Seed Production and Processing of the Indigenous Coastal Sand-Binding Plant *Spinifex sericeus* ©

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Spinifex sericeus **R.Br is an important indigenous sand-binding grass growing on coastal foredunes throughout the North Island and northern South Island of New Zealand. Utilising seed rather than vegetative propagation techniques has typically been more successful in establishing plants for sand dune stabilisation in New Zealand. Since 1998, caryopses (naked "seeds") have been mechanically extracted at Massey University from 43 collections (or sub-collections) sent by interested parties from 16 North Island beaches. Although most collections received were from five beaches of the south western coast of the North Island (25), especially Hokio beach near Levin, a number were also received from a further five west coast and six east coast beaches. Weights of extracted whole seeds ranged from as little as 2.9 g (approximately 210 seeds) to 142 g (approximately 11,270 seeds) per "packed" fertiliser bag of spinifex seedheads (ave. 51.1 g, about 3790 seeds). The ten highest yields obtained were collections from Hokio (8), Foxton (1), and Himatangi (1) beaches. Low yields were more typical of east coast beaches, although the lowest yields recorded were from the west coast beach of Oakura, near New Plymouth. Fungal smut or rodents were identified as causes of low seed yield in some cases. Thousand seed weight varied from 11.7 g (Patea) to 15.6 g (Muriwai). A relationship of declining seed weight with increasing seed yield was only prevalent from the combined Hokio and Kapiti collections (r^2 = 76%).**

The seed extraction/cleaning process used is outlined in this paper and involves the use of four lab-scale seed threshing/cleaning machines plus ancillary equipment. Overall seed quality as a result of the extraction process was acceptable with losses through broken seed typically restricted to around 5%. In today's dollar terms, extraction costs ranged from 1.9¢ to $1.00 per seed, ave. 5.5¢, largely depending on the seed number able to be extracted, or 3.2¢ to $1.67, ave. 9.2¢ per germinable seed based on a conservative germination rate of 60%.

Preliminary laboratory germination tests revealed no loss of quality from mechanical extraction and also confirmed naked seed germinated faster than seed still held in its bracts as spikelets. Subsequent occasional germination tests were conducted on only a few seed lots, at client's request, with results ranging between 60%–81% over 35 days.

Improvements to the process will depend on the scale of the operation desired but are definitely possible through modifications to existing machinery and/or access to and possible modification of other machines such as a cone thresher, hammer mill, and de-awner.

INTRODUCTION

Spinifex sericeus R.Br (also previously identified as *S. hirsutus*) is a stoloniferous, perennial, coastal, sand-dune grass that occurs along much of eastern Australia, New Caledonia, and New Zealand, especially the North Island and northern South Island (Maze and Whalley, 1992; Edgar and Connor, 2000). As one of the few plants able to colonise the seaward face of coastal foredunes it makes an ideal foredune stabiliser and for this reason has often been used in conservation efforts on beaches (Anon., 1981; Barr et al., 1983; McDonald et al., 1983). It thrives on unstable sand and is tolerant of high winds, limited rainfall, salt spray, high light intensity, high temperatures, and moderate sand inundation (Van Kraayenoord, 1986; Hesp, 1991). Spinifex, also known as silvery sand grass and most commonly by Māori as kōwhangatara (according to the Manaaki Whenua — Land Care Research — Plant Names database spinifex is also known by the Māori names of raumoa, turikākoa, and wawatai), is identified by its coarse grass appearance, silvery-green colour, and creeping stolons (Jenks, 2006).

The species has a dioecious habit; female and male flowers borne on separate plants, a rare phenomenon in the Poaceae (Connor, 1984). Overall ratios of male to female plants are reported to be 1 : 1 by Connor (1984) from 15 New Zealand North Island beaches and in New South Wales (Maze and Whalley, 1990) when collected seed was grown out.

Male and female inflorescences are distinctly different in appearance (Wheeler et al., 1982). Male inflorescences are composed of a cluster of racemes or spikes subtended by silky-hairy spathes, usually in a terminal umbel but occasionally with a cluster of racemes below (Maze and Whalley, 1990). The female inflorescence is a globular head of racemes, each raceme with one or sometimes two sessile spikelets with the rachis extending up to 10 cm and ending in a point or bristle (Maze and Whalley, 1990). These large mature seedheads of radiating spikes are the "tumbleweeds" that are commonly observed blowing along the beach, especially in mid to late summer, when they become detached from the female parent (Hesp, 2000).

