949). However most of the above seeds will develop impermeability when stored and it is suggested that at least for *A. senegal*, this is associated with progressive suberisation of the testa as the seed matures (Kaul & Manohar 1966). This is partially confirmed by the work of Isikawa (1964) who collected green seeds with a moisture content of 62% and dried them slowly in the shade and rapidly in light. Impermeability developed at 10-12% moisture, irres-

pective of drying rate, and reached a maximum at about 6% moisture, a level found by Quinlivan (1971) to confer full impermeability in other legumes.

It is evident that more information is required on the nature of seed coat impermeability in Acacias, especially the mechanism of its development in storage. Additionally, it would be very useful to know whether all species contain a high proportion of soft seed if picked green and if low temperature is the only storage requirement to maintain the seeds in this state.

CONDITIONS AFFECTING GERMINATION AND GROWTH:

NATURAL REGENERATION

The ability of a species to replace itself is of major ecological and economic importance. Despite this, surprisingly few species have been studied in detail. (See Everist 1949, Preece 1971a and Symposium, *The Mulga Lands of Australia* 1973 for *A. aneura*, Wickens 1969 for *A. albida*, Coaldrake 1971 and Johnson 1964 for *A. harpophylla* and Cheema & Qadir 1973, Oheid & Seif el Din 1970, 1971 and Seif el Din & Oheid 1971a, 1971b for *A. senegal*.) Most of our current understanding of natural regeneration comes from scattered and often unconnected field ob-

servations. This has sometimes led to confusion as to the status of particular species eg. the valuable fodder reserve, *A. aneura* has been reported to be dying out in areas of Australia (Beadle 1948, Jessup 1951, Lange 1966) and the reasons for this are far from clear. More recent observations, however, suggest that heavy grazing by domestic animals and rabbits might be responsible. In their absence, good regeneration has been noted (Woods and Forests Department, South Australia, pers. comm.). Similar conclusions have been reached by Burroughs (1973). Other species seemingly do not have the ability to withstand competition. In the Sudan, Seif el Din and Oheid (1971a) noted that *Acacia senegal* forests if left undisturbed degenerated into open woodlands, and seedling replacement was insufficient to maintain species dominance. As opposed to this, some species are very aggressive colonisers of new ground and show remarkable persistence even in very adverse conditions. Notable among these are *A. cyclops* and *A. saligna* (Roux & Middlemiss 1963), *A. farnesiana* (Scifres 1974), *A. harpophylla* (Johnson 1964) and *A. melanoxylon* (Farrell & Ashton 1978, Pedley 1978). In some but not all the above cases, vegetative reproduction, usually from damaged roots, can greatly aid the plant's ability to resist attempts to remove or destroy it.

Very little is known of the regeneration processes operating in Acacias in the field. In many species, the situation is complicated by apparent sporadic flowering and seed set, so that with short term observations it is difficult, if not impossible, to determine with certainty which climatic factors influence regeneration. The studies of Davies (1976) are important here. Over the period 1960-1971, he observed a minimum of five individual trees on up to four sites in an arid area of Western Australia. Twenty-four species, twelve of them Acacias, were involved and Davies found that flowering and fruiting were with one exception, seasonal. Fruiting was found to depend on rain falling under particular temperature and/or photoperiod conditions e.g. *A. aneura* fruits after summer rain while for *A. cuthbertsonii*, winter rain is required. Davies concluded that at least for the test area, arid zone shrubs show a remarkably regular calendar of flowering and fruit production.

Some characteristics which appear to be important in regeneration have been discussed from time to time. These include: a combination of suitable temperature and rainfall, disturbance of soil, clearance of forest (which increases light intensity and eliminates competitors), the presence of a moderate layer of mulch and, most importantly in Australia and South Africa, the presence or absence of regular fires. Grazing by animals, insect attack and/or predation of seeds and destruction of seedlings are factors which are claimed to mitigate against successful regeneration.

Particularly in desert areas, a number of species appear to have developed special adaption to the harsh conditions. These include an ability to germinate and establish rapidly, often within 3-5 days of rain (Johnson 1964, Halevy 1974), an ability to survive in high soil temperatures and still form rhizobium nodules (Habish 1970), high tolerance to extreme moisture stress (Burroughs 1973), metabolic processes which are active under a wider range of environmental conditions than are those of most temperate zone species (Hellmuth 1971), and a feature noted in *A. senegal*, and which may exist in other Acacias, of producing two types of seeds, one of which germinates quickly and the other only after an extended period. This characteristic is found not only in seeds from the same tree but also in seeds from individual seed pods. On being wetted, about half will germinate within 48 hours, while the rest will remain unaffected for up to 15 days. This is considered to be a natural provision against total failure if early rains are not followed up (Forests Department of the Sudan 1960).

THE ROLE OF FIRE

Fire plays a major role in controlling the Australian (Gill 1975) and South African (Roux & Middlemiss 1963) flora. Acacias often tend to become dominant species after fire and it is usually assumed that the heat of the fire softens or cracks the seed coat, thus permitting germination if suitable rains fall. Several investigations have been made of the effect of fire on germination of soil-stored seed (Beadle 1940, Floyd 1966, 1976, Omer 1975, Shea et al. 1979) while Martin and co-workers (1966, 1975) have discussed the effects of moist and dry heat on the germination of forest legumes.

The intensity and duration of the fire will control the temperature reached at the surface and at various depths below the surface, and hence will have an important influence on softening of hard seed. Soil temperatures in a number of typical fire types have been measured (Ahlgren & Ahlgren 1960, Beadle 1940, Cromer & Vines 1966, Floyd 1966, Humphries & Lambert 1965, Roberts 1965, Vines 1968); some of this data is summarized in Table 2. The temperatures vary widely, depending on such factors as the soil moisture and soil type, wind and ambient temperature, amount of fuel available and the development of an (insulating) ash bed.

