Tropical pasture establishment.
5. Improved handling of chaffy grass seeds: options, opportunities and value

D.S. LOCH
Department of Primary Industries, Gympie, Queensland, Australia

Abstract

Many useful grasses have 'chaffy' seeds characterised by a range of appendages: awns, sterile spikelets, and surface hairs or bristles. *En masse,* chaffy seeds are light and bulky, and do not flow freely because the individual units tend to become entangled. These attributes add to costs of seed cleaning, testing, storage and transport, and make it impossible to sow chaffy seeds evenly through conventional seeders.

Examples are given of the structural diversity among chaffy grass seeds. The functions of hygroscopic awns and other appendages during establishment are examined, indicating situations where intact seeds (including chaffy appendages) should be sown, and others where structural modification to improve seed handling and distribution would enhance establishment.

Processing methods to remove some or all of the chaffy appendages are reviewed. Machinery available includes hammer mills, de-bearders, brush polishers and de-awners, and cone, belt and filament threshers, as well as equipment for flame treatment and aerodynamic conditioning. Trimming of the normal chaffy seed units is generally preferable to the complete removal of caryopses, especially where caryopses are tightly held within the surrounding floral husk. Leaving a protective husk around the caryopsis reduces the risk of physical damage during processing and improves the reliability of field establishment under marginal moisture conditions.

Processing removes 40% or more of the original weight as inert matter. The advantages of higher seed quality and more uniform seed delivery during sowing, as well as the compensatory effect of lower seeding rates on costs per hectare, should be emphasised in price-sensitive markets. In some situations, artificial coatings applied to processed seeds may also facilitate sowing and improve the competitive ability of establishing seedlings.

Correspondence: Dr D.S. Loch, Queensland Department of Primary Industries, PO Box 395, Gympie, Qld 4570, Australia

Introduction

Many useful pasture and amenity grasses have so-called 'chaffy' seeds. In contrast to the smooth, free-flowing seeds produced by other grasses (see Figures 1 and 2), chaffy seeds are characterised to varying degrees by a range of appendages that interfere with their separate and independent movement, in many cases limiting their commercial use. *En masse*, they are light and bulky and do not flow freely because the individual dispersal units become entangled. For economic species, these characteristics cause problems of handling and space from harvesting through to sowing. Harvesting of chaffy grass seeds with conventional combine harvesters taxes their sieving and seed-transport capabilities and can result in very 'strawy' samples; seed cleaning and testing are slow, difficult and expensive; storage and transport of such light, bulky seeds are costly; and uniform distribution of individual seeds with conventional sowing equipment is impossible.

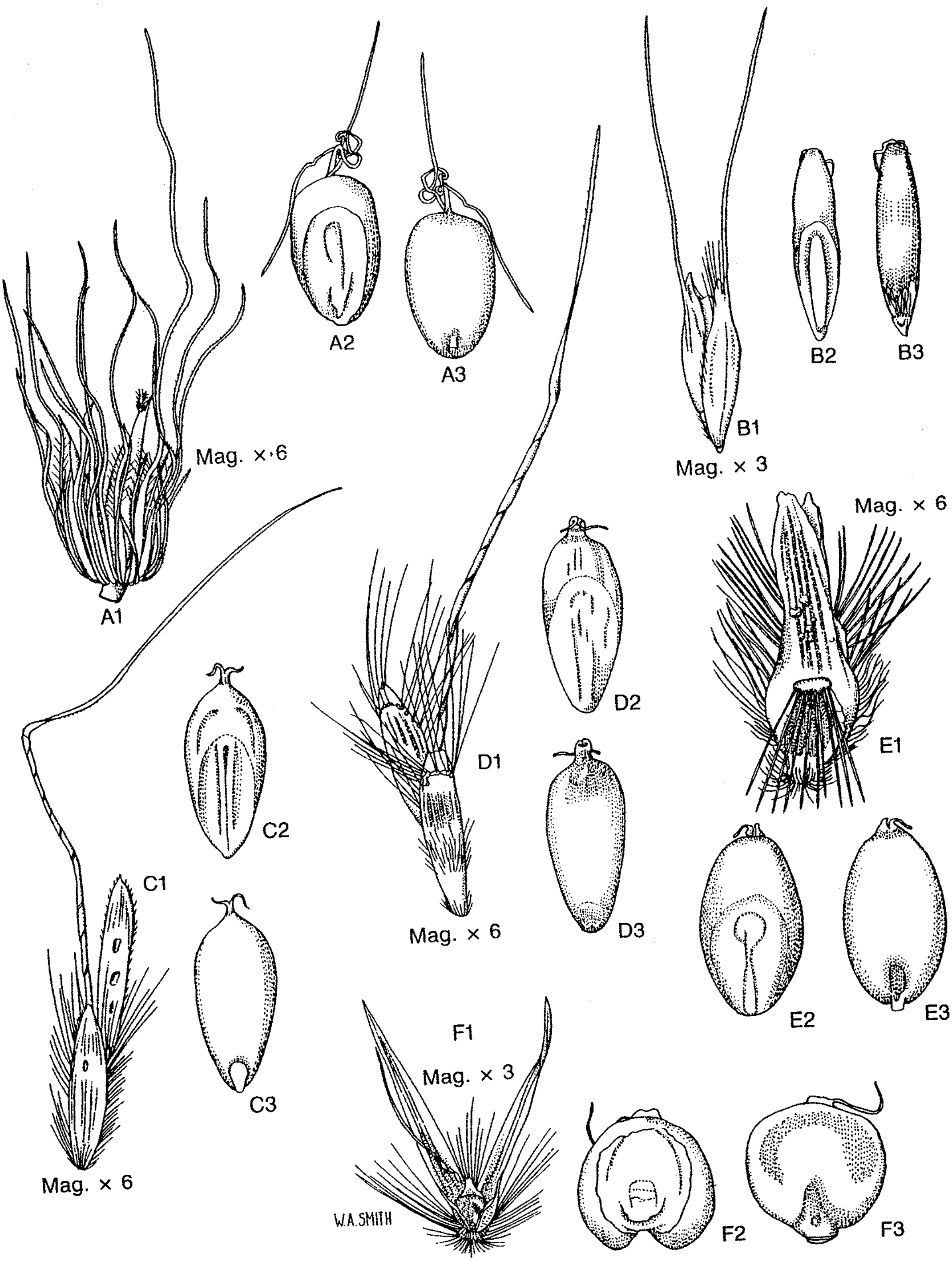

Figure 1. Dispersal units and caryopses of representative chaffy-seeded grasses: $\mathbf{A}_{1\text{-}3}$ *Cenchrus ciliaris* cv. Gayndah; $\mathbf{B}_{1\text{-}3}$ *Chloris gayana* cv. Callide; $\mathbf{C}_{1\text{-}3}$ *Bothriochloa insculpta* cv. Bisset; $\mathbf{D}_{1\text{-}3}$ *Dichanthium sericeum*; $\mathbf{E}_{1\text{-}3}$ *Thyridolepis mitchelliana*; $\mathbf{F}_{1\text{-}3}$ *Monachather paradoxa*. Subscript numbers refer to dispersal units (**1**), abaxial view of caryopsis (**2**), and adaxial view of caryopsis (**3**).
Magnification rate = × 12 unless otherwise stated.

