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The effect of a mixture of seed-borne *Microdochium nivale* var. *majus* and *Microdochium nivale* var. *nivale* infection on Fusarium seedling blight severity and subsequent stem colonisation and growth of winter wheat in pot experiments

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Abstract Greenhouse experiments were conducted in order to determine the impact of seed-borne *Microdochium nivale* var. *nivale* and var. *majus* inoculum, and seed treatment with a carboxin+thiram mixture, on the development of seedling blight, and on subsequent stem colonisation and growth of winter wheat (cv. Cadenza). Experiments were conducted at temperatures favourable (3°C) and unfavourable (22°C) to *M. nivale*. Seed-borne inoculum resulted in seedling blight symptom development when plants were grown at 3°C, but not when plants were grown at 22°C. For seedlings grown at 3°C, plants arising from heavily blighted seedlings developed more severe symptoms of stem colonisation, when compared with those arising from seedlings from carboxin+thiram treated seeds. In addition, the vigour of such plants (assessed by determining the number of tillers and ears per plant, stem length, green leaf area, dry weight and yield) was also significantly lower than for plants arising from carboxin+thiram treated seeds. *Microdochium nivale* var. *majus* and var. *nivale* appeared to have little effect on plant vigour from seedlings grown at 22°C. This is the first recorded incidence of seedling blight affecting subsequent plant growth. *Microdochium nivale* var. *majus* and var. *nivale* stem colonisation increased from growth stage (GS) 40–49 to harvest in plants raised from seedlings grown at both temperatures. *Microdochium nivale* var. *majus* and var. *nivale* were isolated from the second node at GS 40–49 and the third node at harvest of plants from seedlings grown at 3°C. For plants from seedlings raised at 22°C, *M. nivale* var. *majus* and var. *nivale* were isolated from the first node at GS 40–49 and the second node at harvest. Carboxin+thiram seed treatment decreased the extent and severity of stem colonisation on plants from seedlings grown at 22°C.

Keywords Cereals · Fungicide · *Fusarium* pathogens · Seedling blight · Disease progression · Seed treatments

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Introduction

There are four main pathogens responsible for Fusarium seedling blight of temperate cereal crops; *Fusarium avenaceum, Fusarium culmorum, Fusa-*

rium graminearum and *Microdochium nivale*. In the UK, Fusarium seedling blight caused by *M. nivale* can be responsible for poor emergence of winter wheat (Millar and Colhoun 1969a; Hare et al. 1995). *Microdochium nivale* may be soil- or seed-borne; however, seed-borne infection is considered to be the predominant cause of seedling blight of wheat in the UK (Parry et al. 1993). The severity of seedling blight symptoms can vary from localised lesions to extensive necrosis of the coleoptile and roots and pre- and post-emergent seedling death (Millar and Colhoun 1969a). In addition, there may be abnormal development of the radicle or plumule and angular black lesions may be observed on the leaf (Millar and Colhoun 1969a). The severity of seedling blight disease symptoms in wheat is greatest in cold dry soils (Millar and Colhoun 1969b; Hare et al. 1995). *Microdochium nivale* can also cause foot rot and ear blight infections under favourable conditions (Parry et al. 1993). Surveys in the UK have shown *M. nivale* to be the predominant pathogen on stem-bases of winter wheat (e.g. Locke et al. 1987; Pettitt et al. 1993). It has been proposed, in diagrams of Fusarium disease cycles (Parry et al. 1993) that non-lethal seedling blight may act as a source of inoculum for the subsequent development of foot rot and ear blight (Fig. 1). Splash-dispersal of *Fusarium* spp. conidia from infected winter wheat stem-bases can cause ear blight (Jenkinson and Parry 1994) whilst Clement and Parry (1998) demonstrated that *F. culmorum*, *F. graminearum* and *M. nivale* could systemically colonise winter wheat stems from soil-borne inoculum. The possible link between seedling blight and foot rot, and the link between foot rot and ear blight, means that it may be possible to reduce the incidence of ear blight by effectively reducing seedling blight and stem-base inoculum through the use of seed treatments. Field trials conducted by Bateman (2005) using seed contaminated with *M. nivale* and *F. culmorum* suggested that this may be possible.

