14 Overcoming Legume Hardseededness

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INTRODUCTION

Mature seeds of many plant species, particularly legumes, do not germinate readily under favourable environmental conditions, because they are impermeable to water and/or gases or they have a seed-coat that mechanically constrains the embryo. This attribute has been called hard seed-coat dormancy, hard-coatedness, hardseededness, dormancy imposed by the seed-coat, seed-coat impermeability and exogenous dormancy. Hardseededness is heritable and has been found in all commercial legume species except *Arachis hypogaea*. It may or may not be combined with other dormancy mechanisms in the seed.

Seed-coat impermeability is of ecological importance, since it lengthens the lifespan of the viable seed and allows for the progressive germination of small proportions of a given seed lot over time, thus increasing opportunities for species survival. However, it also poses practical problems in commerce, where high hard-seed levels can reduce legume establishment. Hardseededness also complicates germination testing, and must be taken into account when interpreting laboratory results.

Breakdown of hard seed may occur through the action of natural agents, particularly when seeds weather on the soil surface, where they are exposed to cycles of wetting and drying and of heating and cooling. Artificial methods to break down hardseededness have also been developed for tropical and subtropical legumes, particularly non-forage species. These include the use of chemicals, hot water, mechanical means, and constant and fluctuating temperatures.

In this chapter, we discuss the nature and breakdown of hardseededness and its implications for legume establishment. Work on tropical and subtropical species to date has been limited, so that current principles are derived in part from more detailed studies with temperate and grain legumes. However, seeds from these different types of legumes appear to behave similarly – hence the use

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here of a wider range of source material as a guide to hardseededness in tropical and subtropical forage legumes.

CHARACTER AND EXPRESSION OF HARDSEEDEDNESS

Impermeability of the seed-coat to water is widespread in the legume family *Fabaceae*, and its existence has been known for more than 100 years (Guppy, 1912). It also occurs in other plant families, including *Cannaceae*, *Chenopodiaceae*, *Convallariaceae*, *Convolvulaceae*, *Geraniaceae*, *Malvaceae*, *Nymphaeaceae*, *Poaceae* and *Solanaceae* (Watson, 1948; Harrington, 1949).

The cause of hardseededness is the inability of the seed-coat to transmit water and oxygen freely to the inner structures of the seed, but there has been considerable debate as to which layers of the seed-coat are impermeable. In legume seed, the outermost layer is called the palisade layer and consists of macrosclereids or malpighian cells covered by the cuticle on their exposed wall (Esau, 1977; Rolston, 1978), as illustrated in Fig. 14.1.

Early researchers attributed seed-coat impermeability to a waxy layer over the seeds or to the presence of a colloidal layer in the seed-coat, which would absorb moisture readily when slightly damp but rejected water when dry (Harrington, 1916). The thickening of the cuticle and the suberization and cutinization of the malpighian caps has also been associated with the degree of seed-coat impermeability in several legume species (Rees, 1911).

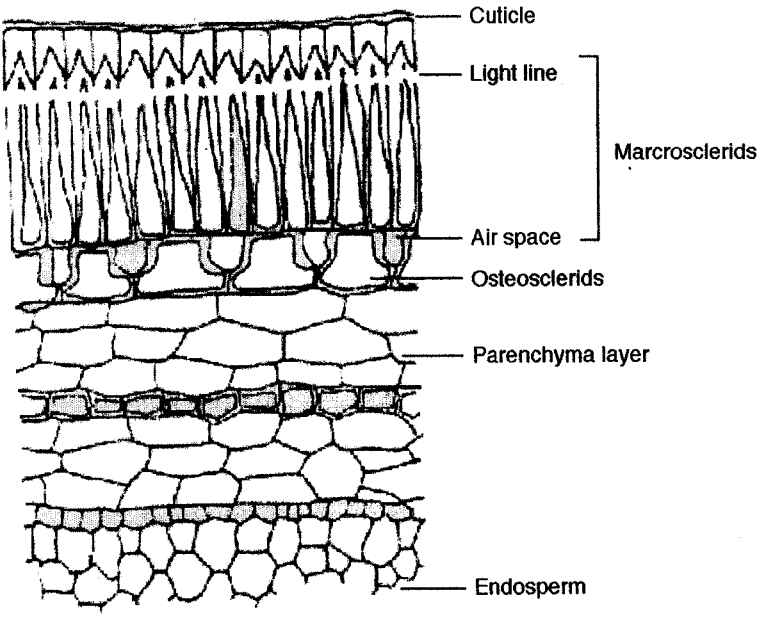

Fig. 14.1. Longitudinal section of a *Melilotus* seed-coat by Martin and Watt (1944) (adapted from Rolston, 1978).

