

Effects of severity of threshing damage on seed quality of Gatton panic (*Panicum maximum*)

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Abstract

Different degrees of severity of threshing were imposed during combine-harvesting of seed of Gatton panic, a cultivar of *Panicum maximum*, to determine effects of degree of threshing damage on subsequent properties of seed. Threshing cylinder peripheral speeds and concave clearances covering the normal range employed commercially were varied experimentally in the harvest of 2 crops grown in north Queensland. Harvested seed was dried and cleaned, then stored under ambient conditions. The extent of physical damage was measured, and samples were tested at intervals for viability, germination, dormancy and seedling emergence from soil in a glasshouse and in the field over the 2 seasons following harvest. Physical damage increased as peripheral rotor speed rose and (though less markedly) as concave clearance was reduced. As the level of damage increased, viability was progressively reduced, life expectancy was shortened, and dormancy was broken. When the consequences were measured as seedling emergence from soil, the adverse effects on viability tended to cancel out the benefits of dormancy-breaking, leaving few net differences attributable to the degree of threshing severity. We concluded that there would be no value in trying to manipulate the quality of seed produced for normal commercial use through choice of cylinder settings, but that deliberate light or heavy threshing could benefit special-purpose seed, destined, respectively, for long-term storage or immediate use.

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Introduction

In an earlier investigation of causes of low quality in stored seed of green panic (*Panicum maximum*), we found that commercial combine-harvesting damaged seed, which broke dormancy but shortened life expectancy (Hopkinson and English 2004). The damage was attributed to threshing, and was confirmed by comparing hand-cut and mechanically harvested seed samples of common origin. However, as the comparisons were between 'all-or-nothing' pairs of treatments, it was not possible to determine response patterns to progressively increasing degrees of threshing severity. To try to identify a level of damage, and hence of threshing severity, that would break dormancy without materially shortening life expectancy, we set up a system that allowed us to produce seed under controlled, variable threshing conditions for evaluation. It was not critical to use green panic, so we chose a sward of another closely related cultivar, Gatton panic (Oram 1990), being used for long-term seed production on Kairi Research Station (17°S, 146°E; 700 m elevation; average annual rainfall about 1280 mm) within the grass seed-producing district of the Atherton Tableland in north Queensland. To harvest the seed crops, we used a 'conventional' Massey-Ferguson 31 combine-harvester (that is, with a cross-flow threshing cylinder and straw walkers, as distinct from the alternative 'rotary' or axial-flow design). While small enough for multiple-plot trial work, it incorporated a threshing system identical with those of the conventional commercial machines and equally adjustable within the required range of threshing cylinder settings.

Methods

The study consisted of the production of seed subjected to a range of severities of threshing

damage during harvest, and its subsequent processing, storage and testing for measurement of physical damage and vital characteristics.

Crop production

Two seed crops were grown in 1985. For each, the sward was mown and the equivalent of 100 kg/ha of elemental nitrogen applied. Crops developed on adequate rainfall and were harvested on February 12 (Crop 1) and April 18 (Crop 2).

Harvester

The MF31 combine harvester took a 1.63 m cut with a conventional open front (reciprocating cutter bar, drop-finger reel, and table auger). It was fitted for the task with a rasp-bar threshing cylinder, the commonest type used locally in grass seed production. Beater, straw walkers, grain pan and riddle box were of standard type, all driven at factory-set constant speed. The riddle box was set up for Gatton panic with a fixed, top lip-sieve with 30 × 36 mm holes and 13 mm lips, and a 5 mm diameter round-hole, flat, bottom sieve. Air flow over the sieves was reduced below design-minimum (necessary on all harvesters with all such crops) by means of adjustable shutters fitted to the fan inlets. Both crops were direct-headed.

The 60 cm diameter threshing cylinder was driven from the constant-speed beater shaft through a pair of changeable sprockets, which governed the rate of rotor revolution and hence peripheral speed. The rasp bars were in almost-new condition. The concave grate was open over its full arc. Concave clearances were set by suspension arms designed to create a narrow gap at the front than the rear when almost closed. With movement of the control lever, front clearance changed at twice the rate of rear, so that front clearance became greater than rear at more open settings.