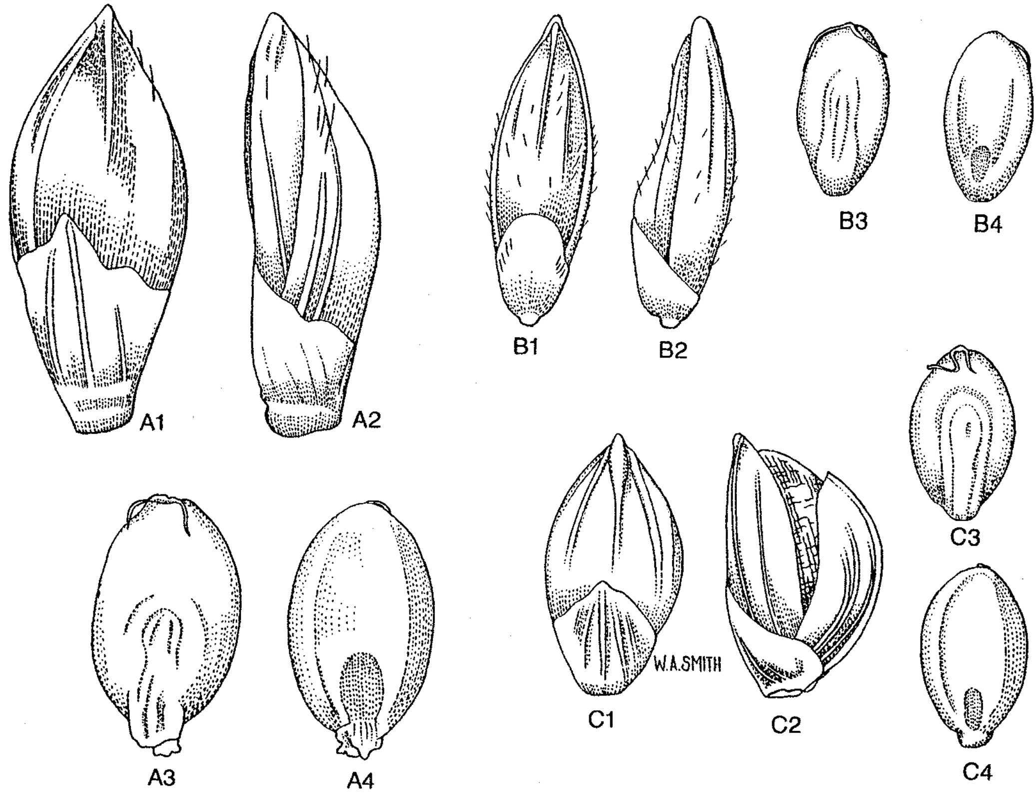

Figure 2. Dispersal units and caryopses of some smooth-seeded panicoid grasses: $\mathbf{A}_{1\text{-}4}$ *Brachiaria decumbens* cv. Basilisk; $\mathbf{B}_{1\text{-}4}$ *Panicum maximum* var. *trichoglume* cv. Petrie; $\mathbf{C}_{1\text{-}4}$ *Setaria incrassata* cv. Inverell. Subscript numbers refer to abaxial (1) and side (2) views of dispersal units, and abaxial (3) and adaxial (4) views of caryopsis.
Magnification rate = × 12.

Many of these grasses, particularly from the *Andropogoneae*, are able to grow on low fertility soils and to stabilise and rehabilitate degraded land (Hopkinson 1990; Loch 1991). This applies both to temperate and tropical grasses, and to exotic species as well as several natives (e.g. *Bothriochloa, Danthonia, Dichanthium* spp.) now being developed for commercial use (Dowling and Garden 1990). Improvements in harvesting technology have been facilitated by the development of brush harvesters in Oklahoma, USA (Dewald and Beisel 1983) and their subsequent adoption and adaptation for similar chaffy-seeded grasses in Australia (Loch *et al.* 1991; Jensen *et al.* 1993). Complementary advances in processing are needed so that chaffy seeds can be marketed in a form that is easier to handle.

As tropical seed markets become more sophisticated, the need for effective, commercial methods of treating chaffy seeds to improve their flow during planting is increasing (Loch 1991). Treatment will involve removal of some or all of the inert appendages that restrict seed flow, possibly used in conjunction with improved seed-coating technology to enhance establishment. These matters are considered in the present paper.

Structure and form of some chaffy grass seeds

While there is little variation in flower structure among members of the *Poaceae*, their dispersal units (or diaspores) show considerable differences in structure and form. In chaffy-seeded species, the dispersal units include one or more appendages that contribute to their characteristically 'fluffy' appearance: a hygroscopically active awn with one or more knees at which bending or flexing can occur; a rigid hygroscopically passive awn; a mucro; long or short hairs on the spikelet surface; attached sterile spikelets; and antrorse (i.e. backwardly pointing) short hairs or stiff bristles around the base (= callus).

The following examples, drawn from the more important or promising economic species, demonstrate both the taxonomic diversity and the wide range of form and structure in the dispersal units of chaffy-seeded grasses (Figure 1). Attention is also drawn to the shape of different caryopses because this is a major factor in determining their vulnerability to physical damage. More detailed descriptions are available from various Floras and other published sources (e.g. Bogdan 1966; Oram 1990).

Cenchrus ciliaris (*Tribe:* Paniceae)

'Seeds' of *C. ciliaris* (buffel grass) are sold in the form of fascicles, each consisting of clusters of spikelets (usually 1–3) surrounded by an involucre comprising 2 rows of wavy bristles. An individual spikelet consists of 2 papery glumes and 2 florets, each with soft papery lemma and palea. The upper floret can produce a caryopsis more or less oblong in shape and dorsally compressed.

Chloris gayana (*Tribe:* Cynodonteae)

In *C. gayana* (rhodes grass), the 'seed' comprises the whole spikelet minus the glumes which are not shed as part of the dispersal unit at maturity. It consists of 2–5 florets, with 2 rigid passive awns (arising from lemma apices on the lower 2 florets) and a sharp hairy callus at the base. The lemma of the lowest floret is fringed with hairs forming a characteristic 'brush' near the top, with a short prominent nerve (usually hairy) on each side. Most caryopses form in the lowest floret, and are spindle shaped (i.e. elongated and rounded) with a more exposed embryo than other grasses discussed.