While *Acacia* seeds can withstand prolonged periods of exposure to dry heat, they are more adversely affected by moist heat (Beadle 1940) and most species are killed by temperatures of 110-120°C for short periods. In very fierce burns such as occur in bulldozed windrows, most seeds to a depth of 100 mm
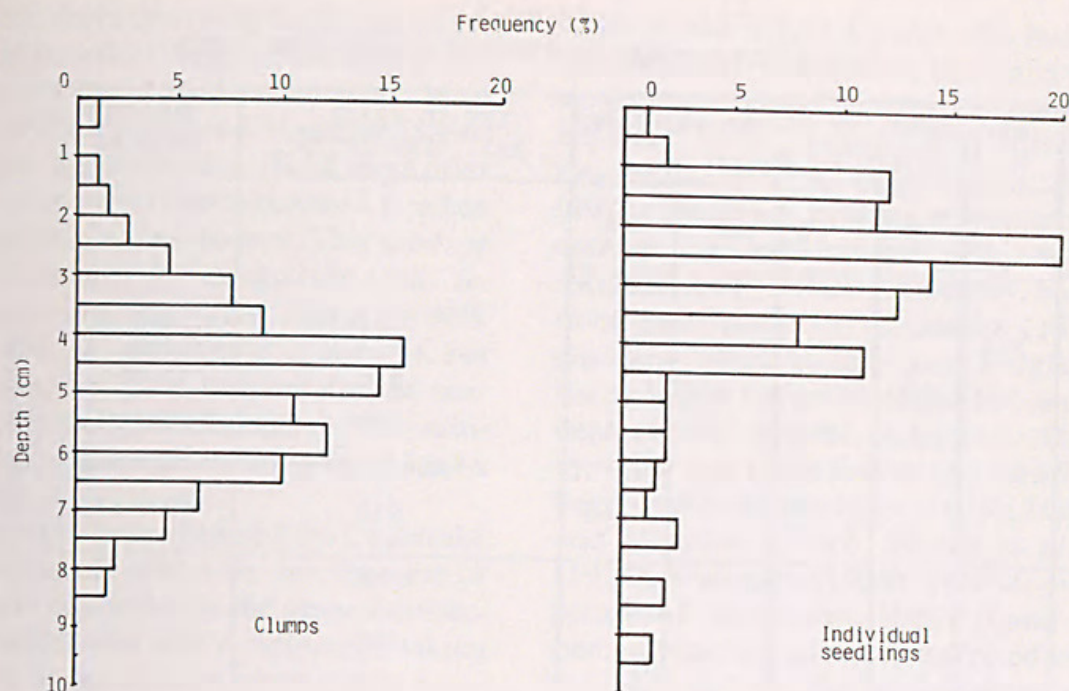
Frequency (%)

Fig. 2—Depths of emergence of *A. pulchella* seedlings fol-
lowing an intense fire [From Shea *et al* (1979) used with
permission]

or more would be destroyed. On the other hand, in light bush and scrub fires, and in controlled burns, only surface seeds would be affected. Vines (1968) has found that soil temperatures even in moderately intense controlled burns often only reach 40°C at a depth of 25 mm. Even though *Acacia* seeds have been shown to be present down to considerable depths in virgin bush-land (Ewart 1908), this apparently is not always the case. Soil samples taken from beneath coastal *A. sophorae* scrub in South Australia revealed that almost no *Acacia* seeds were present in the top 50 mm despite evidence of numerous recently opened pods (Barbour and Lange 1967). Studies with *A. senegal* in the Sudan revealed that up to 84% of surface sown seed was destroyed or removed by insects, millipedes and rodents (Seif el Din & Oheid 1971a). In Western Australia, Shea *et al.* (1979) found that ants frequently buried seeds of *A. pulchella* and other legumes so that two months after seed fall, almost no seeds were seen on the surface. Thus, burial of seeds by ants and other creatures can be a means of ensuring their survival in fire. It has been demonstrated that seedlings of at least some *Acacia* species can emerge from depths of 60 to 90 mm (Scifres 1974, Shea *et al.* 1979). Hence a substantial germination can still be achieved even after a very intense fire, and disturbance of burnt ground can enhance this. However, while many writers have emphasized the role of fire in regeneration of legume species, it appears that it is not a pre-requisite for field germination. Boomsma (1969) and Preece (1971a) have noted widespread regrowth of *A. aneura* in areas not recently subject to fires and, for this species at

least, other factors such as suitable rainfall and/or high ambient or soil temperatures may also be important.

NATURAL SOFTENING AND SEED VIABILITY

In the absence of knowledge to the contrary, it is usually assumed that hard seeds are rendered permeable while lying on the ground through action on the seed coat of fungi, bacteria and possibly soil acids. Softening is thus thought of as being unlocalised in its effect. However, work by Quinlivan (1961, 1966) with several Papilionate legumes and Robbertse (1974) with *A. robusta* indicates this may not always be the case. Quinlivan (1961, 1966) found that long term diurnal temperature fluctuations caused fracture of the strophiole and he was able to correlate laboratory results with field data and establish that seeds softened naturally become permeable substantially only at the strophiole and not elsewhere.

Using similar techniques, Preece (1971b) was not able to increase germination of *A. aneura* even after 12 months, though it is probable that his maximum temperature of 45°C was too low in relation to summer soil temperatures in many areas of Central Australia. Robbertse (1974) collected seeds from the ground under trees of *A. robusta* and after visual examination, found that a high proportion had suffered damage to the rapheole. As laboratory experiments gave germination results in excess of 80% for this seed, Robbertse believed that (damage to) the rapheole might be responsible for overcoming hard seededness in *Acacia* seed.

