# Fungi associated with root and crown rot of wheat and barley in Tanzania

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# FUNGI ASSOCIATED WITH ROOT AND CROWN ROT OF WHEAT AND BARLEY IN TANZANIA

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## RESUMÉ

A total of 37 fungal taxa were isolated from wheat and barley planted to soil collected from the three main small-grain crop production areas in Tanzania, viz. Hanang Wheat Complex, Karatu and West-Kilimanjaro. The most prevalent species were *Bipolaris sorokiniana, Fusarium equiseti, F. nygamai, F. oxysporum, F. subglutinans, Periconia macrospinosa, Phoma macrostroma* and *P. medicaginis*, which were present in soil from all three areas. Roots yielded a greater variety of fungi than crowns. *Fusarium* spp., mainly *F. oxysporum* and *F. nygamai,* dominated the fungi isolated from roots, whereas *F. equiseti* represented the main *Fusarium* sp. isolated from crowns. *B. sorokiniana* was predominantly isolated from crowns of both wheat and barley.

In artificial inoculation studies most of the *Fusarium* isolates tested impeded seedling root and shoot growth and shoot mass of wheat and barley. The most virulent species were *F. nygamai* and *F. chlamydosporum*. *B. sorokiniana* caused the greatest reduction in shoot growth and mass of wheat and was significantly more virulent on wheat than on barley.

*Rhizoctonia solani* anastomosis group (AG) 6, the causal agent of patchy stunting (PS) in Tanzania, was retrieved from soil in all three areas, albeit at low frequencies. Artificial inoculation confirmed its pathogenicity and high virulence to wheat. Pathogenicity of *R. solani* AG-6 to barley was also established, although the latter crop appeared to be less affected than wheat. Observation of patches on different soil types as well as the absence of significant differences in isolation frequencies of *R. solani* AG-6 from different soils showed that PS is not limited to a particular soil type.

# CHAPTER 1

## GENERAL INTRODUCTION

The United Republic of Tanzania (Fig. 1) is the largest country in eastern Africa, comprising an area of 945 087 km$^2$ (including the islands Mafia, Pemba and Zanzibar) between 1°-12°S and 29°-41°E. With a *per capita* income of US$250 per annum and half the population below the poverty line, it is also one of the poorest nations in the world. The economy depends heavily on agriculture, which employs 80 % of the workforce, provides 85 % of all exports and accounts for half the gross domestic product, compared to 17 % contributed by industry. Cultivation of field crops dominates the agricultural sector, representing 80 % of the total production, while animal husbandry accounts for 15 %, fisheries for 5 % and forestry for less than 1 %. However, due to the country's widely varying topography and climate, cultivated crops are limited to only 4 % (37 800 km$^2$) of the total land area. Frequent spells of drought, and flooding over the central plateau during the rainy season, are the primary climatic constraints. The main crops produced are maize (*Zea mays* L.), rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.), cassava (*Manihot esculenta* Crantz), sorghums (*Sorghum* spp.), millet (*Panicum miliaceum* L.), pulses, sugarcane (*Saccharum officinarum* L.), coffee (*Coffea* spp.), tea (*Camellia sinensis* (L.) Kuntze), cotton (*Gossypium hirsutum* L.), tobacco (*Nicotiana tabacum* L.), sisal (*Agave sisalana* Perrine), clove (*Syzygium aromaticum* (L.) Merr. & L.M. Perry), cashewnut (*Anacardium occidentale* L.), coconut (*Cocos nucifera* L.), banana and plantain (*Musa* spp.) (http://www.commact.org). Of these, coffee, tea, cotton, tobacco, clove, sisal and cashewnuts are exported.

Wheat represents 1.3 % of the total area planted to commercial crops in Tanzania and 0.7 % of the tonnage produced. The respective figures for barley (*Hordeum vulgare* L.), which is an emerging crop locally, are 0.05 and 0.04 % (calculated from http://www.fao.org 2001). The main wheat and barley production areas, viz. Hanang Wheat Complex (HWC), Karatu and West-Kilimanjaro, are situated in the Arusha region to the north of the country. HWC consists of a cluster of seven state-owned farms and a central service facility as an eighth unit. The first farm was established in 1968 with the rest following between 1975 and 1984. All the units practise wheat


Fig. 1 Map of Tanzania (http://www.graphicmaps.com)

monoculture, although small plots may be grown to crops like barley, maize, safflower (*Carthamus tinctorius* L.), flax (*Linum usitatissimum* L.), sunflower (*Helianthus annuus* L.) and canola (*Brassica napus* L.) for experimental purposes. The complex produces 80 % of the wheat in Tanzania, satisfying between 45-50 % of the local demand (Majanga & Antapa, 1996). The remaining wheat and most of the barley are grown on farms in West-Kilimanjaro and Karatu, the majority being privately owned by companies such as Tanzania Breweries. Land degradation, mainly due to soil erosion, together with low and erratic rainfall are the major agronomic constraints to wheat and barley production in the area (Antapa, 1996; Mchomvu & Antapa, 1996). Average yields are in the order of 1.5 and 2.2 t $ha^{-1}$ for wheat and barley, respectively (http://www.fao.org 2001). The rainy season lasts from November to May with short rains falling during November, December and January and long rains from mid-March to May. Wheat and barley are sown with the

onset of the long rains. Average rainfall at HWC is about 600 mm per year. However, evapotranspiration during the growing season averages 800-900 mm and this exceeds the mean annual rainfall in all months except December, January and February (Mchomvu & Antapa, 1996).

Production of small-grain cereal crops in the region is further hampered by diseases, particularly patchy stunting (PS). PS has been observed on wheat farms at HWC since the early 1970s and more recently also on farms at West-Kilimanjaro and Karatu. Yield losses amount to 5-30 %, but can be as high as 40-50 % during drier years on newly-broken land (Antapa, 1996). The disease is characterised by distinct patches of severely stunted and chlorotic plants which appear four to five weeks after planting (Kuwite *et al.*, 1996; Meyer *et al.*, 1996). As the season progresses, affected plants either die or remain stunted. In this respect PS resembles bare patch disease of cereals occurring in various other parts of the world (Roberts & Sivasithamparam, 1986). However, unlike bare patch disease where the roots exhibit girdling and necrosis (Weller *et al.*, 1986; Ogoshi *et al.*, 1990), roots of plants affected by PS contain conspicuous nodulose swellings and sclerotial sheaths (Kuwite *et al.*, 1996; Meyer *et al.*, 1996). The latter symptoms are also typical of crater disease (CD) of wheat occurring on the Springbok Flats in South Africa (Deacon & Scott, 1985; Smith & Wehner, 1986). Anastomosis grouping and molecular characterisation (Carling *et al.*, 1996; Meyer *et al.*, 1998) indicated that CD and PS are caused by the same primary pathogen, namely *Rhizoctonia solani* J.G. Kühn anastomosis group (AG) 6, while bare patch disease is mostly ascribed to infection by *R. solani* AG-8 (Neate & Warcup, 1985).

Besides *R. solani,* various other fungi have also been implicated in PS, CD and bare patch disease. Reports from Australia (Harris & Moen, 1985a,b; Roberts & Sivasithamparam, 1987) indicated the co-involvement of *Alternaria alternata* (Fr.: Fr.) Keissl., *Bipolaris sorokiniana* (Sacc.) Shoemaker, *Fusarium avenaceum* (Fr.: Fr.) Sacc., *F. equiseti* (Corda) Sacc., *Idriella bolleyi* (R. Sprague) Arx, *Pythium irregulare* Buisman, *Waitea circinata* Warcup & Talbot, binucleate *Rhizoctonia* sp. and *Mortierella* sp. In South Africa, Scott *et al.* (1979) initially implicated *Periconia macrospinosa* Lefebvre & Aar. G. Johnson, *Pythium oligandrum* Drechsler,

*Rhizoctonia cerealis* van der Hoeven and *R. solani* as the main cause of CD, whereas Maas & Kotzé (1981), Smith & Wehner (1986), Opperman & Barnard (1992) and Meyer & Wehner (2000) isolated pathogens such as *B. sorokiniana*, *Fusarium culmorum* (Wm.G. Sm.) Sacc., *F. equiseti, F. nygamai* L.W. Burgess & Trimboli and *Sclerotium rolfsii* Sacc. from wheat roots on the Springbok Flats. Failure of the agonomycete-specific fungicide, tolclofos-methyl, to reduce severity of CD (Smith *et al.*, 1984) further supported the non-monopoly of *R. solani* in the disease.

In Tanzania, Kuwite *et al.* (1996) consistently isolated *B. sorokiniana*, *Fusarium oxysporum* Schltdl. em. W.C. Snyder & H.N. Hansen and *Rhizoctonia* spp. from wheat plants affected by PS but indicated that the latter was more prevalent, especially at the centre of patches. An earlier but rather limited and late in the season survey of barley fields in West-Kilimanjaro by the Council for Scientific and Industrial Research (CSIR) in South Africa (unpublished data), indicated the presence of pathogens such as *Gaeumannomyces graminis* (Sacc.) Arx & D.L. Olivier var. *tritici* J. Walker, *B. sorokiniana*, and *Rhizoctonia* and *Pythium* spp. Nevertheless, as yet no attempt has been made to compile an inclusive index of fungi associated with root and crown rot of wheat and barley in Tanzania. The purpose of this study therefore was to conduct a comprehensive survey of the soilborne pathogens involved in PS and general unthriftiness of wheat and barley in the main production areas of the country, and to determine the virulence of representative isolates under controlled conditions.

# CHAPTER 2

## LITERATURE REVIEW

Wheat and barley are subject to root and foot rots wherever the crops are grown. These diseases can affect the plant at virtually any stage during growth and development, but are most damaging during the seedling and tillering phases (Cook & Veseth, 1991). Because the ability of wheat and barley plants to tiller and produce a good yield depends almost entirely on a healthy root system, soilborne diseases can be a major constraint to production (Cook & Veseth, 1991; Chen *et al.*, 1996). Their main impact is thinned stands and reduced yields resulting from a decrease in tiller numbers, number of kernels per head and kernel mass (Ledingham *et al.*, 1973; Piening *et al.*, 1976; Chen *et al.*, 1996). In severe cases root and crown rot may lead to stunting and premature plant death (Conner & Atkinson, 1989).

Following germination, wheat and barley plants initially produce a primary or seminal root system which is essential for establishing the young plant (Klepper, 1991). Crown or adventitious roots form at coleoptile nodes and not only supply nutrients and moisture to individual tillers (Belford *et al.*, 1987), but are also important for anchoring the plant and providing resistance to lodging (Ennos, 1991). Seminal roots are particularly important under dry conditions when crown root development can be impeded (Boatwright & Ferguson, 1967) and have been shown to be more effective than the shallower crown root system in accessing water deep in the soil (Belford *et al.*, 1987). Besides impeding establishment and anchoring of the plant, disruption of either root system will affect its ability to provide the shoots with an appropriate balance of nutrients, water and growth factors (Cook & Veseth, 1991). Similarly, decay of the crown prevents it from conducting water and nutrients to the rest of the plant (Cook, 1968; Cook & Veseth, 1991).

An almost infinite number of reports exist on fungi that have been isolated from roots, crowns and subcrown internodes of wheat and barley (Table 1). A number of these fungi are associated with damage to the plants, but the majority are considered to be merely saprophytes whereas the role of others is unclear. The most important fungal

diseases principally observed on roots and stem bases of wheat and barley are briefly discussed below.

## 2.1 TAKE-ALL

When first discovered in Australia 150 years ago, this disease literally "took all" when attacking seedlings, hence the name (Mathre, 1982; Cook & Veseth, 1991). Today, take-all is found worldwide and is recognised as a disease of the roots, crown and foot (Mathre, 1982; Wiese, 1987). The take-all fungus, *G. graminis* var. *tritici*, shows some specialisation for wheat and barley but also attacks common grasses (Mathre, 1982). There is broad consensus that wheat is highly susceptible, whereas barley is usually considered to be somewhat less so (Scott, 1981). Asher (1972) reported reductions in dry mass, leaf area, tiller number and water content of shoots to be equally severe in wheat and barley after inoculation with *G. graminis* var. *tritici*. Production of crown roots by inoculated plants was, however, greater than by healthy plants and resulted in an increase in both the number and proportion of healthy roots following initial infection. This effect was more pronounced in barley and may partly account for this crop's relative tolerance to take-all attack under field conditions.

Early symptoms of take-all are subtle and easily overlooked (Huber & McCay-Buis, 1993). The pathogen begins its attack by infecting the seminal roots, spreading from root to root and plant to plant (Cook & Veseth, 1991). Black lesions and necrotic tips are characteristic root symptoms (Huber & McCay-Buis, 1993). As the fungus grows into tiller roots and bases, the rot extends into the crown and up the stem, where a distinctive dark superficial mycelial mat may form (Wiese, 1987). Grain losses of 10-15 % from reduced root absorption and killed or aborted tillers may go unnoticed in the field (Huber & McCay-Buis, 1993). Symptoms are most obvious near heading, when plants appear uneven in height, begin to die prematurely and exhibit white heads (Wiese, 1987). By this time, yield losses caused by lack of seed development and filling may have reached 50 % or more (Mathre, 1982).

Infection by *G. graminis* var. *tritici* is greatly influenced by soil conditions and the environment (Lawn & Sayre, 1992). Disease is favoured by low fertility soils of

neutral or alkaline pH where moisture is plentiful during most of the growing season (Cook, 1981; Wiese, 1987). A deficiency in any of the essential mineral nutrients further aggravates disease (Huber, 1981; Reis *et al.*, 1982, 1983). Take-all often increases to maximum severity during a continuous succession of wheat or barley (Bateman & Kwasna, 1999). Take-all decline sometimes follows severe disease, often in the fourth or subsequent crops (Rovira & Wildermuth, 1981). The most favoured explanation for this decline is an increase in antagonistic microorganisms during consecutive cropping of the same cereal (Bateman & Kwasna, 1999). Exclusion of wheat or barley for one year usually breaks the disease cycle (Wiese, 1987).

## 2.2 COMMON ROOT ROT

According to Sallans (1965) the term "common root rot" has been widely used to designate a group of diseases characterised by necrosis of the roots, crowns and stem bases of cereals resembling, but distinct from, take-all. Common root rot is an insidious disease that seldom produces definite aboveground symptoms (Conner & Atkinson, 1989). Diseased plants occur scattered throughout fields amongst healthy ones (Broscious & Frank, 1986). In severe cases, root rot can cause stunting and premature plant death (Conner & Atkinson, 1989). Plants that survive usually mature but yield poorly because of a weakened root system and reduced tillering (Verma *et al.*, 1976; Wiese, 1987). Heavily infected plants may also senesce prematurely and produce small, discoloured heads containing shrivelled kernels (Scardaci & Webster, 1982).

Plants weakened by abiotic stresses are predisposed to common root rot (Duczek, 1986, 1989). Losses are most severe when soil moisture is limited and the disease is consequently also referred to as dryland rot (Mathre, 1982; Wiese, 1987). When soil moisture is not limiting, infected plants having fewer tillers may compensate by producing more and heavier kernels per head (Mathre, 1982). Diehl *et al.* (1982) estimated that yield losses in winter wheat range from 1.2-38.1 % with a mean of 15.6 % in fields in Brazil. Wildermuth *et al.* (1992) reported losses of 6.8-43.9 % for three wheat cultivars tested in Queensland, Australia. In Canada, yield reductions of

2.5-17.1 %, depending on the cultivar, have been reported for wheat (Tinline & Ledingham, 1979), while barley cultivars showed losses ranging from 5-42 % (Mathre, 1982).

The etiology of common root rot is complex and varies regionally. The causal fungi are widely distributed as unspecialised pathogens capable of infecting most small-grain cereals as well as numerous grasses (Wiese, 1987). The most commonly encountered pathogens are *B. sorokiniana* and *Fusarium* spp. (Hill *et al.*, 1983), particularly *F. culmorum* and *F. pseudograminearum* O'Donnel & T. Aoki (Mathre, 1982; Wiese, 1987). Less virulent species such as *F. acuminatum* Ellis & Everh., *F. avenaceum*, *F. crookwellense* L.W. Burgess, P.E. Nelson & Toussoun and *F. poae* (Peck) Wollenw. may also be involved (Wiese, 1987). *B. sorokiniana* is considered the major incitant of disease on the Canadian prairies (Harding, 1973; Verma *et al.*, 1974), and in Mexico (Lawn & Sayre, 1992), southern Brazil (Diehl, 1979; Diehl *et al.*, 1982), Texas Panhandle, USA (Specht & Rush, 1988) and Queensland, Australia (Wildermuth, 1986). In eastern Australia (Burgess *et al.*, 1981), and Minnesota and New York, USA (Warren & Kommedahl, 1972; Kane *et al.*, 1987) *F. pseudograminearum* is recognised as dominant. Studies in areas of East Africa (Saari & Wilcoxson, 1974) and California, USA (Scardaci & Webster, 1982) indicate that *B. sorokiniana*, *F. culmorum* and *F. pseudograminearum* are the major pathogens in the disease complex, whereas *B. sorokiniana* and *F. acuminatum* are regarded as the main components in Colorado and Wyoming, USA (Hill *et al.*, 1983). Foot and root rot of wheat is caused primarily by *F. culmorum* and *F. pseudograminearum* in the Pacific Northwest, USA (Cook, 1968, 1980; Smiley & Patterson, 1996) and Western Cape, South Africa (Maas & Kotzé, 1981). In Europe, *Microdochium nivale* (Fr.) Samuels & I.C. Hallett predominates (Cassini, 1981; Parry *et al.*, 1994; Rossi *et al.*, 1995). Complex interactions among environmental conditions and crop production procedures influence dominance between the different pathogens (Smiley & Patterson, 1996). In addition, Scardaci & Webster (1981) indicated that prior colonisation and possession of the host substrate may play an important role in establishing dominance among the pathogens involved. They found *F. pseudograminearum* and *B. sorokiniana* to compete equally well when co-inoculated on barley roots at planting. However, when inoculated in sequence, one

21 days before the other, the pathogen inoculated first was re-isolated more frequently.

In California, Scardaci & Webster (1982) found that isolates of *B. sorokiniana*, *F. culmorum* and *F. pseudograminearum* from wheat or barley showed no evidence of specificity to either host; they were pathogenic to wheat and barley cultivars regardless of their original host. The authors concluded that differences in disease severity on wheat or barley infected with different isolates of each pathogen may simply be attributed to differences in host susceptibility and pathogen virulence. By contrast, Conner & Atkinson (1989) reported that continuous cropping to susceptible cultivars of wheat and barley resulted in selection of *B. sorokiniana* isolates more damaging to the host being grown continuously. Root rot severity did, however, increase gradually with time in the alternative host. Wood (1962) also showed isolates of *B. sorokiniana* from various sources to differ greatly in their pathogenicity towards cereals. Some were pathogenic to wheat as well as barley and oats (*Avena sativa* L.), whereas others were only pathogenic to different combinations of these hosts. Similar findings were reported by Ashworth *et al.* (1960).

