Effect of *Fusarium* seed infection and fungicide seed treatment on wheat and barley establishment and yield

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Abstract

The effects of three fungicide seed treatments (triazole plus imidazole (tri+im), fuberidazole (fub) and carboxin plus thiram (car+thi)) on establishment and yield of a number of paired seed lines of wheat cultivars with different levels of *Fusarium* infection were examined. Without seed treatment, lines of four cultivars with an average of 48% of seeds infected with *Fusarium* had between 9% and 23% lower establishment than lines with 7% of seeds infected. This reduction in establishment was not always directly related to laboratory germination. Tri+im slowed or reduced establishment of some seed lines. Seed lines infected with *Penicillium* spp. or bacteria had greatly reduced emergence and hence yield, and only car+thi improved emergence and yield of infected lines. A second trial examined the effects of tri+im and car+thi seed treatment on establishment and yield of a number of lines of barley cv. Valetta differing in *Fusarium* seed infection. In this trial, treatment with tri+im reduced field establishment in some seed lines, but did not affect yield, although treatment with car+thi produced a greater yield than tri+im.

Additional key words: *germination,* Penicillium, *bacteria*

Introduction

Fusarium species cause several important cereal diseases throughout the world (Parry *et al.*, 1995). In wheat, barley and other small grained cereals, they cause *Fusarium* foot rot, seedling blight and head blight or scab. Head blight can be a devastating disease overseas (McMullen *et al.*, 1997), and can be seasonally or locally serious in New Zealand when warm wet conditions predominate during grain filling (MAF, 1987), as happened in Canterbury in 1993/94 (Cromey, M.G., pers. comm.).

Head blight, if severe, can kill the developing grain. Milder infections can cause white or pink grain, sometimes shrivelled, resulting in reduced yield (McMullen *et al.*, 1997). Some *Fusarium* spp. in the grain produce mycotoxins which may make the grain unsuitable for stockfeed (Hoerr *et al.*, 1982; Smith *et al.*, 1997), human consumption (Joffe, 1978), milling (Dexter *et al.*, 1996) or malting (Schwarz *et al.*, 1996). In New Zealand there have been recent cases of dead poultry apparently linked to *Fusarium* mycotoxins in wheat (Cromey, M.G., pers. comm.). If the grain is used for seed, reduced germination, establishment and seedling vigour may result (Bechtel *et al.*, 1985). However, establishment can also be reduced by other factors such as small seed size, damage to the seed during harvest or storage, or seed-borne pathogens.

Several fungicide products have label recommendations for controlling seed-borne *Fusarium* species (New Zealand Agrichemical Manual, 1997). The most widely used is 150g/kg triadimenol + 50 g/kg imazalil (tri+im), marketed as Baytan IM. This is specified in some wheat contracts because it controls other diseases such as bunts and smuts. Another seed treatment specifically for controlling *Fusarium* is 100 g/kg fuberidazole (fub), marketed as Bayer Fuberidazole. *Fusarium* control is not specified for 200 g/l carboxin + 200 g/l thiram (car+thi), marketed as Vitaflo 200, but the label for this older product states that it controls a wide range of cereal head and seedling diseases.

Some farmers do not treat their seed with fungicide, both to save costs and because it is believed that some or all seed treatments can reduce seedling establishment. This belief has not been verified in New Zealand (Bell and Hampton, 1984; Cane and Hampton, 1989), although there are occasional overseas reports of reduced establishment when seed is treated with certain fungicides (Garmashov *et al.*, 1988; Tonkin, 1988).

This paper reports trials carried out to determine the effects of infection by *Fusarium* spp. and other fungi, and of fungicide seed treatments, on seed germination, field establishment and yield of wheat and barley.

Materials and Methods

Wheat

A number of lines of wheat seed, which were believed to have germination problems, were collected from farms, trials and a mill. Seed lines from other farm and research station crops were also included as potential "clean" seed controls.