Bothriochloa, Dichanthium *spp.* (*Tribe:* Andropogoneae)

Dispersal units of *Bothriochloa* and *Dichanthium* species typically consist of a rachis internode and 2 attached spikelets, one a sessile spikelet (fertile) with a long hygroscopically active awn and the other an awnless pedicelled spikelet (sterile). Most of the sterile spikelets and some of the awns become detached during seed harvesting and cleaning. The 'seeds' also have short hairs and bristles on the glumes and a bearded callus at the base. Caryopses are more or less elliptical in shape, somewhat elongated and dorsally compressed, and have relatively exposed embryos. The examples in Figure 1 are *B. insculpta* (creeping bluegrass) and *D. sericeum* (Queensland bluegrass).

Thyridolepis mitchelliana (*Tribe:* Neurachneae)

The dispersal unit of *T. mitchelliana* (mulga mitchell grass) is the spikelet. It consists of 2 florets, the lower sterile and the upper one fertile. The caryopsis is shortly elliptical in shape and dorsally compressed. Unlike most of the preceding grasses, *T. mitchelliana* lacks a distinct awn but has long, dense surface hairs and bristles on the glumes.

Monachather paradoxa (*Tribe:* Arundineae)

In contrast to the other chaffy seeds discussed, the spikelets of *M. paradoxa* (mulga oats) break up at maturity. Each floret then represents a dispersal unit conspicuous for the elongated lemma lobes and the dense surface hairs on the lemma; the caryopsis is more or less circular in outline and dorsally compressed. The closely related *Danthonia* spp. (wallaby grasses) are also dispersed as individual florets.

Comparison with smooth-seeded grasses

Dispersal units of smooth-seeded (slick-seeded) grasses in the tribe *Paniceae* (Figure 2) vary in size between species, but typically are spikelets, each with 2 florets of which only the upper one is fertile. The caryopsis is held tightly within the hard, stiff lemma and palea. There are no awns and the surrounding glumes may be glabrous or have very short (insignificant) surface hairs. As a result, the 'seeds' are smooth and dense, and flow easily without becoming entangled. The challenge is to remove some or all of the appendages from chaffy seeds so that they also can flow freely.

Function of chaffy seed appendages

At the outset, it is important to understand the functions of the various chaffy seed appendages and to identify any beneficial effects they might have during establishment. There is little point in trying to remove these appendages if the outcome is likely to be deleterious to field establishment.

Awns

There has been considerable speculation about the function of hygroscopic awns, but comparatively little experimental work to validate hypotheses until recently. The action of such awns was first described by Zohary (1937) whose work led to the belief that their primary function was to bury the attached caryopsis by drilling it into an unbroken soil surface (Stebbins 1971, 1974; Pijl 1972). Some lateral creeping movement was also proposed (Pijl 1972), propelling the diaspore into a crack or hole in the soil surface or perhaps under the cover of a stone, a clod of earth or surface litter (Tothill 1969).

Glasshouse and field experiments on a range of grasses in New Zealand (Simpson 1952), Australia (Peart 1979, 1984; Peart and Clifford 1987; Sindel *et al.* 1993) and South Africa (Adams and Tainton 1990) supported a dispersal role for hygroscopically active awns, but provided little evidence to substantiate the widely held seed-burying hypothesis. Diurnal fluctuations in relative humidity produce alternate wetting and drying cycles which cause the awns to twist, moving the attached diaspores laterally across the soil surface until they become lodged firmly in favourable microsites. Sindel *et al.* (1993) found that, when moving diaspores come into contact with obstructions such as stones and cracks, the hygroscopic awn (if still in contact with the soil) pushes the seed firmly into the microsite; there the antrorse bristles at the base anchor the seed and help to counter the force of the radicle pushing into the soil during germination (Peart 1979). In contrast, de-awned seeds generally remain immobile on the soil surface and fail to locate more favourable microsites for germination (Sindel *et al.* 1993). Species with hygroscopic awns tend to predominate on well-structured clay soils which either produce loose crumby surfaces or crack on drying; Peart and Clifford (1987) attributed this to their competitive advantage in locating suitable microsites.

Awned diaspores tend to become entangled, forming 'seed balls' that can act as a sail for wind dispersal, but are not considered a major factor in the overall movement of seeds (Pijl 1972; Adams and Tainton 1990; Sindel *et al.* 1993).

Hygroscopically passive (rigid) awns lack the capacity for lateral movement on the soil surface. Instead, their function is to orientate the falling diaspore, increasing the chances that it will land in a standing orientation with its callused end embedded in the soil surface (Peart 1981; 1984). This position is advantageous during establishment because it enables the antrorse bristles at the base or on the body of the seed to anchor it firmly and helps to counter the force of the radicle penetrating the soil during germination.

The awn may also aid animal dispersal of seeds (Pijl 1972), helping diaspores to adhere to the hair or skin so that they can be transported. Limited experimental support for this view comes from Agnew and Flux (1970) who recorded *Themeda triandra* diaspores (some embedded below the skin) from 15% of hares examined at one of their Kenyan study sites where *T. triandra* was common. Peart (1979), however, examined about 100 carcasses of wild marsupials near Gatton in southern Queensland, but could not find any awned grass diaspores in their fur.

Other chaffy structures

Compared with work to define the functions of awns, much less attention has been paid to the role of other chaffy appendages and the floral 'husk' (lemma, palea, glumes) surrounding the caryopsis. Stebbins (1974) postulated a protective function (mainly from predators) for the husk and possibly a dispersal role for the surface hairs.

These chaffy structures also have a marked influence on moisture relations around the caryopsis during germination. As a result, establishment with naked caryopses is more sensitive to weather conditions than with untreated seeds. This has been demonstrated in field experiments with *C. ciliaris* in Queensland (Grof 1957; Humphreys 1958) and east Africa (Brzostowski 1961): satisfactory stands were established using very low seeding rates of hammer milled caryopses, but only under favourable conditions. Naked caryopses absorbed moisture faster and germinated more rapidly, more completely and after a smaller rainfall event than the intact fascicles, but were more susceptible to loss in the absence of follow-up rain. These results were attributed both to better seed-soil contact for germination and to the more rapid drying of naked caryopses without the chaffy fascicle to help retain moisture. With freshly-harvested seed (Grof 1957; *cf.* Brzostowski 1961), the more rapid and complete germination of naked caryopses may also be due to removal of the chemical inhibitors in the husk that are largely responsible for post-harvest dormancy in *C. ciliaris* (Hacker 1989; Venter and Rethman 1992).

Scope for removal of chaffy appendages

Seeds with their chaffy structures intact should generally be used for pasture sowings on rough seedbeds. In particular, the presence of hygroscopic awns can be expected to improve establishment through lateral movement where favourable microsites are limited. Field studies by Simpson (1952), for example, showed that 'awned' diaspores of *Danthonia penicillata* produced 12 times as many seedlings on a roughly prepared seedbed as did 'de-awned' diaspores.