Seed treatments have been demonstrated to increase establishment, believed to be an important component of yield (Spink et al. 2000). Seed treatments may also reduce the incidence and severity of foot rot and ear blight infections. In Canadian field trials at three sites, Fusarium ear blight symptoms were significantly reduced on wheat plants grown from seeds treated with carbathiin+thiram (Teich and Hamilton

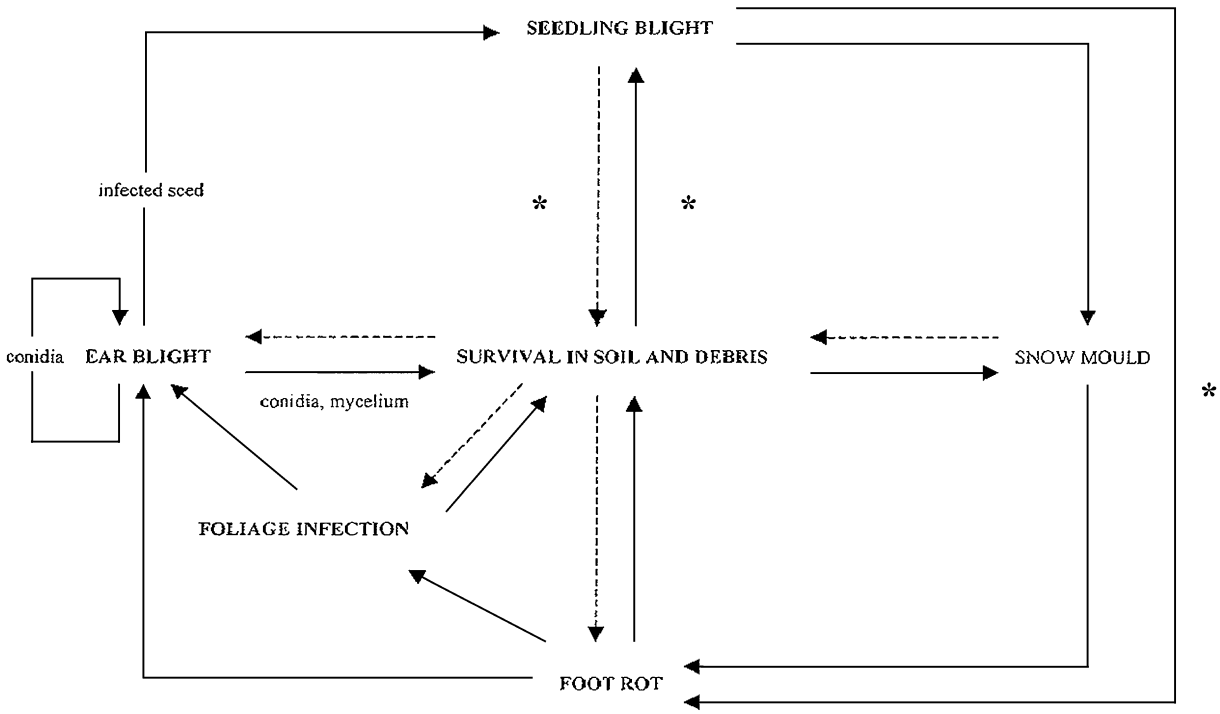

Fig. 1 Generalised life-cycle for *Fusarium* spp. on cereals in maritime climates (adapted from Parry et al. 1993). *Asterisks* indicate where seed treatments could break the disease-cycle

1985). During 2 years of field trials, stem-base infections of *M. nivale* were more frequent on spring barley seedlings from untreated seeds than triadimenol +fuberidazole-treated seeds (Perry 1986). However, in the UK, there has been a reluctance to use fungicide seed treatments in conditions where seedling blight is not expected to be problematic (Cockerall et al. 2001). From five years of field trials, Bateman (2005) reported that seedling infection in plants grown from seed infected by *F. culmorum* and *M. nivale* and treated with fludioxonil or bitertanol+fuberidazole made no significant contribution to ear blight.