Directly related to softening is the question of

TABLE 2
SOIL TEMPERATURES REACHED IN VARIOUS FIRE TYPES

FIRE TYPE/SOIL	MAX. TEMP. AT DEPTHS INDICATED BELOW SURFACE (mm)/°C					TIME TO REACH MAX. TEMP.(MINS.)	DURATION OF HEATING	REFERENCE
	0	25	50	100	200			
Log pile (4.25x2.4x1.8m) Soil-dry sandy, 3% moisture	742	605	393	205	100	250 / 350 / 390 / ≈660 - 700 / 510	1600 mins > 100°C / " / 1570 mins > 100°C / 1420 mins > 100°C / 1200 mins > 100°C	Roberts (1965)
Bulldozed windrow (200x6x2m) Soil - sandy 12% moisture	–	330	≈125	95	70	– / 360 / 570 / 420 / 660	– / 960 mins > 100°C / ≈520 mins > 100°C / ≈900 mins > 95°C / ≈1150 mins > 50°C	Cromer and Vines (1966)
Slash Fires Soil - clay loam "dry" (1) Light burn	500	45	42	30	30	– / – / – / –	– / – / – / –	Humphries and Lambert (1965)
(2) Heavy burn (*Thick ash bed developed)	360*	80	80	75	≈50	130 / 300 / 440 / 450 / 550	≈1000 mins > 100°C / ≈350 mins > 75°C / >1000 mins > 50°C / >800 mins > 50°C / >500 mins, 40-50°C	

seed viability, both in soil and under laboratory storage conditions. Field observations by Althofer (1974) for *A. homalophylla*, Moffatt (1952) for *A. mearnsii* and Farrell and Ashton (1978) for *A. melanoxylon* confirm that *Acacia* seeds can remain viable and unsoftened in soil for at least 50 years, and provide evidence of the very great stability of the seed coat even under adverse conditions. The extensive studies of Ewart (1908) indicate that seeds of some species can remain viable in laboratory storage for at least 68 years. However, no systematic study has been made of the decline in viability with age of Acacias. Aveyard (1968) noted a definite reduction in ability to germinate over a twelve month period. He believed that with older seed, seed coat impermeability was no longer the dominant factor and a more complex breaking of dormancy, probably involving the embryo, was required, e.g. chemical action or moist heat. If such an ageing effect exists, and it should be noted that Shaybany and Rouhani (1976) were unable to substantiate it for *A. cyanophylla* (syn. *A. saligna*), then it may in part explain the widely varying germination results reported in the literature for the same species when given nominally the same severity of seed coat treatment.

More data is required on both long-term viability of seed and the mechanism(s) of natural softening. This information would be valuable in understanding the widespread distribution of Acacias and their ability to colonise new areas given favourable conditions.

VARIABLES INFLUENCING GERMINATION BEHAVIOUR

There are only scattered references to the effects of such features as date of collection of seed before pod dehiscence, seed size and weight, seed moisture, position of seed in pod, age of seed, soil moisture and soil temperature during germination and

seedling growth, and depth of sowing on the germination and subsequent growth of Acacias, and it is unfortunate that more systematic studies have not been made. Isikawa (1960) and Kaul and Manohar (1966) advocated collection approximately 10-14 days after the appearance of green pods filled with seed i.e. when the pods were beginning to turn brown. This seed, at least in species examined, *A. mollissima* (syn. *A. mearnsii*) and *A. senegal* respectively, was up to 90% soft when sown within several months of harvest, but with prolonged storage at room temperature the percentage of hard seeds increased. Storage at 5°C maintained the original percentage germination for at least a year (Isikawa 1960).

Similar data has been obtained by Coaldrake (1971) with *A. harpophylla* where the development of hard seededness was dependent on the area of collection (and hence rainfall and soil conditions), taking between 12 and 90 weeks at room temperature; however, seeds held at −20°C retained viability and remained soft for up to five years.

In areas where insect infestation is severe, it is sometimes advisable to collect green seed and sow it in the hope of arresting the attack before too much of the seed is destroyed. Karschon (1975) found with *A. raddiana* in Israel that very green and immature seed of 156% moisture content gave up to 46% germination. However, seed coat dormancy was induced by storage for 12 days at room temperature or by 24 hours at 65°C. All the above work suggests that if seed is collected at a suitable time, it may germinate without pre-treatment. However, no systematic studies have been made concerning the possibility of an after-ripening period being present in Acacias; Drees (1941) claimed that up to four months was required in four out of eleven species he germinated.

In a number of other species, seed size is known to influence germination or growth behaviour. No similar information exists for Acacias though there is some evidence that the size of the seed can affect germination (Isikawa 1959) and sensitivity of the seed coat to treatment (Moffatt 1952). Moffatt considered that both seed coat hardness and seed size were governed by genetic factors and pointed out that individual trees of *A. mearnsii* will sometimes show significant differences in seed size, a fact already established for *A. decurrens* by Philp and Sherry (1946). Larger seeds either had more sensitive seed coats (i.e. required less drastic treatments for germination) (Moffatt 1952) or remained soft after picking for considerably longer than did smaller seeds (Isikawa 1959). In the latter case, the seed size was related to position of the seeds in the pod, with the larger seeds occurring in the middle portion. The smaller seeds in the top of the pod were predominantly hard, even immediately after harvest,

while in the lower section, the hard proportion was intermediate. What is not known is whether large and small seeds from the same population, or even from adjacent trees, will respond differently to similar treatments. With *A. melanoxylon*, Farrell and Ashton (1978) found no correlation between germination percentage and seed weight with seeds from different localities and rainfalls. Similarly, no specific observations were made by Coaldrake (1971) with *A. harpophylla*, even though seed weights of his samples varied from 1.5 to 24.45gm/100 seeds, again dependent on the area of collection. The effects of soil moisture on germination and seedling growth have been studied by Burrows (1973), Habish (1970), Kaul and Manohar (1966), Pathak *et al.* (1976), Scifres (1974), Watanabe (1959). With *A. mollissima* (syn. *A. mearnsii*) Watanabe (1959) found that germination percent was not adversely affected until the soil moisture fell to 20% (8.4 atmospheres soil moisture tension). By permanent wilting point, 14.5% moisture (15 atmospheres), the percent germination had dropped to less than half. Kaul and Manohar (1966) state that soil bed moisture should not be allowed to drop below 600 joules/kg (= 6 atmospheres) for satisfactory germination of *A. senegal*. In comprehensive experiments with *A. farnesiana*, Scifres (1974) showed that a range of moisture tensions from 0 to 16 atmospheres had little effect on germination at the optimum temperature of 30°C, though seedling growth was adversely affected at the higher moisture tensions.