All lines were assessed for germination and *Fusarium* infection. For the germinations tests, 100 seeds of each line were counted out onto filter paper in petri dishes and incubated at 20°C for eight days. The numbers of seeds germinating after five and eight days were counted. No assessment was made of any abnormalities in the germinating seedlings. For the *Fusarium* tests, 50 seeds of each line were plated onto potato dextrose agar (PDA) at ten seeds per plate. Plates were incubated on a laboratory bench, and the number of seeds infected with *Fusarium* were counted. The identification of *Fusarium* was based on colony morphology, backed up with microscopic examination of spores where necessary. The incidence of any other infection on the seeds was also recorded.

The results of the germination and plate tests were used to select 15 lines of wheat with contrasting germination, and seed-borne *Fusarium* and other micro-organism infection, for a field trial. There were three lines of cv. Otane, and two lines each of cv. Millbrook, Sapphire, Domino, Endeavour, Karamu and CRDW15 (a Crop and Food Research line of Durum wheat). Their germination and plate test results are given in Table 1.

Four sets of each line were then treated with the following fungicide treatments: no treatment, tri+im, fub, and car+thi at the recommended application rate, i.e., 1 kg tri+im/t of seed, 100 g fub/t of seed, and 250 ml car+thi /100 kg of seed. Chemicals were applied by hand and mixed thoroughly into the seed. Each set of seed was divided into four replicates for sowing in the field.

The trial was sown on 22 August 1995 using a Seedmatic experimental drill in a 50 m x 50 m area in a wheat crop (cv. Devoy) near Geraldine. The soil was a Waitohi silt loam. The seeding rate was 240 seeds/m^2. Plots were 3.3 m long by six 0.19 m rows (1.14 m) wide, with 0.6 m between plots. The trial was laid out in a split split plot design. The main plot factor was cultivar, the sub plot factor was lines and the sub sub plot factor was seed treatments. There were four replicates of each treatment, giving a total of 240 plots. The crop was managed in the same manner as the surrounding crop, receiving the same herbicide and fertilizer applications.

After drilling, four 0.222 m lengths of row were marked out with pegs in each plot. On each measurement occasion, a 0.127 m^2 quadrat was placed over the pegs and the number of emerged seedlings in three adjacent rows counted and recorded. Counts were taken on all plots on 14, 18, 22 and 25 September, i.e., 23, 27, 31 and 34 days after sowing.

The wet summer at Geraldine delayed harvest until 12 March. A 'Hege' plot harvester, set for maximum recovery of grain, was used. Considerable late weed growth occurred in many plots, and samples contained a lot of green weed material, necessitating drying overnight at 30-40°C in a forced draught oven to prevent spoilage. The samples were then cleaned and subsampled for moisture and grain weight determinations.

The statistical analysis of the results was modified to account for the wide range in establishment. Three sets of comparisons of wheat lines were made on the data from each of the four sampling dates:

1. within each cultivar, between high and low *Fusarium*-infected lines, without *Penicillium* or bacterial infection (four cultivars);
2. between lines with low *Fusarium* infection and without *Penicillium* or bacterial infection (six cultivars); and
3. between lines infected with *Penicillium* or bacteria, that had reduced establishment in the field (three lines).

Results were analysed using the Genstat statistical package (Genstat 5 Committee, 1993). Analysis of covariance was used to correct for low establishment in one corner of the trial. Preliminary analysis indicated that there was no advantage from analysing the data as a split-split plot, and so they were analysed as a split-plot trial with cultivars and disease levels as the main plots and seed treatments as the subplots. For the seed treatments, the analysis was extended to determine whether there were significant ($P<0.05$) contrasts between specific seed treatments or combinations of treatments. These were (a) nil versus tri+im (b) fub versus car+thi (c) nil and tri+im versus fub and car+thi. Any statistically significant ($P<0.05$) interactions among cultivar, disease level and seed treatment or seed treatment contrasts were also noted.

Barley

Ten lines of barley cv. Valetta seed, some with a high likelihood of *Fusarium* infection, either because the disease was noted on the parent crop, or weather conditions during the growing of the parent crop was conducive to the disease, were collected from trials and farmer's crops in the North and South Islands. All lines were assessed for germination and *Fusarium* infection as for the wheat trial. Each line of seed was treated with the following fungicide treatments: no treatment, tri+im and car+thi. Fungicides were applied at the same rates and in the same method as for the wheat.