Various numbers of caryopses, hereafter referred to as seeds, are held tightly in the centre of this mature inflorescence or seedhead, which once released by the female plant, tend to become initially trapped in nearby vegetation, especially in dune hollows (Bergin, 1999). This permits relatively speedy collection with one person able to collect several sacksful of seedheads per hour (Bergin, 1999).

In recent times, the collection and utilisation of spinifex seedheads (and other sand dune plants) in New Zealand has largely been undertaken by a few specialised nurseries and by largely volunteer coast-care groups coordinated by local district and/or regional councils, and since 1997 has been greatly encouraged at a national level by the Coastal Dune Vegetation Network (CDVN).

Loch et al. (1996) has noted that the extensive commercialisation of native grass species, such as spinifex, is greatly assisted by having access to sufficient supplies of good quality seed in a form that can be sown satisfactorily and gives reliable establishment. Spinifex seedheads, though, are unwieldy and bulky and may contain more than 95% by volume of inert material. So they require some form of threshing and cleaning treatment in order to obtain seed suitable for sowing (McKenzie et al., 1989). This has traditionally been completed by hand within New Zealand (Bergin, 1999). However, the development of appropriate seed harvesting, and preferably mechanical processing technology, is necessary for the development of reliable and profitable seed markets (Loch et al., 1996). This paper reports on some of the issues surrounding the supply of spinifex seed and the sometimes conflicting status and methods of mechanical seed extraction.

Figure 1. Locations of North Island beaches (with collection and/or sub-collection numbers in brackets) where spinifex was sourced for extraction and cleaning at Massey University (1998–2006).

MATERIALS AND METHODS

Description of Seedheads Received. Seedhead collections were received from various parties (nurseries, district councils, regional councils) from 16 North Island beaches, 10 from the west coast and six from the east coast (Fig. 1). Most seedheads received had been compressed into fertiliser bags or similar (typical dimensions 410×850 mm that give an approximately 60-L functional volume; net weight about 2.0–2.4 kg that represents about 350–450 seedheads depending on size). Those that were received in other containers, or were not compressed, were described in terms of a proportion of a compressed standard-sized fertiliser bag for approximate comparison purposes. Not infrequently, multiple bags from one collection were received, and usually these were assigned sub-collection status and processed individually, with seed yields and weights recorded separately. All seedheads received were quite dry, and most were processed within the year they were collected. However, evidence of rodent activity (e.g., dead mice, rodent droppings, feeding damage) was noted, especially if the seed lot received was from a previous year's collection.

Seed Processing Sequence. The normal sequence of steps for the processing of spinifex seedheads at Massey University was as follows:

Pressed seedheads were fed through an Almalco small bundle thresher (SBT), which consisted primarily of a peg-tooth drum that broke up the seedheads to a great extent. A little naked seed was released at this stage, and damage was done to a small proportion of seeds.

Broken seedheads were fed through a Westrup Laboratory brush huller/scarifier (LA-H) that further breaks up the seedheads by the use of a rotating brush shaft (500–700 rpm) against a cylindrical screen (10-mm-square holes). Some further naked seed is released, and some damage is done to a few seeds.

Threshed material was then sucked through a Carter Day fractionating aspirator that removed chaffy matter but retained both naked seed and seed still within its lemma, palea, and glumes (McKenzie et al., 1989) hereafter referred to as spikelets [Bergin (1999) refers to these as scales].

Seed material, largely consisting of spikelets, was then briskly hand-rubbed between two boards with notched rubber surfaces to finally release all seeds. A little surface damage sometimes occurred.

The resulting material was next processed through the fractionating aspirator again (to remove bracts).

Seed was then briefly hand-sieved through a $5\frac{1}{2}/64 \times \frac{3}{4}$ of an inch (2.18 × 19.05 mm) oblong-hole-shaped screen (to remove large chaffy matter) and a $\frac{1}{13}$th of an inch (1.95 mm) round-holed screen (to remove remaining sand).