The influence of soil moisture on seedling growth seems to be governed to a large extent by the origin of the parent plant. Five desert species from the Sudan were able to grow and form nitrogen (rhizobium) nodules at soil moistures as low as 7.5%, though optimum growth occurred at 15% (Habish 1970), which is approximately the permanent wilting point of *A. mearnsii*, a tree from non-arid areas. Watanabe (1959) showed for this species that as soil moisture fell below 30%, the transpiration rate of the plant decreased, though the water content of the leaves did not change significantly until the permanent wilting point was reached. Another arid zone species from Australia, *A. aneura* is especially drought resistant and seedlings can survive at a moisture stress of approximately 500 atmospheres (Burroughs 1973).

High soil temperatures in the field are known to inhibit germination and seedling establishment and similar information has been obtained for several species from laboratory germination trials where fixed temperatures in excess of 30°C have been used (Scifres 1974, Shaybany & Rouhani 1976). *Acacia aneura*, however, again demonstrates the ability of arid zone species to tolerate a wide range of environmental conditions: it is capable of successful germination between

10°C and 35°C (Burroughs 1973). With Sudan Acacias, Habish (1970) established that seedlings were able to grow and produce effective nitrogen nodules at temperatures as high as 35°C; this may be related to the resistance of rhizobium strains of Acacias to high temperatures (Habish & Khairi 1971) and explain their ability to colonise hot and dry areas. In general, Acacias appear to favour coarse textured soils with a pH close to neutral, and germination studies (Scifres 1974) and growth trials (Habish 1970) show that seedling development is retarded by major deviations from neutrality. Subsequent growth in the field may be affected by either inability to form nodules in highly acid soils or by a general decline in both growth and nodulation in alkaline soils.

Almost no attention appears to have been given to the determination of optimum sowing depth for germination. Such information is of value for large scale seed sowing programmes and is also of importance in understanding the natural regeneration of buried seeds. Scifres (1974) determined that the optimum planting depth for *A. farnesiana* was 20 mm, though seedlings could emerge from as deep as 60 mm; however, here the percentage germination was lower and seedlings were much smaller and weaker. Work at the Wattle Research Institute in South Africa showed that *A. mearnsii* could be planted up to 100 mm deep and still yield a 66% survival after eight weeks. Deep sowing is claimed to have some advantage in areas where the soil dries out rapidly or where little post-sowing watering is available (Sherry 1971). By excavating seedlings which established after fire, Floyd (1966, 1976) and Shea *et al.* (1979) demonstrated that many species could emerge from up to 50 mm, while a maximum of 90 mm was measured for *A. pulchella* (Fig. 2). Scifres (1974), Brown and Booysen (1968) and Cheema and Qadir (1973) have all shown that germination and establishment from surface sown seeds, particularly under field conditions, is very poor, the seed must be covered with 10-20 mm of soil, probably to give adequate anchorage to the seedling root and prevent desiccation by the cotyledons.

THE ROLE OF ANIMALS AND BIRDS

The part played by animals and birds in the dispersion, distribution and germination of seeds has been the subject of a number of studies: Gwynne (1969), Halevy (1974), Janzen (1969, 1971), Jarman (1976), Krefting and Roe (1949), Lamprey (1963, 1967), Lamprey *et al.* (1974), Middlemiss (1963). The earliest investigations of *Acacia* seed ingestion appear to be those reported by Troup (1921) covering experiments carried out in the Sind area of India in 1911-1912. Pods of *A. arabica* (syn. *A. nilotica*) were fed to penned sheep and goats. The seed was regurgitated by

the animals and in subsequent trials was found to have an enhancement in germination of up to 35%. Troup remarks that such practice is common in India to obtain treated seeds for nursery sowings.

There is little direct knowledge on the role of animals in seed dispersal in Australia. Among the trees used to provide sheep and cattle fodder, *A. argyrodendron* and *A. oswaldii* are noted as often producing heavy crops of pods which are readily eaten (Hall 1972), while Everist (1949) states that the pods of *A. aneura* are much sought after by sheep; it is possible they are somewhat more palatable than the leaves which are normally eaten. Unpublished reports of the Queensland Department of Agriculture (cited by Pedley 1978) also make reference to cattle and goats as eating the pods and dispersing the seed of the naturalised African species *A. nilotica*. This confirms observations concerning this species made in India and in Africa as discussed below.

Much of our current knowledge of the part played by animals in dispersing seed and enhancing germination comes from the work of Lamprey and co-workers at the Serengetti Research Institute in Tanzania. Lamprey (1963, 1967) found *Acacia* seedlings growing in droppings of impalas, elephants, dik-diks, and gazelles, and in goat dung in abandoned goat enclosures. He also noted that mountain goats, domestic goats and camels, all readily ate *Acacia* pods. Gwynne (1969) showed that in dry periods, up to 65% on a dry weight basis of the food intake of domestic cattle was of *Acacia* pods and seeds.

In the particular case of the African Acacias, two interesting lines of information emerged from these studies. Firstly, it was found that species with non-dehiscent pods were particularly attractive to large herbivores though they had no special nutritional advantage over other species with dehiscent pods (Gwynne 1969). Table 3 gives average analyses of seeds and pods of various African species compared with leaf analyses for a number of Australian species which are used as fodder for sheep and cattle (Everist 1969). The analyses show a remarkable similarity but as Everist states, they tell us nothing about the reason the materials are eaten by animals. Palatability and conspicuousness appear to weigh heavily in favour of the pods as compared with leaves and shoots; the non-dehiscent African species in particular have large, fleshy pods and are readily eaten either on the tree or within a few hours of falling to the ground. Additionally, their seeds are hard and rounded and seemingly ideally suited to easy passage through the animal's digestive tract. Secondly, in both Africa (Lamprey *et al.* 1974) and in Israel (Halevey 1974) a relationship was found to exist between Acacias, bruchid seed beetles and herbivores. The bruchid larvae hatches on

the surface and penetrates the seed while it is still green. As the beetle grows it feeds within the seed which in the meantime has ripened so that the insect is protected by the hard seed coat. The adults emerge by cutting a hole through the coat, in much the same manner as does the chalcid wasp which infests *A. aneura* (Preece 1971b). Infestation as high as 99% was found in some species in Israel. However, even for severely attacked seed lots, Halevy (1974) showed that germination after passage through the digestive tract of gazelles was usually enhanced over control batches. He considered that seed would still be viable if the embryo axis was not damaged by the beetle; in this case, the penetration of fluids, e.g. gastric juices, would result in an increase in germination and an improved germination rate, the latter regarded as im-

portant in desert survival. Similar trends were found in Africa (Lamprey *et al.* 1974) though in this area, the level of detrimental seed infestation was somewhat lower.