At present, the effects of seedling blight from seed-borne *M. nivale* on subsequent disease and the resultant growth and yield of winter wheat are not known although Humphreys et al. (1995) found total grain yield correlated with seedling establishment. The aims of the work reported here were to investigate the effect of seed-borne *M. nivale* infection on the growth of winter wheat and stem colonisation from blighted and healthy seedlings under controlled environment conditions. A second aim was to investigate the effect of seedling blight control, through carboxin+thiram seed treatment, on winter wheat growth and subsequent stem colonisation.

Materials and methods

Plant material

Standard crop husbandry practices were used to maintain ten plots (2×10 m) of winter wheat (cv. Cadenza). Conidia were produced by growing three isolates of *M. nivale* var. *majus* and three isolates of *M. nivale* var. *nivale* on potato dextrose agar (PDA) at 15°C for 2 weeks. Plates were flooded with sterile distilled water (SDW) and conidia dislodged using a spatula. The resulting suspension was passed through two sheets of muslin and adjusted to 3×10^5 spores ml^{-1}. Plots were inoculated at a rate of 33 ml m^{-2} using a knapsack sprayer at growth stage (GS) 65 and mist-irrigated for 21 days after inoculation (Hilton et al. 1999). Grain was harvested at GS 92 (Zadoks et al. 1974) using a small plot combine (Wintersteiger, Austria).

The severity of *M. nivale* var. *majus* and var. *majus* infection was determined by plating 200 surface-sterilised seeds onto PDA amended with 130 μg ml^{-1} streptomycin sulphate (Sigma-Aldrich Company Ltd, Dorset, UK) and 25 μg ml^{-1} Bavistin DF® (50% *w/w* carbendazim; BASF, Bury St. Edmunds, UK). Seeds were surface-sterilised by immersion in 10% sodium hypochlorite (NaOCl) solution (1% available chlorine) for 3 min, rinsed three times in SDW, placed on sterile filter paper and dried in a flow of sterile air.

Seedling blight experiment

Surface-sterilised seeds were left either untreated or treated with 200 g l^{-1} carboxin + 200 g l^{-1} thiram (Anchor® 3 l tonne $seed^{-1}$; Chemtura (Europe) Ltd, Evesham, UK) using a Mini Rotostat (Marline Ltd, Norfolk, UK). Untreated and treated seeds were sown separately (20 mm deep) into sterilised (121°C; 1.08 bar for 1 h on three consecutive days) John Innes No. 2 compost in trays (215 mm×155 mm×50 mm; Ward, West Midlands, UK) which had been sterilised for 10 min in 10% sodium hypochlorite solution and rinsed three times with SDW. Trays were incubated under 12 h light at 3°C (cold incubation) to ensure disease expression, or 22°C (warm incubation) to discourage disease expression. At GS 12, seedlings were uprooted, washed and visually assessed for seedling blight (0—no visible symptoms on roots or coleoptile; 1—slight root and coleoptile necrosis; 2—moderate root and coleoptile necrosis; 3—severe root and coleoptile necrosis and seedling stunting). Isolations taken from coleoptile lesions confirmed *M. nivale* was the causal agent of disease.

Seedling propagation and analysis

Fifty seedlings of each disease score (0, 1, 2 or 3) from the cold incubation experiment were planted into ten surface-sterilised pots (15 cm diam×14.1 cm height; Sankey, Lancashire, UK) containing sterilised John Innes No. 2 compost. As no disease symptoms were observed at 22°C, 50 seedlings from treated seeds or untreated seeds were planted into ten pots. Seedlings from warm and cold incubation temperatures constituted separate experiments but were treated similarly as follows. Pots were placed into a greenhouse (12 h 15°C/12 h 5°C; 12 h light) in a fully randomised design for each experiment. Pots were watered daily by trickle irrigation beneath the pots to prevent spore splash-dispersal. Insecticides and mildew fungicides were applied as necessary. Two grams of Nitram (34.5% *N* fertiliser; Kemira GrowHow,

Ince, UK) were applied to each pot at GS 30. Each experiment was conducted twice.