In *Melilotus alba*, Hamly (1932) described the impermeable region as formed by a layer of tightly appressed suberin caps covered externally by a cuticle. He observed that no structural feature causing impermeability in the testa can be shown to be present in all impermeable and none of the permeable seeds; only differences in the amount of suberin and cutin in the subcuticular and malpighian cells accounted for differences in degree of impermeability.

Hamly's findings, however, differed from those reported by Coe and Martin (1920), Stevenson (1937) and Porter (1949) with *Melilotus alba* and *Melilotus officinalis*. The last two authors attributed seed impermeability to the presence of a narrow but refractive zone below the conical layer of the malpighian cells, called the 'light line' because it refracted the light when observed under the microscope (Fig. 14.1). It seems that the 'light line' is produced by internal thickening of epidermal cells, resulting from the occlusion of the lumen of each cell at the same level and giving the optical illusion of two layers of malpighian cells (Gunn, 1981). The cell wall in the 'light line' region appears to be especially compact (Esau, 1977) and, together with thickness of the palisade layer, has been positively correlated with hardseededness in annual medics (Marouani, 1990).

In general, it appears that seed-coat impermeability does not depend on the properties of one special layer, but is a peculiarity of normal cell constituents in legumes, mainly pectic substances, such as suberin and lignin (Cavazza, 1950; Quinlivan, 1971; Duangpatra, 1976; McKee *et al.*, 1977). Callus has also recently been implicated in seed-coat impermeability in *Sesbania speciosa* by Seth and Vijayaraghavan (1990).

The hard-seed character is heritable, but its expression is strongly related to prevailing climatic factors during plant growth and seed maturation, as well as the degree of seed dehydration. Smith (1988) found that hardseededness of 17 lines in *Trifolium subterraneum* stored under simulated high diurnal fluctuating temperatures was influenced by both production year and plant genotype. Seed production environment set the upper limit for hard-seed levels, but genotype determined rate of seed softening. Similar conclusions were reached by Taylor and Ewing (1992) with *Medicago polymorpha* and Tinius (1991) with soybeans.

Lebedeff (1947) reported that hardseededness in common lines of *Phaseolus vulgaris* was heritable, but pointed out that hard-seed levels could be duplicated only under similar environmental conditions, since season of growth, age and seed moisture content affected numbers of hard seeds. Similarly, James (1949) found that selfed parents of *Trifolium incarnatum* with a difference of about 60% in seed-coat impermeability produced offspring with a difference of less than 1% in the first generation, suggesting that the heritable factors were masked by the environment.

Different degrees of hardseededness are achieved as the seed matures and loses moisture to reach equilibrium in accordance with the prevailing atmospheric humidity (Corner, 1951). This suggests that the expression of hardseededness in the developed seed is a function of dehydration, which in turn is related to storage temperature, relative humidity (RH) and the length of time in which they can act (Biasutti, 1956). However, Argel (1979) and Argel and Humphreys (1983a) reported that, for identical seed moisture contents, seeds of *Stylosanthes hamata* cv. Verano developed different degrees of hardseededness,

depending on the temperature of seed formation: essentially seeds produced under higher temperatures (27°C) developed higher proportions of hardseededness than those produced under lower temperatures (21°C). However, when seed moisture content was below 7%, all seeds developed high percentages of hard seeds, irrespective of temperature.

In legumes, seed moisture content generally declines to equilibrate with the lowest RH experienced during storage (Robertson and Lute, 1939; Brewer and Butt, 1950; Biasutti, 1956). The reduction of seed moisture content in this manner is facilitated by the hilum (Fig. 14.2), which acts like a hygroscopic valve (Hyde, 1954). Different kinds of seeds, however, absorb different quantities of water under identical conditions (Dillman, 1930; Gane, 1948) due to differences in chemical composition of the seed and thickness of the seed-coat (Barton and Crocker, 1948). Thus, factors that influence the chemical composition of the seed, particularly the oil content, will in turn affect the equilibrium seed moisture content at a given RH.

In *S. hamata* cv. Verano, the temperature during seed formation affected the size of palisade cells: shorter cells were present in seeds produced under warmer temperatures, and they also had a lower content of cellulose and higher levels of hemicellulose and lignin. The outer surface of soft seeds of this species presented deformations and structural irregularities not observed in hard seeds (Argel, 1979; Argel and Humphreys, 1983b). Similarly, soft seeds of *Trifolium stellatum* showed a very thin and discontinuous cuticular layer at seed maturation, while a thick and continuous cuticle was characteristic of the hardseeded species *Medicago orbicularis* (Russi *et al.*, 1992).