Differences in susceptibility of wheat and barley to common root rot have been reported. Chinn (1976a) observed a correlation between mean disease ratings and the number of *B. sorokiniana* conidia in the soil, whereas Chinn (1976b) found that barley contributed more than wheat to soil populations of this fungus. Tinline & Ledingham (1979) showed barley cultivars on average to be more susceptible to *B. sorokiniana* than wheat cultivars when tested in the field. Similarly, Fedel-Moen & Harris (1987) reported infections by *B. sorokiniana* to be more numerous on barley than wheat, whereas infections by *Fusarium* spp. occurred with equal frequency on both hosts. Observations by Scardaci & Webster (1982) corroborate the greater sensitivity of barley to *B. sorokiniana*, but indicated that this crop was more susceptible to *F. culmorum* and *F. pseudograminearum* than wheat under most conditions tested.

## 2.3 *RHIZOCTONIA* ROOT ROT

*Rhizoctonia* root rot is an important disease of wheat and/or barley in Australia (Samuel & Garrett, 1932; MacNish, 1983; MacNish & Neate, 1996), Canada (Benedict & Mountain, 1956), England (Dillon-Weston & Garrett, 1943), Scotland (Murray & Nicolson, 1979; Murray, 1981), South Africa (Scott *et al.*, 1979; Smith *et al.*, 1984; Deacon & Scott, 1985), Tanzania (Kuwite *et al.*, 1996; Meyer *et al.*, 1996) and the USA (Weller *et al.*, 1986; Mathieson & Rush, 1991). Various other names have been used to describe the disease, including bare patch or *Rhizoctonia* patch (MacNish, 1983, 1985; Weller *et al.*, 1986; MacNish & Neate, 1996), barley stunt disorder (Murray & Nicolson, 1979; Murray, 1981), crater disease (CD) (Scott et al., 1979; Deacon & Scott, 1985) and patchy stunting (PS) (Kuwite *et al.*, 1996; Meyer *et al.*, 1996). Nevertheless, they all refer to a disease characterised by the development of distinct patches of stunted and/or chlorotic plants (Samuel & Garrett, 1932; Dillon-Weston & Garrett, 1943; Murray & Nicolson, 1979; Scott *et al.*, 1979; Murray, 1981; MacNish, 1983; Smith *et al.*, 1984; Deacon & Scott, 1985; Weller *et al.*, 1986; Ogoshi *et al.*, 1990; Kuwite *et al.*, 1996; MacNish & Neate, 1996; Meyer *et al.*, 1996; Gill *et al.*, 2002). These symptoms may become apparent as early as 3-4 weeks after planting (MacNish, 1984; Weller *et al.*, 1986). Patches can recur in the same field for several years and may change shape or size from one season to the next (MacNish, 1985). In most cases, roots of diseased plants have brown sunken lesions which may girdle and sever the roots, typically leaving pointed brown tips, referred to as "spear tips" (Weller *et al.*, 1986; Ogoshi *et al.*, 1990). The exceptions seem to be CD and PS, where seminal roots contain nodulose swellings and sclerotial sheaths (Deacon & Scott, 1985; Smith & Wehner, 1986; Kuwite *et al.*, 1996; Meyer *et al.*, 1996), rather than exhibiting girdling and rotting.

There is evidence that soil and climatic effects may be of overriding importance in *Rhizoctonia* root rot (Samuel & Garrett, 1932; Murray & Nicolson, 1979; Deacon & Scott, 1985; Moen & Harris, 1985; Smiley & Wilkins, 1993; Gill *et al.*, 2000, 2001a, b). Disease expression may differ with change in soil type or weather conditions, as in Scotland (Murray & Nicolson, 1979) and the USA (Smiley & Wilkins, 1993). Where disease pressure is very high, affected areas may coalesce to create the appearance of widespread stunting across entire fields (Murray & Nicolson, 1979). Low and

localised disease pressure, on the other hand, results in individual stunted plants interspersed with productive ones, or minor root rot that does not cause stunting or other symptoms of reduced plant vigour. Moderate root damage can delay crop maturation up to 3 weeks, even in the absence of patches of stunted plants (Smiley & Wilkins, 1993).

Although *R. solani* is generally regarded as the causal agent of *Rhizoctonia* root rot (Samuel & Garrett, 1932; Dillon-Weston & Garrett, 1943; Benedict & Mountain, 1956; Murray & Nicolson, 1979; Murray, 1981; MacNish, 1983, 1985; Deacon & Scott, 1985; Weller *et al.*, 1986; Wiese, 1987; MacNish & Neate, 1996; Meyer *et al.*, 1996), some discrepancy exists regarding the anastomosis groups (AGs) responsible, while involvement of other *Rhizoctonia* spp. has also been indicated. Murray (1981) reported the *R. solani* responsible for barley stunt disorder in Scotland to be AG-3. Neate & Warcup (1985) identified *R. solani* AG-8 as the cause of bare patch in Australia. Ogoshi *et al.* (1990) found that *R. solani* AG-8 and *Rhizoctonia oryzae* Ryker & Gooch were both involved in root rot of wheat and barley in the Pacific Northwest. Rush *et al.* (1994) reported that *R. solani* AG-4 was the predominant pathogen on wheat in Texas, although AG-2-2 and AG-5 were also recovered from diseased seedlings. CD in South Africa and PS in Tanzania were shown to be caused by *R. solani* AG-6 (Carling *et al.*, 1996; Meyer *et al.*, 1998). Other *Rhizoctonia* spp. and AGs have also been isolated from wheat and barley (Scott *et al.*, 1979; Bolkan & Ribeiro, 1985; Neate, 1985; Neate & Warcup, 1985; Roberts & Sivasithamparam, 1986, 1987; Burton *et al.*, 1988; Ogoshi *et al.*, 1990; MacNish *et al.*, 1994, Yang *et al.*, 1994; Demirci, 1998). A number of reports have also suggested co-involvement of fungi other than *Rhizoctonia* spp. in the disease (Scott *et al.*, 1979; Harris & Moen, 1985a,b; Roberts & Sivasithamparam, 1986, 1987; Meyer & Wehner, 2000). Harris & Moen (1985a) reported that infection by *R. solani* predisposed wheat to a succession of common root rot and minor pathogens. Severity of the short-lived *Rhizoctonia* attack influenced the severity of infections that followed. Harris & Moen (1985b) accordingly described the disease as an "open-ended syndrome" in which a diverse range of organisms may participate in secondary infections and subsequently proposed that the disease should be referred to as *Rhizoctonia*-induced common root rot of cereals. This view is shared by

Roberts & Sivasithamparam (1986, 1987) who suggested a complex composed of one or more AGs of *R. solani* and other associated fungi as the cause of bare patch disease. However, with CD of wheat other root-colonising fungi appear to protect roots against attack by *R. solani*, the exception being *Pythium aphanidermatum* (Edson) Fitzp. (Meyer & Wehner, 2000).

## 2.4 *PYTHIUM* (BROWNING) ROOT ROT

Pythiums are widely distributed in agricultural soils around the world where they attack numerous hosts, including many cereals and grasses (Hendrix & Campbell, 1973; Mathre, 1982; Wiese, 1987). Several *Pythium* spp., acting singly or in combination, are involved in browning root rot of wheat and barley (Mathre, 1982; Wiese, 1987). Species best documented as pathogens on wheat are *P. aphanidermatum*, *P. aristosporum* Vanterpool, *P. arrhenomanes* Drechsler, *P. graminicola* Subraman., *P. irregulare*, *P. myriotylum* Drechsler, *P. ultimum* Trow var. *sporangiiferum* Drechsler and *P. volutum* Vanterpool & Truscott (Wiese, 1987). On barley, *P. arrhenomanes*, *P. graminicola* and *P. tardicrescens* Vanderpool are the most common (Mathre, 1982).

*Pythium* spp. begin their parasitic attack by infecting the embryo of the seed within 24-48 hours after planting (Cook & Veseth, 1991). Seed deterioration with aging can increase the susceptibility of germinating seeds to infection (Hering *et al.*, 1987). Most embryo infections are not lethal but rather lead to stunting of the seedling (Cook & Veseth, 1991). Consequently stand establishment is usually not a problem in *Pythium*-infested soil (Cook *et al.*, 1987). Once established in the embryo the fungus moves to the shoot and roots, initiating new infections at the root tips (Cook & Veseth, 1991). *Pythium* spp. are especially efficient in invading and destroying root hairs and juvenile rootlets (Cook *et al.*, 1987) which are critical to nutrient uptake prior to development of tillers and the associated crown roots (Cook & Veseth, 1991). Reduced seedling vigour caused by embryo infections together with subsequent destruction of rootlets and root hairs (Cook *et al.*, 1987) can account for the smaller size of adult plants, lack of tillering and lower yield when *Pythium* is not controlled (Hering *et al.*, 1987). Cook *et al.* (1980, 1987) reported that wheat yields were

commonly 15-25 % higher where the population of *Pythium* was reduced or eliminated by soil solarisation or fumigation.

According to Cook & Veseth (1991) the extent of *Pythium* infection greatly depends on moisture and other soil factors. The wetter or more poorly drained the soil and the higher the clay content, the more the infection. Infection furthermore increases with soil acidity, down to about pH 5.0.

## 2.5 EYESPOT

Eyespot or strawbreaker is named for its effects on the base of some cereals and grasses (Wiese, 1987). The disease is caused by *Ramulispora herpotrichoides* (Fron) Arx, previously known as *Pseudocercosporella herpotrichoides* (Fron) Deighton (Deighton, 1973) and wheat is more susceptible than barley (Mathre, 1982). Because prolonged periods of cool, wet weather are required for spore production by *R. herpotrichoides* (Cook & Veseth, 1991) winter cereals are damaged more often than spring cereals (Wiese, 1987). Disease is therefore also most severe where winter wheat and barley are grown successively without rotation to spring crops (Mathre, 1982; Wiese, 1987).

Eyespot infection may kill entire plants, but more often weakens or kills individual tillers, reduces kernel size and number, causes culms to lodge and/or senesce prematurely and renders plants difficult to harvest (Mathre, 1982; Wiese, 1987; Cook & Veseth, 1991). Appearance of eye-shaped lesions on leaf sheaths and stem bases is characteristic of eyespot (Mathre, 1982; Wiese, 1987).

## 2.6 SHARP EYESPOT

According to Mathre (1982) and Wiese (1987) sharp eyespot occurs on wheat and barley in most temperate regions of the world, but seldom causes serious losses. Lesions are usually superficial and inconsequential. Although early references link *R. solani* with sharp eyespot (Bruehl, 1951; Pitt, 1964; Clarkson & Griffin, 1977; Sterne & Jones, 1978), it is now generally accepted that the eyespot fungus is

morphologically, taxonomically and pathologically distinct from *R. solani* (Richardson & Cook, 1985). It was described as a new binucleate species, *R. cerealis*, by Boerema & Verhoeven (1977) and early reports can be taken as referring to this fungus instead (Richardson & Cook, 1985).

Sharp eyespot lesions are easily confused with those of eyespot, especially during early growth stages of cereals. Symptoms due to one pathogen may also obscure those caused by the other (Goulds & Polley, 1990). Lesions caused by sharp eyespot are, however, more superficial, more sharply delineated and generally more irregular in shape (Mathre, 1982; Wiese, 1987). Sharp eyespot can also be confirmed by the presence of typical mycelium of *Rhizoctonia* in cortical cells (Pitt, 1964). In recent years, diagnostic assays based on polymerase chain reaction have been developed for specifically detecting *R. cerealis* (Nicholson & Parry, 1996) and *R. herpotrichoides* (Poupard *et al.*, 1993).

## 2.7 MINOR PATHOGENS

There is increasing evidence that many weak pathogens survive and multiply on apparently healthy roots in addition to existing saprophytically in the soil (Salt, 1979). Their effects may be negligible when water and nutrients are readily available, but when supply of either is reduced plant growth can be affected (Colhoun, 1979). Three species commonly regarded as minor pathogens are discussed.

### *2.7.1 Idriella bolleyi*

According to Sprague (1948) *I. bolleyi* is a ubiquitous coloniser of roots, crowns and seeds of wheat, barley and other Poaceae. Isolates are mostly considered non-pathogenic but occasionally cause mild root necrosis (Wiese, 1987). Murray & Gadd (1981) regularly recovered *I. bolleyi* from the roots of healthy field-grown barley, the highest isolation frequencies being from older plants. Isolates were weakly pathogenic, causing limited damage to the coleoptile but having no apparent effect on roots despite heavy colonisation. In pathogenicity studies conducted by Rufenacht (1980), *I. bolleyi* did not affect root and shoot elongation of wheat seedlings, despite being able to produce lesions on the roots and shoots. Salt (1979)

concluded from his own research and that of others that this species can be regarded as a minor pathogen of very young and senescent tissue.

### 2.7.2 *Periconia macrospinosa*

Scott *et al.* (1979) initially thought *P. macrospinosa* to be involved in CD. Rufenacht (1980) frequently isolated this fungus from roots of wheat collected throughout the major production areas in South Africa, particularly on mature plants with CD. Although it did not cause necrosis of the roots or shoots in pathogenicity tests, a considerable reduction in root and shoot growth was noted. This can probably be ascribed to toxin production as reported by Scott *et al.* (1979). According to Harris & Moen (1985a) *P. macrospinosa* may colonise previously damaged root tissues. Other reports indicating this species as being part of the fungal community on wheat or barley roots include Maas & Kotzé (1981), Sturz & Bernier (1991), Opperman & Barnard (1992), Bateman & Kwasna (1999), Gonzalez & Trevathan (2000), Meyer & Wehner (2000), Dawson & Bateman (2001), Lemanczyk & Sadowski (2002) and Meyer & Van Dyk (2002).

### 2.7.3 *Sclerotium rolfsii*

The first report of a wheat disease caused by *S. rolfsii* was by Godfrey (1918) who observed brown lesions on the crowns and lower culms of diseased plants and blighted heads entirely void of grain scattered irregularly throughout fields. Kilpatrick & Merkle (1967) reported pre- and post-emergence killing of wheat seedlings by *S. rolfsii* in Texas and believed that the disease had previously probably been overlooked in the region because of the similarity with symptoms caused by other root pathogens. Of various fungi tested, Rufenacht (1980) found *S. rolfsii* to be the most aggressive invader of wheat seedlings in South Africa, causing severe blighting and large necrotic lesions on both roots and shoots. Although *S. rolfsii* significantly impeded shoot growth of wheat in artificial inoculation studies conducted by Meyer & Van Dyk (2002) in South Africa, reduction in shoot growth was much more pronounced with pathogens such as *P. aristosporum*, *P. arrhenomanes* and *R. solani*.

In conclusion, it is evident that root and foot rots pose a serious threat to sustainable wheat and barley production throughout the world. Based on experimental data, Cook (2001) estimated that root diseases result in an annual loss of about 10 million tonnes of wheat in the USA. Based on figures published in the FAO database (http://www.fao.org 2001), extrapolation of the above estimate implies an annual worldwide loss of approximately 79 million tonnes of wheat. Considering that barley on average is as susceptible to root and foot rots as wheat, the corresponding loss in barley production would be about 20 million tonnes. These figures translate to crop losses of over 10 % for wheat and barley, from root and foot diseases alone. Bearing in mind that many countries, particularly in Africa, do not have the same means of sophisticated and intensive crop production systems as the US, these estimates may even be conservative. It is therefore clear that soilborne diseases should not be viewed as "out of sight, out of mind".

Table 1. Summary of published reports on fungi isolated from roots, crowns and subcrown internodes of wheat and barley.

| Fungus | Host[a] | Isolated from[b] | Location | Reference |
|---|---|---|---|---|
| *Absidia cylindrospora* Hagem | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *A. glauca* Hagem | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *Absidia* spp. | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| *Acremoniella atra* (Corda) Sacc. | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| *Acremonium bacillisporum* (Onions & Barron) W. Gams | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *A. kiliense* Grütz | W | R | South Australia | Harris & Moen, 1985b |
| *A. strictum* W. Gams | W | R, C, SI | Southern Brazil | Diehl *et al.*, 1982 |
| | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Acremonium* spp. | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Alternaria alternata* (Fr.: Fr.) Keissl. | W | R | South Australia | Harris & Moen, 1985a,b |
| | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| | W | R | Springbok Flats, SA | Opperman & Barnard, 1992 |
| | W | R, C | Alabama, USA | Chen *et al.*, 1996 |
| | W | ? | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *A. consortiale* (Thümen) Hughes | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *A. infectoria* Simmons | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *A. solani* Sorauer | W | R, C | Northern Egypt | Fouly *et al.*, 1996 |
| *Alternaria* spp. | W | ? | Washington, USA | Hoes, 1962 |
| | W | R, C, SI | Southern Brazil | Diehl, 1979; Diehl *et al.*, 1982 |
| | W | SI | Minnesota, USA | Windels & Holen, 1989 |
| | W | R | South Australia | Rovira, 1986 |
| | W | R | Central Saudi Arabia | El-Meleigi, 1988 |
| | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| | W | R, SI | Hanang, Tanzania | Kuwite *et al.*, 1996 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| *Arthrinium phaeospermum* (Corda) M.B. Ellis | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |

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|---|---|---|---|---|
| *Ascochyta tritici* Hori & Enjoji | W | ? | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| *Aspergillus niger* Tiegh. | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *A. terreus* Thom | W | R | Springbok Flats, SA | Meyer & Wehner, 2000 |
| *Aspergillus* spp. | W | R | South Australia | Harris & Moen, 1985a,b |
| | W | SI | Minnesota, USA | Windels & Holen, 1989 |
| | W | R, SI | Hanang, Tanzania | Kuwite *et al.*, 1996 |
| | W | ? | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| *Aureobasidium pullulans* (de Bary) G. Arnaud | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| *Aureobasidium* spp. | W | R, SI | Washington, USA | Hoes, 1962 |
| | W | R | South Australia | Rovira, 1986 |
| Binucleate *Rhizoctonia* spp. | W | R | South Australia | Neate, 1985 |
| | W, B | R | Western Australia | Roberts & Sivasithamparam, 1986 |
| | W | R, SI | Texas Panhandle, USA | Specht & Rush, 1988 |
| | W, B | R | Pacific Northwest, USA | Ogoshi *et al.*, 1990 |
| | W | R | Western Australia | Yang *et al.*, 1994 |
| | W, B | C, SI | Erzurum, Turkey | Demirci, 1998 |
| | W | R | Springbok Flats, SA | Meyer & Van Dyk, 2002 |
| *Bipolaris australiensis* (M.B. Ellis) Tsuda & Ueyama | W | R | Springbok Flats, SA | Meyer & Wehner, 2000 |
| *B. sorokiniana* (Sacc.) Shoemaker | W, B | R | Tennessee, USA | Reed, 1952 |
| | W, B | R, C | Montana, USA | Sharp, 1959 |
| | W | SI | Washington, USA | Hoes, 1962 |
| | W | R | Kansas, USA | Wood, 1962 |
| | W | C, SI | Saskatchewan, Canada | Chinn *et al.*, 1962 |
| | W | C | Highveld Region, SA | Jooste, 1965 |
| | W | SI | Saskatchewan, Canada | Sallans & Tinline, 1965; Harding, 1973 |
| | W, B | SI | Saskatchewan, Canada | Harding, 1971 |
| | W | C | Eastern Australia | Burgess *et al.*, 1975 |
| | W | R, C, SI | Southern Brazil | Diehl, 1979; Diehl *et al.*, 1982 |
| | W, B | R | Rothamsted, UK | Salt, 1979 |
| | W | R | Brits, Eastern Free State, Springbok Flats, Vaalharts, Western Cape, SA | Maas & Kotzé, 1981 |