Finally, seed material was blown through a South Dakota seed blower ($6.3\ m^3 \cdot s^{-1}$) to remove light chaffy matter and very light spinifex seeds (that have a low germinability).

Sometimes a Westrup Laboratory indented cylinder separator (LA-T) using a 4-mm indented cylinder was used (to remove round foreign seeds with a similar girth to spinifex and also any broken spinifex seeds).

Germination. Initial and occasional germination tests (by client request) were conducted on two or usually four replicates of 50 seeds that were each placed on two Anchor Paper Company blue seed germination blotters (soaked in a 0.2% solution of potassium nitrate) and positioned within a small sealable plastic box wrapped in aluminium foil to exclude light. Boxes were placed in an alternating temperature cabinet (20±2.0 °C, 16 h; 30±2.0 °C, 8 h) for up to 35 days with approximately weekly interim assessments. Initial germination treatments were:

Hand naked seed = the removal by hand of all outer floret structures leaving a naked caryopsis (no machine or tools used).

Machine naked seed = the removal of all outer structures floret structures from the naked caryopsis using the combination of seed processing machines, described above.

Machine spikelets = the removal of the seed from the seedhead but still leaving the bracts intact surrounding the seed by using the combination of seed processing machines up to step three, described above.

Hand spikelets = the removal of the seed by hand from the seedhead but still leaving the bracts intact that surround the seed (no tools used).

RESULTS AND DISCUSSION

Large Variations in Extracted Seed Yields. Weights of extracted whole seeds ranged from as little as 2.9 g (about 210 seeds) to 142 g (about 11,270 seeds) per "packed" fertiliser bag of spinifex seedheads, ave. 51.1 g (about 3790 seeds) (Fig. 2). The ten highest yields obtained were collections or sub-collections from the south-western coast beaches of Hokio (8 collections), Foxton (1), and Himatangi (1).

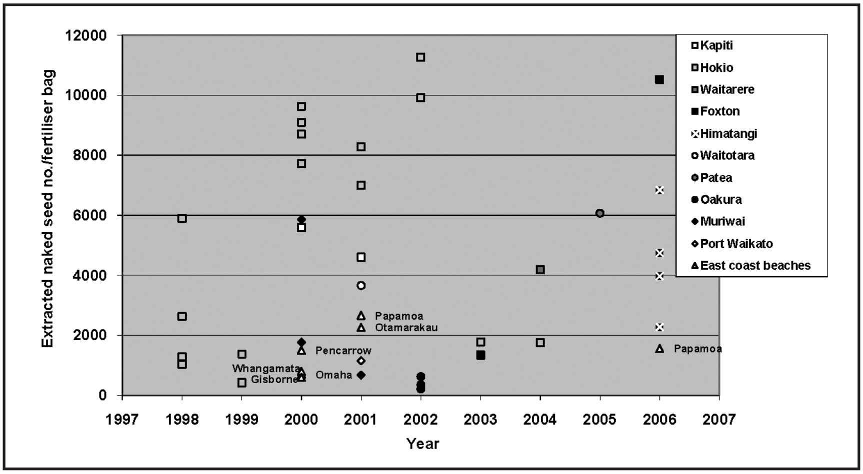

Figure 2. Quantities of intact naked seed extracted from 43 collections from 16 North Island beaches (1998–2006).

The ten lowest yields were obtained from Oakura, near New Plymouth (5 sub-collections), Hokio (1), Gisborne (1), Muriwai (1), Omaha (1), and Whangamata (1). However, the Hokio collection (and at least three additional low-yielding Hokio collections; two in 1998 and one in 2003) had been stored for 12–15 months. Significant rodent activity including mouse bodies and/or significant quantities of mice faecal material was clearly evident in these collections. All seven east coast beach collections revealed quite low yields with the highest (Papamoa, 2,660 seeds, in 2001) being well under the overall average of 3,790 seeds from all collections.