Seed moisture content decreases rapidly as the seed ripens. Quinlivan (1962) reported moisture contents of 18–20% in seeds of *Lupinus varius* (sand-plain lupin) at the time they changed colour and approached the shading stage. However,

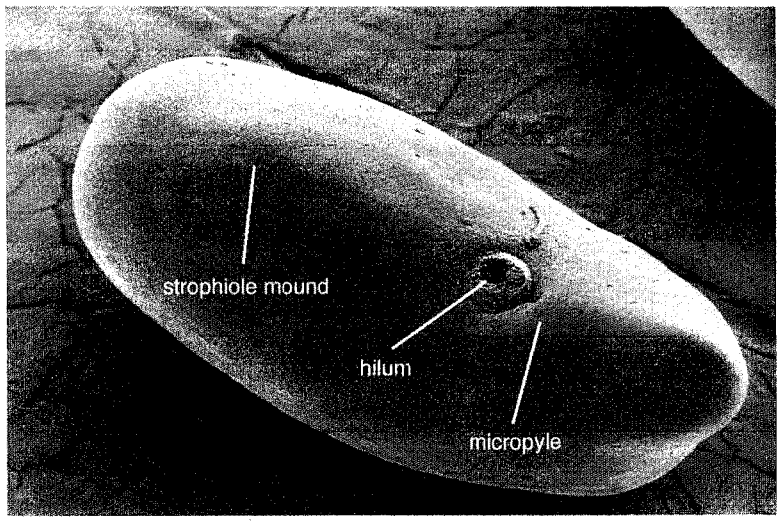

Fig. 14.2. Strophiole in relation to hilum and micropyle structures in *Stylosanthes hamata* cv. Verano seed (digitized image (500×) from Argel, 1979).

after 2–3 days on the soil surface, seed moisture content had decreased to 10–12% and the seeds became impermeable to water. Helgeson (1932) observed that impermeability in seeds of *M. alba* was related to dehydration during the later stages of maturation. Even permeable immature seeds dried for 7 days over calcium chloride became impermeable, indicating that seed moisture content was the main factor governing seed-coat impermeability.

Initial hard-seed levels have been reported to vary from site to site and from season to season in both temperate and tropical legumes. In south-western Australia, Quinlivan (1967) found differences in initial hard-seed percentages in samples of *L. varius* produced some 500 km apart, while, in the north-east, Clements (1977) reported higher proportions of hard seeds in the spring than in the autumn for *Centrosema virginianum* and *Macroptilium atropurpureum*. Cameron (1967) also noted differences in the degree of hardseededness in two consecutive years for 25 lines of *Stylosanthes humilis* grown in the same locality, attributing these differences between years to environmental factors. However, as Quinlivan (1971) stated, differences in hardseededness associated with the effects of weather conditions prevailing during seed formation may well reflect differences in seed moisture content at the time of the test.

ROLE OF THE STROPHIOLE

The strophiole, or lens as preferred by some authors (e.g. Gunn, 1981), is a seed structure located close to the hilum on the side opposite the micropyle (Fig. 14.2), and consists of a mound of specialized tissue (often discoloured) on the seed-coat where the palisade cells are longer and narrower than normal (Fig. 14.3). This controls the entry of water into the seed after absolute seed impermeability is reached (Ballard, 1973; Pritchard *et al.*, 1988).

This structure is present in all three legume families. It is usually conspicuous and dome-shaped in the *Papilionoideae* (where cells are bent along the main axes and very often a cleft extends from the osteosclerid cells), in contrast to the

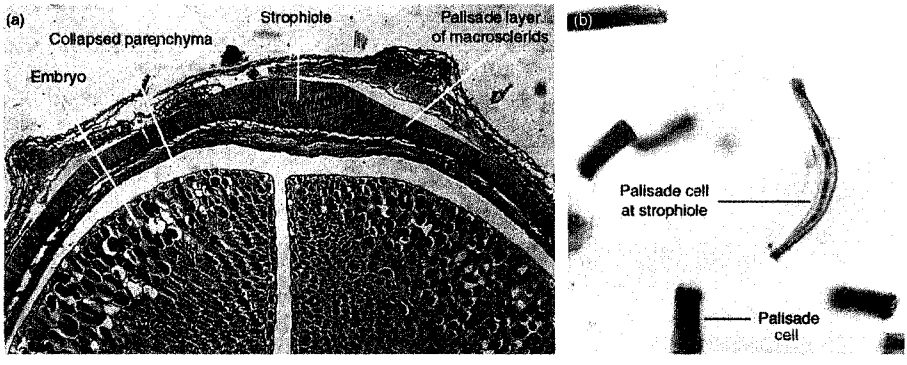

Fig. 14.3. (a) Cross-section of *Stylosanthes hamata* cv. Verano seed through the strophiole showing the enlargement of macrosclerids cells (100 ×); (b) strophiole cell (bent) and single palisade adjacent cell of the malpighian layer (500 ×) (digitized images from Argel, 1979).