The lines were sown in a field on the Crop and Food Research farm at Lincoln on 16 October 1996 at a seeding rate of 264 seeds/m^2 using a Seedmatic experimental drill. The soil was a Templeton silt loam. Plots were 3.5 m long by six 0.19 m rows (1.14m) wide, with 0.6 m between plots. The trial was laid out in a split plot design, with the main plot factor being barley seed lines, and the sub plot factor being seed treatments. There were four replicates of each treatment, giving a total of 120 plots.

Establishment counts were taken using the same method as for the wheat in all plots on 29 October and 1 and 4 November, i.e., 13, 16 and 19 days after sowing.

Good weed, disease and aphid control were achieved by appropriate applications of clopyralid, chlorsulphan, pirimicarb and tebuconazole on 7 December, triadimenol and pirimicarb on 20 December and propiconazole on 23 January. The crop was irrigated on 10 and 30 December, with about 30 mm water applied on each occasion. Because of considerable second growth, the crop was desiccated with diquat and a surfactant on 4 March. Plots were harvested on 12 March using a Wintersteiger plot harvester, and dried and processed in the same way as for the wheat.

Results were analysed using the Genstat statistical package (Genstat 5 Committee, 1993).

Results

Wheat germination and *Fusarium* tests

Two lines, one each of cv. Endeavour and cv. Otane, had very low germination, which was associated with *Penicillium* infections in the seed. One line each of cv. Millbrook and cv. CRDW15 had under 90% germination after five days, but germination was 100% by day eight. All other lines had germination percentages of 90% or more, irrespective of the level of *Fusarium* infection or the presence of other micro-organisms (Table 1).

The incidence of *Fusarium* spp. in or on the lines varied widely from 0 to 72%. *Penicillium* spp. occurred on four of the lines where there was a low incidence of *Fusarium* spp. In a few lines, unidentified bacteria were present, either alone or in association with *Penicillium* spp., and the widespread growth of *Penicillium* spp. and/or bacteria may have masked any growth of *Fusarium*. Two of the lines with *Penicillium* spp. had very low germination, but the other two had over 90% germination (Table 1).

Table 1. Wheat cultivars used in the field trial, their source, percentage *Fusarium* infection in or on the seed, germination percentage, *Penicillium* infection and thousand grain weight (TGW).

Cultivar	Source	*Fusarium* infection (%)	Germination (%)	*Penicillium* infection	TGW (g)
Millbrook	Trial	54	100	- [1]	43.3
Millbrook	Farm	8	99	-	41.7
Sapphire	Trial	58	95	-	46.2
Sapphire	Farm	5	99	-	47.9
Domino	Mill	6	90	yes	43.6
Domino	Mill	72	100	-	34.1
Endeavour	Farm	2	11	yes	50.0
Endeavour	Farm	8	99	-	27.1
CRDW15	Trial	4	100	-	51.8
CRDW15	Farm	12	93	-	45.8
Karamu	Farm	2	99	yes	45.4
Otane	Farm	0	64	yes	28.7
Otane	Farm	54	99	-	40.4
Otane	Trial	14	95	-	50.2

[1]No *Penicillium* spp. detected.

Wheat establishment and yield

It was intended to sow the trial in June, but sowing was delayed for two months because of wet weather. However, cold wet weather during plant emergence aided discrimination among the treatments.

Emergence started about 23 days after sowing and most plants had emerged 11 days later. By that time, counting plants was difficult as some cultivars were starting to tiller. In lines with low levels of *Fusarium* infection and without *Penicillium* or bacterial infection, about 85% of the seeds produced established plants. Only the data from the establishment counts taken 34 days after sowing are presented (Tables 2-5).

Four of the five lines infected with *Penicillium* spp. or bacteria had poor establishment; in the worst line of cv. Endeavour, which had a germination of only 11%, very few plants established. The other affected lines averaged 100 plants/m^2, in contrast to the average of 190 plants/m^2 in lines not infected with *Penicillium* spp. or bacteria.