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|---|---|---|---|---|
| | W, B | C, SI | California, USA | Scardaci & Webster, 1982 |
| | W | R, C, SI | Colorado & Wyoming, USA | Hill *et al.*, 1983 |
| | W | R | Springbok Flats, SA | Smith *et al.*, 1984; Opperman & Barnard, 1992; Meyer & Wehner, 2000; Meyer & Van Dyk, 2002 |
| | W | R | South Australia | Harris & Moen, 1985a,b |
| | W | SI | Pennsylvania, USA | Broscious & Frank, 1986 |
| | W, B | R | Western Australia | Roberts & Sivasithamparam, 1986 |
| | W, B | R, C, SI | South Australia | Fedel-Moen & Harris, 1987 |
| | B | SI | Western Canada | Piening & Orr, 1988 |
| | W | R, SI | Texas Panhandle, USA | Specht & Rush, 1988 |
| | W | SI | Queensland, Australia | Tinline *et al.*, 1988 |
| | W, B | SI | Alberta, Canada | Conner & Atkinson, 1989 |
| | W | C, SI | North Dakota, USA | El-Nashaar & Stack, 1989 |
| | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| | W | R | El Batan, Mexico | Lawn & Sayre, 1989, 1992 |
| | W | R, C | Arkansas, USA | Milus & Rothrock, 1989 |
| | W | C, SI | Minnesota, USA | Windels & Holen, 1989 |
| | W, B | SI | Minnesota, USA | Windels & Wiersma, 1992 |
| | W | C | Northwest Italy | Rossi *et al.*, 1995 |
| | W | R, C | Alabama, USA | Chen *et al.*, 1996 |
| | W, B | C | Saskatchewan, Canada | Duczek *et al.*, 1996 |
| | W | R, C | Northern Egypt | Fouly *et al.*, 1996 |
| | W | R, SI | Hanang, Tanzania | Kuwite *et al.*, 1996 |
| | B | SI | Northern Syria | Van Leur *et al.*, 1997 |
| | W | R | Saskatchewan, Canada | Bailey *et al.*, 2000 |
| | W | R, C, SI | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| | B | C, SI | Northern Syria | Van Leur & Bailey, 2000 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *B. spicifera* (Bainier) Sabraman | W | R | Texas Panhandle, USA | Specht & Rush, 1988 |
| | W | R, C | Northern Egypt | Fouly *et al.*, 1996 |
| | W | R, C, SI | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| *Bispora* spp. | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |

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|---|---|---|---|---|
| *Botrytis cinerea* Pers.: Fr. | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Botrytis* spp. | W | R, SI | Hanang, Tanzania | Kuwite *et al.*, 1996 |
| *Brachysporium* sp. | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| *Broomella acuta* Schoem. & E. Müll. | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| *Cephalosporium* sp. | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *Ceratobasidium* spp. | W | R | South Australia | Rovira, 1986 |
| *Chaetomium cochlioides* Pall | W | ? | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| *C. funicola* Cooke | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *C. globosum* Kunze | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *C. indicum* Corda | W | ? | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| | W | R | Springbok Flats, SA | Meyer & Wehner, 2000 |
| *Chaetomium* sp. | W | R | South Australia | Rovira, 1986 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| *Chalara* sp. | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *Chrysosporium pannorum* (Link) Hughes | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Cladosporium cladosporioides* (Fresen.) G.A. de Vries | W | R | Springbok Flats, SA | Opperman & Barnard, 1992 |
| | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W | ? | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| *C. herbarum* (Pers.: Fr.) Link | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *C. macrocarpum* Preuss | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *C. sphaerospermum* Penz. | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *Cladosporium* spp. | W | R, SI | Hanang, Tanzania | Kuwite *et al.*, 1996 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| *C. scorpioidea* Linder | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *C. thaxteri* Linder | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *Coemansia* sp. | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |

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|---|---|---|---|---|
| *Colletotrichum graminicola* (Ces.) G.W. Wilson | W | C | Southern Brazil | Diehl, 1979; Diehl *et al.*, 1982 |
| | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| | W | ? | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| *Colletotrichum* spp. | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Cunninghamella* sp. | W | R, SI | Hanang, Tanzania | Kuwite *et al.*, 1996 |
| *Curvularia inaequalis* (Shear) Boedijn | W | ? | Wyoming, USA | Hill *et al.*, 1983 |
| *C. lunata* (Wakker) Boedijn | W | R | Springbok Flats, SA | Opperman & Barnard, 1992 |
| | W | ? | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| *Curvularia* spp. | W | R, C, SI | Southern Brazil | Diehl, 1979; Diehl *et al.*, 1982 |
| | W | R | Texas Panhandle, USA | Specht & Rush, 1988 |
| | W | R, SI | Hanang, Tanzania | Kuwite *et al.*, 1996 |
| | W | R | Springbok Flats, SA | Meyer & Van Dyk, 2002 |
| *Cylindrocarpon destructans* (Zinssm.) Scholten | W | R | South Australia | Rovira, 1986 |
| | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *C. macroconidialis* Brayford & Samuels | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *C. magnusianum* Wollenw. | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| *Cylindrocarpon* spp. | W, B | R | Rothamsted, UK | Salt, 1979; Dawson & Bateman, 2001 |
| | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *Dactylaria appendiculata* Cazau, Aramb. & Cabello | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *Dactylaria* sp. | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *Dendryophion nanum* (Nees ex Gray) Hughes | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Doratomyces stemonitis* (Pers.: Fr.) Morton & Smith | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| *Doratomyces* sp. | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Drechslera bisepta* (Sacc. & Roum.) Richardson & Fraser | W | R | South Australia | Harris & Moen, 1985b |
| *Drechslera phlei* (Graham) Shoemaker | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| *Echinostelum elachiston* Alexop. | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *Embellisia chlamydospora* (Hoes, Bruehl & Shaw) Simmons | W | R | South Australia | Harris & Moen, 1985a,b |
| | W | R, C, SI | Mississippi, USA | Gonzalez & Trevathan, 2000 |

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|---|---|---|---|---|
| *Emericellopsis* sp. | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Epicoccum nigrum* Link | W | R, C, SI | Southern Brazil | Diehl *et al.*, 1982 |
| | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| | W | R | Springbok Flats, SA | Opperman & Barnard, 1992 |
| | W | R, C | Alabama, USA | Chen *et al.*, 1996 |
| | W | R, C | Northern Egypt | Fouly *et al.*, 1996 |
| | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W | ? | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Epicoccum* spp. | W | SI | Minnesota, USA | Windels & Holen, 1989 |
| *Exophiala* sp. | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *Exserohilum novae-zelandiae* Upadhyay & Mankau | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| *E. rostratum* (Drechs.) K.J. Leonard & E.G. Suggs | W | R, C | Kadawa, Nigeria | Marley & Adeoti, 1995 |
| *Fusarium acuminatum* Ellis & Everh. | W | C, SI | Saskatchewan, Canada | Chinn *et al.*, 1962 |
| | W | R | Washington, USA | Hoes, 1962 |
| | W | SI | Saskatchewan, Canada | Sallans & Tinline, 1965; Harding, 1973 |
| | W | C | Eastern Australia | Burgess et al., 1975 |
| | W | R, C, SI | Southern Brazil | Diehl, 1979; Diehl *et al.*, 1982 |
| | W | C, SI | Colorado & Wyoming, USA | Hill *et al.*, 1983 |
| | W, B | R, C, SI | South Australia | Fedel-Moen & Harris, 1987 |
| | W | C | Orange Free State, SA | Van Wyk *et al.*, 1987 |
| | W | R, SI | Texas Panhandle, USA | Specht & Rush, 1988 |
| | W | C, SI | Minnesota, USA | Windels & Holen, 1989 |
| | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| | W, B | SI | Minnesota, USA | Windels & Wiersma, 1992 |
| | W | R, C | Fars Province, Iran | Ravanlou & Banihashemi, 1999 |
| | W | R | Saskatchewan, Canada | Bailey *et al.*, 2000 |
| | W | R, C, SI | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| | B | C, SI | Northern Syria | Van Leur & Bailey, 2000 |
| *F. anthophilum* (A. Braun) Wollenw. | W | C | Northwest Italy | Rossi *et al.*, 1995 |

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|---|---|---|---|---|
| *F. avenaceum* (Fr.: Fr.) Sacc. | W, B | R, C | Montana, USA | Sharp, 1959 |
| | W | ? | Lancashire, Cheshire, UK | Colhoun & Park, 1964 |
| | W | C | Pacific Northwest, USA | Cook, 1968 |
| | W | R | Victoria, Australia | Chambers, 1972 |
| | W | C | Eastern Australia | Burgess *et al.*, 1975 |
| | W | R, C, SI | Southern Brazil | Diehl, 1979 |
| | W | ? | Colorado & Wyoming, USA | Hill *et al.*, 1983 |
| | W | R | South Australia | Harris & Moen, 1985a,b |
| | W | R | Texas Panhandle, USA | Specht & Rush, 1988 |
| | W | C, SI | Minnesota, USA | Windels & Holen, 1989 |
| | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| | W, B | SI | Minnesota, USA | Windels & Wiersma, 1992 |
| | W | C | Northwest Italy | Rossi *et al.*, 1995 |
| | B | R, C | Prince Edward Island, Canada | Sturz & Carter, 1995 |
| | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W | R, C | Fars Province, Iran | Ravanlou & Banihashemi, 1999 |
| | W | R, C, SI | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *F. camptoceras* Wollenw. & Reinking | W | R | Victoria, Australia | Chambers, 1972 |
| *F. chlamydosporum* Wollenw. & Reinking | W | C | Orange Free State, SA | Van Wyk *et al.*, 1987 |
| | W | SI | Queensland, Australia | Tinline *et al.*, 1988 |
| | W | R | Springbok Flats, SA | Opperman & Barnard, 1992; Meyer & Wehner, 2000; Meyer & Van Dyk, 2002 |
| | W | R, C, SI | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| | W | C | Northwest Italy | Rossi *et al.*, 1995 |
| *F. compactum* (Wollenw.) Gordon | W | C | Orange Free State, SA | Van Wyk *et al.*, 1986, 1987 |
| | W | R, C, SI | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| *F. concolor* Reinking | B | R | Tanzania | Ebbels & Allen, 1979 |
| | W | C | West Kilimanjaro, Tanzania | |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| *F. crookwellense* L.W. Burgess, P.E. Nelson & Toussoun | W | C | Orange Free State, SA | Van Wyk *et al.*, 1987 |
| | W | C | Minnesota, USA | Windels & Holen, 1989 |

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|---|---|---|---|---|
| | W | C | Northwest Italy | Rossi *et al.*, 1995 |
| *F. culmorum* (Wm.G. Sm.) Sacc. | W | C, SI | Saskatchewan, Canada | Chinn *et al.*, 1962 |
| | W | ? | Lancashire, Cheshire, UK | Colhoun & Park, 1964 |
| | W | C | Highveld Region, SA | Jooste, 1965 |
| | W | SI | Saskatchewan, Canada | Sallans & Tinline, 1965; Harding, 1973 |
| | W, B | R, C, SI | Pacific Northwest, USA | Cook, 1968 |
| | W | R | Victoria, Australia | Chambers, 1972 |
| | W | C | Eastern Australia | Burgess *et al.*, 1975 |
| | W | R | Eastern Free State, Vaalharts, Western Cape, SA | Maas & Kotzé, 1981 |
| | W, B | C, SI | California, USA | Scardaci & Webster, 1982 |
| | W | ? | Colorado & Wyoming, USA | Hill *et al.*, 1983 |
| | W | R | Springbok Flats, SA | Smith *et al.*, 1984; Smith & Wehner, 1986 |
| | W | C | Orange Free State, SA | Van Wyk *et al.*, 1987 |
| | B | SI | Western Canada | Piening & Orr, 1988 |
| | W | R | El Batan, Mexico | Lawn & Sayre, 1989 |
| | W | C, SI | Minnesota, USA | Windels & Holen, 1989 |
| | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| | W, B | SI | Minnesota, USA | Windels & Wiersma, 1992 |
| | W | C | Northwest Italy | Rossi *et al.*, 1995 |
| | W | R, C | Northern Egypt | Fouly *et al.*, 1996 |
| | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W | R, C | Fars Province, Iran | Ravanlou & Banihashemi, 1999 |
| | W | R | Saskatchewan, Canada | Bailey *et al.*, 2000 |
| | W | R, C, SI | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *F. dimerum* Penz. | W | C, SI | Minnesota, USA | Windels & Holen, 1989 |
| | W | C | Northwest Italy | Rossi *et al.*, 1995 |
| | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *F. equiseti* (Corda) Sacc. | W | C, SI | Saskatchewan, Canada | Chinn *et al.*, 1962 |
| | W | R | Washington, USA | Hoes, 1962 |
| | W | SI | Saskatchewan, Canada | Sallans & Tinline, 1965; Harding, 1973 |
| | W | R | Victoria, Australia | Chambers, 1972 |

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| | W | C | Eastern Australia | Burgess *et al.*, 1975 |
| | W | R, C, Sl | Southern Brazil | Diehl, 1979; Diehl *et al.*, 1982 |
| | W | ? | Colorado & Wyoming, USA | Hill *et al.*, 1983 |
| | W | R | Springbok Flats, SA | Smith *et al.*, 1984; Smith & Wehner, 1986; Opperman & Barnard, 1992; Meyer & Wehner, 2000; Meyer & Van Dyk, 2002 |
| | W | R | South Australia | Harris & Moen, 1985a,b |
| | W | R, C | Orange Free State, Transvaal, SA | Maas & Kotzé, 1985 |
| | W, B | R, C, Sl | South Australia | Fedel-Moen & Harris, 1987 |
| | W | C | Orange Free State, SA | Van Wyk *et al.*, 1987 |
| | W | R, Sl | Texas Panhandle, USA | Specht & Rush, 1988 |
| | W | C, Sl | Minnesota, USA | Windels & Holen, 1989 |
| | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| | W | R, C | Transvaal, SA | Lubbe *et al.*, 1992 |
| | W | R, C | Kadawa, Nigeria | Marley & Adeoti, 1995 |
| | W | C | Northwest Italy | Rossi *et al.*, 1995 |
| | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W | R, C | Fars Province, Iran | Ravanlou & Banihashemi, 1999 |
| | W | R | Saskatchewan, Canada | Bailey *et al.*, 2000 |
| | W | R, C, Sl | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| | B | C, Sl | Northern Syria | Van Leur & Bailey, 2000 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *F. flocciferum* Corda | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *F. graminearum* Schwabe | W | C | Eastern Australia | Burgess *et al.*, 1975 |
| | W | C, Sl | Minnesota, USA | Windels & Holen, 1989 |
| *F. heterosporum* Nees | W | C | Eastern Australia | Burgess *et al.*, 1975 |
| | W | R, Sl | Hanang, Tanzania | Kuwite *et al.*, 1996 |
| *F. lateritium* Nees: Fr. | W | C | Northwest Italy | Rossi et al., 1995 |
| *F.* cf. *longipes* Wollenw. & Reinking | W | C | Orange Free State, SA | Van Wyk *et al.*, 1987 |
| *F. merismoides* Corda | W | R | South Australia | Harris & Moen, 1985b |
| | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |

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| *F. nygamai* L.W. Burgess & Trimboli | W | C | Orange Free State, SA | Van Wyk *et al.*, 1987 |
| | W | R, C | Transvaal, SA | Lubbe *et al.*, 1992 |
| | W | R | Springbok Flats, SA | Opperman & Barnard, 1992; Meyer & Wehner, 2000; Meyer & Van Dyk, 2002 |
| | W | R, C | Fars Province, Iran | Ravanlou & Banihashemi, 1999 |
| *F. oxysporum* Schltdl. em. W.C. Snyder & H.N. Hansen | W | C, SI | Saskatchewan, Canada | Chinn *et al.*, 1962 |
| | W | R | Washington, USA | Hoes, 1962 |
| | W | SI | Saskatchewan, Canada | Sallans & Tinline, 1964 |
| | W | R | Victoria, Australia | Chambers, 1972 |
| | W | C | Eastern Australia | Burgess *et al.*, 1975 |
| | W | R, C, SI | Southern Brazil | Diehl, 1979; Diehl *et al.*, 1982 |
| | W | R | West Kilimanjaro, Tanzania | Ebbels & Allen, 1979 |
| | W | ? | Colorado & Wyoming, USA | Hill *et al.*, 1983 |
| | W | R | Springbok Flats, SA | Smith & Wehner, 1986; Opperman & Barnard, 1992; Meyer & Wehner, 2000 |
| | W, B | R, C, SI | South Australia | Fedel-Moen & Harris, 1987 |
| | W | C | Orange Free State, SA | Van Wyk *et al.*, 1987 |
| | W | R, SI | Texas Panhandle, USA | Specht & Rush, 1988 |
| | W | C, SI | Minnesota, USA | Windels & Holen, 1989 |
| | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| | W | R | El Batan, Mexico | Lawn & Sayre, 1992 |
| | W | C | Northwest Italy | Rossi *et al.*, 1995 |
| | B | R, C | Prince Edward Island, Canada | Sturz & Carter, 1995 |
| | W | R, C | Alabama, USA | Chen *et al.*, 1996 |
| | W | R, C | Northern Egypt | Fouly *et al.*, 1996 |
| | W | R, SI | Hanang, Tanzania | Kuwite *et al.*, 1996 |
| | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W | R, C | Fars Province, Iran | Ravanlou & Banihashemi, 1999 |
| | W | R, C, SI | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *F. pallidoroseum* (Cooke) Sacc. | W | R | Victoria, Australia | Chambers, 1972 |
| | W | C | Eastern Australia | Burgess *et al.*, 1975 |