The mechanism of action on the seed coat during passage through the digestive tract is not known. It is usually considered that the coat is 'softened' in some way, perhaps by gastric juices, or may suffer damage in the animal's mouth during mastication or regurgitation. The waxy, water-repellent seed coat of Acacias is remarkably resistant even to strong reagents such as concentrated sulphuric acid so it is unlikely that stomach acids will have much effect. With larger animals such as elephants (Lamprey *et al.* 1974) and domestic cattle (Gwynne 1969), apparently little of the seed is damaged and this is reflected in the relatively

TABLE 3

ANALYSIS OF PODS, SEEDS AND LEAVES OF VARIOUS *Acacia* SPECIES (Moisture Free %)

SPECIES	PORTION	CRUDE PROTEIN	CRUDE FAT	CRUDE FIBRE	N.F.E.**	ASH	REFERENCE
A.albida*	P + S	13.48	1.59	37.26	43.26	4.41	Gwynne (1969)
	S	26.59	2.69	6.92	58.94	4.86	
	P	7.81	1.38	32.84	52.46	5.51	
A.albida*	P + S	10.03	1.76	25.21	58.84	4.16	
	S	28.36	2.55	6.6	58.71	3.78	
	P	7.42	0.84	32.84	54.75	4.15	
A.nilotica subsp subulata*	P + S	12.44	4.76	31.87	46.65	4.28	
	S	20.04	9.65	32.50	33.09	3.92	
	P	6.84	1.81	23.19	63.23	4.93	
A.sieberana*	P + S	11.73	–	39.82	42.81	4.84	
	S	18.95	3.56	20.51	53.33	3.65	
	P	6.84	1.81	23.19	63.23	4.93	
A.hockii[+]	P + S	16.53	2.23	27.52	48.04	5.68	
	S	25.92	4.16	32.32	31.68	5.92	
	P	8.96	1.15	45.50	40.33	4.06	
A.aneura[++]	L	11.7	2.7	28.0	49.6	6.9	
A.pendula[++]	L	13.2	3.4	29.6	46.2	7.8	Everist (1969)
A.cana[++]	L	11.3	3.2	30.2	48.6	6.8	
A.cambagei	L	13.3	3.1	15.9	55.2	11.0	
A.harpophylla	L	13.6	2.2	25.8	53.0	5.3	
A.deanei	L	14.3	4.8	18.9	55.6	3.4	

* Indehiscent Pods   ** Nitrogen Free Extract   P = Pods
+ Dehiscent Pods   ++ Most useful as fodder   L = Leaves
                                                              S = Seeds

low percentage germination enhancements observed, typically less than 40%. On the other hand, gazelles (Halevy 1974) and impalas (Jarman 1976) destroy most of the seed consumed and often less than 5% is passed whole. It is highly probable that most of this has also suffered some damage.

While birds are often credited with widespread dispersal of seed, there is little positive evidence to support this. Examination of stomach and crop contents (Frith & Barker 1975, Frith *et al.* 1974, 1976, Lea & Gray 1935) and observations of eating habits (Davies 1976, Middlemiss 1963, Pedley 1978, Preece 1971b) reveal that emus, doves, pigeons, cockatoos, galahs, parrots and perhaps lorikeets are the main species likely to eat *Acacia* seeds. In some cases, if the seed is passed whole and the birds are wide-ranging, they are likely to be highly efficient agents of dispersal. With parrots, galahs, cockatoos and pigeons, a high proportion of the seed is probably damaged or destroyed, if not during feeding then by grinding in the bird's gizzard. It is not often realized that this grinding action can be very severe though Schorger (cited by Janzen 1971) found that Peccan nuts with a crushing strength of 333.6 N were completely ground up by turkeys within an hour. It would be interesting to learn of the fate of *Acacia* seeds during passage through turkeys as Johnson (1964) suggests that the Australian turkey (Bustard-*Eupodotis australis*) might be responsible for distributing seed.

The results of Krefting and Roe (1949) are also of interest here. Though they did not test *Acacia* seed, of the other 16 species fed to birds, eight were shown to have marked improvement in germination after passage through the birds intestines. Weight losses of up to 20% were recorded as compared with controls, and the authors attributed this to seed coat thinning.

Some species of *Acacia* appear to be ecologically adapted to dispersal by birds and ants. The size, shape and colour of the funicle may attract birds e.g. the bright orange, encircling funicle of *A. cyclops* (Middlemiss 1963). Red or orange arils (Pedley 1978) or seeds enclosed in pulp such as occurs in some Central American species (Janzen 1969) are also examples of specialized development. Berg (1975) estimates that up to 300 Australian *Acacia* species are distributed by ants. They apparently possess well-developed 'elaiosomes' (ant attracting structures). The ants remove the elaiosome and discard the seed, often by burial under rocks or in the soil. The distance over which large seeds can be moved by this means is not great but Shea *et al.* (1979) observed one ant species transport a total of 46 seeds a distance of 1.9 m in one hour. The main effect of ants is to re-distribute seeds in the soil; such burial can often ensure their survival in fires.