Effect of fungicide treatment on lines with different levels of* Fusarium *infection

Four cultivars were investigated in this category: Millbrook, Sapphire, Karamu and the two lines of Otane which were not affected by *Penicillium* infection. Overall, seedling establishment was about 10% lower in plots sown with seed infected with higher levels of *Fusarium* than in those with low levels (Table 2). Fub and car+thi had no effect on establishment. However, tri+im significantly slowed (P<0.05) emergence, so that at 23 days after sowing, when the crop was first emerging, tri+im plots had 40% fewer plants. At 34 days after sowing, this had reduced to 12% fewer plants (Table 2). The response to tri+im varied among lines, but was not related to level of *Fusarium* infection. Seed treatment with tri+im reduced establishment of cv. Karamu under both levels of infection, but had little effect on the two lines of cv. Millbrook and cv. Otane (Table 3). In cv. Sapphire tri+im reduced establishment of the line with low *Fusarium* infection.

The level of *Fusarium* infection in the seed had no overall effect on yield (Table 2) indicating that extra tillering compensated for any reduced establishment caused by high levels of *Fusarium* infection. Overall, tri+im reduced (P<0.05) yield by 8%. However, as with establishment, this effect differed among lines. It was only statistically significant (P<0.05) in cv. Sapphire with low *Fusarium* infection, and in cv. Karamu with high infection, where yield was reduced by around 20% (Table 3). In the cv. Karamu line with low *Fusarium* infection, there was a 15% reduction (P<0.1) in yield. In these three seed lines the reduction in yield with tri+im seed treatment was of the same order as the reduction in establishment, suggesting no compensation for reduced establishment by increased tillering. There was no effect of seed treatment on seed weight.

Six cultivars with low levels of* Fusarium *infection

In the lines of cv. Millbrook, Sapphire, Endeavour, CRDW15, Karamu and Otane with low levels of *Fusarium* infection, tri+im significantly slowed (P<0.05) emergence, so that at 23 days after sowing, when the crop was first emerging, tri+im plots had 40% fewer plants. At 34 days after sowing, this had reduced to 10% fewer plants (Table 4). Significant (P<0.05) differences in response occurred between untreated seed and seed treated with tri+im versus seed treated with fub and

Table 2. Mean numbers of wheat plants/m^2 emerged 34 days after sowing (DAS) and mean grain yields, adjusted to 14% moisture content, from seed lines of four pairs of wheat cultivars with different levels of *Fusarium* seed infection and treated with different fungicide seed treatments.

	Plants/m^2 at 34 DAS	Grain yield (t/ha)
Fusarium seed infection (I)		
Low[1]	202a[3]	7.82
High[2]	180b	7.49
LSD (P<0.05)	10	0.39
Seed Treatment (ST)		
T1 Nil	194a	7.88
T2 Tri+im	171b	7.28
T3 Fub	198a	7.67
T4 Car+thi	199a	7.78
LSD (P<0.05)	10	0.47
Significant contrasts[4]	T3,4 vs T1,2 T2 vs T1	T2 vs T1
Significant interactions	Cult x ST	Cult x I x ST

1 less than 14% of seed/line carrying *Fusarium* spp.
2 more than 24% of seed/line carrying *Fusarium* spp.
3 means for *Fusarium* infection or for seed treatment accompanied by the same letters are not significantly different at P=0.05. If no letters are given then there is no significant difference at P=0.05.
4 See text for explanation.

Table 3. Effects of tri+im on number of plants emerged at 34 days after sowing and yield, adjusted to 14% moisture, of four wheat cultivars with either low or high levels of *Fusarium* infection. Significant (P<0.1) differences between the nil and tri+im treatments within each seed line are indicated where they occurred.

Cultivar/ Seed line	*Fusarium* infection (%)[1]	Plants/m² Nil	Plants/m² Tri+im	Grain yield (t/ha) Nil	Grain yield (t/ha) Tri+im
Millbrook					
Low	8	211	205	8482	8414
High	54	192	167	8582	7331
Sapphire					
Low	5	218	177(P<0.001)	8348	6775(P<0.05)
High	58	186	183	7634	7881
Karamu					
Low	2	212	158(P<0.001)	7859	6785(P<0.1)
High	24	177	142(P<0.05)	8301	6631(P<0.05)
Otane					
Low	14	203	192	6868	7350
High	54	157	143	6966	6666
Horizontal (within each seed line) LSD (P<0.05)		29		1320	