Jenks (2006) advises that usually less than one-third of spikelets have formed seed attached, presumably from Bay of Plenty beaches (east coast). Bergin and Kimberley (1999) also reported a large range in spinifex seed production from Port Waikato (west coast) and a few east coast beaches (one Bay of Plenty and three Coromandel beaches). In their study, seedheads comprised a range of 41–160 spikelets with the proportion of sound seed per spikelet ranging from 0.2% to 42.9% (which would produce from 0.1 to 38 seeds per seedhead, ave. 13). This is similar to that reported in Queensland, where the typically low seed-fill proportion observed in spinifex seedheads was reported to range from 1%–60% (Davidson, 1998). Bergin (2001) reported that sized spinifex seedheads (unknown provenance) yielded about an average 27, 34, and 38 germinable seeds per small, medium, and large seedheads, respectively. So in an attempt to recover seeds more efficiently it has been generally recommended to avoid collecting smaller seedheads (Bergin, 1999). However, results from the Bergin and Kimberley (1999) study would appear not to necessarily support this contention, with some large heads producing less seed than some small heads.

Reasons for Low Yields.

Inadequate Pollination. As a dioecious species, adequately sized and adjacently growing male and female populations is an obvious requirement for effective pollination leading to good seed production. Also as a wind-pollinated grass, smaller populations of spinifex, in particular, may be more vulnerable to poor pollination. This is especially the case if localised female populations outweigh male populations or if flowering is not well synchronised. Overall ratios of male to female sex form frequencies reported by Connor (1984) from 15 North Island beaches were 1 : 1. However, two beaches (Himatangi and Waikanae) had significantly different ratios (20% and 75% females, respectively), and five further beaches, also had ratios as low as 23% and as high as 68% but which apparently were not statistically significant. Furthermore, ratios from as many as nine of the 15 beaches were based on less than 20 plants, while three of these had ratios reportedly based on five plants or less. When overall colony size was compared, only Wanganui was reported to vary significantly from the 1 male : 1 female ratio.

In New South Wales, Maze and Whalley (1990) reported a general male flowering bias from three beaches, but variation occurred between and within seasons and amongst beaches. For example, during one year's flowering episode at one of the beaches male inflorescences exceeded females in September; ratios were similar in October; and females dominated in November. Male inflorescences also matured earlier, and the flowering period was less protracted compared with females. However, even if the overall ratio and/or size of male : female colonies within a beach are adequate, microsites within a beach may well have uneven ratios. The prevailing climatic conditions, especially wind direction and strength over the flowering period, may influence the degree of effective pollination and subsequent seed production within these microsites. It is interesting to note that all east coast collections (seven), with typically less extensive dune systems and smaller colonies, were below the average yield. Bergin and Kimberley (1999) observed that there was an irregular distribution of male and female plants at Whiritoa beach (Coromandel Peninsula, east coast). From eight discrete female populations the proportion of spikelets containing viable seeds, varied considerably from 0.2% to 42.9%. This appears to reveal widely fluctuating pollination efficacy. Oakura, with a greatly reduced dune system, may be a special west coast case, more akin to a typical east coast beach. As such it is quite possibly subject to poor and fluctuating yields, similar to that reported at Whiritoa, due to smaller colony size and in places low male : female ratios. In contrast, west coast beach collections averaged as much as 75.7 g (about 5,867 seeds), especially when collections affected by mice or smut and the Oakura sub-collections were removed. This is more than twice the best east coast yield of 2,660 (Papamoa, 2001) and over four times the east coast average yield of 1,440 seeds. West coast beaches, typically with more extensive dune systems, support much larger spinifex colonies. This appears to significantly increase the chances of successful pollination and subsequent seed production, presumably due to greater pollen availability. Collection of spinifex seedheads within the vicinity of good male populations is therefore recommended, especially in beaches with small dune populations.