In contrast, there seems little or no advantage in using awned rather than de-awned seeds for pasture sowings on well prepared seedbeds with an abundance of favourable microsites for establishment. For these situations and for alternative uses (e.g. land stabilisation, amenity or turf use), emphasis is placed on sowing seeds easily and uniformly, preferably with conventional planting equipment. These markets are also more accustomed to a higher quality, more uniform product than is the case with unmodified chaffy grass seeds. Removing the various appendages (awns, sterile spikelets, short surface hairs) that restrict the flow of chaffy seeds is an important step towards meeting these different market needs.

Complete de-hulling of caryopses is a more extreme option than de-awning and removal of other chaffy appendages. Naked caryopses may be easier to sow with conventional planting equipment, but the risk of establishment failure is higher because the amount and distribution of rainfall (or irrigation) are critical. In general, naked caryopses should be sown only where good soil moisture can be assured (e.g. through irrigation).

Sowing unmodified seeds

Relatively inexpensive but specialised planters have been developed for sowing unmodified chaffy seeds, including air seeders and drum seeders (Cavaye 1990). Some other equipment can also be used or adapted for this purpose (e.g. the fertiliser box of a combine planter, fertiliser spreaders) and aerial seeding has been widely used, particularly with *C. ciliaris*. Invariably, the distribution of individual seeds by these methods is uneven and actual seeding rates fluctuate considerably, though results are generally acceptable for large-scale plantings at low cost per hectare.

Problems of sowing chaffy grass seeds evenly and at a reasonably constant rate led to the development of an inexpensive chaffy-seed drill in Texas, USA during the late 1970s. This design is now widely used for rangeland seeding in the USA where it has become the industry standard and is built commercially by at least 6 manufacturers (Wiedemann and Cross 1990), but has not been used in Australia despite its apparent potential. It combined a semi-circular seedbox with an auger agitator and a pickerwheel delivery system for more accurate metering of seeds (Wiedemann *et al.* 1979; Wiedemann and Cross 1981). Experiments with a range of difficult seeds including *Bothriochloa caucasicus* and *C. ciliaris* showed that at least 97% of seeds in the box could be dispensed through this system (Wiedemann 1982; 1983). Although variation in seeding rate was much less than with previous rangeland drills, it was still evident with declines of 14 and 33% in the seeding rate of *B. caucasicus* and *C. ciliaris*, respectively, by the time three-quarters of a full seedbox had been sown. This illustrates the virtual impossibility of achieving uniform seeding rates with chaffy seeds unless their handling characteristics can be improved.

Treatment to improve physical properties

Required outcomes

Depending on the particular species and the end use, treated seeds may be reduced either to a caryopsis closely surrounded by the 'husk' from fertile spikelets or florets, or to naked caryopses where the surrounding husk is completely removed. For any process of physical modification to be judged successful, chaffy seeds must be treated without significant physical damage to caryopses and at a sufficiently high rate per hour to minimise the cost of treatment and make processing commercially viable. The risk of associated damage is greater where naked caryopses are extracted, either because the caryopses are not strongly held within the husk (e.g. *C. gayana* cf. *Bothriochloa* spp., *C. ciliaris* — Loch *et al.* 1985; 1988) or because of more aggressive treatment. The risk of damage is also greater if the individual caryopses are elongated and with more exposed and easily damaged embryos (e.g. *Bothriochloa* spp., *C. gayana*) than on shorter, more compact caryopses with better protected embryos (e.g. *C. ciliaris)* (see also Figure 1).

Equipment

A variety of equipment has been used, proposed or recommended for the treatment of chaffy grass seeds to remove inert appendages and even the 'husk' around the caryopsis.

Hammer mills. Conventional hammer mills have been used to process difficult-to-handle grass seeds for almost 60 years (Weber 1939) with outcomes ranging from de-awning through to complete dehulling of caryopses. After treatment, the processed material is cleaned to remove light inert matter and return unprocessed seeds to the hammer mill.

Much of this activity has taken place in the Great Plains region of USA and has covered a wide variety of mainly native grasses (including *Andropogon, Bouteloua, Calamovilfa, Elymus, Oryzopis, Sorghastrum* and *Stipa* spp.) as well as introduced grasses like *Bothriochloa ischaemum* (Weber 1939; Schwendiman *et al.* 1940; Smith 1946; Hoover *et al.* 1947; Stoesz 1952; Kneebone and Brown 1953; Cooper *et al.* 1957; Ahring *et al.* 1964; Atkins and Smith 1967). Investigations have also been carried out in Zimbabwe (Schwim 1952) and Australia (Grof 1957) with *C. ciliaris* and *C. gayana*.

Operating recommendations have remained virtually unchanged (Hoover *et al.* 1947; *cf.* Cooper *et al.* 1957; *cf.* Atkins and Smith 1967). It has long been recognised (e.g. Weber 1939; Schwendiman *et al.* 1940; Hoover *et al.* 1947) that the outcome depends on cylinder speed, size and shape of screen perforations, and rate of feed.

To minimise seed damage, cylinder speed should be reduced to less than half the normal grinding speed. Depending on the species, safe operating speeds for a 25 cm cylinder range from 600–1400 rpm, but must be reduced with larger diameter cylinders to maintain an equivalent peripheral hammer speed. In general, the longer the caryopses relative to their thickness, the slower the cylinder speed must be to minimise breakages.

Screen perforations should be slightly larger than the modified seed units to be accommodated. Dehulling of caryopses therefore requires smaller holes than simply 'trimming' the seed units and leaving the surrounding husks intact. Slotted openings provide a better fit for long narrow seeds, causing less breakage than round holes. Cylinder speed and screen size do not operate independently: for example, near optimum results can be achieved with a coarser screen than necessary, provided cylinder speed is also increased slightly to compensate.

A hammer mill should be fed to its full capacity. The large amount of unprocessed material in the cylinder then provides a cushioning effect to negate the grinding action of the hammers. If the rate of feed drops and cylinder speed stays the same, the level of seed damage will increase because the cushioning effect is reduced. For the same reason, hammer milling should start at a slow speed until the cylinder has been filled with seed.

Skill and experience of the operator are important factors in successful hammer milling of grass seeds. Over-aggressive processing can cause excessive cracking or breakage of caryopses, leading to lower germination and shorter storage life (e.g. Hoover *et al.* 1947; Grof 1957; Ahring *et al.* 1964); but if processing is not sufficiently aggressive, fewer seed units will be modified and more material will need reprocessing (Atkins and Smith 1967). Repeated trial runs are necessary to adjust the machine properly at the outset.

The rate of processing varies for seeds of different grasses and is generally slowest for species with low bulk density (i.e. forming light, fluffy masses). For example, Schwendiman *et al.* (1940) reported approximate hammer milling rates of 90–360 kg/h for a range of 7 North American grasses.