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| | W | R, C | Alabama, USA | Chen *et al.*, 1996 |
| | W | R, C | Fars Province, Iran | Ravanlou & Banihashemi, 1999 |
| | W | R, C, SI | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| *F. poae* (Peck) Wollenw. | W | R | Victoria, Australia | Chambers, 1972 |
| | W | C, SI | Minnesota, USA | Windels & Holen, 1989 |
| | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| | W, B | SI | Minnesota, USA | Windels & Wiersma, 1992 |
| | W | C | Northwest Italy | Rossi *et al.*, 1995 |
| | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *F. polyphialidicum* Marasas, P.E. Nelson, Toussoun & van Wyk | W | R | Springbok Flats, SA | Opperman & Barnard, 1992 |
| *F. proliferatum* (Matsushima) Nirenberg | W | C | Northwest Italy | Rossi *et al.*, 1995 |
| | W | R, C | Alabama, USA | Chen *et al.*, 1996 |
| | W | R, C | Fars Province, Iran | Ravanlou & Banihashemi, 1999 |
| *F. pseudograminearum* O'Donnel & T. Aoki | W | R | Western Cape, SA | Gorter, 1943 |
| | W | C, SI | Saskatchewan, Canada | Chinn *et al.*, 1962 |
| | W | ? | Lancashire, Cheshire, UK | Colhoun & Park, 1964 |
| | W, B | R, C, SI | Pacific Northwest, USA | Cook, 1968 |
| | W | R | Victoria, Australia | Chambers, 1972 |
| | W | C | Eastern Australia | Burgess *et al.*, 1975 |
| | W | R, C, SI | Southern Brazil | Diehl, 1979; Diehl *et al.*, 1982 |
| | W | C | West Kilimanjaro, Tanzania | Ebbels & Allen, 1979 |
| | W | R | Eastern Free Sate, Vaalharts, Western Cape, SA | Maas & Kotzé, 1981 |
| | W, B | C, SI | California, USA | Scardaci & Webster, 1982 |
| | W | ? | Colorado & Wyoming, USA | Hill *et al.*, 1983 |
| | W, B | R | Western Australia | Roberts & Sivasithamparam, 1986 |
| | W | R | South Australia | Rovira, 1986 |
| | W | C | Orange Free State, SA | Van Wyk *et al.*, 1987 |
| | W | C | Southern Cape, SA | Marasas *et al.*, 1988b |
| | W | R | Texas Panhandle, USA | Specht & Rush, 1988 |
| | W | R | El Batan, Mexico | Lawn & Sayre, 1989, 1992 |

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| | W | C, SI | Minnesota, USA | Windels & Holen, 1989 |
| | W | C | New South Wales, Australia | Klein *et al.*, 1991 |
| | W, B | SI | Minnesota, USA | Windels & Wiersma, 1992 |
| | W | R, C | High Valleys, Mexico | Leyva & Villaseñor, 1993 |
| | W, B | C, SI | New South Wales, Australia | Nelson & Burgess, 1995 |
| | W | C | Northwest Italy | Rossi *et al.*, 1995 |
| | W | R, C | Northern Egypt | Fouly *et al.*, 1996 |
| | W | C | Queensland, Australia | Wildermuth *et al.*, 1997 |
| | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W | R | Saskatchewan, Canada | Bailey *et al.*, 2000 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *F. sambucinum* Fuckel | W | R | Victoria, Australia | Chambers, 1972 |
| | W | ? | Colorado & Wyoming, USA | Hill *et al.*, 1983 |
| | W | C | Orange Free State, SA | Van Wyk *et al.*, 1987 |
| | W | R, SI | Texas Panhandle, USA | Specht & Rush, 1988 |
| | W | R | Springbok Flats, SA | Opperman & Barnard, 1992 |
| | W | C | Northwest Italy | Rossi *et al.*, 1995 |
| | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W | R, C | Fars Province, Iran | Ravanlou & Banihashemi, 1999 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| *F. scirpi* Lambotte & Fautrey | W | C | Orange Free State, SA | Van Wyk *et al.*, 1987 |
| | W | R, SI | Texas Panhandle, USA | Specht & Rush, 1988 |
| *F. solani* (Mart.) Appel & Wollenw. | W | C | Eastern Australia | Burgess *et al.*, 1975 |
| | W | R, C, SI | Southern Brazil | Diehl, 1979 |
| | W | R | West Kilimanjaro, Tanzania | Ebbels & Allen, 1979 |
| | W | ? | Colorado & Wyoming, USA | Hill *et al.*, 1983 |
| | W | R | Springbok Flats, SA | Smith & Wehner, 1986; Opperman & Barnard, 1992; Meyer & Wehner, 2000; Meyer & Van Dyk, 2002 |
| | W | C | Orange Free State, SA | Van Wyk *et al.*, 1987 |
| | W | R, SI | Texas Panhandle, USA | Specht & Rush, 1988 |
| | W | C, SI | Minnesota, USA | Windels & Holen, 1989 |
| | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |

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| | W | R | El Batan, Mexico | Lawn & Sayre, 1992 |
| | W | C | Northwest Italy | Rossi *et al.*, 1995 |
| | W | R, C | Alabama, USA | Chen *et al.*, 1996 |
| | W | R, C | Northern Egypt | Fouly *et al.*, 1996 |
| | W | R, SI | Hanang, Tanzania | Kuwite *et al.*, 1996 |
| | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W | R, C | Fars Province, Iran | Ravanlou & Banihashemi, 1999 |
| | W | R, C, SI | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *F. sporotrichioides* Sherb. | W | R | Victoria, Australia | Chambers, 1972 |
| | W | C, SI | Minnesota, USA | Windels & Holen, 1989 |
| | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| | W | C | Northwest Italy | Rossi *et al.*, 1995 |
| | W | R, C, SI | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| *F. subglutinans* (Wollenw. & Reinking) P.E. Nelson, Toussoun & Marasas | W | C | Eastern Australia | Burgess *et al.*, 1975 |
| | W | C | Orange Free State, SA | Van Wyk *et al.*, 1987 |
| | W | C, SI | Minnesota, USA | Windels & Holen, 1989 |
| | W | C | Northwest Italy | Rossi *et al.*, 1995 |
| *F. tricinctum* (Corda) Sacc. | W | C | Eastern Australia | Burgess *et al.*, 1975 |
| | W | ? | Wyoming, USA | Hill *et al.*, 1983 |
| | W | C | Northwest Italy | Rossi *et al.*, 1995 |
| | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W | R, C | Fars Province, Iran | Ravanlou & Banihashemi, 1999 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *F. verticillioides* (Sacc.) Nirenberg | W | C | Eastern Australia | Burgess *et al.*, 1975 |
| | W | R | Texas Panhandle, USA | Specht & Rush, 1988 |
| | W | C | Northwest Italy | Rossi *et al.*, 1995 |
| | W | R, C | Alabama, USA | Chen *et al.*, 1996 |
| | W | R, C | Northern Egypt | Fouly *et al.*, 1996 |
| | W | R, C | Fars Province, Iran | Ravanlou & Banihashemi, 1999 |
| *Fusarium* spp. | W | SI | Saskatchewan, Canada | Sallans & Tinline, 1965; Harding, 1973 |

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| | W | R | Victoria, Australia | Chambers, 1972 |
| | B | C | Tanzania | Ebbels & Allen, 1979 |
| | W, B | R | Rothamsted, UK | Salt, 1979; Dawson & Bateman, 2001 |
| | W | R, C, SI | Southern Brazil | Diehl *et al.*, 1982 |
| | W, B | C, SI | California, USA | Scardaci & Webster, 1982 |
| | W | SI | Pennsylvania, USA | Broscious & Frank, 1986 |
| | W | R | South Australia | Rovira, 1986 |
| | W, B | R | Western Australia | Roberts & Sivasithamparam, 1986 |
| | W, B | R | Pacific Northwest, USA | Weller *et al.*, 1986 |
| | W | R | Central Saudi Arabia | El-Meleigi, 1988 |
| | W | C | Orange Free State, SA | Van Wyk *et al.*, 1988 |
| | W, B | SI | Alberta, Canada | Conner & Atkinson, 1989 |
| | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| | W | R | El Batan, Mexico | Lawn & Sayre, 1992 |
| | W | R, C | Transvaal, SA | Lubbe *et al.*, 1992 |
| | W | C | Grignon, Péronne, La Rheu, La Verrière, Chartres, France | Colbach *et al.*, 1996 |
| | W | R, C | Northern Egypt | Fouly *et al.*, 1996 |
| | W | R, SI | Hanang, Tanzania | Kuwite *et al.*, 1996 |
| | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W | R | Saskatchewan, Canada | Bailey *et al.*, 2000 |
| | B | C, SI | Northern Syria | Van Leur & Bailey, 2000 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Gaeumannomyces graminis* (Sacc.) Arx & D.L. Olivier var. *graminis* J. Walker | W | R, C | Northern Egypt | Fouly *et al.*, 1996 |
| *Gaeumannomyces graminis* (Sacc.) Arx & D.L. Olivier var. *tritici* J. Walker | W | R | Western Cape, SA | Dippenaar, 1930; Gorter, 1943 |
| | W, B | R, C | Montana, USA | Sharp, 1959 |
| | W | R | UK | Asher, 1972 |
| | B | ? | Cambshire, Yorkshire, Northern Ireland, UK | Deacon, 1974 |
| | W | ? | Berkshire, Cambshire, UK | |
| | W | R | Eastern Free State, SA | Scott, 1978 |
| | W, B | R | Rothamsted, UK | Salt, 1979 |

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| | W | R | Brits, Eastern Free State, Vaalharts, Western Cape, SA | Maas & Kotzé, 1981 |
| | W | R | Texas Panhandle, USA | Specht & Rush, 1988 |
| | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| | W | R | El Batan, Mexico | Lawn & Sayre, 1992 |
| | W | R, C | Alabama, USA | Chen *et al.*, 1996 |
| | W | C, SI | Northern Syria | Van Leur & Bailey, 2000 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Gaeumannomyces* spp. | W | R | Central Saudi Arabia | El-Meleigi, 1988 |
| | W | R, C | High Valleys, Mexico | Leyva & Villaseñor, 1993 |
| *Geotrichum candidum* Link | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| *Geotrichum* spp. | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| *Gliocladium catenulatum* Gilm. & Abbott | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| | W | R | Springbok Flats, SA | Meyer & Wehner, 2000 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *G. roseum* Bainier | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| *G. viride* Matr. | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *Gliocladium* spp. | W | ? | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| *Gliomastix cerealis* (Kart.) Dickinson | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Gliomastix murorum* (Corda) Hughes | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Gliomastix* sp. | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Gymnoascus reesii* Baranetzky | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Helminthosporium* spp. | W | R | South Australia | Rovira, 1986 |
| | W | R | Central Saudi Arabia | El-Meleigi, 1988 |
| *Heteroconium chaetospira* (Grove) M.B. Ellis | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| *Humicola grisea* Traaen | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Humicola* spp. | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| *Hyalodendron* sp. | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |

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| *Idriella bolleyi* (R. Sprague) Arx | W, B | R, C | Montana, USA | Sharp, 1959 |
| | W | R, SI | Washington, USA | Hoes, 1962 |
| | W, B | R | Rothamsted, UK | Salt, 1979; Dawson & Bateman, 2001 |
| | B | R | Morayshire, Dundee, UK | Murray, 1981; Murray & Gadd, 1981 |
| | W, B | C, SI | California, USA | Scardaci & Webster, 1982 |
| | W | R | South Australia | Harris & Moen, 1985a,b; Rovira, 1986 |
| | W | R, SI | Texas Panhandle, USA | Specht & Rush, 1988 |
| | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| | W | R | Western Cape, SA | Crous *et al.*, 1995 |
| | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W | R, C, SI | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| | B | C, SI | Northern Syria | Van Leur & Bailey, 2000 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *I. lunata* Nelson & Wilhelm | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *Idriella* spp. | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| *Isthmolongispora minima* Matsushima | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| *Macrophomina phaseolina* (Tassi) Goid. | W | R | South Australia | Harris & Moen, 1985a |
| | W | R | Springbok Flats, SA | Opperman & Barnard, 1992 |
| | W | R, C | Northern Egypt | Fouly *et al.*, 1996 |
| *Magnaporthe rhizophila* D.B. Scott & Deacon | W | R | Transvaal, SA | Scott & Deacon, 1983 |
| *Marasmius* sp. | W | ? | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| *Metarhizium anisopliae* (Metschnikow) Sorokin var. *major* (Johnston) Tulloch | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *Metarhizium* sp. | W | R, SI | Hanang, Tanzania | Kuwite *et al.*, 1996 |
| *Microdochium nivale* (Fr.) Samuels & I.C. Hallett | W | SI | Washington, USA | Hoes, 1962 |
| | W | ? | Lancashire, Cheshire, UK | Colhoun & Park, 1964 |
| | W | ? | Colorado & Wyoming, USA | Hill *et al.*, 1983 |
| | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| | W | C | Northwest Italy | Rossi *et al.*, 1995 |
| | W | C | Grignon, Péronne, La Rheu, La Verrière, Chartres, France | Colbach *et al.*, 1996 |
| | W | R, SI | Hanang, Tanzania | Kuwite *et al.*, 1996 |
| | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |

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| | B | C, SI | Northern Syria | Van Leur & Bailey, 2000 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Monacrosporium psychrophilum* (Drechsl.) R. Cook & Dickson | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *Monilia* sp. | W | R, SI | Hanang, Tanzania | Kuwite *et al.*, 1996 |
| *Monocillium indicum* Saksena | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Monocillium* sp. | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Mortierella alpina* Peyroud | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *M. elongata* Linn. | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *M. exigua* Linn. | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *M. humulis* Linn. ex W. Gams | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *M. hyalina* (Harz) W. Gams | W | ? | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *M. hygrophila* Linn. | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *M. marburgensis* Linn. | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *Mortierella* spp. | W, B | R | Western Australia | Roberts & Sivasithamparam, 1986 |
| | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Mucor hiemalis* Wehmer f. *hiemalis* | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *M. plumbeus* Bonord. | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| *Mucor* spp. | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Myrothecium cinctum* (Corda) Sacc. | W | ? | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| *M. roridum* Tode | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *M. verrucaria* (Albertini & Schwein.) Ditmar: Fr. | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |

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| *Nigrospora sphaerica* (Sacc.) Mason | W | ? | Wyoming, USA | Hill *et al.*, 1983 |
| | W | ? | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| *Nigrospora* spp. | W | SI | Saskatchewan, Canada | Harding, 1973 |
| | W | C | Minnesota, USA | Windels & Holen, 1989 |
| | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| | W | R | Springbok Flats, SA | Opperman & Barnard, 1992 |
| | W | R, SI | Hanang, Tanzania | Kuwite *et al.*, 1996 |
| *Ochroconis humicola* (Barron & Busch) de Hoog & v. Arx | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| *Paecilomyces farinosus* (Holmskiol) A.H.S. Brown & G. Sm. | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *P. lilacinus* (Thom) Samson | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *P. varioti* Bainier | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Paecilomyces* spp. | W | R | South Australia | Rovira, 1986 |
| | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Papularia* spp. | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| *Papulaspora immersa* Hotson | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *P. irregularis* Hotson | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Papulospora* sp. | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W | ? | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| *Penicillium crustosum* Thom | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *P. janczewskii* Zaleski | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *P. islandicum* Sopp. | W | R | Springbok Flats, SA | Meyer & Wehner, 2000 |
| *P. miczynskii* Zaleski | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *P. notatum* Westling | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *P. rubrum* Stoll | W | R | Springbok Flats, SA | Meyer & Wehner, 2000 |
| *P. simplicissimum* (Oudem.) Thom | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *P. spinulosum* Thom | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *P. variabile* Sopp. | W | R | Springbok Flats, SA | Meyer & Wehner, 2000 |
| *P. viridicatum* Westling | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *P. vulpinum* (Cooke & Massee) Sifert & Sams. | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |

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|---|---|---|---|---|
| *Penicillium* spp. | W | ? | Washington, USA | Hoes, 1962 |
| | W | SI | Saskatchewan, Canada | Harding, 1973 |
| | W | R, C, SI | Southern Brazil | Diehl *et al.*, 1982 |
| | W | R | South Australia | Harris & Moen, 1985a,b |
| | W | C | Minnesota, USA | Windels & Holen, 1989 |
| | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| | W | R | Springbok Flats, SA | Opperman & Barnard, 1992 |
| | W | R, SI | Hanang, Tanzania | Kuwite *et al.*, 1996 |
| | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W | ? | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Periconia byssoides* Pers. ex Merat | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| *P. circinata* (L. Mangin) Sacc. | W | R | Eastern Free State, Vaalharts, SA | Maas & Kotzé, 1981 |
| *P. macrospinosa* Lefebvre & Aar. G. Johnson | W | R | Springbok Flats, South Africa | Scott *et al.*, 1979; Opperman & Barnard, 1992; Meyer & Wehner, 2000; Meyer & Van Dyk, 2002 |
| | W | R | Brits, Eastern Free State, Springbok Flats, Vaalharts, Western Cape, SA | Maas & Kotzé, 1981 |
| | W | R | South Australia | Harris & Moen, 1985a |
| | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W | ? | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Periconia* spp. | W | ? | Washington, USA | Hoes, 1962 |
| | W | R, SI | Hanang, Tanzania | Kuwite *et al.*, 1996 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| *Phialophora radicicola* Cain | B | ? | Hertshire, UK | Deacon, 1974 |
| | W | ? | Cambshire, UK | |
| | W | R | Springbok Flats, SA | Meyer & Van Dyk, 2002 |
| *Phialophora* spp. | W | R, SI | Hanang, Tanzania | Kuwite *et al.*, 1996 |

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|---|---|---|---|---|
| | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *Phoma chrysanthemicola* Hollős | W | R | South Australia | Harris & Moen, 1985b |
| *P. eupyrena* Sacc. | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| *P. glomerata* (Corda) Wollenw. & Hochapfel | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W | ? | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| *P. medicaginis* Malbr. & Roum. var. *pinodella* (L.K. Jones) Boerema | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *P. sorghina* (Sacc.) Boerema, Dorenb. & Kesteren | W | ? | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| *Phoma* spp. | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Phytophthora cactorum* (Lebert & Cohn) J. Schröt. | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *Piptocephalis xenophila* Cobbs & English | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *Pleurocatena acicularis* G. Arnaud ex Aramb. | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| *Polyscytalum fecundissimum* Ries. | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *Pyrenochaeta* sp. | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *Pyrenophora graminea* Ito & Kuribayashi | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| *Pythium aphanidermatum* (Edson) Fitzp. | W | R | Springbok Flats, SA | Meyer & Wehner, 2000 |
| *P. aristosporum* Vanterpool | W | R | Saskatchewan, Canada | Vanterpool, 1938 |
| | W | R | Pacific Northwest, USA | Chamswamg & Cook, 1985 |
| | W | R | Arkansas, USA | Rhoads *et al.*, 1993 |
| | W | R | Springbok Flats, SA | Meyer & Van Dyk, 2002 |
| *P. arrhenomanes* Drechsler | W | R | Rothamsted, Lincolnshire, UK<br>Saskatchewan, Canada | Vanterpool, 1938 |
| | W | R | Northern Great Plains, USA | Vanterpool & Sprague, 1942 |
| | W, B | R | Tennessee, USA | Reed, 1952 |
| | W | R | Arkansas, USA | Rhoads *et al.*, 1993 |
| | W | R | Springbok Flats, SA | Meyer & Van Dyk, 2002 |
| *P. graminicola* Subraman. | W | R | Cambridge, UK | Vanterpool, 1938 |
| | W | R | Arkansas, USA | Rhoads *et al.*, 1993 |
| *P. heterotallicum* W.A. Campb. & J.W. Hendrix | W | R | Pacific Northwest, USA | Chamswamg & Cook, 1985 |