Fungal Smut. Kirby (1988) reported that the occurrence of spinifex smut fungi (*Ustilago spinificis*) was common in regions where the host is abundant. The mean frequency of smutted inflorescences was 22% on 29 Australian and 1 New Zealand beach (Raglan), although the occurrence of the smut was noted on all four additional New Zealand beaches surveyed (all in the Coromandel Peninsula). Since the fungus significantly reduces seed yields and smutted seedheads are easily identified, avoiding collecting smutted seedheads has been recommended (Bergin, 1999; Bergin and Kimberley, 1999). Smutted seedheads were received from only one beach (Muriwai, 2000). Two sub-collections were received from Muriwai together that year, the nonsmutted bag yielding over three times (5,860 seeds) the smutted bag (1,770 seeds). As only one of 43 collections/sub-collections received in the study period was smutted, it appears that collectors are indeed deliberately avoiding smutted seedheads.

Rodents. Clear signs of significant rodent feeding, including bag holes, mice bodies, large quantities of mice faecal material, partially eaten seeds, and/or spikelets, were evident from six west coast collections (Hokio 1998 [3], 1999 and 2003; Foxton 2003). Collections stored for 1 year or more seemed particularly vulnerable. Numerous other collections had small quantities of mice faecal material, often not evident until the final stages of seed cleaning, but this was not considered to have influenced seed yields too significantly. Good rodent control, through regular trapping, poisoning, and/or suspending sacks of seedheads from the ceiling, is therefore highly recommended (Bergin, 1999; Bergin and Kimberley, 1999).

Seed Weights. Thousand seed weight (TSW) varied from 11.7 g (Patea) to 15.6 g (Muriwai), ave. 13.4 g (Fig. 3). A relationship of declining seed weight with increasing seed yield (Fig. 4) was only prevalent from the relatively large combined Hokio (13) and Kapiti (2) collections (r^2 = 76%). This is in contrast to cultivated forage and turf grasses where processed seed lots of the same species have a relatively constant seed weight uninfluenced by variable yields (Hampton, 2006). Insufficient data is available to relate seed weight to germination. However, it is well known that very low seed weights caused by a cessation in seed reserve accumulation will result in seeds of low germinability, which seed processing will normally remove (Habstritt, 2006).

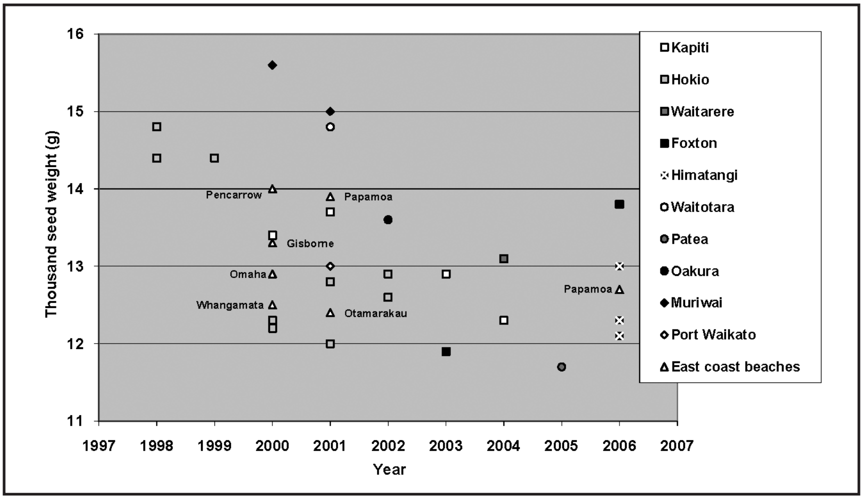

Figure 3. Spinifex naked thousand seed weights from 43 collections from 16 North Island beaches (1998–2006).

The Mechanical Seed Extraction Process. Naked seed has the following advantages:

- Facilitates ease of storage;
- Facilitates mechanical seed sowing, enabling a more efficient use of resources when raising greenhouse plants (staff time, greenhouse space, media, and containers);
- Permits the effective removal of empty spikes (and other chaffy matter), giving a close and reliable estimate of seed number and subsequent plant number that will become available to be used;
- Speeds up germination (Loch, 1993; Bergin, 1999).