De-bearder. A de-bearder consists of a motor-driven rotor with several steel fingers operating offset and among stationary fingers inside a steel drum. Its mixing action rubs and stirs dried seeds, breaking off awns and other appendages. As such, de-bearders offer a more gentle and potentially less damaging alternative to the striking action of hammer mills with chaffy grass seeds.

Atkins and Smith (1967) suggested using a de-bearder for this purpose, but gave no details of processing or any attendant hazards. Brown *et al.* (1983) later used a de-bearder (followed by a standard air-screen cleaner) to improve purity, germination and handling qualities of *Andropogon gerardii* and *Sorghastrum nutans* seeds; viability was maintained in storage for up to 3 years, indicating no apparent seed damage.

Cone thresher. A range of chaffy grass seeds can be treated through a resilient tapered (cone) thresher. As seed passes through the machine, the resilient surface on the inner rotor rubs it against a second resilient surface lining the stationary outer cone. This facilitates subsequent cleaning (mainly by aspiration), though long straws should be removed before cone threshing to avoid breaking them into fine fragments that are more difficult to remove.

Loch *et al.* (1985; 1988) showed that analytical purity could be increased considerably with little or no reduction in germination, even after storage for up to 20 months. In *C. gayana* where caryopses are not strongly held within the surrounding husk, the majority were easily dehulled. In most species, however, treatment produced <5% of naked caryopses and the main effect was to 'trim' the chaffy seed units by removing awns, sterile spikelets and some surface hairs (*Andropogon gayanus, Bothriochloa insculpta, B. pertusa, Hyparrhenia hirta, H. rufa*). There was also scope for shortening or removing stiff bristles on involucres of *C. ciliaris*, but the degree of modification was generally less than in *A. gayanus* and the *Bothriochloa* and *Hyparrhenia* spp. Where cone threshing produced few naked caryopses, longer narrow ones (e.g. *A. gayanus, B. insculpta*) seemed more prone to damage than shorter compact caryopses with less exposed embryos (e.g. *C. ciliaris*) (see also Figure 1).

In all cases, the end product was less bulky, higher quality seed that flowed more readily than unprocessed samples. Due to the cushioning effect of the resilient linings, there was a reasonable degree of tolerance between the desired result and excessive seed damage. The rate of processing (10–25 kg/h with 300 mm cone diameter) was not commercially viable, but could be raised to more acceptable levels by increasing the size of the cone.

Belt thresher. Belt threshers consist of 2 endless belts operating face-to-face and moving at different speeds in the same direction, in either the vertical (Berlage *et al.* 1986) or the horizontal plane. Spring-loaded pressure plates behind each belt help to maintain a small but uniform clearance between the operating surfaces. Intensity of threshing can be increased by a greater speed differential between belts, by increasing contact pressures on the belts, and by choosing belts with a rougher surface texture.

Preliminary evaluations of a belt thresher were made (D.S. Loch, unpublished data) before identifying the cone thresher as a better option. Both machines rub seeds between 2 resilient surfaces; in the belt thresher, some seeds can be lost over the edges of the belts during processing, whereas the cone thresher retains all seeds within the threshing chamber until discharged.

Brushing machines[1]. In preliminary tests by D.S. Loch and V.A. Harrison (unpublished data), a Le Coq Clover Polisher model 510® was effective in dehulling *C. gayana* caryopses and in removing chaffy appendages from *B. insculpta* seeds. Processing rates of 50–60 kg/h were achieved. Samples fed into the horizontal cone-shaped polishing chamber were rubbed against the surrounding mesh screen (0.83 mm apertures) by nylon brushes rotating at 945 rpm. Fine material (including caryopses and trimmed seed units) passed through the screen, while oversized material was discharged at the end of the chamber after repeated rubbing. In *C. gayana* cv. Callide, processing extracted 50–70% of caryopses from the surrounding husks, especially the larger caryopses, though only 2% of these were visibly damaged. With *B. insculpta* cv. Hatch, the clover polisher removed awns and sterile spikelets, but left most of the short surface hairs (*cf.* cone threshing) which were still a minor restriction on handling. As with cone

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

threshing, visible physical damage to the small proportion (1%) of naked caryopses removed in *B. insculpta* was much greater than in *C. gayana*. In both species, caryopses remaining within protective husks retained their viability in storage, whereas naked caryopses deteriorated more rapidly, dropping to 50–70% of the control germination level in tests 29 months after processing.

Similar outcomes were achieved using a Westrup LA-H Laboratory Scarifier® (D.S Loch and D.B. Churchill, unpublished data — Table 1). In this machine, seeds were rubbed against a horizontal cylindrical woven wire screen (0.97 mm openings — *C. gayana* cv. Callide; 1.27 mm openings — *B. insculpta* cv. Bisset) by coarse brushes rotating at 400 rpm. After processing, inert matter was easily removed by screening and aspiration, raising purity levels and reducing sample weights by 52% and 75% in *B. insculpta* and *C. gayana*, respectively. Processed seeds deteriorated more rapidly in storage, though little or no effect on germination was evident 8 months after treatment. About 55% of naked caryopses were extracted from *C. gayana* with no visible injury; these were mainly the larger caryopses with higher germination. *B. insculpta* caryopses again tended to remain within their protective husk minus the awns and sterile spikelets, though more naked caryopses were extracted (*ca.* 6%) and more short surface hairs were removed than with the Le Coq polisher, probably due to the coarse brushes used.

Filament thresher. An experimental filament thresher was designed by Bilsland and Berlage (1987) to remove seed appendages from a range of specialty, low volume, high value flower and crop seeds. It consists of a number of spools of threshing filament (nylon monofilament fishing line) mounted on a rotor shaft in a vertical cylinder. Seeds are fed in through a side entry port. A vacuum applied at the top of the cylinder removes light inert material, while heavy processed seeds fall through the discharge at the lower end as their terminal velocities are increased by processing.

In preliminary trials, the filament thresher proved too severe on *C. gayana* cv. Callide seed, causing physical damage to two-thirds of the caryopses extracted (D.S Loch and D.B. Churchill, unpublished data). It was more effective with *B. insculpta* cv. Bisset where caryopses were protected by the persistent husks; the purity level was almost doubled by processing and the trimmed seed units flowed easily. However, the rate of processing was quite slow, making the filament thresher better suited to very high value, low volume seeds rather than 'bulk' commodities like grass seeds.

Flame treatment. Attempts to remove chaffy appendages from various seeds using naked flames (Schwendiman *et al.* 1940; Schwim 1952; Grof 1957; Pogue 1983) have usually proved unsuccessful, often damaging a high percentage of the seeds. For example, dropping *B. insculpta* seeds through gas flames from strip burners removed inert matter, reduced sample weights by 40–50%, and resulted in higher purity levels and smaller individual seed units (D.S. Loch, unpublished data — Table 2). However, many of the caryopses were damaged, causing drastic reductions in germination.