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|---|---|---|---|---|
| *P. intermedium* de Bary | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *P. irregulare* Buisman | W | R | Pacific Northwest, USA | Chamswarng & Cook, 1985 |
| | W, B | R | Western Australia | Roberts & Sivasithamparam, 1986 |
| | W | R | Arkansas, USA | Rhoads *et al.*, 1993 |
| | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *P. monospermum* Pringsh. | W | R | Arkansas, USA | Rhoads *et al.*, 1993 |
| *P. oligandrum* Drechsler | W | R | Springbok Flats, SA | Scott *et al.*, 1979 |
| | W | R | Brits, Eastern Free State, Springbok Flats, Vaalharts, Western Cape, SA | Maas & Kotzé, 1981 |
| *P. sylvaticum* W.A. Campb. & J.W. Hendrix | W | R | Pacific Northwest, USA | Chamswarng & Cook, 1985 |
| | W | R | Arkansas, USA | Rhoads *et al.*, 1993 |
| *P. tardicrescens* Vanderpool | W | R | Slough, UK | Vanterpool, 1938 |
| | | | Saskatchewan, Canada | |
| *P. torulosum* Coker & Patterson | W | R, C | Rothamsted, UK | Vanterpool, 1938 |
| | | R | Reading, UK | |
| | W | R | Pacific Northwest, USA | Chamswarng & Cook, 1985 |
| | W | R | Arkansas, USA | Rhoads *et al.*, 1993 |
| *P. tracheiphilum* Matta | W | R | Springbok Flats, SA | Meyer & Van Dyk, 2002 |
| *P. ultimum* Trow | W | R, C | Pacific Northwest, USA | Cook *et al.*, 1980 |
| | W | R | Arkansas, USA | Rhoads *et al.*, 1993 |
| | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *P. ultimum* Trow var. *sporangiiferum* Drechsler | W | R | Pacific Northwest, USA | Chamswarng & Cook, 1985 |
| P. *ultimum* Trow var. *ultimum* | W | R | Pacific Northwest, USA | Chamswarng & Cook, 1985 |
| *P. vanterpoolii* V. Kouyeas & H. Kouyeas | W | R | Arkansas, USA | Rhoads *et al.*, 1993 |
| P. *volutum* Vanterpool & Truscott | W | R | Ramsgate, Slough, UK | Vanterpool, 1938 |
| *Pythium* spp. | W, B | R, C | Montana, USA | Sharp, 1959 |
| | W | R, C, SI | Southern Brazil | Diehl, 1979; Diehl *et al.*, 1982 |
| | W, B | R | Rothamsted, UK | Salt, 1979; Dawson & Bateman, 2001 |
| | W | R | Pacific Northwest, USA | Chamswarng & Cook, 1985 |
| | W | SI | Pennsylvania, USA | Broscious & Frank, 1986 |
| | W, B | R | Western Australia | Roberts & Sivasithamparam, 1986 |
| | W, B | R | Pacific Northwest, USA | Weller *et al.*, 1986 |
| | W | R | Eastern Washington | Cook *et al.*, 1987 |

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|---|---|---|---|---|
| | W | R | Central Saudi Arabia | El-Meleigi, 1988 |
| | W | R, C | Arkansas, USA | Milus & Rothrock, 1989 |
| | W | C | Minnesota, USA | Windels & Holen, 1989 |
| | W | R, C | High Valleys, Mexico | Leyva & Villaseñor, 1993 |
| | W | C | Northwest Italy | Rossi *et al.*, 1995 |
| | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W | R, C, SI | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Ramichloridium schulzeri* (Sacc.) de Hoog | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| *Ramulispora anguioides* (Nirenberg) Crous | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| *R. herpotricoides* (Fron) Arx | W, B | R, C | Montana, USA | Sharp, 1959 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| *Rhizoctonia cerealis* van der Hoeven | W | R | Springbok Flats, SA | Scott *et al.*, 1979 |
| | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| *R. oryzae* Ryker & Gooch | B | R | Norton Disney, Lincshire, UK | Burton *et al.*, 1988 |
| | W, B | R | Pacific Northwest, USA | Ogoshi *et al.*, 1990 |
| *R. solani* J.G. Kühn | W, B | R | South Australia | Samuel & Garrett, 1932 |
| | W, B | R | Norfolk, UK | Dillon-Weston & Garrett, 1943 |
| | W, B | R, C | Minnesota, North & South Dakota, USA | Bruehl, 1951 |
| | W | R | Southwestern Ontario, Canada | Benedict & Mountain, 1956 |
| | W | C | Eastern Australia | Burgess *et al.*, 1975 |
| | W | R, C | Arkansas, USA | Sterne & Jones, 1978 |
| | W | R, C, SI | Southern Brazil | Diehl, 1979; Diehl *et al.*, 1982 |
| | B | R | Scotland, UK | Murray & Nicolson, 1979; Murray, 1981 |
| | W | R | Springbok Flats, SA | Scott *et al.*, 1979; Smith *et al.*, 1984; Deacon & Scott, 1985; Smith & Wehner, 1986; Opperman & Barnard, 1992; Meyer *et al.*, 1998; Meyer & Wehner, 2000; Meyer & Van Dyk, 2002 |
| | B | R | Goias, Rio Grande do Sul, Brazil | Bolkan & Ribeiro, 1985 |
| | W | R | Goias, Brazil | |
| | W | R, SI | South Australia | Harris & Moen, 1985a,b |

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|---|---|---|---|---|
| | W | R | South Australia | Neate, 1985; Neate & Warcup, 1985; Rovira, 1986; Thongbai *et al.*, 1993 |
| | W, B | R | Western Australia | Roberts & Sivasithamparam, 1986 |
| | W | R | New South Wales, Australia | Rovira *et al.*, 1986 |
| | W, B | R | South Australia | |
| | W, B | R, SI | Pacific Northwest, USA | Weller *et al.*, 1986 |
| | B | R | Barnham Broom, Norfolk, Watton, UK | Burton *et al.*, 1988 |
| | W | R | South Australia | |
| | W | R, SI | Texas Panhandle, USA | Specht & Rush, 1988 |
| | W | C | Minnesota, USA | Windels & Holen, 1989 |
| | W, B | R | Pacific Northwest, USA | Ogoshi *et al.*, 1990 |
| | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| | W | R, C | High Valleys, Mexico | Leyva & Villaseñor, 1993 |
| | W | C | Texas Panhandle, USA | Rush *et al.*, 1994 |
| | W | R | Western Australia | Yang *et al.*, 1994, 1995 |
| | B | R, C | Prince Edward Island, Canada | Sturz & Carter, 1995 |
| | W | R, C | Alabama, USA | Chen *et al.*, 1996 |
| | W | R, C | Northern Egypt | Fouly *et al.*, 1996 |
| | W | R | Hanang, Tanzania | Meyer *et al.*, 1996, 1998 |
| | W, B | C, SI | Erzurum, Turkey | Demirci, 1998 |
| *Rhizoctonia* spp. | W | C | Highveld Region, SA | Jooste, 1965 |
| | W | R | Eastern Free State, Springbok Flats, SA | Maas & Kotzé, 1981 |
| | W | R, C | Arkansas, USA | Milus & Rothrock, 1989 |
| | W | R, SI | Hanang, Tanzania | Kuwite *et al.*, 1996 |
| | W | ? | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Rhizopus stolonifer* (Ehrenb.: Fr.) Vuill. | W | R | South Australia | Harris & Moen, 1985a,b |
| | W | SI | Pennsylvania, USA | Broscious & Frank, 1986 |
| | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| *Rhizopus* spp. | W | R, SI | Hanang, Tanzania | Kuwite *et al.*, 1996 |
| | W | ? | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| *Sclerotium rolfsii* Sacc. | W | C | Alabama, USA | Godfrey, 1918 |
| | W, B | R | Texas, USA | Kilpatrick & Merkle, 1967 |

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|---|---|---|---|---|
| | W | C | Eastern Australia | Burgess *et al.*, 1975 |
| | W | R | Brits, Eastern Free State, Springbok Flats, SA | Maas & Kotzé, 1981 |
| | W | R | Springbok Flats, SA | Smith *et al.*, 1984; Meyer & Van Dyk, 2002 |
| *Scopulariopsis brevicaulis* (Sacc.) Brainier | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Scopulariopsis* spp. | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Septonema secedens* Corda | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| *Sordaria* spp. | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| *Spicaria* spp. | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| *Sporothrix schenckii* Hektoen & Perkins | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| *Sporotrichum* sp. | W | R | South Australia | Harris & Moen, 1985b |
| *Stemphylium* spp. | W | ? | Washington, USA | Hoes, 1962 |
| | W | R | Central Saudi Arabia | El-Meleigi, 1988 |
| *Thielavia terricola* (Gilman & Abbott) Emmons | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Thielavia* sp. | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Torula herbarum* (Pers.) Link ex S.F. Gray | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| *Torula* spp. | W | ? | Washington, USA | Hoes, 1962 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Tricellula aquaticia* J. Webster | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| *Trichoderma atroviride* Karsten | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *T. aureoviride* Rifai | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *T. crassum* Bissett | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *T. hamatum* (Bon.) Bain. | W | R | Manitoba, Canada | Sturz & Bernier, 1991 |
| | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *T. harzianum* Rifai | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *T. koningii* Oudem. | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *T. longipilis* Bissett | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *T. polysporum* (Link) Rifai | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |

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|---|---|---|---|---|
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *T. viride* Pers.: Fr. | W | R | South Australia | Harris & Moen, 1985a |
| | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W | ? | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Trichoderma* spp. | W | ? | Washington, USA | Hoes, 1962 |
| | W, B | R | Western Australia | Roberts & Sivasithamparam, 1986 |
| | W | C | Minnesota, USA | Windels & Holen, 1989 |
| | W | R, SI | Hanang, Tanzania | Kuwite *et al.*, 1996 |
| | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Ulocladium atrum* Preuss | W | R | South Australia | Rovira, 1986 |
| *U. botrytis* Preuss | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| *Verticillium bulbillosum* W. Gams & Malla | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *V. catenulatum* (Kamyschko ex Barron & Onions) W. Gams | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *V. chlamydosporium* Goddard | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *V. fungicola* (Preuss) Hassebrauk | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *V. lamellicola* (F.E.V. Sm.) W. Gams | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *V. lecanii* (A.W. Zimmerm.) Viegas | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *V. nigrescens* Pethybr. | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| *V. tenerum* Ness | W | R | North-western Poland | Lemanczyk & Sadowski, 2002 |
| *Verticillium* spp. | W | R | Rothamsted, UK | Bateman & Kwasna, 1999 |
| | W | ? | Mississippi, USA | Gonzalez & Trevathan, 2000 |
| | W, B | R | Rothamsted, UK | Dawson & Bateman, 2001 |
| *Waitea circinata* Warcup & Talbot | W, B | R | Western Australia | Roberts & Sivasithamparam, 1986 |
| | W, B | C, SI | Erzurum, Turkey | Demirci, 1998 |
| *Waitea* spp. | W | R | Western Australia | Yang *et al.*, 1994 |
| *Wojnowicia hirta* Sacc. | W, B | R, C | Montana, USA | Sharp, 1959 |
| | W | ? | Wyoming, USA | Hill *et al.*, 1983 |
| | W | C | Northwest Italy | Rossi *et al.*, 1995 |

[a]W = wheat, B = barley

[b]R = roots, C = crowns, SI = subcrown internodes, ? = not specified whether isolated from roots, crowns or subcrown internodes

# CHAPTER 3

# MATERIALS AND METHODS

## 3.1 SAMPLING

Sampling was conducted during the wheat and barley growing seasons in 1997 and 1998. A total of 96 wheat and six barley plant and soil samples were collected from the seven farming units at HWC in April 1997. Samples of PS-affected and non-affected areas were taken in triplicate from different soil types on each farm, approximately four weeks after sowing. Due to late planting, farms in Karatu and West-Kilimanjaro could not be sampled at this time. In May 1998, 42 wheat and 42 barley plant and soil samples were collected from nine farms, five in Karatu and four in West-Kilimanjaro, four to six weeks after sowing. Where possible, three samples were taken from diseased areas and three from disease-free areas on different soil types on each farm. Where affected and non-affected areas could not be discerned, three replicate samples were collected randomly. Flooding in HWC precluded sampling there in 1998.

All samples were transported in plastic bags to Selian Agricultural Research Institute in Arusha, Tanzania. At the institute, plant and soil samples were separated and transferred to paper bags which were packed into carton boxes and sealed. The boxes with samples were dispatched by air to South Africa.

## 3.2 ISOLATION

### 3.2.1 Direct isolation from wheat and barley plants

At the University of Pretoria, each sample comprising 10 plants was washed free of soil and rated on a scale of 0-5 for the incidence of root nodules and sclerotial sheaths of *R. solani*, and for pinkish to purplish discoloration of roots and brown discoloration of crowns indicative of infection by *Fusarium* spp. and *B. sorokiniana*, respectively. The rating scales were as follows:

1. Root nodules and sclerotial sheaths
   0 = 0
   1 = 1-2
   2 = 3-4
   3 = 5-7
   4 = 8-10
   5 = >10

2. Discoloration
   0 = none
   1 = trace
   2 = slight
   3 = moderate
   4 = extensive
   5 = entire

Roots and crowns were cut into segments ca. 10 mm long, disinfested superficially in 3 % sodium hypochlorite for one minute, rinsed in sterile distilled water (SDW) and blot-dried aseptically. Twenty randomly-selected root and five crown segments per sample were plated on half-strength potato-dextrose agar (½PDA) supplemented with 50 mg $l^{-1}$ rifampicin. A further 10 root and five crown segments were plated on water agar. Fungi that developed from the root and crown segments on ½PDA after incubation for 5-10 days at 27 °C were recorded, isolated and identified. The water agar plates served as back-up and fungal colonies developing on them were only considered when the presence of fast-growing fungi on ½PDA plates precluded isolation of colonies developing less rapidly. Representative isolates of each species were maintained in SDW at 8 °C.

### 3.2.2 Indirect isolation from soil

The three replicates of each of the various soil samples were pooled, mixed and dispensed into eight 250 ml plastic cups. The soil in the cups was allowed to settle for six weeks (Gill *et al.*, 2002) and was watered once a week with tap water. After the six weeks, four cups per sample were each planted to five wheat (cv. Palmiet)

seeds and the remaining four to five barley (cv. Clipper) seeds. Seeds were surface-disinfested for one minute in 3 % sodium hypochlorite and rinsed in SDW prior to planting. Cups were randomly arranged in a greenhouse compartment set to a temperature regime of 28 °C (day) and 20 °C (night), and received tap water twice a week. Plants were removed from the cups after eight weeks, rated and processed as above.

## 3.3 CHARACTERISATION OF *RHIZOCTONIA* ISOLATES

### 3.3.1 Nuclear number

Mature actively-growing hyphae from all *Rhizoctonia* isolates were mounted on microscope slides, stained with acridine orange (Yamamoto & Uchida, 1982), and observed at 400x magnification under UV illumination. The number of nuclei per cell was determined from 15 observations per isolate.

### 3.3.2 Anastomosis grouping

Anastomosis group affinity of representative *R. solani* isolates with tester isolates of 11 anastomosis groups of *R. solani* were established according to a modification (Carling *et al.*, 1987) of the method described by Parmeter *et al.* (1969).

## 3.4 PATHOGENICITY TESTS

Representative isolates of various fungal taxa, selected according to frequency of isolation and probability of pathogenicity, were screened for pathogenicity on wheat (cv. Inia) and barley (cv. Clipper) seedlings according to a modified "paper doll" method (Rivera & Bruehl, 1963). Seeds were surface-disinfested in 3 % sodium hypochlorite for 5 minutes, rinsed in SDW, blot-dried aseptically, plated on water agar and allowed to germinate at 27 °C for 48 hours. Ten mycelium-containing discs were removed with a sterile 10-mm-diameter cork borer from a 7-day-old culture of each isolate on ½PDA and positioned ca. 30 mm apart in a row on three layers of 255 x 380 mm germination paper (Anchor). A germinated wheat seed was placed on each of five of the mycelium discs and a barley seed on each of the remaining five discs. The seeds were covered with an additional layer of germination paper, and the stack of sheets was moistened with 75 ml SDW, rolled sideways and secured with elastic bands. Each "paper doll" was placed in a plastic bag, the bag loosely tied with an

elastic band and incubated vertically in the dark in a controlled environment cabinet at 25 °C. Six "paper dolls" were included per isolate. Controls comprised "paper dolls" with uncolonised ½PDA discs on which the seeds were placed.

Seedling mortality was recorded after 10 days. Seedlings were also assessed for ectotrophic fungal growth on the roots and shoots, and extent of root and shoot necrosis. Ratings were according to the following scales (Rufenacht, 1980):

1. Seedling mortality (%)
   0 = 0
   1 = 1-30
   2 = 31-60
   3 = 61-100

2. Ectotrophic growth from inoculation site (mm)
   0 = 0
   1 = 5-10
   2 = 11-30
   3 = >30

3. Root and shoot necrosis
   0 = no lesions
   1 = microscopic lesions
   2 = lesions >3 mm diameter
   3 = extensive necrosis

Total disease score for each isolate was calculated using the formula:

Total score = mortality rating + ectotrophic growth ratings + necrosis ratings

The roots and shoots of each seedling were measured and the shoots were weighed. Mean root and shoot length and fresh shoot mass of the seedlings were used to compare the effect of fungal infection on seedling growth.

For reisolation of the inoculated fungi, roots and crowns were cut into segments ca. 10 mm long, surface-disinfested for one minute in 3 % sodium hypochlorite, rinsed in SDW and blot-dried aseptically. For each paper doll, 10 root and five crown segments from wheat and barley, respectively, were plated on ½PDA supplemented with 50 mg $l^{-1}$ rifampicin, incubated for 5-10 days at 27 °C, and the identity of the inoculated fungus confirmed.

## 3.5 SOIL ANALYSIS

A sub-sample of each pooled soil sample was submitted to the Soil Science Laboratory, University of Pretoria, for determination of the soil texture.