[1] Percentage of seeds per line carrying *Fusarium* spp.

car+thi. In the cv. Karamu line there was a large increase (P<0.001) in establishment with fub and car+thi compared with no seed treatment and tri+im, but this did not occur in the other cultivars. The cv. Karamu line was also infected with *Penicillium* spp., although not severely enough to affect germination, and the *Penicillium* spp. may have been controlled by fub and car+thi, but not tri+im, in the field. Across all lines, seedling establishment was significantly higher with car+thi treatment than with fub after 34 days from sowing, but neither treatment gave different (P<0.05) emergence compared with untreated seed.

Cultivars with Penicillium *or bacterial infections*

Two of these lines, cv. Domino and cv. CRDW15, had laboratory germination of more than 90%, but establishment was only 54 and 36% respectively in the field (Table 5). The line of cv. Otane had 64% laboratory germination, but only 38% field establishment. In these lines, seed treatment with tri+im and fub did not improve emergence. However, after 34 days, emergence was greater (P<0.05%) in plots treated with car+thi than those treated with the other two fungicides, although establishment was still less than 50%. The cv. Endeavour line, with only 11% laboratory germination, had no plants establish in the field, and so was omitted from the analysis.

The improved establishment from seed lines infected with *Penicillium* or bacteria infected lines when treated with car+thi resulted in improved yields (Table 5), but the effect depended on cultivar; it was large in cv. Domino, and not statistically significant in cv. Otane. Seed treatment did not significantly affect seed weight.

Barley germination and *Fusarium* tests

The incidence of *Fusarium* was generally low to moderate, ranging from 2 to 25% of the seed infected. Two lines had poor germination of less than 85% after 8 days. However, there was no relationship evident between germination percentage and the incidence of *Fusarium* infection (Table 6).

Barley establishment.

The plants in this trial emerged quickly and evenly, as would be expected for a late-sown spring barley crop. The average establishment after 19 days was 214 plants/m², representing a field establishment of 80%.

The emergence data from 19 days after sowing were used to compare seed lines and fungicide treatments.

Neither laboratory germination nor the incidence of *Fusarium* infection appeared to influence the establishment of untreated seed (Table 6). Seed treated with tri+im decreased emergence (P<0.05) compared to no seed treatment in two of the lines most infected with *Fusarium* (Cust and Kaiapoi), but increased emergence (P<0.05) in both Marton lines (Table 6). Treatment with car+thi increased emergence in the Wanganui line compared with untreated seed. Both Marton lines and the Wanganui line had poorer field emergence but also lower *Fusarium* levels compared to the other lines which were all from the South Island. The Cust, Kaiapoi, Lyndhurst and Oreti lines, which were four of the lines most infected with *Fusarium*, had greater emergence (P<0.05) with car+thi compared to tri+im seed treatments.

Table 4. Mean number of plants emerged at 34 days after sowing, yield and thousand grain weight (TGW) of six wheat cultivars grown from seed with low levels of *Fusarium* infection and either left untreated or treated with different fungicides. Yield and TGW have been adjusted to 14% moisture content.

	Plants/m^2	Grain yield (t/ha)	TGW (g)
Cultivar (C)			
Millbrook	205	8.29	34.9
Sapphire	202	7.89	30.6
Endeavour	211	7.68	32.6
CRDW15	174	4.78	25.1
Karamu	198	7.59	31.3
Otane	194	7.54	40.3
$LSD_{P<0.05}$	18	0.62	3.0
Seed Treatment (ST)			
T1 Nil	202 ab[1]	7.34	33.0
T2 Tri+im	182 c	6.99	32.6
T3 Fub	194 b	7.55	32.1
T4 Car+thi	210 a	7.28	32.2
$LSD_{P<0.05}$	11	0.50	1.2
Significant contrasts[2]	T3,4 vs T1,2 T2 vs T1 T4 vs T3	-	-
Significant interactions	C x (T3,4 vs T1,2)	-	-

[1] Figures for cultivar level or for seed treatment accompanied by the same letters are not significantly different at P=0.05. If no letters are given then there is no significant difference at P=0.05.

[2] See text for explanation.