Dropping seeds of *C. ciliaris* through a series of mild flame treatments, however, produced no detrimental effects on germination (Pogue 1983).

Table 1. Effects on clean seed quality of brushing seeds of *Bothriochloa insculpta* cv. Bisset and *Chloris gayana* cv. Callide through a woven wire screen.

Species	Treatment	Purity[1]	1000-seed weight[2]	Germination[3] 8 mth	Germination[3] 24 mth
		(%)	(g)	(%)	
Bothriochloa insculpta	Control	38	0.94	77	61
	Brushed product	52	0.81	74	48
Chloris gayana	Control	72	0.23	43	38
	Brushed product	99	0.27	51	34

[1]International purity method.
[2]*B. insculpta* 'seeds' = caryopses + floral husks;
C. gayana 'seeds' = caryopses only.
[3]Germinated 8 months and 24 months after processing: 21-day counts (water, light, 20/35 °C), 4 × 100 seeds per treatment.

Table 2. Effects of flame treatment on seed quality of *Bothriochloa insculpta* cv. Hatch.

Treatment	Purity[1]	1000-seed weight	Germination[2]
	(%)	(g)	(%)
Control	58.9	0.956	80
Single burner (one pass)	81.3	0.840	46
Single burner (two passes)	93.3	0.808	27
Single burner (three passes)	95.9	0.806	18
Double burner (one pass)	81.8	0.828	27
LSD (P = 0.05)	2.0	0.031	7

[1]International purity method.
[2]Germinated one month after flame treatment: 21-day counts (water, light, 20/35 °C), 2 × 100 seeds per treatment.

R.J. Bateman (personal communication) also found that *C. ciliaris* seeds could be safely passed through a gas flame. These results suggest that the bristles on involucres of *C. ciliaris* protect the enclosed caryopses from burning more than the chaffy structures in most other grasses.

Aerodynamic conditioning. A radically different approach to the processing of chaffy grass seeds has been taken in the Woodward Chaffy Seed Conditioning System designed by Aaron Beisel in Oklahoma and subsequently developed as described by Dewald *et al.* (1983; 1986; 1987). This system is centred around aerodynamic principles, but also integrates prior mechanical conditioning to improve the efficiency of aerodynamic processing. The aerodynamic components of the Woodward system have been developed as a small bench-top model (the Woodward Laboratory Air-Seed Shucker) designed for rapid determination of caryopsis content in samples of chaffy grass seeds, and as a large commercial unit (the Woodward Commercial Air-Seed Shucker).

The large-scale Woodward system starts with a variable-speed, tumbling basket dispenser to break up the entangled material and deliver seeds and trash uniformly on to an inclined scalping screen that oscillates at high, though variable, speed. The scalper separates individual seeds and removes stems, leaves and other light debris that would otherwise clog up the aerodynamic components. Heavier material passing through the scalper is accelerated in a jet of air before being segregated into density (quality) classes in a momentum-discrimination chamber. In contrast to conventional winnowing, the heavier, high quality seeds gain more momentum than chaff or low quality seeds — hence they travel further through the discrimination chamber before settling out as a result of inertia.

Aerodynamic conditioning here serves a dual purpose. Firstly, the air blast and resulting acceleration force detach some or all of the chaffy appendages, and even the husk surrounding the caryopsis if the force is high enough; in extreme cases, however, complete dehulling can cause significant physical damage to naked caryopses (D.S. Loch and C.L. Dewald, unpublished data) as with other processing alternatives already discussed. Secondly, the accelerated seeds undergo momentum discrimination to achieve quality classification.

Marketing of modified seeds

After processing and cleaning, modified seeds can be planted without further treatment. The major advantages are consistently higher seed quality and more uniform seed delivery during sowing. In addition, planting rates can be reduced because of the concentration of equivalent numbers of germinable units into smaller weights of seed.

The cost of seed per hectare should remain about the same or perhaps increase slightly, reflecting the added costs of processing. Essentially, lower planting rates will be offset by increases in the price per kilogram, which must inevitably accompany reductions in weight: for example, cleaned processed weights are about 40–60% of the original for husked seeds of *Bothriochloa* spp. (Loch *et al.* 1985; 1988) and usually 25% or less for naked caryopses of *C. gayana* (D.S. Loch, unpublished data). This point must be emphasised to counter possible buyer resistance in price-sensitive markets.

Seed coating

Handling of chaffy seeds can also be improved by coating them before sale. Although the intact dispersal units are normally used, coating of processed seeds would be preferable, thereby reducing the amount of coating material that must be applied. In certain situations, this may offer complementary benefits during establishment.

The range of artificial seed coatings available and their effects on establishment were recently reviewed by Scott (1989). 'Seed coating' is a general term for the application of finely ground solids or liquids containing dissolved or suspended solids to form a more-or-less continuous layer covering the natural seed coat. It also covers more specific terms such as 'seed pelleting' which involves the application of solid materials to seeds in sufficient quantity to make the pelleted seeds substantially larger and/or heavier and approaching a spherical or elliptical shape.

In the tropics and subtropics, seed coating has not been widely used commercially and has been largely neglected by research workers. Most of the available commercial technology and coating recipes are confidential proprietary information. In general, the older, heavier coatings in commercial use are lime-based and, depending on their thickness, can add inert material at a rate of 100–400% or more of seed weight. In contrast, recently developed polymer-based film coatings increase seed weight by 5% or less depending on the particular additives (Powell and Matthews 1988; Scott 1989).

The heavier coatings improve seed ballistics. This ensures that grass and legume seeds behave similarly during sowing, reducing the tendency for different fractions to separate out when broadcast by air or through a fertiliser spreader. Increasing unit size and weight also enables more precise and uniform sowing of very small seeds. In practice, however, the economics of using these heavier coatings is doubtful, with up to three- to four-fold cost increases calculated from the weights of coated and uncoated seeds required to plant equivalent numbers of viable seeds (S.J. Cook, personal communication).

Seed coating is seen as a way of improving the competitive ability of seedlings during establishment, ensuring that more seeds germinate and that these will grow more rapidly. This should provide opportunities to reduce costs through lower seeding rates. Commercial seed coatings incorporating registered fungicides and insecticides to control insect pests and diseases are available. The apparent benefits of such additives, particularly different insecticide formulations, are evident in results from preliminary field experiments with proprietary polymer-based seed coatings at 2 sites near Gympie (D.S. Loch, unpublished data — Table 3). Trends at both sites were similar, even though good germinating rains were received at Spring Valley 5 days after sowing while the Brooyar experiment remained dry for more than a month before germinating progressively on a series of light falls of rain.