Spinifex has an oblong seed about 5 mm long, similar in shape and look but considerably smaller (TSW = 11.7–15.6 g in this study) than a wheat grain (TSW = about 48 g) (Watt and Wickham, 1983; ISTA, 2004). Spinifex seed is considered to be relatively soft and easily damaged by some forms of mechanical processing (Harty and McDonald, 1972; Brooks, 1987; McKenzie et al., 1989). Initially, mechanical seed cleaning had proven very difficult and was discarded as a commercial proposition by some workers (McDonald, 1979). Others recommend that when caryopses are tightly held in the surrounding floral husk (bracts) the trimming of the normal chaffy seed units (for example, using a de-awner) may be preferable to the complete removal of the caryopses both in terms of inflicting less damage and considerably speeding-up the process (Harty and McDonald, 1972; McKenzie et al., 1989; Loch, 1993; Loch et al., 1996). However, Watt and Wickham (1983) reported on three threshing/cleaning machines, only one of which severely damaged spinifex seeds (the Riffle flow mill). The resilient tapered thresher was reported to do a very good job of threshing the spinifex resulting in very little seed damage. A similar cone thresher was also recognised as giving the best results for spinifex in Queensland (Davidson, 1998), although for large quantities it was rejected as being far too slow (McKenzie et al., 1989).

Harty and McDonald (1972) used a hammer mill to extract spinifex seeds, but this caused excessive damage and lowered the germination rate from 79% (control) to 58%. However, another hammer mill using a special sieve size of 6.3 mm and a threshing speed of 500 rpm resulted in the threshing of 10 to12 × 72-L bags of spinifex seedheads per hour with only a 5% rate of damaged seed (Watt and Wickham, 1983). Brooks (1987) also reports the extensive use by the Associated Minerals Consolidated Ltd. of a peg-tooth drum for threshing large annual quantities of spinifex. Harty and McDonald (1972) had previously used a peg-tooth drum but preferred the de-awner that gave more evenly clipped spines. In contrast, McKenzie et al. (1989) preferred one of two peg-drum threshers tested to the de-awner, which tended to block. It should be noted that of two peg-tooth threshers used, one (CSIRO) caused 34% seed damage with germination of remaining seeds only 4%. The second peg-tooth thresher (Beach Protection Authority) did not cause significant external damage and only dropped the germination by 5%. However, their preference was for a McCullock Super Sweeper, a device for sucking-up and shredding various organic materials. It consisted primarily of a combination impeller/shredder wheel driven by an electric motor and was able to produce 15-mm-long spikelet units at an acceptable 25 kg seed heads per hour. There was no effect on seed germination compared with hand-threshed seed, but spikelets are the product rather than bare seed. Spikelets, though, may be quite acceptable to many nursery workers or others working to stabilise beach foredunes.

An initial small processing trial (only 20 seed heads per treatment) conducted at Massey University but assessed by Forest Research staff apparently showed a great loss in germinable seed. This study indicated that through a combination of seed loss, breakage, and/or damage, the number of germinated seeds per seed head decreased substantially with increasing mechanical processing. Specifically, the process that mechanically reduced the sample to naked seed reported an 81% loss in germinable seed compared with the control (Bergin, 2001). However, refinements in the process since that time and using a combination of occasional damage assessments and germination tests show losses more typically in the range of only 3%–7% while laboratory germination tests on resultant naked seed were between 60%–81%. This amount of damage is similar (5%) to that reported by Watt and Wickham (1983) using a specially adjusted hammer mill and McKenzie et al. (1989) using a peg-drum thresher, with subsequent threshed material readily cleaned with conventional seed-cleaning machines such as with a sequence of scalper, screens, and gravity table.

In today's dollar terms, extraction costs from this study would range from 1.9¢ to $1.00 per seed (ave. 5.5¢) or 3.2¢ to $1.67 (ave. 9.2¢) per germinable seed based on a conservative germination rate of 60%. If seed yields are reasonable, this is a relatively small contributor to the estimated cost of producing 12- to 15-month-old plants raised in Hillson rootrainers available from North Island nurseries at $1.30 to $2.00 each (Bergin, 1999). Improvements to the process will depend on the scale of the operation desired but are definitely possible through modifications to existing machinery and/or the use and possible modification of other machines. Some initial suggestions could include modifications to the Almalco small bundle thresher to allow better seedhead flow; obtaining a smaller cylindrical screen for the Westrup dehuller/scarifier; and trialling a locally available Walter-Wintersteiger Seedmaster Universal (hydrostatic) combine plot harvester (built in 1974). Further trials utilising a hammer mill, cone thresher, and perhaps a modified de-awner, and possibly others, would be desirable (Harty and McDonald, 1972; Loch, 1993; Loch et al, 1996), although some machines may not presently be available in New Zealand or may possibly require modifications.