Harvesting

The objective was to produce seed with different degrees of physical damage by harvesting over a range of concave clearances and threshing cylinder peripheral speeds comparable with the usual commercial range. Meanwhile, other machine settings were kept constant so that

differences in seed characteristics could be attributed specifically to conditions within the threshing cylinder.

The harvest of Crop 1 was used to determine the range of threshing damage possible, and took the form of single runs of 47.3 m length each at different threshing cylinder settings (Table 1). The large number of settings chosen precluded field replication of individual combinations. A hand-cut sample of seed heads was taken from each strip immediately before harvest. The samples were bulked to provide a single sample representative of seed as it entered the harvester.

From the experience gained with the harvest of Crop 1, a narrower range of combinations of cylinder settings was chosen for the harvest of Crop 2 comprising 2 minimum concave clearances (15.5 and 2.3 mm) combined with 2 peripheral cylinder speeds (64 and 115 km/h). This made it possible to take 3 field replicate runs of 47.3 m at each combined setting in a randomised block layout. At the same time, 10 random 0.4 m² quadrat hand-cuts were made to permit estimates of presentation yield and hence recovery efficiency.

Seed processing

The seed from each run of both combine harvests was bagged off, dried at 35°C to about 10% moisture, cleaned, sampled and packaged. The hand-cut seed was first sweated (Hopkinson *et al.* 2003) to detach all pure-seed spikelets and then dried and subsequently treated identically to the combine-harvested seed. All seed was stored for the duration of the study at ambient temperature averaging about 22.5°C in the Walkamin Research Station seed store.

Pure seed was separated by hand-sorting and aspiration of samples for routine purity analysis. Before being subsampled for subsequent testing, pure seed was further aspirated at higher air flow rates to remove spikelets containing immature caryopses. Such caryopses are known to have a short life expectancy, and to produce only weak seedlings of negligible field survival potential even when still technically viable (Hopkinson and English 1985). Remaining mature spikelet populations were then subjected to the tests described below.

Measurement of physical damage

Naked floret content. The percentage content of spikelets stripped of their membranous covering structures, so that they consist only of the naked upper fertile floret, is a useful measure of the severity of threshing in the examination of commercial seed samples and is indicative of the extent of physical damage to the florets (Hopkinson and English 2004). It was quantified in the present experiments by counts made on 3 subsamples of 100 pure mature spikelets each.

Ink penetration. The husk of a *Panicum maximum* seed consists of an indurated lemma and palea the edges of which overlap to form, in intact and mature seeds, a tight seal that restricts entry of water (but not in immature seeds, where the seal is slack). Physical damage may split the lemma or disrupt the seal, and hasten water entry. Early water penetration thus provides a direct and sensitive measure of physical damage, provided immature spikelets are excluded. Subsamples of 3×100 mature spikelets from Crop 2 were steeped in red ink for 6 hours at 25°C (details chosen by prior trial) and then rapidly dried under an infra-red lamp. They were stored, examined under magnification, and the proportion of spikelets visibly penetrated was recorded.

Seed quality testing

After completion of the physical tests, some exclusion of lines of Crop 1 was necessary to reduce numbers to manageable proportions for subsequent tests of vital quality. The full range of peripheral rotor speeds was included, but only in combination with the minimum concave clearance (Table 1). Hand-harvested seed of Crop 1 was included, but that of Crop 2 rejected as unreliable when tests showed that damage had inadvertently been caused during sweating (an ever-present risk with such an imperfectly controllable process). All the remaining Crop 2 seed was included, and samples from field replicates were kept separate to serve as test replicates. With seed from Crop 1, for which only a single field replicate of each harvest treatment existed, test replicates were obtained from repeat subsampling of single field samples.

Seed samples of 4 treatments of Crop 1 and 4 of Crop 2 were tested for quality. Their identities and details are shown in Table 3.

Viability. Tetrazolium tests of viability were conducted on 2 occasions beginning on August 19, 1985 and February 6, 1987 using 4 replicates of 50 and 3 replicates of 100 caryopses, respectively. Details of the method of testing, for which caryopses are de-husked before the start of imbibition, were as previously described (Hopkinson and English 2004). Crop 2 results were subjected to conventional analysis of variance after due transformation of percentage values (arc-sin for the earlier tests, when values were high; probit transformation when results of earlier and later tests were combined for analysis).