The inclusion of specific nutrients to enhance early seedling growth and herbicide antidotes (or 'safeners') to protect seedlings from pre-emergence herbicides has been less successful. In particular, the effectiveness of nutrient coatings depends on a number of factors including species, type of coating, time of sowing, and soil type, fertility and texture. As Scott (1989) concluded, there is little likelihood of developing a universally effective nutrient coating for seeds. There is also a significant risk of injury from concentrated nutrient salts if placed too close to the germinating seed.

The use of either hydrophilic or hydrophobic coatings (depending on circumstances) might also

Table 3. Effects of artificial seed coating[1] on establishment of *Chloris gayana* cv. Katambora near Gympie, Queensland.

Site	Days after sowing	Seedlings/m^2			LSD (P = 0.05)
		Control	PFI_1[2]	PFI_2	
Spring Valley (sown 15.1.91)	35	28	47	64	19
Brooyar (sown 15.3.91)	90	41	51	76	14

[1]Control = no artificial seed coating;
[2]P = seed coated with proprietary polymer;
F = fungicide added;
I_1, I_2 = insecticide added (formulations 1 and 2).

improve reliability of establishment by controlling moisture availability to the germinating seeds. However, considerable work remains before such compounds could be applied routinely to grass and legume seeds for pasture use.

Conclusions

Various techniques have been devised to remove chaffy appendages from difficult-to-handle grass seeds. However, their commercial applicability to particular species depends on both the rate at which seed can be processed and the likely degree of damage to the individual seed units.

In general, it is preferable only to trim the normal chaffy seed units, especially where caryopses are tightly held within the surrounding floral husk. This leaves the caryopses still surrounded by their protective husk, both reducing the risk of physical damage during processing and improving the reliability of field establishment under marginal moisture conditions. Naked caryopses should be sown only where adequate soil moisture can be guaranteed during early establishment.

The coating of processed seed units before sowing might further enhance establishment, especially by increasing the competitive ability of establishing seedlings. However, the available technology has been developed mainly in temperate areas, and more detailed work is required before these potential benefits can be realised at a practical level with tropical and subtropical species.

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References

ADAMS, K.M. and TAINTON, N.M. (1990) The function of the hygroscopic awn of *Themeda triandra*. *Journal of the Grassland Society of Southern Africa*, **7**, 271–273.

AGNEW, A.D.Q. and FLUX, J.E.C. (1970) Plant dispersal by hares (*Lepus capensis* L.) in Kenya. *Ecology*, **51**, 735–737.

AHRING, R.M., DUNCAN, G.L. and MORRISON, R.D. (1964) Effect of processing native and introduced grass seed on quality and stand establishment. *Technical Bulletin T-113. Oklahoma Agricultural Experiment Station.*

ATKINS, M.D. and SMITH, JR, J.E. (1967) Grass seed production and harvest in the Great Plains. *Farmers' Bulletin No. 2226. United States Department of Agriculture.*

BERLAGE, A.G., BILSLAND, D.M. and HOLMAN, P.M. (1986) Belt thresher with adjustable threshing action. *Transactions of the ASAE*, **29**, 413–415.

BILSLAND, D.M. and BERLAGE, A.G. (1987) A filament thresher for seed. *Applied Engineering in Agriculture*, **3**, 33–35.

BOGDAN, A.V. (1966) Seed morphology of some cultivated African grasses. *Proceedings of the International Seed Testing Association*, **31**, 789–799.

BROWN, R.R., HENRY, J. and CROWDER, W. (1983) Improved processing for high-quality seed of big bluestem, *Andropogon gerardii*, and yellow Indiangrass, *Sorghastrum nutans*. *Proceedings of the XIV International Grassland Congress, Lexington, 1981*. pp. 272–274.

BRZOSTOWSKI, H.W. (1961) Establishment of *Cenchrus ciliaris* from caryopses. *East African Agricultural and Forestry Journal*, **26**, 242–244.

CAVAYE, J. (1990) *The Buffel Book*. (Queensland Department of Primary Industries: Brisbane).

COOPER, H.W., SMITH, JR, J.E. and ATKINS, M.D. (1957) Producing and harvesting grass seed in the Great Plains. *Farmers' Bulletin No. 2112. United States Department of Agriculture.*

DEWALD, C.L. and BEISEL, A. (1983) The Woodward Flail-Vac Seed Stripper. *Transactions of the ASAE*, **26**, 1027–1029.

DEWALD, C.L., BEISEL, V.A. and COWLES, S. (1983) The Woodward Chaffy Seed Conditioning System. In: Wiedemann, H.T. and Cadenhead, J.F. (eds) *Range and Pasture Seeding in the Southern Great Plains.* Proceedings of a Symposium at Vernon, Texas, October 19, 1983. pp. 69–80. (Texas A & M University Agricultural Research and Extension Center: Vernon).

DEWALD, C.L., SIMS, P.L. and BEISEL, A. (1986) New developments in chaffy seed conditioning. *Proceedings 10th North American Prairie Conference, June 1986, Denton TX.* Paper 03.01.

DEWALD, C.L., BEISEL, A. and SIMS, P.L. (1987) Concepts and principles of the Woodward Chaffy Seed Conditioning System. In: Frasier, G.W. and Evans, R.A. (eds) *Seed and Seedbed Ecology of Rangeland Plants.* Proceedings of a Symposium at Tucson, Arizona, April 21-23, 1987. pp. 278–282. (United States Department of Agriculture Agricultural Research Service).

DOWLING, P.M. and GARDEN, D.L. (eds) (1990) *Native Grass Workshop Proceedings, 16 & 17 October, 1990, Dubbo, NSW.* (Australian Wool Corporation: Melbourne).

GROF, B. (1957) Notes on Biloela buffel grass. *Queensland Agricultural Journal*, **83**, 111-118.

HACKER, J.B. (1989) The potential for buffel grass renewal from seed in 16-year-old buffel grass-siratro pastures in south-east Queensland. *Journal of Applied Ecology*, **26**, 213-222.

HOOVER, M.M., SMITH, JR, J.E., FERBER, A.E. and CORNELIUS, D.R. (1947) Seed for regrassing Great Plains areas. *Farmers' Bulletin No. 1985. United States Department of Agriculture.*

HOPKINSON, J.M. (1990) Tropical pasture seed production research. In: *Proceedings, Seed Industry Research Workshop in Canberra, October 14-15, 1990.* pp. 51-54. (Rural Industries Research and Development Corporation & Grains Council of Australia: Canberra).

HUMPHREYS, L.R. (1958) *Studies in the germination, early growth, drought survival, and field establishment of buffel grass* (Cenchrus ciliaris *L.) and of birdwood grass* (C. setigerus *Vahl.) with particular reference to the Yalleroi district of Queensland.* M. Sc. (Agr.) Thesis. University of Sydney.

JENSEN, T.A., LOCH, D.S. and ROBOTHAM, B.G. (1993) Evaluation and development of brush harvesting for chaffy seeded grasses in Queensland, Australia. *Proceedings of the XVII International Grassland Congress, Lincoln, 1993.* (in press).