## 3.6 STATISTICAL ANALYSIS

All data were analysed using GenStat (2000). Frequencies or proportions of the different disease rating categories were analysed by chi-square at 5 % level of significance. Where frequencies were too low to allow analysis, some categories were pooled. Data for isolation of fungi from wheat and barley roots and crowns were extremely unbalanced. As the data could not be normalised by any transformation, analysis of variance was precluded. Some of the data could be analysed by grouping the isolation frequencies of a particular fungus into categories (e.g. 0, 1-10, 11-20, 21-50 and >50 %) and analysing the proportions by chi-square. This was, however, only possible for fungi isolated at relatively high frequencies and even so, categories sometimes had to be pooled to allow analysis. Data of isolations from crowns could also not be analysed statistically. Where appropriate, data of isolations from roots and crowns were combined. For pathogenicity tests, analysis of variance was used to test for differences between variables. Because data for percentage root growth, shoot growth and shoot mass were extremely unbalanced, square root transformation was used to stabilise variances. Total score data were not transformed. Fisher's protected *t*-test least significant difference was used to separate means at 1 % level of significance.

# CHAPTER 4

# RESULTS

Patches of severely stunted and chlorotic plants were observed on all seven farms at HWC. Patches ranged from a few centimetres to several metres in diameter and were scattered irregularly throughout fields (Figs 2, 3). No patches were observed in the other two areas sampled, except at one farm in West-Kilimanjaro (Fig. 4). In these regions diseased areas in fields appeared as thinned and uneven stands with or without plants displaying stunting and chlorosis.

Soils in the wheat and barley growing areas of northern Tanzania are medium to fine textured (Antapa, 1996). Four soil types, viz. clay, sandy clay, sandy clay loam and clay loam, were identified from the three areas sampled. Clay soil predominated at HWC, but was found on only one farm in West-Kilimanjaro and not at all in Karatu, whereas sandy clay loam soils were absent at HWC.

Fig. 2 Patches of stunted wheat on Gawal farm at Hanang Wheat Complex in Tanzania.

Fig. 3 Close-up of a patch of stunted wheat on Basotu farm at Hanang Wheat Complex in Tanzania.

Fig. 4 Patch of stunted barley on Namuai farm at West-Kilimanjaro, Tanzania.

Overall, 39.1 % of the wheat and 43.6 % of the barley plants showed no symptoms of infection by *B. sorokiniana*, whereas 47.8 and 21.1 % displayed slight symptoms (rating 1-2), and 13.1 and 35.3 % moderate to severe symptoms (rating 3-5) of infection by this pathogen. A total of 51.7 % of the wheat and 9.3 % of barley samples rated in the zero category for infection by *Fusarium* spp., whereas 39.1 and 52.4 % rated as slightly, and 9.2 and 38.3 % as moderately to severely affected. The vast majority of wheat and barley plants evaluated contained no root nodules (93.5 and 99.6 %) or sclerotial sheaths (95.7 and 100 %) of *R. solani*. Chi-square tests indicated that the distribution of disease categories differed highly significantly ($P \leq 0.004$) between wheat and barley for all four symptoms rated. Highly significant chi-square values ($P < 0.0001$) also indicated that the distribution of disease categories for symptoms of *B. sorokiniana* and *Fusarium* was dependent on the area. Bonferonni pairs-wise tests furthermore showed that HWC differed significantly ($P < 0.05$) from both Karatu and West-Kilimanjaro, which did not differ between each other. No significant differences ($P = 0.078$) in rating categories for root nodules and sclerotial sheaths were evident between areas.

Due to the time lapse between sample collection in Tanzania and their arrival in South Africa (two to three weeks), severe problems with contamination were experienced when isolating directly from wheat and barley plants. Results therefore only reflect indirect isolation from soil by using wheat and barley as trap plants. In the course of the study 9 920 root and 2 480 crown segments were plated out, yielding a total of 11 758 fungal isolates. Almost 30 % of these isolates remained sterile, whereas those which could be identified represented 37 different taxa (Table 2). The most prevalent species were *B. sorokiniana, F. equiseti, F. nygamai, F. oxysporum, F. subglutinans* (Wollenw. & Reinking) P.E. Nelson, Toussoun & Marasas, *P. macrospinosa, Phoma macrostroma* Mont. and *P. medicaginis* Malbr. & Roum., all of which were present in soil from all three areas. Roots yielded a much greater variety of fungi than crowns. *Fusarium* spp. comprised the largest component of the fungal community associated with roots and represented 33.1 % of the total number of root isolates. Of the fusaria isolated from roots 41.2 % were *F. oxysporum* and 27.7 % *F. nygamai*. According to chi-square analysis and irrespective of area, *F. equiseti* and *F. oxysporum* were isolated at significantly higher

($P$<0.0001) frequencies from wheat than from barley roots, whereas the incidence of *F. nygamai* on the two crops did not differ ($P$=0.058). Crowns were mostly infected with *B. sorokiniana*, which comprised 65.4 % of the total isolates from crowns. *F. equiseti* respresented 61.5 % of the fusaria isolated from crowns.

*F. nygamai* and *F. oxysporum* were isolated the most frequently from roots of wheat and barley in soil from HWC. Isolation frequencies of *F. nygamai* were significantly higher ($P$<0.0001) from both wheat and barley, but those of *F. oxysporum* only from barley in this region, compared to Karatu and West-Kilimanjaro. The incidence of *P. macrospinosa* was similar in wheat and barley, but also significantly higher ($P$<0.0001) at HWC than in the other two areas. *P. macrostroma* was isolated the most frequently from wheat roots in soil from Karatu and West-Kilimanjaro, whereas roots of barley in soil from these two areas mostly yielded *P. medicaginis*. Isolation frequency of *P. macrostroma* from wheat roots was significantly lower ($P$<0.0001) in soil from HWC than from the other two areas, whereas that of *P. medicaginis* from barley roots was significantly higher ($P$<0.0001) for Karatu only. *B. sorokiniana* was predominantly isolated from crowns of both wheat and barley in soil from all three areas. *S. rolfsii* was not isolated from HWC soil and only sporadically from Karatu and West-Kilimanjaro soil.

Isolation frequencies from healthy samples never differed significantly from those of diseased samples. Frequencies from healthy and diseased samples did, however, differ significantly ($P\leq0.02$) from randomly collected samples for *F. nygamai, F. subglutinans, P. macrospinosa, P. macrostroma* and *P. medicaginis* , but not ($P\geq0.054$) for *B. sorokiniana, F. equiseti, F. oxysporum* and *R. solani*. Frequencies were lower from randomly collected than from healthy or diseased samples for the former three species and higher for the latter two.

In total, 47 *Rhizoctonia* isolates were retrieved by trapping from soil. All but seven of the isolates proved to be multinucleate and belonged to *R. solani* AG-6. Binucleate *Rhizoctonia* isolates were recovered exclusively from the Karatu area, whereas *R. solani* was found in all three areas. However, despite HWC being the main area affected by PS, samples from this region yielded only two *R. solani* isolates. *R.*

*solani* was also the only fungus for which meaningful, albeit non-significant, differences were evident between soil types.

Root growth, and shoot growth and mass of barley were generally impeded less than that of wheat by most fungi included in the artificial inoculation study (Table 3). The *t*-probabilities for pair-wise differences between isolates and crops for percentage root growth, shoot growth and -mass, and for total disease score, according to Fisher's protected *t*-test least significant difference ($P \leq 0.01$), are given in Appendix 1.

Root growth of wheat was retarded more than that of barley by all fungi tested except *P. medicaginis*, albeit significantly ($P \leq 0.007$) so only for *B. sorokiniana*, *F. oxysporum*, *F. nygamai*, *R. solani* and *S. rolfsii*. *F. nygamai* aggressively colonised roots and caused the highest reduction in root growth for both wheat (94.4 %) and barley (75.8 %). It retarded root growth significantly more than any of the other fungi, except *S. rolfsii* on wheat ($P=0.411$) and *Fusarium chlamydosporum* Wollenw. & Reinking on wheat ($P=0.045$) and barley ($P=0.220$).

Similar trends were observed for reduction in shoot growth and mass. Significantly greater ($P \leq 0.007$) reduction in percentage shoot growth and mass of wheat compared to barley was noted for *B. sorokiniana*, *F. chlamydosporum*, *F. nygamai* and *R. solani*. This effect was most pronounced for *B. sorokiniana*, with both shoot growth and mass of wheat almost five times less than that of barley. *F. oxysporum* also significantly reduced ($P=0.006$) shoot growth, but not shoot mass ($P=0.011$), of wheat more than that of barley. Although *B. sorokiniana* caused the most retardation of shoot growth (86.5 %) and mass (86.3 %) in wheat, this decrease was not significantly more ($P \geq 0.048$) than that incited by *F. chlamydosporum*, *F. nygamai* and *S. rolfsii*. *F. nygamai* caused the greatest reduction in barley shoot growth (49.2 %) and mass (55.6 %), but differed significantly ($P \leq 0.008$) only from *P. medicaginis* and *P. macrospinosa* for reduction in shoot growth and from the former two fungi as well as *Fusarium solani* (Mart.) Appel & Wollenw. and *F. subglutinans* for reduction in

Table 2. Fungi isolated from roots and crowns of wheat and barley planted to soil collected from the three main wheat and barley production areas in Tanzania.

| Fungal taxon | Area | Frequency[a] | | Incidence (%)[b] | | | |
|---|---|---|---|---|---|---|---|
| | | Wheat | Barley | Wheat roots | Wheat crowns | Barley roots | Barley crowns |
| *Alternaria* spp. | HWC | 1 | 2 | 0 | 0.3 | 0.1 | 0.2 |
| | Karatu | 0 | 0 | 0 | 0 | 0 | 0 |
| | West-Kilimanjaro | 0 | 0 | 0 | 0 | 0 | 0 |
| Binucleate *Rhizoctonia* spp. | HWC | 0 | 0 | 0 | 0 | 0 | 0 |
| | Karatu | 3 | 1 | 0.5 | 1.0 | 0 | 0.5 |
| | West-Kilimanjaro | 0 | 0 | 0 | 0 | 0 | 0 |
| *Bipolaris cynodontis* | HWC | 0 | 0 | 0 | 0 | 0 | 0 |
| | Karatu | 0 | 0 | 0 | 0 | 0 | 0 |
| | West-Kilimanjaro | 3 | 0 | 0.6 | 0 | 0 | 0 |
| *B. indica* | HWC | 0 | 0 | 0 | 0 | 0 | 0 |
| | Karatu | 0 | 0 | 0 | 0 | 0 | 0 |
| | West-Kilimanjaro | 1 | 0 | 0.1 | 0 | 0 | 0 |
| *B. papendorfii* | HWC | 0 | 1 | 0 | 0 | 0.2 | 0 |
| | Karatu | 0 | 0 | 0 | 0 | 0 | 0 |
| | West-Kilimanjaro | 0 | 0 | 0 | 0 | 0 | 0 |
| *B. sorokiniana* | HWC | 31 | 26 | 3.5 | 57.3 | 2.9 | 5.4 |
| | Karatu | 10 | 11 | 1.6 | 30.9 | 4.2 | 57.1 |
| | West-Kilimanjaro | 15 | 17 | 2.9 | 33.8 | 4.5 | 44.1 |
| *Chaetomella* sp. | HWC | 1 | 0 | 0.1 | 0 | 0 | 0 |
| | Karatu | 0 | 0 | 0 | 0 | 0 | 0 |
| | West-Kilimanjaro | 0 | 0 | 0 | 0 | 0 | 0 |
| *Chaetomium* spp. | HWC | 4 | 2 | 0.3 | 0 | 0.2 | 0.2 |
| | Karatu | 0 | 7 | 0 | 0 | 3.9 | 1.0 |
| | West-Kilimanjaro | 8 | 10 | 1.0 | 0.3 | 4.2 | 1.6 |
| *Cladosporium cladosporioides* | HWC | 1 | 3 | 0.1 | 0 | 0.5 | 0 |
| | Karatu | 0 | 0 | 0 | 0 | 0 | 0 |
| | West-Kilimanjaro | 0 | 0 | 0 | 0 | 0 | 0 |
| *Drechslera poae* | HWC | 1 | 0 | 0 | 0.2 | 0 | 0 |
| | Karatu | 0 | 0 | 0 | 0 | 0 | 0 |
| | West-Kilimanjaro | 0 | 0 | 0 | 0 | 0 | 0 |
| *Epicoccum nigrum* | HWC | 2 | 1 | 0.1 | 0 | 0.1 | 0 |
| | Karatu | 0 | 0 | 0 | 0 | 0 | 0 |
| | West-Kilimanjaro | 0 | 0 | 0 | 0 | 0 | 0 |
| *Exserohilum rostratum* | HWC | 0 | 2 | 0 | 0 | 0.3 | 0 |
| | Karatu | 0 | 0 | 0 | 0 | 0 | 0 |
| | West-Kilimanjaro | 0 | 0 | 0 | 0 | 0 | 0 |
| *Fusarium chlamydosporum* | HWC | 11 | 14 | 1.1 | 0 | 1.1 | 0 |
| | Karatu | 4 | 4 | 0.8 | 0.5 | 0.1 | 1.4 |
| | West-Kilimanjaro | 4 | 0 | 1.0 | 0 | 0 | 0 |
| *F. equiseti* | HWC | 26 | 24 | 7.2 | 1.7 | 4.8 | 0.5 |
| | Karatu | 11 | 10 | 8.2 | 11.4 | 1.0 | 20.5 |
| | West-Kilimanjaro | 17 | 16 | 10.2 | 7.1 | 2.1 | 14.7 |

Table 2. (continued)

| Fungal taxon | Area | Frequency[a] | | Incidence (%)[b] | | | |
|---|---|---|---|---|---|---|---|
| | | Wheat | Barley | Wheat roots | Wheat crowns | Barley roots | Barley crowns |
| *F. nygamai* | HWC | 27 | 34 | 19.8 | 1.5 | 19.6 | 1.5 |
| | Karatu | 7 | 3 | 5.0 | 2.3 | 0.5 | 0.5 |
| | West-Kilimanjaro | 8 | 4 | 2.0 | 0.9 | 0.9 | 0 |
| *F. oxysporum* | HWC | 29 | 34 | 19.5 | 0.3 | 19.2 | 0.3 |
| | Karatu | 11 | 8 | 15.6 | 0.5 | 3.3 | 4.3 |
| | West-Kilimanjaro | 17 | 14 | 25.4 | 1.5 | 6.2 | 4.7 |
| *F. pallidoroseum* | HWC | 1 | 3 | 0.05 | 0 | 0.3 | 0 |
| | Karatu | 0 | 0 | 0 | 0 | 0 | 0 |
| | West-Kilimanjaro | 0 | 0 | 0 | 0 | 0 | 0 |
| *F. solani* | HWC | 10 | 4 | 0.8 | 0 | 0.6 | 0 |
| | Karatu | 0 | 0 | 0 | 0 | 0 | 0 |
| | West-Kilimanjaro | 0 | 0 | 0 | 0 | 0 | 0 |
| *F. subglutinans* | HWC | 15 | 21 | 2.3 | 0.8 | 5.7 | 0 |
| | Karatu | 10 | 3 | 6.4 | 0.9 | 1.3 | 0 |
| | West-Kilimanjaro | 12 | 7 | 9.0 | 1.2 | 3.6 | 0.6 |
| *Fusarium* spp. | HWC | 9 | 9 | 1.0 | 0.3 | 1.8 | 0.3 |
| | Karatu | 2 | 1 | 0.2 | 0 | 0.1 | 0 |
| | West-Kilimanjaro | 2 | 2 | 0.3 | 0 | 0.6 | 0 |
| *Gliocladium catenulatum* | HWC | 3 | 0 | 0.4 | 0 | 0 | 0 |
| | Karatu | 2 | 0 | 0.2 | 0 | 0 | 0 |
| | West-Kilimanjaro | 2 | 0 | 0.1 | 0 | 0 | 0 |
| *Macrophomina phaseolina* | HWC | 0 | 1 | 0 | 0 | 0.04 | 0 |
| | Karatu | 2 | 0 | 0.1 | 0 | 0 | 0 |
| | West-Kilimanjaro | 0 | 0 | 0 | 0 | 0 | 0 |
| *Melanospora* sp. | HWC | 0 | 0 | 0 | 0 | 0 | 0 |
| | Karatu | 0 | 3 | 0 | 0 | 0.9 | 0 |
| | West-Kilimanjaro | 0 | 10 | 0 | 0 | 3.9 | 3.1 |
| *Microsphaeropsis olivacea* | HWC | 0 | 0 | 0 | 0 | 0 | 0 |
| | Karatu | 1 | 0 | 0 | 1.0 | 0 | 0 |
| | West-Kilimanjaro | 2 | 0 | 0.1 | 0.3 | 0 | 0 |
| *Myrothecium verrucaria* | HWC | 0 | 1 | 0 | 0 | 0.04 | 0 |
| | Karatu | 0 | 0 | 0 | 0 | 0 | 0 |
| | West-Kilimanjaro | 1 | 1 | 0.1 | 0 | 0.3 | 0 |
| *Paecilomyces lilacinus* | HWC | 3 | 0 | 0.1 | 0 | 0 | 0 |
| | Karatu | 0 | 0 | 0 | 0 | 0 | 0 |
| | West-Kilimanjaro | 0 | 0 | 0 | 0 | 0 | 0 |
| *Periconia macrospinosa* | HWC | 31 | 32 | 13.0 | 0 | 17.3 | 0 |
| | Karatu | 3 | 5 | 0.9 | 0 | 0.9 | 0 |
| | West-Kilimanjaro | 10 | 5 | 2.9 | 0 | 1.4 | 0 |
| *Phoma chrysanthemicola* | HWC | 0 | 1 | 0 | 0 | 0.04 | 0 |
| | Karatu | 0 | 0 | 0 | 0 | 0 | 0 |
| | West-Kilimanjaro | 0 | 0 | 0 | 0 | 0 | 0 |
| *P. macrostroma* | HWC | 15 | 11 | 1.6 | 0 | 1.8 | 0 |
| | Karatu | 11 | 10 | 19.9 | 0 | 29.4 | 1.4 |
| | West-Kilimanjaro | 17 | 13 | 28.4 | 1.2 | 15.7 | 0 |

Table 2. (continued)

| Fungal taxon | Area | Frequency[a] | | Incidence (%)[b] | | | |
|---|---|---|---|---|---|---|---|
| | | Wheat | Barley | Wheat roots | Wheat crowns | Barley roots | Barley crowns |
| *P. medicaginis* | HWC | 28 | 21 | 11.0 | 0 | 7.3 | 0.5 |
| | Karatu | 4 | 10 | 3.1 | 0 | 30.1 | 0.5 |
| | West-Kilimanjaro | 14 | 12 | 18.6 | 0 | 21.4 | 0.6 |
| *Pithomyces* sp. | HWC | 1 | 6 | 0.1 | 0 | 0.2 | 0.3 |
| | Karatu | 0 | 0 | 0 | 0 | 0 | 0 |
| | West-Kilimanjaro | 0 | 0 | 0 | 0 | 0 | 0 |
| *Ramichloridium schulzeri* | HWC | 7 | 0 | 1.8 | 0 | 0.1 | 0 |
| | Karatu | 8 | 6 | 12.4 | 0 | 1.6 | 0 |
| | West-Kilimanjaro | 13 | 10 | 6.5 | 0 | 4.2 | 0 |
| *Rhizoctonia solani* | HWC | 2 | 0 | 0.1 | 0 | 0 | 0 |
| | Karatu | 2 | 2 | 1.0 | 0 | 0 | 1.9 |
| | West-Kilimanjaro | 10 | 2 | 1.5 | 0.9 | 0.2 | 0 |
| *Sclerotium rolfsii* | HWC | 0 | 0 | 0 | 0 | 0 | 0 |
| | Karatu | 1 | 1 | 0 | 1.0 | 0 | 2.9 |
| | West-Kilimanjaro | 1 | 0 | 0 | 0.6 | 0 | 0 |
| *Stachybotrys elegans* | HWC | 1 | 0 | 0.3 | 0 | 0 | 0 |
| | Karatu | 0 | 0 | 0 | 0 | 0 | 0 |
| | West-Kilimanjaro | 4 | 0 | 0.3 | 0.6 | 0 | 0 |
| *Talaromyces trachyspermus* | HWC | 1 | 0 | 0.05 | 0 | 0 | 0 |
| | Karatu | 0 | 0 | 0 | 0 | 0 | 0 |
| | West-Kilimanjaro | 0 | 0 | 0 | 0 | 0 | 0 |
| *Trichothecium roseum* | HWC | 0 | 1 | 0 | 0 | 0.04 | 0 |
| | Karatu | 0 | 0 | 0 | 0 | 0 | 0 |
| | West-Kilimanjaro | 0 | 0 | 0 | 0 | 0 | 0 |
| Sterile isolates | HWC | 31 | 29 | 18.1 | 8.1 | 24.0 | 2.0 |
| | Karatu | 11 | 11 | 89.0 | 15.5 | 54.1 | 1.0 |
| | West-Kilimanjaro | 17 | 16 | 61.8 | 9.7 | 33.5 | 1.3 |

[a]Number of samples out of 34 for Hanang Wheat Complex, 11 for Karatu and 17 for West-Kilimanjaro from which the taxon was isolated.