Seedling establishment (GS 15–25), tillers (GS 39) and ears (GS 75) per plant were recorded. At GS 40–49, one plant per pot was uprooted and washed under running water. Stem length (stem-base to flag leaf ligule) of the main tiller was measured and leaf area determined using the WINDIAS 2.0 programme (Delta-T Devices Ltd, Cambs, UK). Plants were dried at 102°C for 24 h and dry weights recorded. At harvest, plant survival (GS 15–25 to harvest) was recorded and yield at 85% dry matter, grains ear^{-1} and grain weight ear^{-1} determined.

A 20 mm segment of tissue, from each uprooted plant at GS 40–49 and at harvest, was removed from the stem-base, each node and the ear where present. Each tissue segment was surface-sterilised in a 10% sodium hypochlorite solution for 3 min, washed three times in SDW, placed on sterile blotting paper and dried in a flow of sterile air. Tissue segments were plated onto PDA amended with 130 µg ml^{-1} agar streptomycin sulphate and 25 µg ml^{-1} agar Bavistin DF® and incubated at 15°C. Tissue segments were assessed for *M. nivale* presence after 7–10 days based on colony characteristics and spore morphology (Booth 1971).

Statistical analysis

The two seedling incubation temperature experiments were analysed separately. Data from the two cold incubation experiments were combined and subjected to ANOVA using Genstat 5.0 (Rothamsted Experimental Station, Herefordshire, UK) with seedling blight severity as factors and tillers plant^{-1}, stem length, leaf area, plant dry weight, ears plant^{-1}, yield, grains ear^{-1} and grain weight ear^{-1} as variables. Where appropriate, data were transformed prior to analysis. Data from the two warm incubation experiments were combined and analysed using *t*-tests. The incidence of *M. nivale* isolations from the stem-base and stem colonisation data was presented as percentage of plants infected. These data were not suitable for meaningful statistical analysis; hence standard errors were calculated.

Results

Plant growth from seedlings grown from untreated seeds showing seedling blight symptoms and seedlings from carboxin+thiram-treated seeds not exhibiting symptoms raised at 3°C

Seed-borne *M. nivale* infection was estimated at 29% from agar plating. Seedlings grown at 3°C from untreated seeds exhibited the full range of seedling blight symptoms. Carboxin+thiram seed treatment prevented seedling blight and was used to provide seedlings with a disease score of 0. Plant survival from GS 15–25 to GS 40–49 was 100% for seedlings with disease scores of 0, 1 and 2, and 91% for seedlings with a disease score of 3. Seedling blight severity had no significant effect (P=0.062) on tillers plant^{-1} but seedlings with a disease score of 0 and 1 produced numerically more tillers plant^{-1} than seedlings with disease scores of 2 and 3 (Table 1). Stem length was significantly affected (P=0.004) by seedling blight severity. Seedlings with a disease score of 0 had the longest stems (50.1 cm), whilst seedlings

Table 1 Growth characteristics of winter wheat (cv. Cadenza) at GS 40–49 from seedlings grown at 3°C exhibiting different seedling blight severities from seed-borne *Microdochium nivale* infection

Seedling blight severity	Tillers plant^{-1}	Stem length (cm)	Plant leaf area (cm^2)	Plant dry weight (g)
0	2.92	50.1	134	2.21 (0.36)
1	3.03	46.0	104	1.65 (0.25)
2	2.86	49.0	124	2.07 (0.33)
3	2.56	43.2	109	1.72 (0.35)
LSD (P< 0.05)	0.104	3.94	0.260	
SEM	0.037	1.39	0.092	
DF	57	57	57	
cv (%)	9.7	13.2	8.6	

Numbers in parenthesis represent standard error. Analyses were performed on square root-transformed data for tillers plant^{-1} and natural logarithm-transformed data for plant leaf area. Means shown are back-transformed data but statistics refer to the transformed data. Data are means of two experiments

with a disease score of 3 produced the shortest plants (43.2 cm). Plants developing from seedlings with a disease score of 0 had the greatest leaf area (Table 1); however plant leaf area was not significantly affected by seedling blight severity (P=0.174).