Mimosoideae and *Caesalpinioideae*, where it is usually inconspicuous and not dome-shaped (Gunn, 1981).

The strophiolar cells are described as being in a state of metastable equilibrium, which, when upset, produces seed softening through a split along the middle lamellae in such a way that the palisade cells pull apart to allow the slow entry of water into the seed (Hamly, 1932; Rolston, 1978). This type of softening appears to be restricted to the *Papilionoideae*, since the strophioles in the other legume families have an eruptive rather than a cleaving form (Hopkinson, 1993b). Under sudden heat, for instance, a tiny plug of tissue blows out to allow entry of water into the embryo. This is a recently reported but not fully understood mechanism for controlling water uptake by hard seeds (Dell, 1980). Rupturing of the strophiole by artificial means has been reported to occur by alternating and constant temperatures on hard seeds of *T. subterraneum* (Aitken, 1939; Hagon, 1971; Taylor, 1981), by high temperature treatments on seeds of *Stylosanthes humilis*, *Stylosanthes hamata*, *Stylosanthes scabra* and *Stylosanthes viscosa* (Mott, 1979), by soaking and drying seeds of *Lupinus angustifolius* (Burns, 1959), by heating and bouncing seeds of *Melilotus alba* (Hamly, 1932) and by radio-frequency electric fields on hard seeds of *Medicago*, *Stylosanthes* and *Trifolium* (Ballard *et al.*, 1976).

Ballard (1976) also demonstrated that strophioles do not need to be acted on directly to become permeable to water by mechanical action on the seeds. Thus, 30–90% of impermeable seeds of *Medicago scutellata*, *S. humilis* and *Trifolium* spp. became conductive at the strophiole when stressed either by squeezing or by striking at sites remote from this structure. However, permeability induced by percussion and opening of strophioles is not absolute and can be reversed by manipulation of RH. Hagon and Ballard (1970) demonstrated that percussed seeds of *T. subterraneum* stored at RHs low enough to make seeds lose water (i.e. < 20% RH) caused some seeds to revert to the impermeable condition, as shrinkage of the seed on drying resealed the slit again at the strophiole. This occurs only within the *Papilionoideae*, according to Hopkinson (1993b), since seeds with ruptured strophioles in the families *Caesalpinioideae* and *Mimosoideae* cannot later close up.

Hopkinson (1993b) also gave a detailed account of the nature of the strophiole of leguminous seeds from an agronomist's viewpoint. He argued that a better understanding of its function would enhance legume establishment by allowing its action in the breakdown of hardseededness to be manipulated.

BREAKDOWN OF HARDSEEDEDNESS

The breakdown of hardseededness implies rupturing of the seed-coat and the subsequent absorption of water and/or gases by the seed, which in turn will initiate the process of germination in a viable non-dormant seed. This can be achieved by artificial methods or by the action of natural agents acting on the seed over a period of time.

Many artificial methods have been developed to rupture, remove or dissolve the impermeable portions of the seed-coat to stimulate germination. However,

different species (and even different seed lots within species) will not react the same to a given treatment method. The result depends on seed origin, age, moisture content and storage conditions.

Alternating and Constant Temperatures

High constant temperatures and temperature fluctuations are major factors in softening hard legume seeds (Quinlivan, 1961, 1966; Quinlivan and Mellington, 1962; Barrett-Lennard and Gladstones, 1964; Hagon, 1971; McComb and Andrews, 1974; Taylor, 1981; Lodge *et al.*, 1990; Evers, 1991). However, temperature treatments capable of causing significant rates of hard-seed breakdown for any particular species do not occur until the amplitude of the temperature fluctuation, or the maximum temperature, reaches a certain level (Quinlivan, 1966). In a comparative experiment across 19 temperate legumes, Quinlivan (1968b) showed that softening of 15 cultivars from six *Trifolium* species increased as maximum temperatures rose, in contrast to four cultivars from *Medicago* spp. (Fig. 14.4); and he also found the rate of softening to be dependent on cultivar. Based on these principles, Le Bransky and King (1986) developed a thermal aerator to overcome problems associated with such techniques for reducing hard-seed levels in legumes. The instrument blows hot air through a block chamber designed for rapid placement and removal of the seed. This proved effective in reducing hardseededness without increasing seed mortality when batches of