KNEEBONE, W.R. and BROWN, H.W. (1953) A modified hammermill for processing grass seed. *Agronomy Journal*, **45**, 389-391.

LOCH, D.S. (1991) Tropical herbage seed production — origins, progress, and opportunities. *Supplement to Journal of Applied Seed Production*, **9**, 14-26.

LOCH, D.S., HARDING, W.A.T. and HARVEY, G.L. (1985) Improved handling of chaffy grass seeds through cone threshing. *Proceedings of the XV International Grassland Congress, Kyoto, 1985.* pp. 277-279.

LOCH, D.S., HARDING, W.A.T. and HARVEY, G.L. (1988) Cone threshing of chaffy grass seeds to improve handling characteristics. *Queensland Journal of Agricultural and Animal Sciences*, **45**, 205-212.

LOCH, D.S., ROBOTHAM, B.G., JOHNSTON, P.W., JENSEN, T.A., HARVEY, G.L., CONWAY, M.J., EVENSON, C.J., EDSER, C.R., GORE, C.J., BEAVEN, J.A., NEVILLE, R.P. and SCATTINI, W.J. (1991) Evaluation and development of brush harvesting for chaffy-seeded grasses in the Australian subtropics. *Supplement to Journal of Applied Seed Production*, **9**, 52. (Abstract).

ORAM, R.N. (1990) *Register of Australian Herbage Plant Cultivars.* 3rd Edn. (CSIRO: Melbourne).

PEART, M.H. (1979) Experiments on the biological significance of the morphology of seed-dispersal units in grasses. *Journal of Ecology*, **67**, 843-863.

PEART, M.H. (1981) Further experiments on the biological significance of the morphology of seed-dispersal units in grasses. *Journal of Ecology*, **69**, 425-436.

PEART, M.H. (1984) The effects of morphology, orientation and position of grass diaspores on seedling survival. *Journal of Ecology*, **72**, 437-453.

PEART, M.H. and CLIFFORD, H.T. (1987) The influence of diaspore morphology and soil-surface properties on the distribution of grasses. *Journal of Ecology*, **75**, 569-576.

PIJL, L. van der (1972) *Principles of Dispersal in Higher Plants.* 2nd Edn. (Springer-Verlag: Berlin).

POGUE, G. (1983) Flame-Coat® seed treatment process. In: Wiedemann, H.T. and Cadenhead, J.F. (eds) *Range and Pasture Seeding in the Southern Great Plains.* Proceedings of a Symposium at Vernon, Texas, October 19, 1983. pp. 65-68. (Texas A & M University Agricultural Research and Extension Center: Vernon).

POWELL, A.A. and MATTHEWS, S. (1988) Seed treatments: developments and prospects. *Outlook on Agriculture*, **17**, 97-103.

SCHWENDIMAN, J.L., SACKMAN, R.F. and HAFENRICHTER, A.L. (1940) Processing seed of grasses and other plants to remove awns and appendages. *Circular No. 558. United States Department of Agriculture.*

SCHWIM, W.F. (1952) A simple method of preparing clean grass seed for mechanical planting. *Rhodesia Agricultural Journal*, **49**, 176-177.

SCOTT, J.M. (1989) Seed coatings and treatments and their effects on plant establishment. *Advances in Agronomy*, **42**, 43-83.

SIMPSON, M. (1952) Value of the awn in establishing seed of *Danthonia penicillata* (Labill.) Palisot. *New Zealand Journal of Science and Technology*, **34**, 360-364.

SINDEL, B.M., DAVIDSON, S.J., KILBY, M.J. and GROVES, R.H. (1993) Germination and establishment of *Themeda triandra* (kangaroo grass) as affected by soil and seed characteristics. *Australian Journal of Botany*, **41**, 105-117.

SMITH, JR, J.E. (1946) Grass seed harvesting, cleaning, and processing. A summary of techniques developed by the Soil Conservation Service, U.S. Department of Agriculture. In: *Oklahoma Crops and Soils, 1946. Bulletin B-295. Oklahoma Agricultural Experiment Station.* pp. 96-99.

STEBBINS, G.L. (1971) Adaptive radiation of reproductive characteristics in angiosperms, II: Seeds and seedlings. *Annual Review of Ecology and Systematics*, **2**, 237-260.

STEBBINS, G.L. (1974) *Flowering Plants: Evolution above the Species Level.* (Harvard University Press: Cambridge MT).

STOESZ, A.D. (1952) Harvesting, processing, and seeding of native grasses in the central and northern Great Plains. *Agronomy Journal*, **44**, 378-383.

TOTHILL, J.C. (1969) Soil temperatures and seed burial in relation to the performance of *Heteropogon contortus* and *Themeda australis* in burnt native woodland pastures in eastern Queensland. *Australian Journal of Botany*, **17**, 269-275.

VENTER, P.S. and RETHMAN, N.F.G. (1992) Germination of fresh seed of thirty *Cenchrus ciliaris* ecotypes as influenced by seed treatment. *Journal of the Grassland Society of Southern Africa*, **9**, 181-182.

WEBER, G.L. (1939) A method of preparing some native grass seeds for handling and seeding. *Journal of the American Society of Agronomy*, **31**, 729-733.

WIEDEMANN, H.T. (1982) Fluffy grass seed metering device for rangeland seeders. In: Aldon, E.F. and Oaks, W.R. (eds) *Reclamation of Mined Land in the Southwest.* Proceedings of a Symposium at Albuquerque, NM. pp. 178-182. (Soil Conservation Society of America).

WIEDEMANN, H.T. (1983) Fluffy seed metering system for drills. In: Wiedemann, H.T. and Cadenhead, J.F. (eds) *Range and Pasture Seeding in the Southern Great Plains.* Proceedings of a Symposium at Vernon, Texas, October 19, 1983. pp. 36-42. (Texas A & M University Agricultural Research and Extension Center: Vernon).

WIEDEMANN, H.T., BROCK, J.H., FISHER, C.E. and CROSS, B.T. (1979) Seed metering and placement devices for rangeland seeder. *Transactions of the ASAE*, **22**, 972-977.

WIEDEMANN, H.T. and CROSS, B.T. (1981) Rangeland seeder development using semicircular seedbox and auger agitator seed metering concept. *Journal of Range Management*, **34**, 340-342.

WIEDEMANN, H.T. and CROSS, B.T. (1990) Innovative devices for rangeland seeding. *Paper No. 90-1564 presented at ASAE Meeting, Chicago IL, December 18-21, 1990.*

ZOHARY, M. (1937) Die verbreitungsökologischen Verhaltnisse der Pflanzen Palästinas. I. Die anti-telechorischen Erscheinungen. *Beihefte zum Botanischen Zentralblatt*, **56**, 1-155. (Cited by Peart 1979).