Plant survival from GS 40–49 to harvest was 100% for plants developing from seedlings with disease scores of 0, 1 and 2, and 94% for plants developing from seedlings with a disease score of 3. Ears plant^{-1} was not significantly affected (P=0.141) by seedling blight severity although seedlings with a disease score of 3 produced the fewest ears plant^{-1} (Table 2). Seedling blight severity significantly affected yield (P=0.002). Plants developing from seedlings with a disease score of 3 had the lowest yields (Table 2) whilst plants developing from seedlings with a disease score of 1 had the highest yields. Grains ear^{-1} was not significantly affected by seedling blight severity (P=0.882). Seedling blight severity had no significant effect on grain weight ear^{-1} (P=0.632) but seedlings with a disease score of 3 had the lowest grain weight ear^{-1} (Table 2).

Stem colonisation of plants from seedlings grown from untreated seeds showing seedling blight symptoms and seedlings from carboxin+thiram-treated seeds not exhibiting symptoms raised at 3°C

Microdochium nivale from seed-borne infection colonised up to the second plant node at GS 40–49. The incidence of *M. nivale* isolations declined from the stem-base to the first node and from the first node to the second node. Seedling blight severity had no significant effect on the incidence of *M. nivale* isolations from the stem-base or nodes (Fig. 2a) but the incidence of *M. nivale* isolations for plants from seedlings with a disease score of 0 was always the lowest.

At harvest, *M. nivale* had colonised up to the third node of plants from heavily diseased seedlings (disease scores 2 and 3). The incidence of *M. nivale* isolations at harvest was similar to the incidence of *M. nivale* isolations at GS 40–49. However, the incidence of *M. nivale* isolations typically increased on nodes one and two at harvest (Fig. 2b). The incidence of *M. nivale* isolations declined with increasing node number. *Microdochium nivale* stem colonisation increased in plants from seedlings with disease scores 2 and 3.

Table 2 Productivity of winter wheat (cv. Cadenza) at harvest from seedlings grown at 3°C exhibiting different seedling blight severities from seed-borne *Microdochium nivale* infection

Seedling blight severity	Ears plant^{-1}	Yield pot^{-1} (g)	Grains ear^{-1}	Grain weight ear^{-1} (g)
0	2.96	14.9	29.7	1.32
1	3.06	16.4	31.5	1.39
2	2.92	16.1	30.6	1.42
3	2.62	11.5	30.9	1.28
LSD (P< 0.05)	0.110	0.190	0.154	0.091
SEM	0.039	0.067	0.054	0.032
DF	57	57	57	57
cv (%)	10.3	11.2	7.1	12.4

Analyses were performed on square root-transformed data for tillers plant^{-1} and natural logarithm-transformed data for plant leaf area. Means shown are back-transformed data but statistics refer to the transformed data. Data are means of two experiments

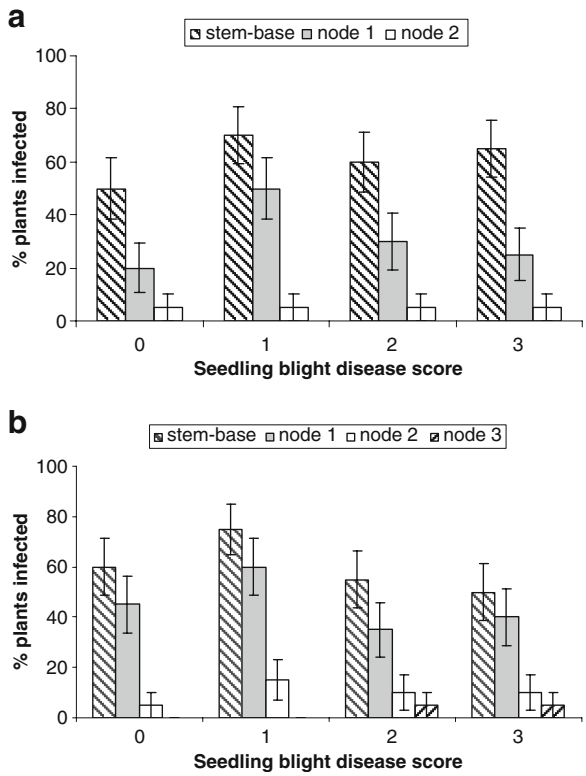

Fig. 2 Effect of seedling blight severity on seedlings grown at 3°C on the incidence of *Microdochium nivale* isolations from the stem-base and nodes of winter wheat (cv. Cadenza) at GS 40–49 **a** and harvest **b** from seed-borne infection