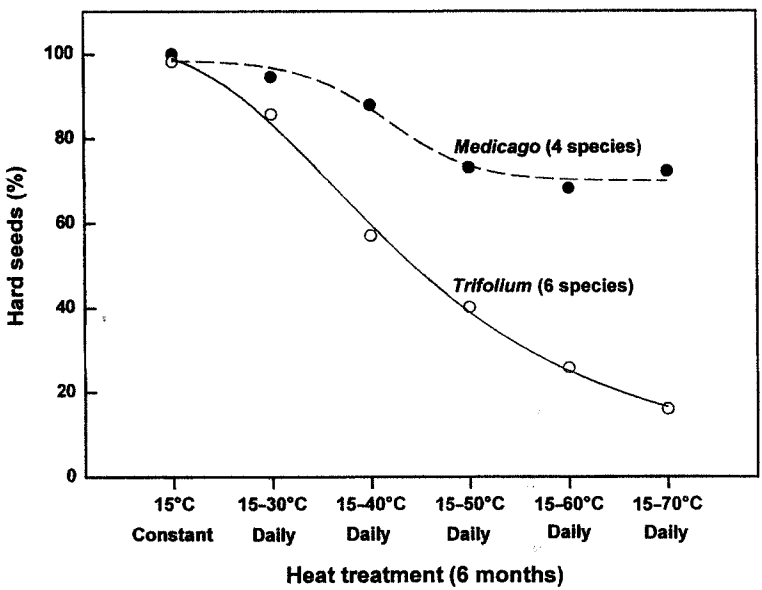

Fig. 14.4. Effect of different heat treatments (constant and daily fluctuating temperatures) on hard seed of *Medicago* (mean of four species) and *Trifolium* (mean of 15 cultivars from six species) over a 6-month period (adapted from Quinlivan, 1968b).

S. scabra cv. Fitzroy and *T. subterraneum* cv. Daliak seeds were exposed to temperatures between 70 and 85°C for short durations.

Wide temperature fluctuations can occur near the soil surface on summer days of the subtropics; and daily temperature fluctuations may widen under heavy grazing or following the removal of the dry top growth from a pasture during the dry months. Such environments are therefore likely to induce significant breakdown of impermeability in hard legume seeds. Evidence for this has been reported in hard-seed breakdown studies with the temperate legumes *Trifolium hirtum*, *T. incarnatum* and *T. subterraneum* (Williams and Elliott, 1960; Quinlivan, 1965). Mott *et al.* (1981) also found that the reduction in hard-seed content of *S. hamata* cv. Verano, *S. humilis* cv. Paterson, *S. scabra* cv. Fitzroy and *S. viscosa* CPI 34904 at three sites in northern Australia was dominated by changes in soil temperature, with the formation of germinable seeds controlled by the time of year at which the temperature rose above 50–55°C. From these observations, they developed a predictive relationship that linked the hard-seed content of seed samples to field soil temperatures. Thus, all the factors that affect soil temperature – latitude, season, soil colour, wind and cover – indirectly influence the rate of hard-seed breakdown (Gardener, 1975).

Quinlivan (1961) subjected hard seeds of *T. subterraneum* and other legume species to constant and fluctuating temperatures for a period of 5 months, and recorded maximum permeability with a range of 15/60°C. Taylor (1981) also compared hard-seed breakdown of *T. subterraneum* at a series of constant temperatures (15–80°C) with 60/15°C fluctuating temperature, and found rapid softening of hard seeds after 28 days of fluctuating temperature, because this weakened the strophiolar region and increased strophiolar permeability to water. The range 60/15°C has been used by many researchers to determine genetic and environmental factors that influence the rate of hard-seed breakdown, and has been adopted by the Australian National Subterranean Clover Program as a routine test to quantify hard-seed levels (Taylor and Ewing, 1992).

The rate of softening of hard seeds by alternating temperatures increases as their moisture content increases. This relationship has been demonstrated in studies with *P. vulgaris* (Lebedeff, 1943), with *Lupinus digitatus* (Gladstones, 1958) and with *L. varius* (Quinlivan, 1968a). In *L. angustifolius*, when the hard-seed moisture content fell from approximately 15% to 9% (wet weight basis), Quinlivan (1970) recorded a corresponding fall in the rate of softening when these seeds were subjected to alternating temperatures of 15/65°C. The proportion of lignin in the seed-coat also affects the rate of hard-seed breakdown by alternating temperatures. A white-seeded mutant of *T. subterraneum* cv. Geraldton, with significantly less seed-coat lignin than the parent line, showed a higher rate of hard-seed breakdown in storage than its parent when subjected to fluctuating temperatures of 15/60°C for 3 months (Francis and Hume, 1971). Agrawal and Menon (1974) also demonstrated that varieties of soybean with low lignin content tend to soften more easily than varieties with a high lignin content in the seed-coat.