[b]Percentage root and crown segments yielding the taxon.

shoot mass. *P. medicaginis* did not impair root growth, shoot growth or shoot mass of wheat, whereas *P. macrospinosa* had no impeding effect on barley.

Total score of all isolates tested was consistently higher on wheat compared to barley (Table 4), but significantly ($P \leq 0.001$) so only for *B. sorokiniana*, *F. chlamydosporum*, *F. oxysporum*, *F. nygamai*, *P. macrospinosa* and *R. solani*. *F. nygamai* and *S. rolfsii* had the highest total score on wheat but did not differ significantly ($P \geq 0.124$) from *B. sorokiniana* and *F. chlamydosporum*. Total score of

*S. rolfsii* furthermore did not differ significantly ($P$=0.082) from that of *R. solani* on wheat. On barley, *S. rolfsii* had the highest score but did not differ significantly ($P \geq 0.033$) from *B. sorokiniana*, *F. equiseti*, *F. chlamydosporum*, *F. nygamai* or *R. solani*. *P. medicaginis* had the lowest total score on wheat, whereas *F. solani* had the lowest score on barley. However, total score of *P. medicaginis* on wheat was not significantly lower ($P$=0.031) than that of *F. solani*, whereas total score of *F. solani* on barley was not significantly lower ($P \geq 0.023$) than that of *F. subglutinans*, *P. medicaginis* or *P. macrospinosa*. Except for total score, which was significantly higher ($P$<0.001) on wheat than on barley, the effect of *P. macrospinosa* did not differ significantly ($P \geq 0.036$) between wheat and barley for any of the variables considered.

Isolates of the same species varied in their ability to impede root growth, and shoot growth and mass of wheat and barley (Figs 5-13). Likewise, total scores of isolates within a particular species also varied notably. This was especially true for isolates of *B. sorokiniana* on barley, *P. macrospinosa* on wheat and *F. equiseti* and *R. solani* on both wheat and barley. For instance, root and shoot growth and mass of wheat, as a percentage of the control, was only 9.0, 9.4 and 13.8 %, respectively, when inoculated with *F. equiseti* isolate no. 2 compared to 92.0, 97.6 and 104.8 % when inoculated with isolate no. 4. Similarly, total score of the former isolate was 11.3, whereas that of the latter was only 3.2. Except for *B. sorokiniana* isolates which originated from HWC soil and were more virulent on wheat than on barley, no correlation was evident between the area or source from which isolates were obtained and their pathogenicity towards wheat and barley.

Within a particular species, the isolate impeding root growth the most usually also impaired shoot growth and mass most and had the highest total score on wheat and barley, respectively. Trends for wheat and barley were similar, with isolates causing a high percentage reduction and having a high total score on wheat commonly having a corresponding effect on barley.

All fungi were reisolated from wheat and barley roots and crowns. *P. medicaginis* was, however, generally reisolated at lower frequencies than the other fungi,

whereas *P. macrospinosa* was commonly reisolated more readily from wheat than barley.

*P. macrostroma* and binucleate *Rhizoctonia* spp. could not be retrieved after storage in SDW and were therefore not included in the pathogenicity tests.

Table 3. Root growth, shoot growth and shoot mass of wheat and barley seedlings inoculated with soilborne fungi isolated from roots and crowns of wheat and barley in Tanzania.

| | Root growth (%)[a] | | Shoot growth (%)[a] | | Fresh shoot mass (%)[a] | |
|---|---|---|---|---|---|---|
| Fungus | Wheat | Barley | Wheat | Barley | Wheat | Barley |
| *Bipolaris sorokiniana* | 13.9 ± 10.7 | 45.8 ± 27.7* | 13.5 ± 13.5 | 64.5 ± 42.9* | 13.7 ± 14.0 | 65.9 ± 44.9* |
| *Fusarium equiseti* | 52.5 ± 36.7 | 54.7 ± 36.8 | 54.8 ± 42.5 | 60.9 ± 40.4 | 60.1 ± 39.7 | 64.7 ± 43.8 |
| *F. chlamydosporum* | 16.9 ± 15.2 | 34.0 ± 22.9 | 29.5 ± 31.5 | 67.7 ± 56.2* | 31.9 ± 30.7 | 67.2 ± 58.9* |
| *F. solani* | 55.7 ± 21.0 | 111.0 ± 71.2 | 92.5 ± 25.8 | 88.1 ± 35.7 | 73.2 ± 14.9 | 90.8 ± 36.4 |
| *F. oxysporum* | 35.8 ± 16.8 | 58.4 ± 29.6* | 39.7 ± 24.5 | 65.5 ± 29.9* | 37.3 ± 20.9 | 62.9 ± 34.4 |
| *F. nygamai* | 5.6 ± 7.1 | 24.2 ± 18.5* | 14.9 ± 17.6 | 50.8 ± 33.4* | 16.6 ± 21.1 | 44.4 ± 27.1* |
| *F. subglutinans* | 54.0 ± 28.8 | 73.3 ± 17.8 | 74.0 ± 40.5 | 66.7 ± 19.6 | 68.7 ± 36.7 | 77.7 ± 29.5 |
| *Phoma medicaginis* | 104.1 ± 54.8 | 89.5 ± 33.8 | 109.0 ± 62.2 | 100.9 ± 37.3 | 105.3 ± 57.0 | 96.9 ± 47.7 |
| *Periconia macrospinosa* | 78.3 ± 34.8 | 100.0 ± 35.9 | 98.8 ± 79.1 | 111.2 ± 54.6 | 90.8 ± 45.2 | 107.6 ± 50.4 |
| *Rhizoctonia solani* | 36.3 ± 33.7 | 73.6 ± 61.2* | 36.1 ± 37.7 | 74.8 ± 64.6* | 38.1 ± 31.1 | 65.9 ± 58.9* |
| *Sclerotium rolfsii* | 22.7 ± 15.0 | 82.8 ± 20.3* | 15.6 ± 10.3 | 54.9 ± 18.4 | 28.3 ± 29.7 | 69.1 ± 35.0 |

[a]Growth per plant as a percentage of the control ± standard deviation using six paper dolls each containing five wheat and five barley seedlings per isolate. Mean of 14 *B. sorokiniana*, 4 *F. equiseti*, 2 *F. chlamydosporum*, 1 *F. solani*, 5 *F. oxysporum*, 5 *F. nygamai*, 2 *F. subglutinans*, 8 *P. medicaginis*, 5 *P. macrospinosa*, 11 *R. solani* and 1 *S. rolfsii* isolate(s). The *t*-probabilities for pair-wise differences between isolates and crops for percentage root growth, shoot growth and mass, according to Fisher's protected *t*-test least significant difference ($P \leq 0.01$), are given in Appendix 1.

*Significantly different from wheat according to Fisher's protected *t*-test least significant difference ($P \leq 0.01$).

Table 4. Total disease score for fungi inoculated onto wheat and barley seedlings.

| | Total score[a] | |
|---|---|---|
| Fungus | Wheat | Barley |
| *Bipolaris sorokiniana* | 11.8 ± 2.0 | 7.6 ± 2.2* |
| *Fusarium equiseti* | 7.7 ± 3.9 | 6.7 ± 2.8 |
| *F. chlamydosporum* | 11.2 ± 2.7 | 7.1 ± 1.3* |
| *F. solani* | 6.6 ± 2.4 | 3.2 ± 2.2 |
| *F. oxysporum* | 8.9 ± 1.9 | 6.2 ± 1.7* |
| *F. nygamai* | 12.4 ± 2.5 | 8.2 ± 2.0* |
| *F. subglutinans* | 7.3 ± 3.3 | 6.0 ± 1.7 |
| *Phoma medicaginis* | 4.4 ± 2.7 | 4.0 ± 2.6 |
| *Periconia macrospinosa* | 6.9 ± 2.6 | 3.7 ± 2.0* |
| *Rhizoctonia solani* | 10.6 ± 2.5 | 8.5 ± 2.5* |
| *Sclerotium rolfsii* | 12.4 ± 1.9 | 9.1 ± 1.1 |

[a]Total score (Rufenacht, 1980) ± standard deviation of fungi tested using six paper dolls each containing five wheat and five barley seedlings per isolate. Mean of 14 *B. sorokiniana*, 4 *F. equiseti*, 2 *F. chlamydosporum*, 1 *F. solani*, 5 *F. oxysporum*, 5 *F. nygamai*, 2 *F. subglutinans*, 8 *P. medicaginis*, 5 *P. macrospinosa*, 11 *R. solani* and 1 *S. rolfsii* isolate(s). The *t*-probabilities for pair-wise differences between isolates and crops for total score, according to Fisher's protected *t*-test least significant difference ($P \leq 0.01$), are given in Appendix 1.

*Significantly different from wheat according to Fisher's protected *t*-test least significant difference ($P \leq 0.01$).

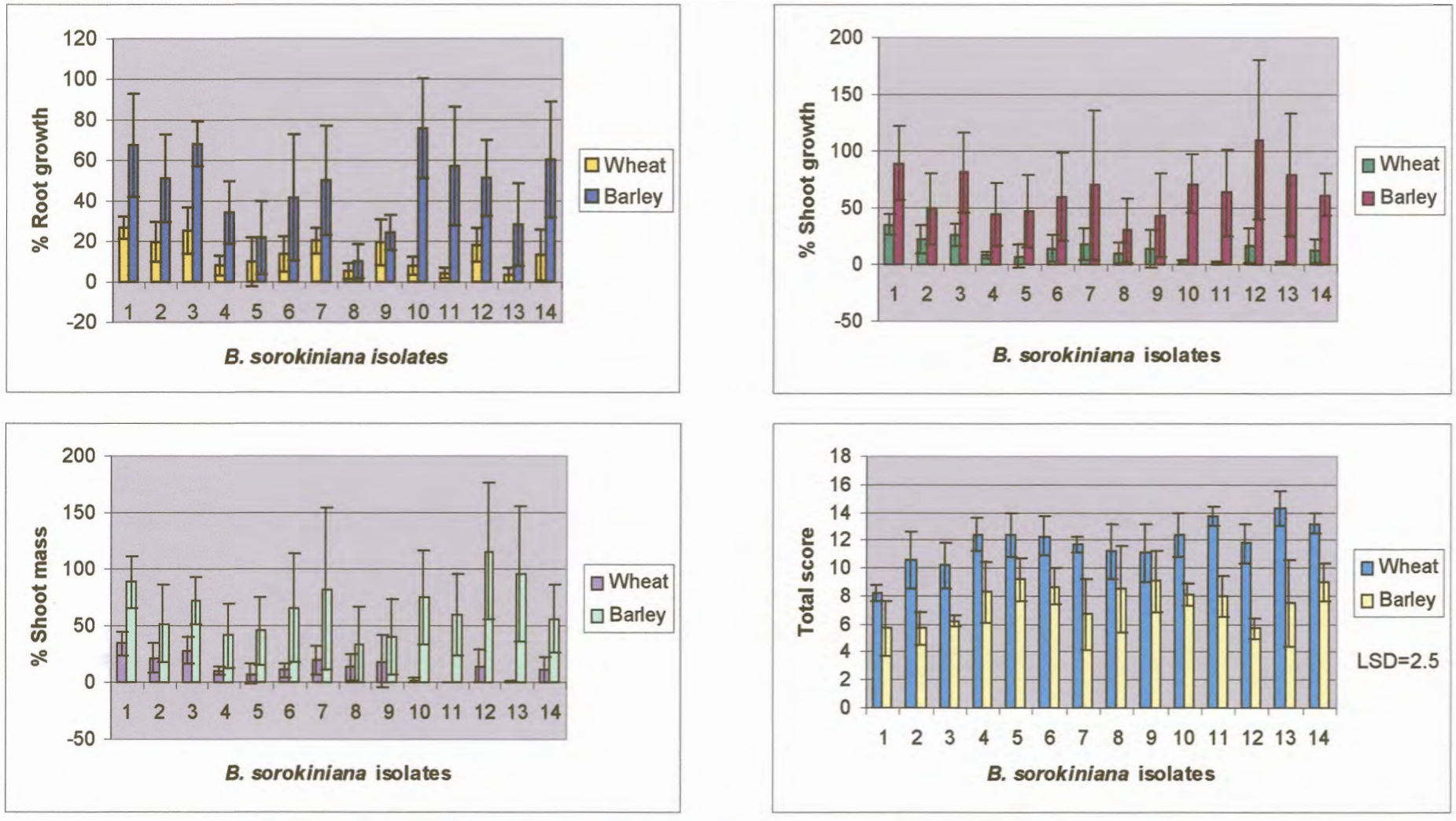



Fig. 5 Percentage root growth, shoot growth and shoot mass of wheat and barley inoculated with different *Bipolaris sorokiniana* isolates and total disease score for each isolate. Error bars indicate standard deviations. (Data for percentage root growth, shoot growth and shoot mass were transformed and LSD values are therefore only indicated for total score).