Barley header yield, grain size and % screenings

There was no significant effect of seed line on yield. Thus the differences in establishment between seed lines were compensated for in some way, most likely through increased tillering in the lines with lower plant populations. The trial had two fungicide applications during its growth, and other fungal diseases such as scald or net blotch were not apparent on the plots.

Yields from either tri+im or car+thi treatments were not significantly different from untreated seed yields.

Table 5. Mean number of plants emerged at 34 days after sowing, yield and thousand grain weight (TGW) of plants grown from *Penicillium* or bacteria-infected wheat seed of different cultivars, either left untreated or treated with different fungicides. Yield and TGW have been adjusted to 14% moisture content.

	Plants/m^2	Grain yield (t/ha)	TGW (g)
Cultivar (C)			
Domino	130	6.64	36.1
CRDW15	86	3.47	24.5
Otane	93	4.78	34.1
LSD (P<0.05)	24	0.90	3.9
Seed Treatment (ST)			
Nil	89 b[1]	4.84 b	30.8
Tri+im	86 b	4.42 b	31.5
Fub	92 b	4.93 ab	31.0
Car+thi	113 a	5.66 a	33.0
LSD (P<0.05)	14	0.76	2.0
Significant contrasts[2]	T3,4 vs T1,2 T4 vs T3	T3,4 vs T1,2	-
Significant interactions	-	C x ST	-

[1] Figures for cultivar or for seed treatment accompanied by the same letters are not significantly different at P=0.05. If no letters are given then there is no significant difference at P=0.05.

[2] See text for explanation.

Table 6. Percentage *Fusarium* infection in or on the seed, laboratory germination percentage, and mean number of plants emerged per m^2 19 days after sowing for ten lines of barley cv. Valetta.

	Fusarium Infection (%)	Germination after 8 days (%)	Plants/m^2		
			Nil	Tri+im	Car+thi
Line					
Balfour	25	83	247	249	254
Cust	10	99	248 a[1]	203 b	261 a
Kaiapoi	12	94	248 a	194 b	267 a
Lyndhurst	16	100	251 ab	220 b	254 a
Marton 1	4	96	186 b	245 a	180 b
Marton 2	2	90	146 b	196 a	170 ab
Oreti	16	92	240 ab	226 b	270 a
Rakaia	14	74	220	214	215
Waimate	6	95	238	226	239
Wanganui	2	96	168 b	193 ab	205 a
$LSD_{P<0.05}$ within each line	-	4.3[2]		33	

1 Seed treatments within the same row accompanied by the same letters are not significantly different at P=0.05. If no letters are given there is no significant difference between seed treatments within that line at P=0.05.
2 Standard error of the mean. Since germination results were back transformed from angular transformed data. SEM increases as germination percentage increases. The largest value is given.

However, seed treated with car+thi produced a mean yield increase of 380 kg/ha (4%) (P<0.05) over tri+im treated seed (Table 7).

There was little difference between lines in grain size which averaged 51.5 mg (Table 7). However, seed treated with tri+im produced increased grain size (P<0.05) from two lines compared to untreated seed, whereas car+thi had reduced grain size in one line compared to untreated seed, explaining the significant interaction between line and seed treatment. There was no effect (P<0.05) of line or seed treatment on screenings percentages, which were very low at 1.8% (Table 7).

Table 7. Mean yield, thousand grain weight (TGW) and screenings percentage of barley cv. Valetta from untreated seed or seed treated with different fungicides. Yield, TGW and screenings have been adjusted to 14% moisture content.

	Yield (t/ha)	TGW (g)	Screenings (%)
Seed Treatment (ST)[1]			
Nil	9390ab[1]	51.3b	1.6
Tri+im	9170b	51.8a	1.8
Car+thi	9550a	51.3b	1.8
$LSD_{P<0.05}$	295	0.35	0.20
Significant interactions	-	Line x ST	-

1 Values accompanied by the same letter within a column are not significantly different at P=0.05. If no letters are given there is no significant difference at P=0.05.