Germination (standard tests). First germination tests were begun on January 13, 1986. Dormancy-breaking treatments were omitted, the aim being to measure germination of non-dormant seed directly and to estimate dormancy from the difference between numbers of germinating and viable seeds. Tests were done on 4 replicates of 100 seeds each (Crop 1) and 2 replicates of 100 for each of 3 replicate plot samples (Crop 2), in petri dishes on paper germination pads irrigated with rain water in a germinator set at 35/20°C with 8-hour light and 16-hour dark cycles. They ran for 14 days.

Later germination tests were begun on January 6, 1987 in the alternative temperature regimen of 35/15°C, to obtain values comparable with those of official tests, and at the same time, to derive other measures of dormancy. There were 3 replicates of 100 seeds each for each of 2 treatments, with (+K) and without (-K) 0.2% potassium nitrate for every seed lot in petri dishes on germination pads. Tests ran for 27 days, after which residual dormant seed was tetrazolium-tested for viability.

Germination (de-husked seed). Once seed of Gatton panic has passed out of the early stages of dormancy, naked caryopses germinate readily, and their germination behaviour provides viability estimates which serve as checks on the validity of the viability interpreted from tetrazolium tests. For this reason, in the later series of tests, 2 replicates of 100 spikelets each of each treatment of Crop 1 and 3 replicates of 100 each of Crop 2 were individually de-husked with scalpel and forceps and set to germinate in the same conditions as those of the -K treatment above.

Seedling emergence from soil (field). Tests of seedling emergence in the field were carried out

on a prepared seedbed at Kairi Research Station starting on January 10, 1986 and January 6, 1987. Replicates consisted of 1-metre lengths of row along which 100 seeds were hand-sown, lightly covered, and firmed down in miniature imitation of commercial sowing. Six replicates of each seed lot were laid out in a randomised block design. Emerged seedling numbers were recorded until the first of these produced multiple tillers.

Seedling emergence from soil (greenhouse). Greenhouse tests of seedling emergence from soil were conducted as insurance against failure of field tests through drought, during the first and second sowing seasons after harvest and began on January 14, 1986 and January 7, 1987. Each unit was a plastic seedling tray compartment containing soil of 25 cm² surface area in which were sown 100 seeds, lightly covered. In each run, there were 6 replicates of each seed lot of Crop 1 and 3 of each field replicate (*i.e.* 9 of each line) of Crop 2. The units containing seed from the 2 crops were laid out in adjacent but separate randomised block designs. Compartments were watered as needed (usually daily) until seedling emergence ceased (45 days in the first run, 34 days in the second). Seedlings were counted and removed daily over this period. Trays were then dried off, but re-watered periodically over 11 (1986 sowing) and 9 (1987 sowing) periods until November 1991, after which no more seedlings

emerged. Total emerging seedling numbers were recorded, the final value providing another estimate of total viable seed, and the proportion of these emerging over the first watering episode an estimate of dormancy in soil.

Results

Physical effects

The numerous combinations of peripheral rotor speed and minimum concave clearance applied to Crop 1 produced no detectable interactions between the 2 variables. For this reason, and for simplicity, only a single sequence of each is presented in Table 1.

Spikelet selectivity. In both crops, purity of sieved seed and 100-seed weight (an indication of the proportion of pure-seed spikelets containing mature caryopses) tended to decrease as rotor speed rose and as concave clearance narrowed (Tables 1 and 2).

Spikelet damage. Naked floret content increased markedly as rotor speed rose and showed a lesser, inconsistent tendency to fall as concave clearance widened (Tables 1 and 2). Ink-penetrated floret numbers followed a similar trend (Table 2). The two sets of results were thus consistent in showing that the proportions of physically damaged spikelets rose greatly as rotor

Table 1. Crop 1. Threshing cylinder settings and physical properties of seed harvested at different settings. Standard errors of means were: purity \pm 1.04%; 100-seed weight \pm 1.08 mg; naked floret content \pm 1.62%.