TECHNIQUES FOR ENHANCING THE RATE OF GERMINATION:

LABORATORY GERMINATION STUDIES

The International Seed Testing Association (1966) lists the following recommendations for germination studies of Acacias: germinate on top of filter papers in petri dishes either at constant temperature of 20°C, or alternating temperatures between 20° and 30°C, the cycle being 16 hours at the lower temperature and 8 hours at the higher, with up to three hours changeover period. Germination should be done under light for at least 8 hours in each 24 hours; with alternating temperature cycles, the illumination period is during the high temperature section of the test. The prescribed duration of the test is approximately 28 days with maximum permissible of 35 days; the first count is made between six and 8 days.

Because of the practical difficulties with some aspects of the above procedures, most germination studies have been carried out at constant temperatures or in the fluctuating temperatures of greenhouses. For temperate zone species, fixed temperatures between 23 and 27°C have been found satisfactory. Arid zone and tropical species usually require a higher temperature and the range of 27 to 32°C has been employed. Acacias are not usually regarded as light sensitive and germination studies have been made in complete darkness and under continuous illumination. Preece (1971b) and Scifres (1974) have shown that for *A. aneura* and *A. farnesiana* respectively, germination results were identical whether darkness or light was used. Both nursery soil and sand have been used as germination media and in both it appears that the duration of the test should be extended to perhaps 45 or even 60 days. To minimise fungal attack, seeds are often dipped in a fungicide solution prior to test or even germinated in a weak solution of the fungicide. The criteria of germination is usually taken as extension of the radicle 1-3 mm beyond the testa or as emergence of the cotyledons above the soil.

SEED COAT TREATMENTS

The water impermeable seed coat has already been established as the major reason for dormancy in *Acacia* seeds. Numerous techniques have been developed aimed at rendering the coat permeable but essentially they all fall into one of two major classes.
(a) 'Dry' treatments: heat, impaction or percussion, temperature fluctuations, microwave energy, nicking or chipping, and machine scarification.
(b) 'Wet' treatments: boiling or hot water, acids, organic solvents, oxidising agents such as hydrogen peroxide and alcohols, freezing, and the use of gases such as carbon dioxide.

Of these, boiling water treatment is by far the

most common, and for small quantities of seed is probably the most convenient. However, on occasions boiling water has been found to have detrimental effects on germination (Clemens *et al.* 1977, Larsen 1964), probably through its effect on the embryo. It should be noted that for most species, the time at 100°C should be as short as possible, preferably less than five seconds. Table 4 lists species which do not require boiling water, together with details of recommended treatments. The list is by no means complete and more data are required on the effect of lower temperatures and longer times to provide much needed practical information. It is evident from the results of Clemens *et al.* (1977) and Aveyard (1968) that no one type of treatment has a universally high level of effectiveness and each species responds in a different manner to a given treatment. Some of the techniques noted above, however, appear to have had little effect, at least on the species tested, and are probably not worth pursuing. These include the use of the following chemicals: hydrogen peroxide (Aveyard 1968), organic solvents except for methyl alcohol, ethyl alcohol and acetone (Brown & Booysen 1969), freezing in ice (Brown & Booysen 1969) and liquid nitrogen (Al-Saadawi &

Abdul-Wahab 1977), and exposure to CO_2 and diurnal temperature fluctuations (Preece 1971b). Several other techniques have been little used, though for a number of species they proved quite effective. Among these are impaction (Barton 1947), dry heat (Aveyard 1968, Jones 1963), microwave heating (Cavanagh & Tran 1979, Nelson *et al.* 1978, Tran & Cavanagh 1979), and machine scarification (Aveyard 1968, McIntyre 1972). However, other studies show that machine scarification can cause extensive seedling damage (Watanabe 1954). There is little doubt that except on rare occasions any process which physically damages the seed coat e.g. manual chipping, can allow nearly 100% germination of viable seed, provided that the seeds do not rot. Chipping also increases the germination rate and in some cases reduces the total time required to less than half that of seeds given optimum hot water treatment (Clemens *et al.* 1977).

INFLUENCE OF TREATMENT ON PERMEABILITY

Surprisingly few studies have been undertaken to determine the areas made permeable by various seed coat treatments (see Brown & Booysen 1969, Cavanagh & Tran 1979, Robbertse 1974, Tran & Cavanagh

TABLE 4
SPECIES ADVERSELY AFFECTED BY BOILING WATER AND/OR LONG TERM HEATING

SPECIES	RECOMMENDED TREATMENT	REFERENCE
A.acuminata	5 secs. max. at 100°C	Harding (1940)
A.argryodendron	None if fresh	Pedley (1978)
A.cambageii	None if fresh	Hall et al (1975a)
A.harpophylla	None if fresh	Hall et al (1975b)
A.lineata	?	Larsen (1964)
A.peuce	None if fresh	Hall et al (1975c)
A.pycnantha	5 secs. max. at 100°C	Harding (1940)
A.senegal	(None if fresh: For. Dept. Sudan 1960)	Larsen (1964)
A.suaveolens	200 - 600 secs at 80°C	Clemens et al (1977)
A.sylvestris	Short periods at up to 85°C	Floyd (1966)
A.terminalis	30 secs max. at 100°C, or 100 - 600 secs at 80°C	Clemens et al (1977)

1979). It is usually assumed that hot or boiling water softens the seed coat while fire or dry heat cracks it, thus allowing water entry at random sites on the surface. The superficial observations of Rees (1911) and White (1908) that the cuticle is removed by sulphuric acid has led to the mistaken belief that this layer is responsible for impermeability. More recently, Al-Saadawi and Abdul-Wahab (1977) claimed that boiling water caused destruction of part of the testa and facilitated water entry; however, this evidence is not conclusive as the actual depth of attack was not measured. In other legumes, impermeability extends to well below the light line (Ballard 1973). If a similar situation exists with Acacias , then perhaps as much as 60-80 μm must be removed if general water penetration is to occur. Observations of treated seeds (A. Cavanagh unpublished research) show that long term boiling and sulphuric acid remove the cuticle and sometimes part of the palisade cells (see also Li, 1974, for sulphuric acid) while dry heat and microwave energy cause cracks which rarely extend beyond the light line. In order to determine actual sites of water entry, a more positive test is required over and above simple observation of the seed coat.