Discussion

The levels of *Fusarium* infection in the seeds used in these trials were not high compared to those reported in the 1993/94 season (M.G.Cromey, unpublished data). Even so, establishment from the four lines of wheat which averaged 50% infection with *Fusarium* was 10-20% less than for lines which averaged 7% infection. However, in other wheat seed lines and in the barley, standard germination tests and *Fusarium* incidence in the seed line often gave no indication of field establishment. Hampton (1981) showed that establishment is closely related to seed vigour, and so a vigour test such as that proposed by Hampton (1981) could be useful when diseases or seed damage are suspected.

Substantial growth of *Penicillium* and/or bacteria occurred from some seed lines. *Penicillium* is a common storage mould. Its presence at high levels in some seed lines is indicative of heating damage, which suggests that those lines were either harvested with high moisture levels and not dried correctly, or storage conditions were not optimal. Heating damage can rapidly reduce seed germination through accelerating the physiological deterioration of seed lines. It is therefore consistent that seed lines carrying *Penicillium* spp. performed poorly in the field, either because germination prior to sowing was low (cv. Endeavour and cv. Otane), or physiological deterioration of high germinating lines (cv. Domino and cv. Karamu) meant that these lines coped poorly with the environmental stresses at sowing (Hampton, 1981). Heating damage is promoted by warm temperature, seed injury, contaminant debris and, especially moisture. The maximum safe storage moisture content for wheat is 14.5% (Hampton, 1984). However, temperature fluctuations in storage bins may cause moisture migration and condensation, which can induce fungal growth on grain that is otherwise dry enough. Grains damaged mechanically are also more prone to infection than intact seed, so care needs to be taken in harvesting. The bacteria present on the grains were not identified, but it is likely that they were encouraged by the same conditions as the *Penicillium*.

The seed treatment fungicide tri+im did not improve field establishment over untreated seed, and reduced establishment ($P<0.05$) for a number of seed lines, irrespective of their levels of *Fusarium* infection. The reduction in establishment due to tri+im treatment was 25% for the *Penicillium*-infected line of Karamu, and was also 19% in the clean line of Sapphire. The most likely reason for this reduction is that the seed was damaged in some way, probably at harvest. Scott *et al.* (1985) reported similar problems with seed treatment of Karamu and other New Zealand wheat cultivars. The label recommendation for tri+im (New Zealand Agrichemical Manual, 1997) states that if seed is cracked or damaged, germination may be impaired. Hard threshing during harvest can damage the seed coat just above the embryo or growing point of the grain. The problem may be reduced by correct setting and speeds of header drums, and more careful harvesting, especially if grain moisture content is low and the weather at harvest is hot and dry. These conditions make the seed more brittle (Cross, 1981). Careful harvesting may not eliminate the problem completely, since there are other reports of reductions in establishment with tri+im (Garmashov *et al.*, 1988), which has been found to retard coleoptile elongation (Tonkin, 1988) and seedling vigour (Cane and Hampton, 1989). This effect is more likely to be a problem if the seed is sown too deep in cold, wet conditions. However, the barley trial was sown in warm conditions, conducive to rapid germination and establishment, and yet tri+im still reduced field establishment in two lines. Conversely, this treatment also increased field establishment in two lines. This indicated that favourable seedbed conditions will not necessarily overcome establishment problems for seed treated with this product, and that the effects of this product are very dependent on individual seed lines.

Fub and car+thi did not reduce the establishment of any wheat seed lines, and car+thi did not reduce the establishment of any barley seed lines. Fub and car+thi are therefore probably safe fungicides to use for *Fusarium* control if seed is suspected to have harvest or storage damage. In addition, car+thi slightly improved the establishment of seed infected with *Penicillium* or bacteria, and this improvement resulted in 0.8 t/ha extra yield.

The possible effect of dormancy slowing germination and establishment of any of the seed lines was not considered in this trial, but was unlikely as the seed had been harvest for at least four months (W.B. Griffin, pers. comm.). In an earlier study, Bell and Hampton (1984) noted reduced germination of fungicide treated seed in dormant seed of wheat cv. Takahe.

Despite differences in establishment between seed lines, there were, in most cases, no statistically significant effects on yield, indicating that the plants were able to compensate for differences in establishment, possibly by increased tillering. However, barley seed treated with car+thi produced a higher yield compared with tri+im treatment because more plants established.

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