Different Peripheral Rotor Speeds (PRS) with Minimum Concave Clearances (2.3, 6.4 and 9.5 mm) combined:				
Harvest method	Hand-cut		Direct-headed	
PRS (km/h)	—	64	88	115
Purity (%)	53.2	54.4	50.6	46.3
100-seed wt (mg) ¹	67.2	70.7	67.5	66.8
Naked florets (%) ²	0	5.2	8.3	14.6

Different Minimum Concave Clearances (MCC) at a single PRS of 115 km/h:								
MCC (mm)	2.3	6.4	9.5	11.9	13.1	14.3	15.5	15.9
Purity (%)	42.3	49.2	47.4	49.5	52.5	50.5	53.0	55.4
100-seed wt (mg) ¹	67.1	66.6	66.7	65.4	68.0	65.5	67.3	70.0
Naked florets (%) ²	15.0	15.8	13.1	11.8	11.2	13.1	9.8	11.1

¹ 100-seed weights were determined on samples of pure-seed spikelets.

² Naked floret contents are expressed as percentage by number of total pure-seed spikelets.

speed rose and to a lesser extent as concave clearance narrowed. They provided reassurance that the preliminary objective — the creation of gradients of levels of threshing damage — had been achieved.

Recovery efficiency. The average hand-cut yield of Crop 2 serves as a best estimate of 'presentation yield' and a base figure from which to estimate efficiency of recovery of the combine-harvested strips (Table 2). The most severe threshing (treatment FC) produced by far the greatest yield of dried sieved seed, but the purity of the raw product was low, resulting in low percentage pure seed recovery. This, considered along with inexplicably low apparent efficiency of threshing treatment FO, makes it difficult to see any clear pattern in the efficiency of recovery of pure seed in relation to threshing cylinder setting.

Effects on viability

Measurements of viability in seed of *Panicum maximum* are really only estimates that reflect, and differ with, the method chosen. Since seed loses viability through aging in storage, age at testing must obviously be taken into account. At any age, the presence of dormancy and the restrictive influence of the husk affect the record of germination and its interpretation. The defects of germination tests force reliance on tetrazolium

tests, which, while greatly useful, themselves have other defects. There is value, therefore, in considering together the viability estimates from a range of tests conducted on a number of occasions, and Table 3 has been constructed with this in mind.

Although the accuracy of each estimate of the quality attributes of Crop 1 seed lots recorded in Tables 3 and 4 can be judged (standard errors of test record estimates were mostly about 4% of the mean), these estimates cannot, in the absence of field replication, be compared statistically across treatments. Trends can nevertheless be detected and their reality subjectively judged where differences are great.

The results varied across times and test methods as expected. Viability estimates by tetrazolium slightly exceeded values derived from roughly contemporary germination tests done on de-husked caryopses. This is normal. Residual dormancy of 2-year-old seed is eliminated by de-husking, so that germination is, at that time, theoretically synonymous with viability. However, weak embryos can be deemed viable by tetrazolium while lacking the capacity to complete germination. Viability estimated by the sum of germination and live dormant seed in the routine germination test (conducted on intact spikelets) creates an even greater discrepancy because death of living but weak caryopses occurs through their inability to break out of the

Table 2. Crop 2. Threshing cylinder settings, yield components and physical properties of seed harvested at different settings.

Harvest method	Hand		Direct-headed			
MCC (mm) ¹	—	15.5	2.3	15.5	2.3	
PRS (km/h) ¹	—	64	64	115	115	
Treatment identifier code ¹		SO	SC	FO	FC	
Sieved seed yields (kg/ha)	479 ± 30 ²	179	183	174	239	± 12.0 ²
Purity (%)	66.4 ± 2.6	75.0	73.1	63.3	63.5	± 1.5
Pure seed yield (kg/ha)	318 ± 31	132	131	109	149	± 9.2
Recovery efficiency (%)	N/A	42	41	34	47	N/A
100-seed weight (mg)	71.0 ± 0.99	75.3	74.7	73.6	71.2	± 0.99
Naked florets (%) ³	0.4	9.9	9.3	20.7	28.7	± 3.0
Ink-penetrated florets (%) ³	—	14.7	15.0	28.3	34.7	± 3.0
Mature caryopsis content (%) ²	70.3	74.5	74.0	73.0	70.6	

¹ MCC = minimum concave clearance; PRS = peripheral rotor speed; F = fast; S = slow; O = open concave clearance; C = closed concave clearance.

² Values shown are standard errors. Those for hand-cut seed are different from those for direct-headed seed. Mature caryopsis contents are calculated from 100-seed weights and have no standard errors.