High constant temperatures have been reported to decrease seed-coat impermeability in many legumes, particularly under conditions of dry heat (Martin *et al.*, 1975; Lehane, 1981; Butler, 1983). Dry-heat treatment has

commercial advantages over some other treatment methods because it allows treatment of large quantities of seed in heated rotating drums, as demonstrated by Mott (1979) with hard seeds of *Stylosanthes* spp. and by Paton (1993) with seeds of *Stylosanthes guianensis* var. *intermedia*. However, optimum temperature treatments and exposure times vary between species and between seed lots within a species (Mott *et al.*, 1982). It is therefore recommended that a preliminary test be carried out on subsamples of seed to check the optimum temperature and exposure time before treating large batches of seed, because reductions in hardseededness without seed mortality require stable and precise treatment times (Mott *et al.*, 1982; Le Bransky and King, 1986). Heat treatment, however, is not always effective: for instance, a range of heat-dose levels (degree-seconds above 90°C) applied to seed of *S. scabra* cv. Seca by Hopkinson and Paton (1993) often produced a high proportion of dead seeds, and so cannot be recommended for commercial use with 'Seca'.

Studies to determine the rate at which hard seeds break down under constant or fluctuating temperatures have been carried out by subjecting seed-softening data to analysis of variance (Quinlivan, 1966), and by fitting linear or quadratic models using linear-regression analysis techniques (Quinlivan, 1965). Quadratic models do not fit data from genotypes with rapid rates of breakdown (Fairbrother, 1991), but Fairbrother and Pederson (1993) were able to fit data from the literature and from their own observations with *T. subterraneum* to the non-linear Weibull model (used to describe the characteristic curve of cumulative germination of plant seeds; Bahler *et al.*, 1989). This latter model is useful in describing the decline of hardseededness over time for legume species with divergent rates of breakdown (Fig. 14.5). Temperature treatments (either constant or fluctuating) ranked the rate of hard-seed breakdown among cultivars in a similar order, although the rate was faster for constant temperature treatments than for fluctuating temperatures.

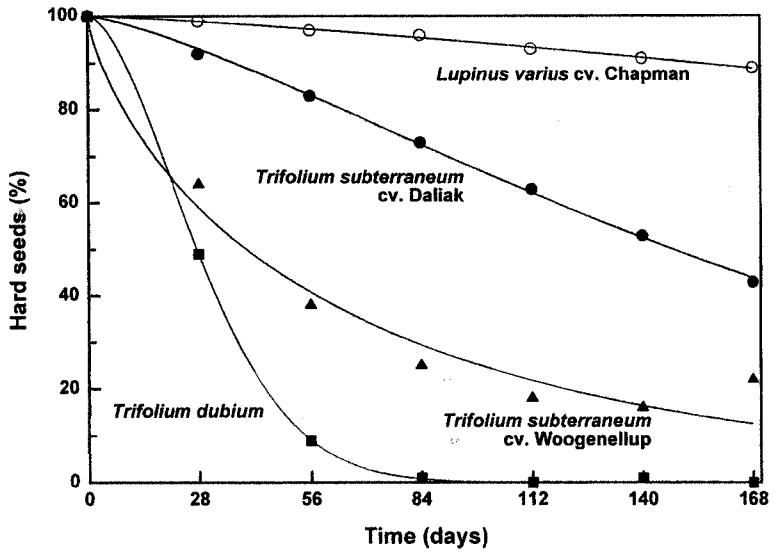

Fig. 14.5. Trends for loss of hardseededness with time estimated by the Weibull model for data on four legumes (adapted from Fairbrother and Pederson, 1993).

Hot-water Treatment

The literature contains numerous references to the use of either hot or boiling water to break down hardseededness in legumes. Hot-water treatment can severely rupture the seed-coat by ejecting the strophiolar plug and cracking the testa (Dell, 1980). It is a simple and reproducible method that does not require special equipment, but considerable variation within particular legume species is again reported in relation to optimum water temperatures and immersion times required to promote seed germination (and normal seedlings).

Seeds of *Leucaena leucocephala* have been successfully scarified without affecting seed viability and plant vigour by immersion in hot water either at 60°C for 15–30 min or at 80–100°C for 1–3 min (Alvarez-Racelis and Bagaloyos, 1977; Oliveira *et al.*, 1979; Lasso and Melendez, 1980). Oakes (1984) also reported good results with K8 and the accession K67 by immersion in hot water for 2–5 min at 80°C or for 2–5 s at 100°C. He suggested that temperature had a greater effect on hardseededness breakdown than immersion time. Current recommendations for commercial treatment of *L. leucocephala* seed in Australia (mainly 'Cunningham' and 'Peru') is to immerse in boiling water for 3–4 s using eight parts of water to one part of seed by volume (Partridge, 1989).

Increases in germination of *Centrosema pubescens* have been reported when immersing the seeds in boiling water from 1 s up to 20 min or leaving it to cool down with the seed (Phipps, 1973; Aragao and da Costa, 1983). *Pueraria phaseoloides*, *Clitoria ternatea*, *Macroptilium atropurpureum* and *Desmodium intortum* seeds respond similarly (Cabrales and Bernal, 1983). With *S. guianensis* var. *intermedia*, Butler and Rickert (1981) achieved an adequate breakdown of hardseededness (and normal seedlings) by soaking seeds in hot water at 55°C for 20 min. Similarly, seeds of *Desmodium ovalifolium* and *Desmodium velutinum* produced high germination percentages after immersion in water at 80°C for 4 and 7.5 min, respectively (Rojas and Herrera, 1989; Akinola *et al.*, 1991).