Brown and Booysen (1969) soaked treated seeds in osmic acid. This material (chemically osmium tetroxide) is readily reduced to black, amorphous osmium in the presence of active oxygen acceptors such as unsaturated carbon compounds, but is not affected by saturated fats (Hamly 1932). At openings or permeable areas, the unsaturated compounds present in the palisade layer rapidly reduce the osmic acid and leave a dark stain on the surface. Brown and Booysen allowed the seeds to imbibe the solution for a short time and confirmed their surface observations by preparing sections through suspect areas. Their results are included in Table 5 and the evidence points strongly to the strophiole (lens) as being the predominant site of water entry, though some severe treatments lead to unlocalised attack and random penetration.

These original observations were confirmed independently by Robbertse (1974) following examination of seed that had become soft by long term exposure on the ground and by Cavanagh and Tran (1979) and Tran and Cavanagh (1979) who had noted that the strophiole became raised and golden after microwave exposure. They interpreted this as indicating a change in its structure, most probably caused by heating. Pl. 23 shows the hilum and strophiolar region of A. suaveolens after microwave exposure during which the seed was heated to 100°C; the surface crack pattern which also developed is shown in Pl. 24. However, the cracks apparently play little role in water imbibation; when the strophiole of treated seed was covered with petroleum jelly and seeds were then soaked in water, no seeds swelled. Seed from the same batch with strophiole uncovered gave between 60% and 70% germination. Germinating seeds almost invariably swell from the hilum end and take up to 24 hours to completely imbibe. Nicked and heavily acid-scarified seeds swell most rapidly, while boiling water, dry heat and microwave energy treatments are usually

TABLE 5
SITES OF INITIAL WATER ENTRY AFTER VARIOUS SEED COAT TREATMENTS

| TREATMENT	SITE(S) OF ENTRY	REFERENCE
Boiled 1 - 10 mins.	Unlocalised areas of seed coat	Brown & Booysen (1969) Al-Saadawi and Abdul-Wahab (1977)
Boiling water poured over seed	Strophiole	Cavanagh & Tran (1979)
Dry Heat	Predominantly lens.	Brown & Booysen (1969)
" "	Strophiole	A. Cavanagh (unpub.)
Microwave heating	Strophiole	Tran & Cavanagh (1979)
Organic solvents (a) Acetone	Probably lens area	Brown & Booysen (1969)
(b) Ethanol	Hilum and/or lens	" " "
(c) Methanol	Random areas of coat	" " "
Natural weathering	Rapheole	Robbertse (1974)
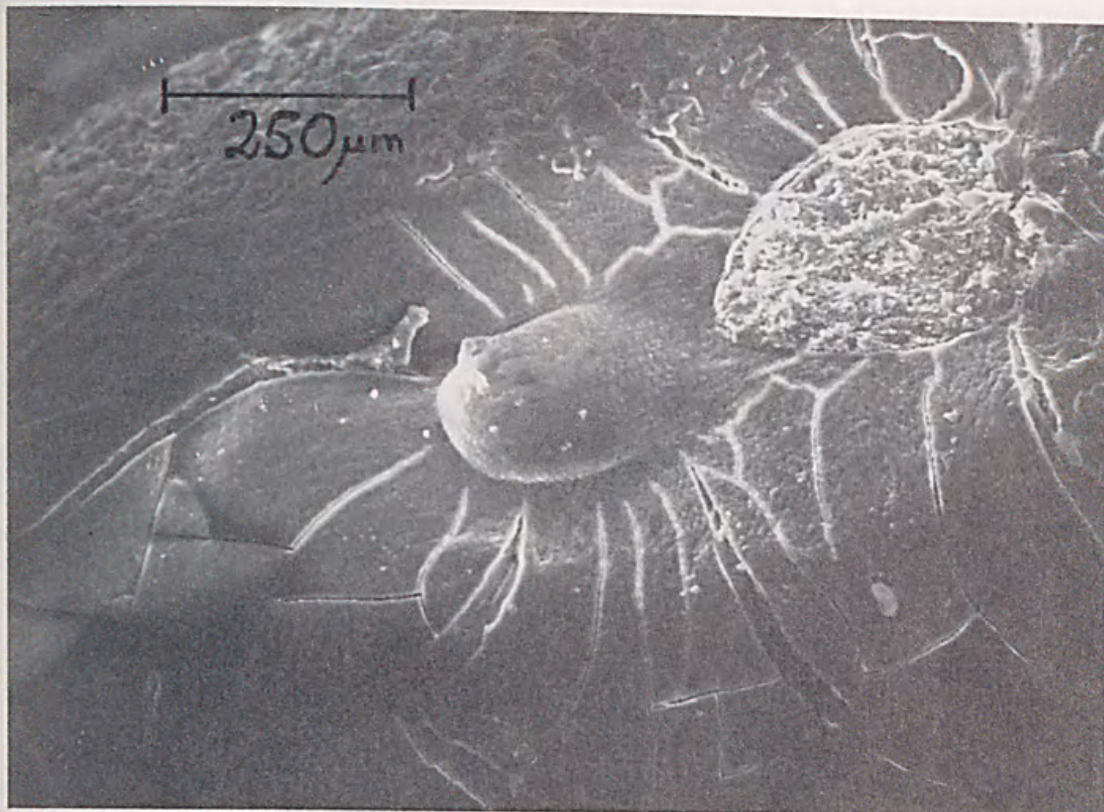
PLATE 23
Scanning electron micrograph of seed treated by microwave heating. Note swollen
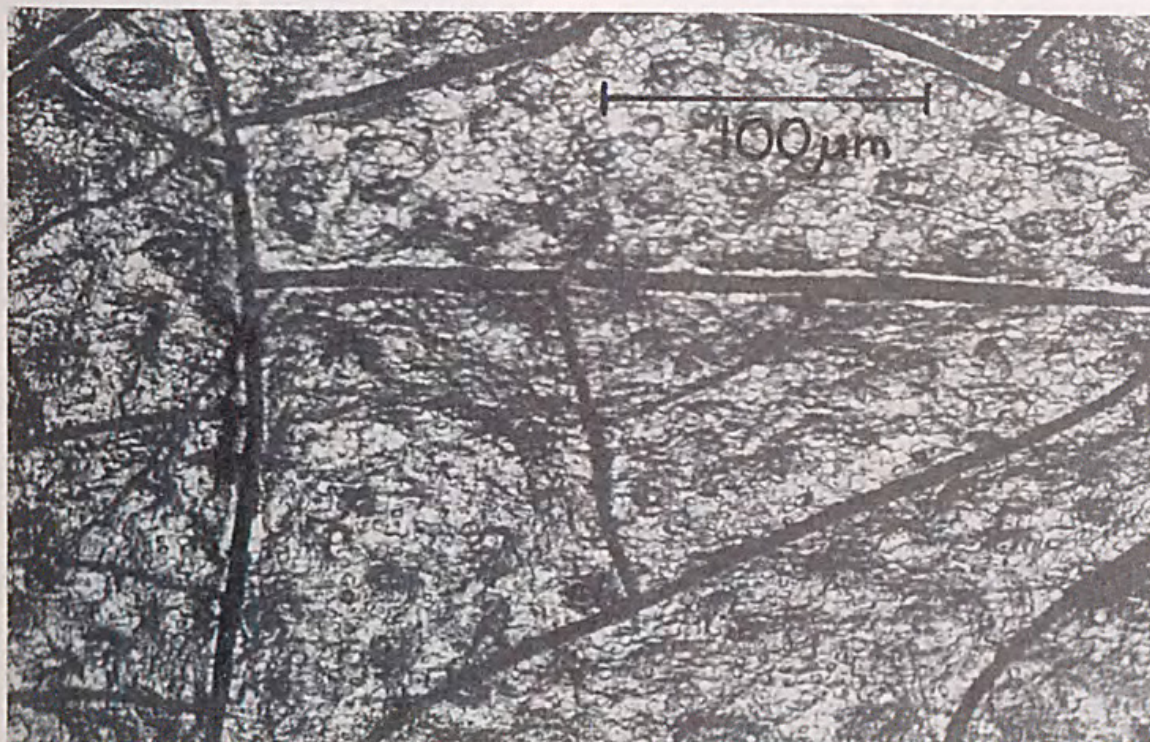appearance of strophiole.