³ Determinations of naked floret and ink-penetrated floret contents were made on samples containing only mature pure-seed spikelets.

Table 3. Estimates of viability of mature seed in relation to threshing severity, made by various test methods. All values are shown as percentages of total seeds tested.

Crop 1		Treatment ¹				
Age at test (yr)	Test ²	H	SC	MC	FC	
Laboratory						
0.52	TZ	100.0	97.5	90.5	87.5	
	TZ	96.5	83.5	74.5	68.5	
2.10	GD	91.5	83.0	70.5	58.5	
1.90	G+TZ	92.8	75.8	62.5	48.3	
Greenhouse						
0.92	E _{Cum}	92.3	76.5	69.3	59.0	
1.90	E _{Cum}	69.3	49.7	56.0	37.8	
Crop 2		Treatment ¹				
Age at test (yr)	Test ²	SO	SC	FO	FC	LSD (P = 0.05)
Laboratory						
0.34	TZ	97.7	94.7	91.0	88.3	4.5 ³
	TZ	90.3	87.7	83.3	79.7	8.3
1.92	GD	89.7	85.3	77.7	77.0	6.4
1.72	G+TZ	73.2	77.2	65.3	63.3	6.9
Greenhouse						
0.74	E _{Cum}	68.9	64.7	65.1	61.1	9.3
1.72	E _{Cum}	47.8	46.7	39.8	51.7	8.4

¹ H = hand-cut, F = fast, M = medium, and S = slow peripheral rotor speeds. O = open, C = closed concave clearances.

² Abbreviations for types of test are as follows: TZ = tetrazolium; GD = germination of de-husked caryopses; G + TZ = germination in routine tests plus viability by tetrazolium on ungerminated residues; E_{Cum} = cumulative seedling emergence from soil in greenhouse over 5 (1st sowing) and 4 (second sowing) years following sowing ('age at test' is age at sowing time).

³ Approximate values only, being back-transformed differences.

husk upon germinating and because some dormant seed fails to survive the prolonged hydration that the germination test entails. Still greater numbers of seedlings from initially living seeds fail to emerge successfully from soil, partly because emergence is one stage later than germination in the sequence of development and the individual is exposed to risk for longer, partly because the soil environment introduces hazards that are absent from the petri dish, and partly because the duration of the period over which inactive seed may age and die is much longer.

When these sources of variation were taken into account, treatment effects appeared remarkably consistent. The table layout was chosen so that threshing severity increased from left to right and, with only 3 exceptions, estimated viability

percentage declined in the same direction. Two of the exceptions are small enough to attribute to mere experimental variation, and only one (Crop 2, E_{Cum} sown at 1.72 yr, the difference between FO and FC) need be treated as an anomaly warranting specific attention. Even this may be no more than the chance juxtaposition of estimates at the low and high end of the range of each, and scrutiny of both the primary data and associated records suggests no better reason for the anomaly.

Despite this inconsistency, the overall record provides overwhelming evidence that, at any time and by any method of measurement, viability diminished as threshing severity increased; and the records for Crop 2 show additionally that the increase in peripheral rotor speed had a more

marked effect than concave closure. The effects are most convincing when viewed graphically. In Figure 1, the tetrazolium test viability records (the most thorough in terms of numbers of estimates) have been translated into population

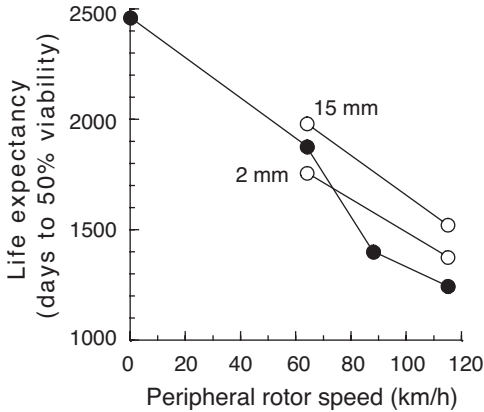


Figure 1. Effect of peripheral cylinder rotor speed and concave clearance on the life expectancy of seed. Closed circles refer to Crop 1, the value for zero rotor speed being that of hand-cut, unthreshed seed. Open circles refer to Crop 2, the 2 joined pairs representing open (15 mm clearance) and closed (2 mm) concave settings.