Continuous immersion in boiling water for 1 min was successful in breaking down hard seeds of *S. hamata* cv. Verano, but was unsuitable for *S. scabra* cv. Fitzroy and *S. guianensis* cv. Cook because high proportions of dead seeds were recorded (McIvor and Gardener, 1987). These results contrast with those of Gilbert and Shaw (1979), who did not find significant effects on hardseededness in 'Verano' by immersing seeds in hot water (65–95°C) for 1–5 min. Differences in seed moisture content may account for these discrepancies.

Most reports on the use of hot water to overcome hardseededness are based on small quantities of seed treated in laboratory tests. However, Paton and Robbins (1986) successfully heat-treated commercial quantities of seed of *Stylosanthes* spp. by immersing 20–30 kg at a time in hot water at 80°C for 10 min. Before storing it, rapid drying of the treated seed was necessary to avoid premature germination or fungal contamination.

In general, the optimum period for immersion in boiling water varies considerably with species. For this reason, temperatures and immersion times need to be calibrated to minimize seed damage that could result in abnormal seedlings or dead seeds.

Chemical Scarification

While 20% caustic soda has been used to scarify small quantities of legume seeds successfully (Seiffert, 1982), the most widely used chemical substance to break down hard legume seeds is sulphuric acid (H_2SO_4) in concentrations from 50 to 98%. Immersion times have varied from 1 to 30 min with 50–100 ml of H_2SO_4 per kg of seed, depending on the species. As with the previous methods, optimum acid concentration and exposure time vary with species. Low concentrations (< 20%), however, are not effective (Lulandala, 1981).

Significant increases in seed germination using acid scarification have been reported for *Centrosema pubescens* (Win Pe et al., 1975; Aragao and da Costa, 1983), *Leucaena leucocephala* (e.g. Ramdeo, 1971; Lasso and Melendez, 1980; Seiffert, 1982), *Desmanthus virgatus* (Nascimento, 1982; Ramamoorthy and Rai, 1990), *Calopogonium mucunoides*, *Clitoria ternatea*, *Desmodium intortum*, *Macroptilium atropurpureum*, *Neonotonia wightii* and *Pueraria phaseoloides* (Phipps, 1973; Febles and Padilla, 1977; de Almeida *et al.*, 1979; Cabrales and Bernal, 1983). Nascimento (1982) also reported that 1–20 min exposure to concentrated H_2SO_4 (98%) increased germination from hard seeds of *Cratylia floribunda* (syn. *Cratylia argentea*) and *Stylosanthes capitata*. However, Barker and Abdi (1987) found that germination of *Indigofera tinctoria* was drastically reduced by as little as 3 min scarification with 95% H_2SO_4.

Sulphuric acid scarification is commonly used in laboratory seed-germination tests, but particular care is required, since it may cause skin irritation if not handled properly. It is also highly corrosive to metal containers, implying the utilization of special equipment to scarify large volumes of seeds.

Mechanical Scarification

Sandpaper, dehulling and abrasive elements (i.e. sand, percussion and hammer-milling) are mechanical methods commonly used to break down hardseededness in legumes (Hanna, 1973; Grant, 1979; Butler *et al.*, 1982; Nascimento, 1982; Ramamoorthy and Rai, 1990). Their practicality, however, depends on the species and the type of seed used. Mechanical methods are often suitable for small amounts of seed, but impractical on a commercial scale (i.e. for tonnes of seed); however, there are exceptions, although species must still be considered on a case-by-case basis. For example, Hopkinson and Paton (1993) reported that large quantities of *S. scabra* cv. Seca seed can be scarified satisfactorily by hammer-milling: laboratory germination and soil emergence are increased, although there is a slightly increased risk of causing seed death. In this case, milling tended to dehull proportionally more mature than immature seeds, and also improved seed flow by abrading the hooks. The success with *S. scabra*, however, is in contrast to earlier work by Grant (1979) showing that hammer-milling to scarify *S. guianensis* var. *intermedia* was ineffective and also damaged some seeds.

The Simon Le Coq Clover Polisher* has been used by commercial seed producers in northern Australia to scarify seed of *Stylosanthes* spp. by dehulling and also

*Mention of trade names is for identification purposes only and does not imply a preference over other products not mentioned.

seed of *Chamaecrista rotundifolia* cv. Wynn by abrasion (Loch and Harvey, 1992). It is capable of processing about 500 kg of seed h^{-1} and, while successful with 'Wynn', the degree of dehulling and amounts of hard seed softened in *Stylosanthes* spp. were inconsistent. Use of the Clover Polisher has since been largely replaced by hammer-milling (Hopkinson and Paton, 1993) and, more recently, by the Semco stock feed mixer.