Plant growth from seedlings raised at 22°C and not showing seedling blight symptoms

Seedling survival was 97% for carboxin+thiram-treated seeds and 100% for untreated seeds. Carboxin+thiram–seed treatment had no significant effect on tillers plant^{-1} (P=0.340), stem length (P=0.905), leaf area (P=0.315) or plant dry weight (P=0.425) at GS 40–49 (Table 3).

All plants survived from GS 15–25 to harvest. Plants from untreated seeds produced significantly more (P=0.023) ears plant^{-1} than carboxin+thiram-treated seeds but this did not result in significantly increased yields (P=0.529). Plants from untreated seeds did not have significantly different grains ear^{-1} (P=0.360) or grain weight ear^{-1} (P=0.913) compared to plants from carboxin+thiram-treated seeds (Table 4).

Stem colonisation from seedlings raised at 22°C and not showing seedling blight symptoms

At GS 40–49, *M. nivale* had only colonised up to the first node (Fig. 3a). The incidence of *M. nivale* isolations on the first node was less than on the stem-base. Carboxin+thiram treatment reduced the incidence of *M. nivale* isolations on the stem-bases and first nodes. At harvest, *M. nivale* was isolated from the second node of plants from untreated seeds (Fig. 3b). The incidence of *M. nivale* isolations declined with increasing node number. Carboxin +thiram seed treatment reduced the incidence of *M. nivale* isolations from the stem-base compared with untreated seeds and prevented subsequent stem colonisation.

Table 3 Winter wheat (cv. Cadenza) productivity at GS 40–49 from seedlings grown at 22°C from carboxin+thiram-treated seeds and untreated seeds with *Microdochium nivale* infection

Treatment	Tillers plant^{-1}	Stem length (cm)	Plant leaf area (cm^2)	Plant dry weight (g)
Untreated	4.31	46.0	216	1.77
Carboxin+thiram	4.38	45.6	246	1.99
t-test statistic	0.97	−0.12	1.02	0.81
DF	32	32	32	32

Data are means of two experiments

Table 4 Winter wheat (cv. Cadenza) productivity at harvest from seedlings grown at 22°C from carboxin+thiram-treated seeds and untreated seeds with *Microdochium nivale* infection

Treatment	Ears plant^{-1}	Yield pot^{-1} (g)	Grains ear^{-1}	Grain weight ear^{-1} (g)
Untreated	3.61	15.4	8.7	19.0
Carboxin+thiram	3.03	14.0	12.1	18.3
t-test statistic	−2.38	−0.64	0.93	−0.11
DF	32	32	32	32

Data are means of two experiments

Discussion

In UK surveys, *Microdochium nivale* was the predominant Fusarium pathogen isolated from winter wheat seeds (Reeves and Wray 1994) and stem-bases (Locke et al. 1987; Parry 1990; Pettitt et al. 1993; Polley and Turner 1995). However, the source of *M. nivale* inoculum causing foot rot was not determined. Parry et al. (1995) reported *M. nivale* was the dominant *Fusarium* pathogen isolated from winter