Germination. An initial trial was conducted to ascertain differences in laboratory germination between naked seed versus spikelets and comparing machine versus hand extraction (Table 1). The higher levels of dead seed from both intact treatments may reveal a slightly non-homogeneous seed lot with retention of immature seeds or possibly even a few empty spikelets. However, some conclusions can still be drawn. When spikelets were left intact, germination had effectively not occurred within the 28 days of the test (1%–2% germination). This confirmed a previous trial that indicated naked seed germinated within 30 days while spikelets took up to 60 days (Bergin, 1999). A similar finding of delayed germination when seed remained within their floral bracts (spikelets) had also been reported by Harty and McDonald (1972). In this present study, mechanical extraction of seed caused no harm and in fact may have increased the speed of germination, presumably due in some way to the minor abrasion of the seed coat. Occasional subsequent germination tests were conducted at client request on collections with results ranging from 60%–81% normal germinants over 35 days.

Table 1. Preliminary spinifex germination results comparing hand versus machine extraction of seeds for both naked seed and spikelets (1998).

Treatment	Interim count (10 days) (%)[1]	Final count (28 days) (%)[2]	Fresh ungerminated (%)[3]	Total viability (%)[4]	Abnormal seedlings (%)[5]	Dead (%)
Hand, naked seed	26 ± 2.0	49 ± 9.0	20 ± 8.0	69 ± 1.0	2 ± 2.0	29 ± 2.0
Machine, naked seed	53 ± 4.0	68 ± 3.1	7 ± 1.7	75 ± 3.2	5 ± 0.6	20 ± 3.6
Machine, spikelets	1 ± 1.0	1 ± 1.0	58 ± 2.0	59 ± 1.0	1 ± 0.0	39 ± 1.0
Hand, spikelets	0 ± 0.0	2 ± 2.0	58 ± 2.0	60 ± 0.0	0 ± 0.0	40 ± 0.0

[1] Normal seedlings developed by 10 days.

[2] Total normal seedlings (having all the essential structures for continued development) by 28 days.

[3] Seeds that have imbibed water, have remained firm but have not germinated by the end of the test period.

[4] Total of normal seedlings and viable ungerminated seeds.

[5] Damaged or deformed seedlings resulting from mechanical damage, chemical injury, disease, immature development, or aging.

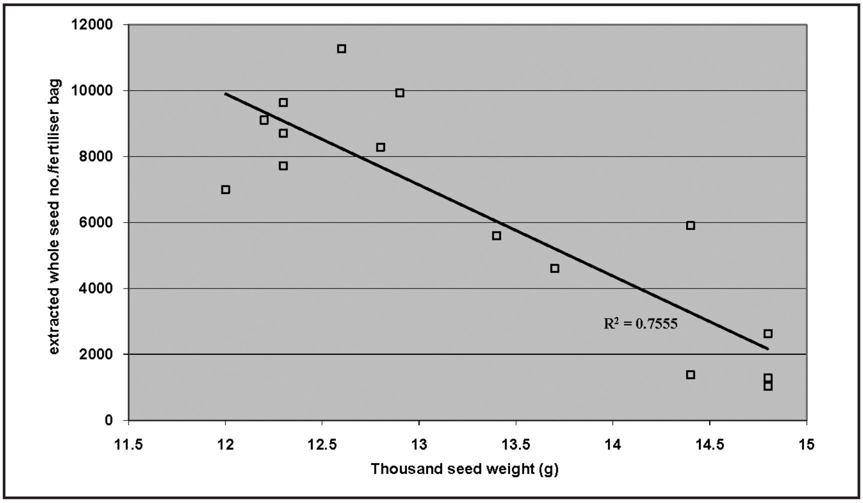

Figure 4. Declining seed weight as seed yields increase was shown from Hokio and Kapiti beaches (1998–2006**)**.

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