life expectancies under the particular storage conditions of the experiment. The basis for doing so was the principles of viability loss over time embodied in the models conceived by Roberts (1972) and developed by his group (Ellis and Roberts 1981). The essential point in the present context is that, under uniform storage, the course of viability loss should follow a straight line relationship of probits of percentage viability over time with a slope common to all populations of seed and characteristic of the particular storage conditions. The slope (an index of the rate of loss of viability) can be estimated from differences in probits of viability recorded between separate points in time. For purposes of comparison between populations, the viability characteristics of any population of seeds can be represented by a single value, expressed either as the viability on entry into storage or (as here) the average life expectancy (Roberts's 'mean viability period'). Given a common history of seed populations up to their different threshing experiences, and identical subsequent storage conditions, these values provide the best possible single measure of the effects of different levels of threshing severity on viability.

Table 4. Crop 1. Germination, greenhouse seedling emergence, field seedling emergence, and derived records indicative of dormancy, all in relation to threshing severity. Values are shown as percentages of total seed tested, except where otherwise stated.

Age at test (yr)	Test ²	Treatment ¹			
		H	SC	MC	FC
Laboratory 0.92	G(-K)	6.0	51.8	42.3	44.0
	G(-K) as % of viable	6.3	60.2	58.6	66.2
Laboratory 1.90	G(-K)	59.3	65.3	55.0	45.3
	D(-K)	34.7	11.7	7.0	4.0
1.90	G(+K)	71.3	68.0	58.7	46.0
	D(+K)	20.3	6.7	4.3	1.3
Greenhouse 0.92	E ₁	31.8	49.8	47.0	46.2
	E ₁ as % of E _{Cum}	34.4	65.1	67.8	78.3
1.90	E ₁	57.7	46.5	49.7	35.3
	E ₁ as % of E _{Cum}	83.3	93.6	88.8	93.4
Field 0.91	E	1.5	5.5	6.2	6.7
	1.90	E	0.5	1.7	2.2

¹ H = hand-cut. F = fast, M = medium, and S = slow peripheral rotor speeds. C = closed concave clearance.

² Test abbreviations are as follows: G = germination, with (+K) or without (-K) potassium nitrate. D = surviving dormant seed on completion of test, as determined by tetrazolium. E = seedling emergence. E₁ = emergence from soil over the first germination episode after sowing (c. 1 month duration). E_{Cum} = cumulative emergence over 5 years following sowing.

Figure 1 shows the following clearly: the general similarity, where there are points of legitimate comparison, between seed of Crops 1 and 2; the progressively increasing damage with increasing rotor speed over the entire measured range; and the still distinct but lesser increase in damage attributable to the change from a fully open to an almost closed concave. Figure 1 and Table 3, taken together, leave no doubt about the reality of the threshing effect on seed viability.

Effects on dormancy

Hand-cut seed of Crop 1 remained conspicuously dormant in germination tests done 0.92 years after harvest (Table 4). Combine-harvested seed tested at the same time had much lower levels of dormancy, which differed only slightly across threshing treatments. A year later, much of the dormancy of the hand-cut seed had been broken. However, whether judged in terms of the survival of dormant seed or the response to potassium, the level of remaining dormancy was still higher than in any of the combine-harvested seed. By this time, an effect of severity of threshing was apparent, with the amount of surviving dormant seed decreasing as peripheral cylinder speed increased. Unlike hand-cut seed, the threshed seed did not respond detectably to potassium, indicating generally more advanced loss of dormancy.

The early dormancy of hand-cut seed was also evident from the relatively poor early emergence of its seedlings from soil in the greenhouse and in the field (Table 4). Differences between threshing treatments in early emergence were too small to be statistically convincing, though there is a suggestion of a trend to less dormancy at high peripheral speeds. Two disastrously dry sowing seasons resulted in very little seedling emergence in the field and largely rendered the results valueless apart from the record of early dormancy of the hand-cut seed.

Similar dormancy-related treatment records for Crop 2 are presented for simplicity only in the form of main effects (Table 5) as no statistically significant interactions between peripheral speed and concave clearance were detectable in the 2×2 factorial analysis.