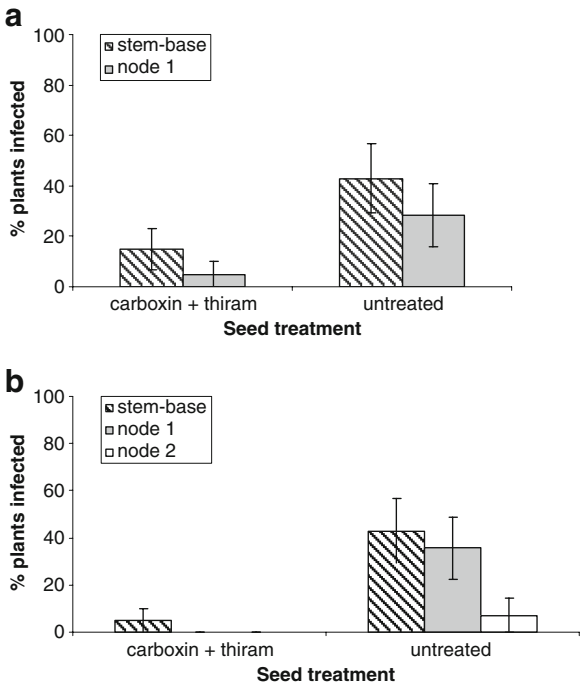

Fig. 3 Effect of carboxin+thiram seed treatment on seedlings grown at 22°C on the incidence of *Microdochium nivale* isolations from the stem-base and nodes of winter wheat (cv. Cadenza) at GS 40–49 **a** and harvest **b** from seed-borne infection

wheat stem-bases and seeds; however, this is the first investigation to demonstrate a link between seed-borne *M. nivale* infection and stem-base disease albeit under controlled environment conditions. Significant correlations between percentage *F. graminearum* winter wheat (cv. Frederick) seed infection and shoot infection during early plant growth and tiller-base infection (GS 92) in 2 years of field trials have been reported (Duthie and Hall 1987).

The proximity of the seed to the stem-base and *M. nivale* frequently being the predominant seed-borne pathogen of UK winter wheat (Reeves and Wray 1994) may allow stem-base infection by *M. nivale* before competing soil-borne *Fusarium* spp., as suggested by Parry (1990). The increased incidence of *M. nivale* in plants from seedlings grown at 3°C in this study, compared with 22°C would support this hypothesis. The lower *in vitro* base temperature for *M. nivale* growth (1.5°C) compared to that for *F. culmorum* (5°C) would enable earlier infection of stem-bases (Pettitt et al. 1996) especially in autumn and winter sown crops. Throughout this investigation no attempt was made to distinguish between *M. nivale* var. *majus* and *M. nivale* var. *nivale*, which were reclassified as species by Glynn et al. (2005). In mixed inoculum experiments on wheat seedlings at 15°C and 20°C, *F. culmorum* suppressed growth of *M. nivale* var. *majus* and *M. nivale* var. *nivale*. However, if *M. nivale* var. *majus* became established it was able to co-suppress colonisation by *F. culmorum* (Simpson et al. 2004). This suggests there are significant differences between *M. majus* and *M. nivale* with respect to their competitive abilities, and further work is required to determine how additional factors such as inoculum sources affect their incidence and severity on stem-bases of winter wheat crops.

Hutcheon and Jordan (1992) and Clement and Parry (1998) have demonstrated that *M. nivale* foot rot can lead to stem colonisation. Although the results reported here are not directly comparable to previous work due to the different inoculum sources employed, stem colonisation was similar to that reported by Clement and Parry (1998) under conditions precluding splash-dispersal. In this investigation, seedling blight was not a prerequisite for subsequent stem-base infection implying seed-borne inoculum alone is capable of causing stem-base disease in the absence of competing soil-borne pathogens. For both temperature experiments, stem colonisation decreased with increasing node number. This is in line with Clement and Parry (1998) and adds to the evidence that splash-dispersal is required for longer-distance dispersal. No obvious effect of seedling blight severity on stem-base disease incidence was observed, but *M. nivale* was consistently isolated from higher nodes of plants from heavily diseased seedlings. Increased inoculum levels associated with heavily diseased seedlings probably reduces plant height, allowing colonisation of a greater proportion of these plants compared to taller plants from lesser diseased or healthy seedlings.

Stem-base disease incidence typically increased between GS 40–49 and harvest during this investigation. As isolations were from main tillers, the death of plant parts is probably not responsible for the reductions seen in *M. nivale* levels observed under field conditions (Locke et al. 1987). Gradually increasing temperatures during the season (Daamen et al. 1991) may favour faster-growing and more aggressive pathogens, such as *F. culmorum* over *M. nivale*.