The latter machine holds roughly 2 t of seed in an upright cylinder with a central auger. The auger draws seed from the bottom and moves it to the top, where the seed spills out into the greater cylinder, thus creating a continuous mixing action. On the way through the auger, seed is abraded between the auger and cylinder wall. Leaving the mixer running for up to 24 h can completely dehull seed of *Stylosanthes* spp., but treatment for 3–8 h generally achieves the required degree of seed softening. Again, the quantity of seed treated in each batch, legume species, moisture content, history and many other characteristics of the seed can influence the outcome.

A very recent development in Queensland has been the use of a Satake Cereal Grain Abrader to scarify seed of *Desmanthus virgatus* (D.S. Loch, Queensland, 1996, personal communication). This machine was designed for rice polishing, and is also used commercially to remove the outer layers selectively from cereal and grain legume seeds at rates of > 1 t h^{-1}. Central to its action is an abrasive stone wheel, which revolves at high speed as the seed is passed through. Preliminary trials have also given good results with a range of other legumes, including *Chamaecrista rotundifolia*, *Lotononis bainesii*, *Trifolium semipilosum* and *Vigna parkeri*. Optimum settings vary for different species and cultivars, the main factors being the abrasive grade of the wheel, its speed of rotation and the length of time taken for seed to pass through the machine.

During harvest, some degree of mechanical scarification may also occur, depending on the method used. Hand-harvested samples tend to have higher percentages of hard seeds than mechanically harvested samples. Similarly, mechanical processing and cleaning will soften more legume seeds than manual methods.

HARDSEEDEDNESS IN RELATION TO FIELD ESTABLISHMENT

Legume establishment depends on the interaction of biological, environmental and management variables. Our knowledge of these factors can be used in predictive relationships leading to enhanced establishment and hence greater production, profitability and other benefits (Gardener, 1981; Gramshaw *et al.*, 1993).

Among the biological aspects to be considered are levels of hardseededness and rates of breakdown. As discussed, dehulling of podded seeds and mechanical scarification can fracture the testa, allowing rapid imbibition of water followed by germination, while heat treatment or sudden physical shocks breach the strophiole. The course of germination in populations of soft seeds is related directly to the route of water penetration, either immediately through fractures or slowly through the strophiole (Hopkinson, 1993b). Scarified seeds imbibe water rapidly,

while water penetration through the strophiole is much slower. Consequently, scarified and strophiole-softened seeds have different rates of germination and different survival patterns under field conditions.

Hopkinson (1993a) reported rapid and high germination levels from scarified seed of *S. scabra* cv. Seca in the field, but also relatively high seedling mortality (apparently from pathogens that invade damaged tissues after scarification). Strophiole-softened seeds of 'Seca', on the other hand, produced better legume stands, particularly under limited rainfall conditions. This is significant, because seedbed moisture availability is a key factor in determining the success or failure of legume establishment in the tropics. It is therefore very important to know the category of soft seed being used when planting, because of differences in the water absorption and germination patterns for each category in the field. In tropical areas with reliable rainfall, batches of seed with high proportions of scarified seed (i.e. with damaged testas) are likely to give good establishment. Scarified seeds germinate quickly on the first rainfall and have a better chance of out-competing weeds than the slower germinating strophiole-breached seeds. Conversely, in environments with intermittent moisture supply, scarified seed is apt to germinate quickly on limited moisture and to desiccate during subsequent dry periods, whereas the strophiole-breached seed tends to germinate when there is ample moisture for subsequent growth. Consequently, a desirable seed batch might contain a mix in equal proportions of scarified, strophiole-breached and hard seeds.

CONCLUSIONS

Hardseededness is an important aspect of seed quality in relation to legume establishment. Mechanical, chemical and hot-water treatments, as well as high constant and alternating temperatures, are used to overcome hardseededness. However, the rate of water absorption (and hence the outcome of germination) by individual seeds differs, depending on whether the testa has been damaged or the strophiole breached.

More information is needed on appropriate ways to optimize legume establishment by overcoming hardseededness. However, some observations can still be made.

1. Each seed lot should be considered individually when choosing a method for reducing its hard seed content. Aspects such as the proportion of hard seed, moisture content, species, seed morphology, climate at the planting site and quantity of seed to be treated need to be considered.
2. There are ample methods for treating small quantities of hardseeded legumes, but no one technique for the rapid treatment of large, commercial quantities that will give predictable results for a variety of seed types.
3. Further research is required on treatments that will give variable proportions of strophiole-breached and scarified seeds.