Seed threshed at fast peripheral speed had substantially less first-season dormancy in germination tests than that at slow speed, though there is no way to judge the statistical significance of the difference. There was a similar though lesser

difference between seed threshed with closed and open concave. The following year, though no effect of K could be detected, there remained distinctly more dormancy in the seed threshed at slow speed or with the concave open than in seed more severely treated.

Seedling emergence from soil

The only notable differences in seedling emergence numbers were from Crop 1 between hand-cut seed and the rest, and these reflect the more prolonged persistence of dormancy of the former (Table 4). Differences between threshing treatments in seedling numbers in either field or greenhouse were remarkably absent, in spite of the clear demonstration elsewhere of big differences in viability and dormancy, that might be assumed to have influenced them. While the field records were meaningless in the drought conditions, the greenhouse results cannot be explained away and demand more careful scrutiny.

The simplest and most obvious explanation for the scarcity of differences (Tables 4 and 5) is that the benefits of dormancy-breaking and the disadvantages of reduced life expectancy tended to cancel each other out when *net* effects such as seedling emergence were measured. This obviously occurred over the full range of levels of threshing damage because the extent of the component effects increased with severity of damage more or less in parallel with each other. This would then reduce differences to insignificance against the background of unaccountable experimental variation, and this indeed seems to be the best face-value interpretation of the results. The occurrence of occasional apparent differences such as those due to the low seedling numbers of FC of Crop 1 at age 1.90 years (Table 4) in no way conflicts with such an explanation.

Discussion

Threshing damaged seed physically at all levels of severity applied, and life expectancy of seed was shortened and some dormancy broken in all threshed seed, even the most gently treated. Judged by the simple comparison between threshed and unthreshed seed, Gatton panic behaved in the same way as green panic had done in the earlier study (Hopkinson and English 2004).

Table 5. Crop 2. Summary of main effects of threshing cylinder settings on seed properties influenced by variation in dormancy characteristics. All values are in percentages.

Age at test (yr)	Test	Threshing cylinder settings					
		Peripheral rotor speed			Concave clearance		
		Slow (64 km/h)		Fast (115 km/h)	Open (2.5 mm)		Closed (15.5 mm)
Laboratory²							
0.74	Germination (-K)	46.6	NS	53.3	46.8	NS	53.1
	Germ. as % of viable	53.6	NA ¹	70.3	56.1	NA ¹	67.7
1.72	Germination (-K)	41.0	NS	46.7	35.2	***	52.5
	Germination (+K)	42.2	NS	46.4	40.2	*	48.4
	Germination (+ & -K)	41.6	NS	46.5	37.7	***	50.4
1.72	Dormant (-K)	34.7	**	20.9	34.5	**	21.0
	Dormant (+K)	30.9	**	14.9	28.7	*	17.0
	Dormant (+ & -K)	32.8	***	17.9	31.6	***	19.0
Greenhouse³							
0.74	Emergence (E ₁)	52.9	NS	48.8	50.9	NS	50.9
	Emergence (E _{cum})	66.8	NS	63.1	67.0	NS	62.9
	E ₁ as % of E _{cum}	76.8	NS	83.0	80.0	NS	79.9
1.72	Emergence (E ₁)	35.9	NS	37.6	34.3	NS	39.1
	Emergence (E _{cum})	47.2	NS	45.7	43.8	NS	49.2
	E ₁ as % of E _{cum}	80.4	NS	78.5	76.8	NS	82.0
Field							
0.73	Emergence	4.3	NS	5.8	4.7	NS	5.4
1.72	Emergence	1.0	NS	1.1	1.1	NS	1.0

¹ NA = test of significance not applicable.

² +K and -K mean with and without potassium nitrate; + & -K indicates combined record.

³ E₁ = emergence from soil during the first germination episode after sowing (c. 1 month duration). E_{cum} = cumulative emergence over 5 years following sowing.

Physical damage included stripping of the membranous parts of the spikelet and enough disruption of the husk to accelerate the entry of water into the husk cavity of mature florets. The extent of both effects increased markedly with the vigour of the thresh, that is, as peripheral rotor speed was increased or minimum concave clearance reduced. This confirms that the main cause of damage lay in the threshing cylinder rather than with other potentially destructive but fixed-speed components of the harvest process such as augers and beater bars.