The two experiments reported here cannot be directly compared due to the effects of temperature during seedling development on wheat physiology (Porter and Gawith 1999). Negative effects for *M. nivale* on plant growth were only evident for plants from diseased seedlings. Increased seedling blight severity reduced tillers plant^{-1} and plant dry weight, at GS 40–49. Duthie and Hall (1987) described a significant correlation between percent *F. graminearum* seed-borne infection (0% to 43.5%) and tillers m^{-2} for plants from eight winter wheat seedlots. However, in a subsequent year with six winter wheat seedlots with 0% to 14.5% infection, no such correlations were observed, and it is likely that lower seed infection levels were responsible. In 1 year of field trials, significant correlations occurred between the extent of *M. nivale* seed infection, tillers plant^{-1} and ears m^{-2} for nine untreated wheat seedlots (Humphreys et al. 1995) and six untreated oat cultivars (Humphreys et al. 1998). Heavily diseased seedlings produced shorter plants which may have important consequences for ear blight control strategies since it has been suggested that taller cultivars hold their ears above sources of *Fusarium* spp. inoculum (Mesterhazy 1995). This is the first recorded incidence for seedling blight severity affecting subsequent growth of winter wheat.

Plant productivity, measured by ears plant^{-1}, grains ear^{-1} and grain weight ear^{-1} declined with increased

seedling blight severity. However, only plants from heavily diseased seedlings (score of 3) had significantly reduced yields. This may be attributed to continued and severe *M. nivale* challenges to these plants. *Microdochium nivale* inoculation of glasshouse-grown winter wheat (cv. Avalon) stem-bases at GS 21 reduced grains ear^{-1} and yield compared to an uninoculated control (Hutcheon and Jordan 1992). This investigation contradicts the findings of these authors; however, it was not clear what caused the reductions in their experiment. Bateman (2005) in field trials over 5 years demonstrated that fludioxonil and bitertanol+fuberidazole seed treatments made a significant contribution to reducing ear blight infections.

Carboxin+thiram treatment reduced stem-base disease incidence and stem colonisation compared with untreated seeds on plants from seedlings grown at both temperatures. Disease incidence and stem colonisation of plants from carboxin+thiram-treated seeds did not increase between GS 40–49 and harvest for seedlings grown at 22°C. However, increased stem-base and first node disease incidence between GS 40–49 and harvest and second node infection did occur on plants from treated seeds grown at 3°C. This result may have been caused by increased disease pressure on plants from seedlings grown at lower temperatures. Seed treatments reduced winter wheat stem-base infection from soil-borne *Fusarium* inoculum in field trials (Celetti and Hall 1987) and a glasshouse trial (Hutcheon and Jordan 1992). Seed treatments may improve plant productivity through reduced stem colonisation. However, increased yields are predominantly through increased establishment which has been shown to be directly correlated to yield (Humphreys et al. 1995).

Plant survival from treated seeds grown at 3°C was very high and treated seeds produced plants with the greatest leaf area, plant dry weight and longest stem length. Escape from seedling blight and continued disease pressure may increase plant vigour; however, yield was only increased above heavily diseased seedlings. Rawlinson and Colhoun (1970) attributed increased oat vigour and yield from organomercury-treated disease-free seeds to protection of the mesocotyl from soil-borne fungi. For seedlings grown at 22°C, carboxin+thiram treatment had no significant effect on plant vigour above untreated seeds. Seed-borne inoculum alone may be insufficient to adversely affect plant growth in the absence of soil-borne inoculum. In pot experiments using soil-borne *Fusarium* inoculum, triadimenol+bitertanol+fuberidazole, tebuconazole+thiram and bitertanol+fuberidazole seed treatments significantly reduced diseased ear area, but no treatment significantly increased winter wheat yields (Hutcheon and Jordan 1992). Beneficial effects of seed treatments on wheat productivity and yield for plants growing from seeds surface-inoculated with *Fusarium roseum* and *Alternaria alternata* spores (El-Tayeb et al. 1987) and in soil containing *Fusarium equiseti* and *Exserohilum rostratum* inoculum (Marley and Adeoti 1995) have been reported. In all instances, seed treatments are probably improving plant productivity by reducing disease challenge.

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