PLATE 24
Surface crack pattern developed by microwave heating.

somewhat slower in action. Heating causes a breakdown of the shortened palisade cells covering the vascular bundle at the strophiole; water penetration can then occur. However, the rate of water imbibation is restricted, at least initially, by the small diameter of the strophiole, typically 0.1 mm in *A. longifolia*. It is possible that once some swelling has commenced, the seed coat becomes softened and permeable at random sites on its surface.

STORAGE AFTER TREATMENT

The prevailing notion about treated seed is that it cannot be stored but must be sown immediately (Hockings 1975, Turnbull 1972, Western Australia Wildflower Society 1973). This is probably related to the fears expressed by Wycherley (1960) '. . . unless (the seeds) are rapidly dried after treatment, *before germination commences* (italics mine) the absorbed water allows germination in the field even if there is inadequate moisture in the soil. Complete loss may result if rain fails after sowing.' Just how far the germination process can proceed before drying out induces death of the embryo is not known. Preece (1971b) showed that in *A. aneura*, providing the time between desiccation and re-wetting was of no more than 24 hours duration, the seed can be dried out after germination has commenced and after the radicle has began to extend, and will resume growth when moisture is available. Knowledge which would be of important practical value in large scale seeding programmes is the age at which a part-germinated seed loses its ability to revive after drying out, and the time interval between drying out and re-wetting which proves fatal.

Harding (1940), Isikawa (1965), Moffatt (1952) and Osborn and Osborn (1931) have established that seed dried after boiling water treatment can be safely stored for long periods with no loss of viability. In fact the Osborns showed that stored seed invariably had an improved germinating ability over freshly treated material. They also dispelled the notion that seed should be boiled or soaked till soft or swollen . . . 'the general physical appearance of the majority of seeds remains unchanged by normal treatments with boiling water.' Their findings were corroborated by Harding (1940) who concluded:
(1) Boiling accelerates germination considerably but is detrimental after a period of five seconds.
(2) There is no justification for prolonged soaking.
(3) Storage for considerable periods is quite practical.
(4) For any extensive sowing programme, the seed can be treated in advance and stored until required instead of being treated and sown wet in the field.

In experiments aimed at determining the length of time treated seed remained viable, Isikawa (1965) demonstrated that *A. mearnsii* seeds boiled for five minutes gave a consistent 75-85% germination after two years storage at room temperature; seed held at 5°C lasted nearly three years. Times of boiling ranging from 15 seconds to five minutes had no significant effect on storage life. Acid-scarified seeds of *A. senegal* were stored for six months with no loss in viability (Cheema & Qadir 1973) and several months successful storage has also been achieved with *A. longifolia* after microwave treatment (A. Cavanagh unpublished).

Moffatt (1952) believed that storage had a beneficial effect in allowing 'recovery' of seed whose germination was impaired by boiling or prolonged heating and which gave relatively poor results when sown immediately. He suggested that some substance, possibly an enzyme, might be partially destroyed and required time to be replaced, so allowing normal germination rates to be regained.

CONCLUSION:

In common with germination studies in other species, there has been insufficient fundamental work carried out on Acacias. In general, most investigators have been concerned with finding a means of improving germination rather than with understanding the mechanism(s) which control the germination process. With the possible exception of *A. mearnsii* no single species has been systematically studied, though for several economically important trees, there is much accrued general ecological information. Surprisingly few attempts have been made to establish optimum treatment conditions even for widely grown species and this situation should be remedied. Serious consideration should be given to investigating the use of 'green' seed where possible as this may obviate the need for seed coat treatment. More use could also be made of biochemical and metabolic data (currently almost non-existent) as this could prove useful in determining the onset of embryo damage in seeds which have been heated or allowed to dry out after partial germination.

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