As threshing severity and physical damage increased, initial viability was reduced and life expectancy of the seed population was shortened. Over the range of cylinder settings used, changes to rotor speed had greater effects than changes to concave clearance. The effects were clear and consistent across crops, and were evident irrespective of the method chosen for measuring viability.

As viability was reduced, so too was dormancy broken. The effects were less consistently detectable, but this was to be expected as the measurement of dormancy is far less consistent than the measurement of viability. Its expression is elusive, depending on seed age and conditions of measurement in ways that are seldom fully under control. There is nevertheless ample evidence that the success of dormancy breaking increased with the severity of the thresh. The effect differed slightly from that on viability in that dormancy was broken to a similar extent by concave closure and increase in rotor speed.

The argument supporting a causal link between physical damage on the one hand and reduction of both viability and dormancy on the other was advanced by Hopkinson and English (2004). It is readily extended to the link between degrees of damage and differences in behaviour, where, indeed, its basis is strengthened by the parallel changes in cause and effect.

Attempts to measure the effects of different levels of threshing damage on seedling emergence in the field were thwarted by drought, and only the most extreme difference — that between hand-cut and all machine-threshed seed — was demonstrable. It is impossible to tell if, given better opportunities for them to be expressed, other effects would have been detected.

The greenhouse record of seedling emergence showed few statistically convincing differences beyond that between hand-cut seed and the rest. Despite the clear patterns of degree of damage and its effects on viability and dormancy in laboratory tests, only the single record of the poor performance of hard-threshed seed of Crop 1 in the greenhouse in the second season stands out. Without corroborative support from elsewhere, it is hard to attach much importance to this isolated result. Otherwise, the opposing effects of reduction in viability and release from dormancy appeared to cancel each other out. Having a common cause in physical damage, they varied together as the severity of that damage varied. The similarity extended to the way in which they changed over time, and deviations from these patterns were presumably too slight to create detectable differences, at least for the period of recording.

This does not exclude the possibility of the level of threshing severity having an effect in other circumstances, for example in different conditions for seedling emergence or after seed had deteriorated further under more prolonged or less favourable storage. Records of seedling emergence from soil in the greenhouse go only part way to bridging the gap between laboratory and field behaviour, essentially because they are too benign. We have observed in later experiments (records still unpublished) that conditions in the greenhouse may mask ill-effects, conspicuous in the field, of both loss of vigour and dormancy-induced slow germination. Thus, while the greenhouse results probably accurately reflect the way that the seed would have behaved if sown at the same age in the field under the most favourable conditions possible, assumptions cannot be further extended. The errors inherent in trying to assess net consequences of co-varying but opposing effects are simply too great.

A little more confidence is justified with attempts to foresee the changing behaviour of seed as it continues to age, as generally we expect dormancy to be extinguished before

viability (Harty *et al.* 1983). If this is so, inevitably the shorter life expectancy of hard-threshed seed will become the dominant variable as time passes, and the down-side of such treatment become increasingly apparent.

Overall, however, the possibility raised in the earlier investigation (Hopkinson and English 2004), that a producer might purposefully influence the properties of his seed through choice of cylinder settings, now seems unlikely. The opposing nature of the two main effects creates far too much uncertainty, especially as the timetable of future use of commercial seed is seldom known at harvest. For specific, pre-determined uses, more definite policies are possible. Pedigree seed destined for prolonged storage would benefit from the gentlest possible threshing, while seed to be sown prematurely for hurried multiplication (as during early commercialisation of a new cultivar) could be better hard-threshed.

While other consequences of changes in threshing practice were not the focus of the investigation, the records provide additional peripheral information worth noting. Purity and pure-seed maturity were reduced as severity of threshing increased, reflecting increasingly frequent detachment of empty and immature spikelets. The explanation presumably lies in the changing resistance of spikelets to detachment, which is always greatest in their early life, and diminishes with the progressive development of the abscission layer that accompanies the general development and maturation of an attached spikelet. There are 2 practical implications of the effect: hard threshing must raise drying and cleaning costs through inclusion of excess inert matter; and it slightly reduces potential pure-seed quality through raising the immature seed content. The latter effect, reducing mature seed content by a maximum of about 4%, would have slightly amplified differences in viability attributable to direct damage to caryopses. The records reinforce the view that, despite the most severe thresh producing the greatest quantity of unprocessed seed, no commercial advantage accrues to the grower from hard-threshing.

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