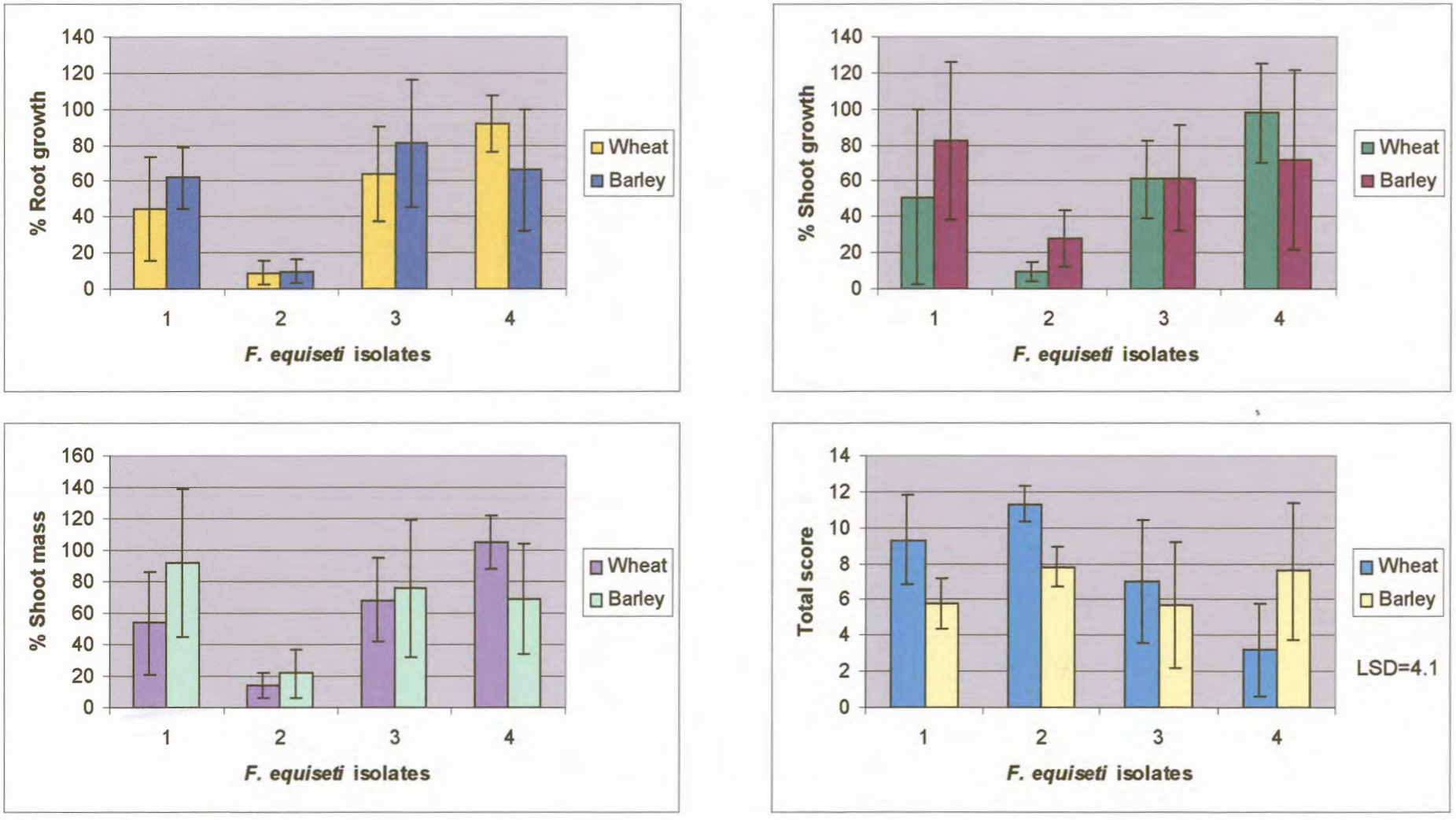
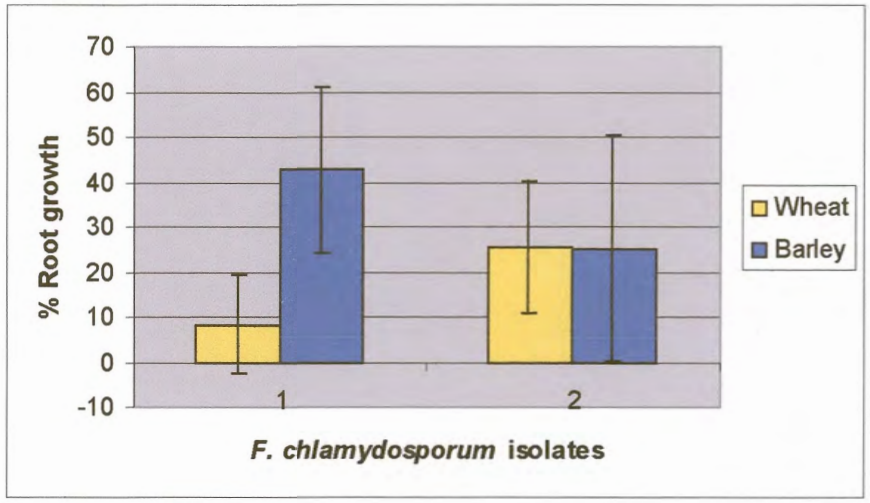
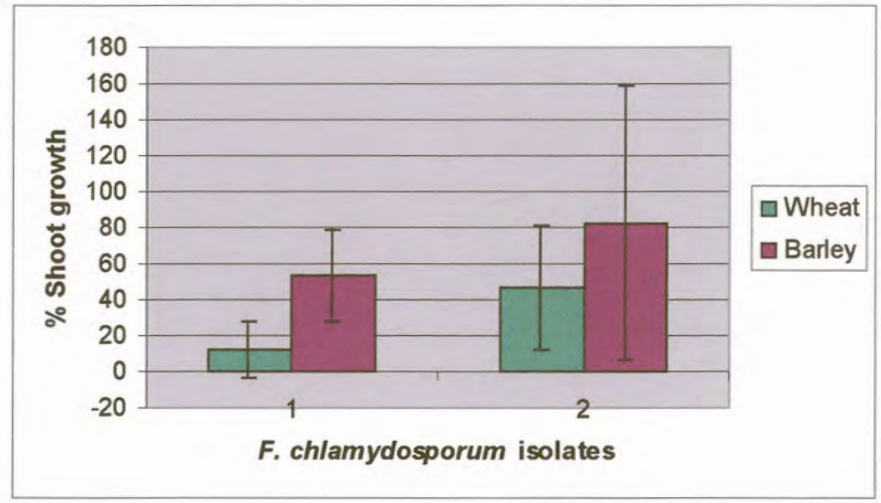
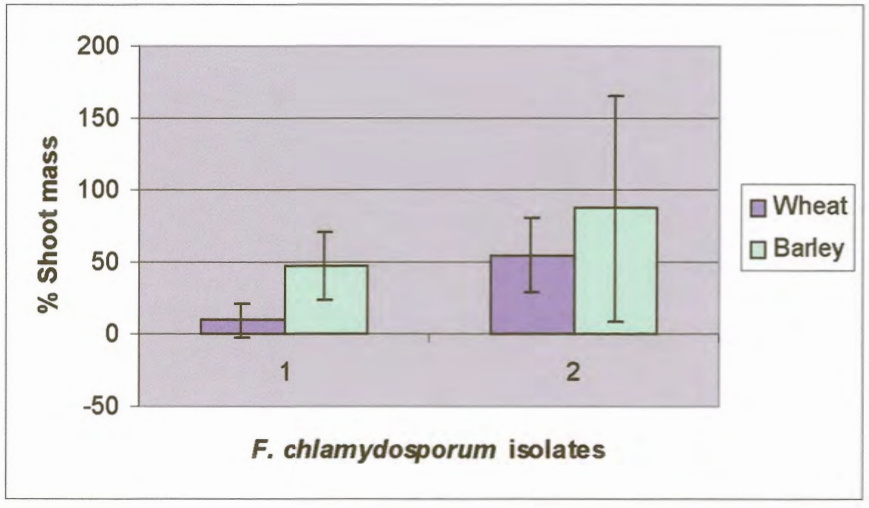



Fig. 6 Percentage root growth, shoot growth and shoot mass of wheat and barley inoculated with different *Fusarium equiseti* isolates and total disease score for each isolate. Error bars indicate standard deviations. (Data for percentage root growth, shoot growth and shoot mass were transformed and LSD values are therefore only indicated for total score).



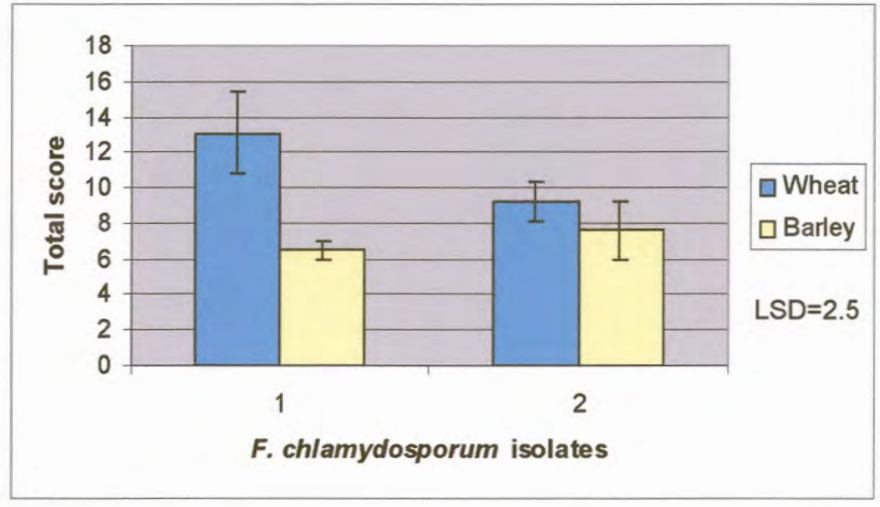




Fig. 7 Percentage root growth, shoot growth and shoot mass of wheat and barley inoculated with different *Fusarium chlamydosporum* isolates and total disease score for each isolate. Error bars indicate standard deviations. (Data for percentage root growth, shoot growth and shoot mass were transformed and LSD values are therefore only indicated for total score).

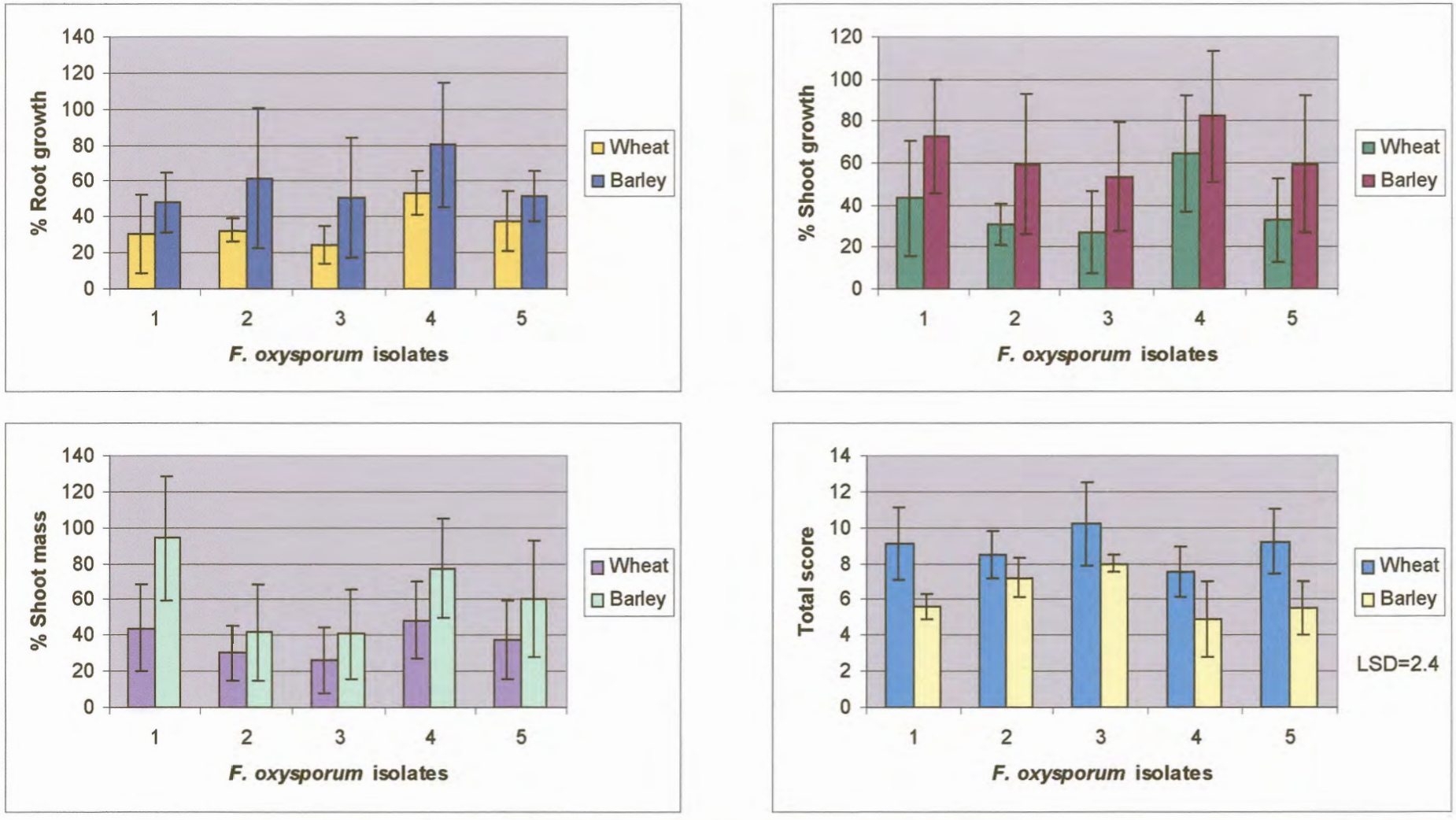



Fig. 8 Percentage root growth, shoot growth and shoot mass of wheat and barley inoculated with different *Fusarium oxysporum* isolates and total disease score for each isolate. Error bars indicate standard deviations. (Data for percentage root growth, shoot growth and shoot mass were transformed and LSD values are therefore only indicated for total score).

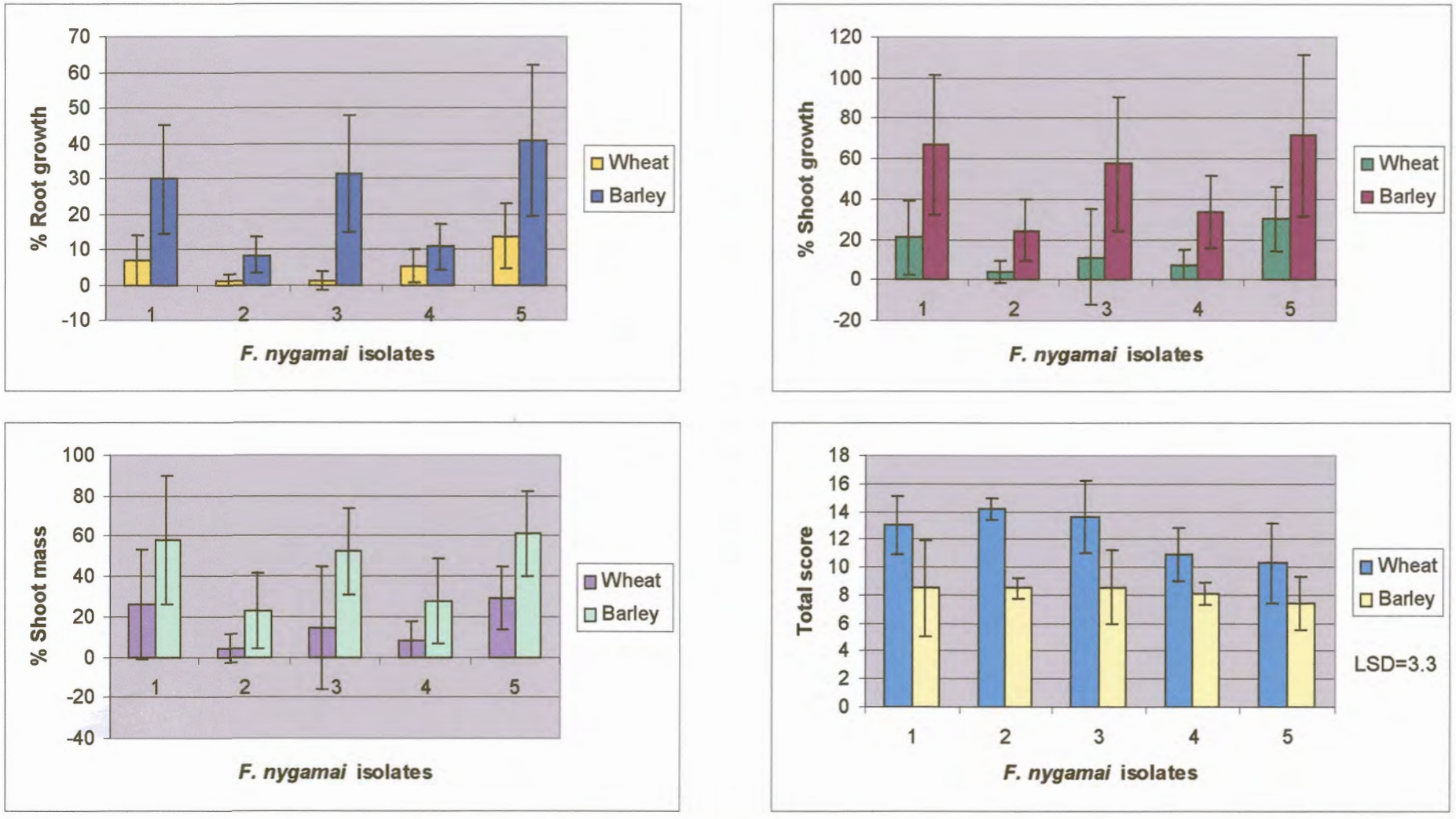



Fig. 9 Percentage root growth, shoot growth and shoot mass of wheat and barley inoculated with different *Fusarium nygamai* isolates and total disease score for each isolate. Error bars indicate standard deviations. (Data for percentage root growth, shoot growth and shoot mass were transformed and LSD values are therefore only indicated for total score).

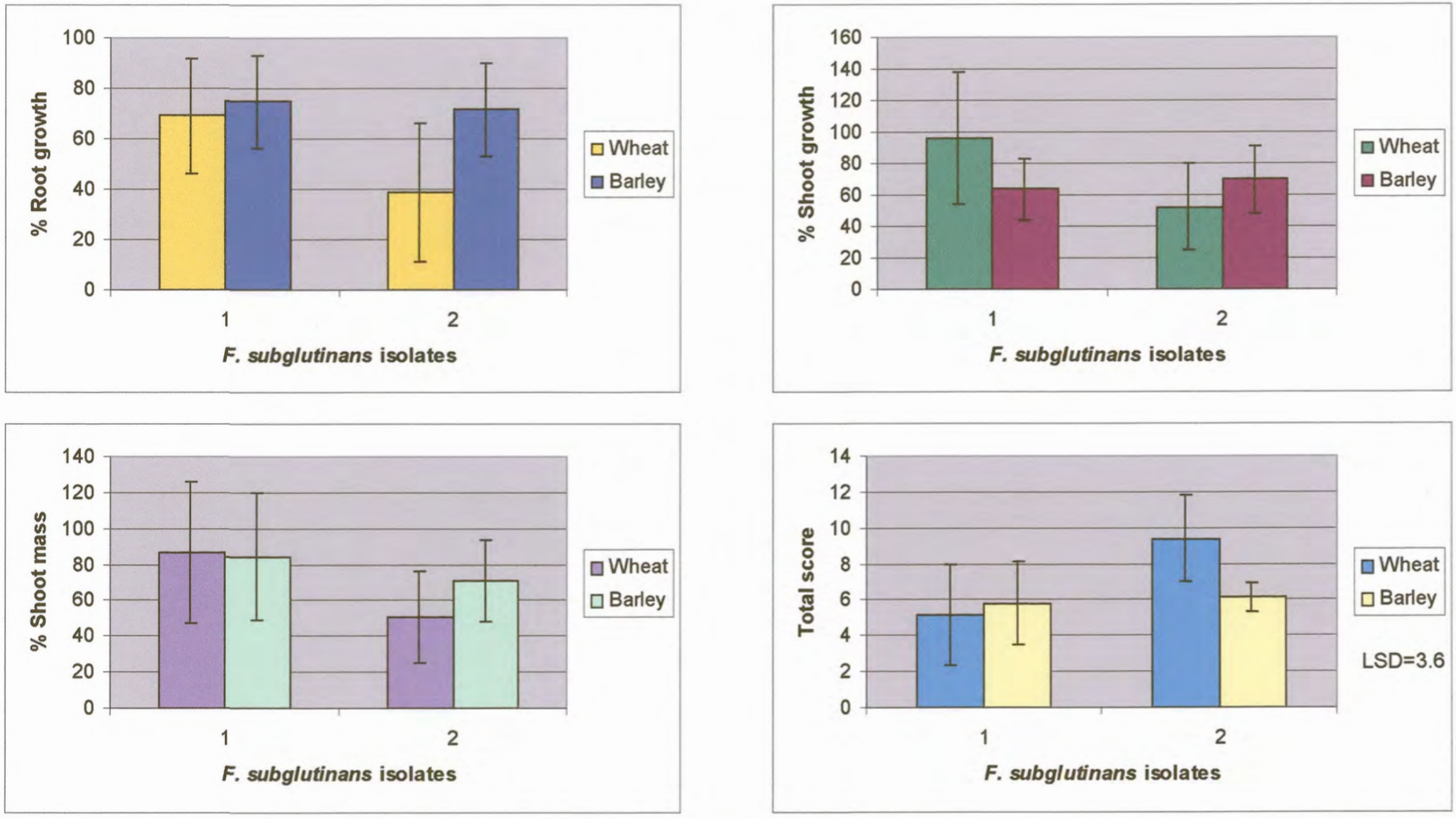



Fig. 10 Percentage root growth, shoot growth and shoot mass of wheat and barley inoculated with different *Fusarium subglutinans* isolates and total disease score for each isolate. Error bars indicate standard deviations. (Data for percentage root growth, shoot growth and shoot mass were transformed and LSD values are therefore only indicated for total score).

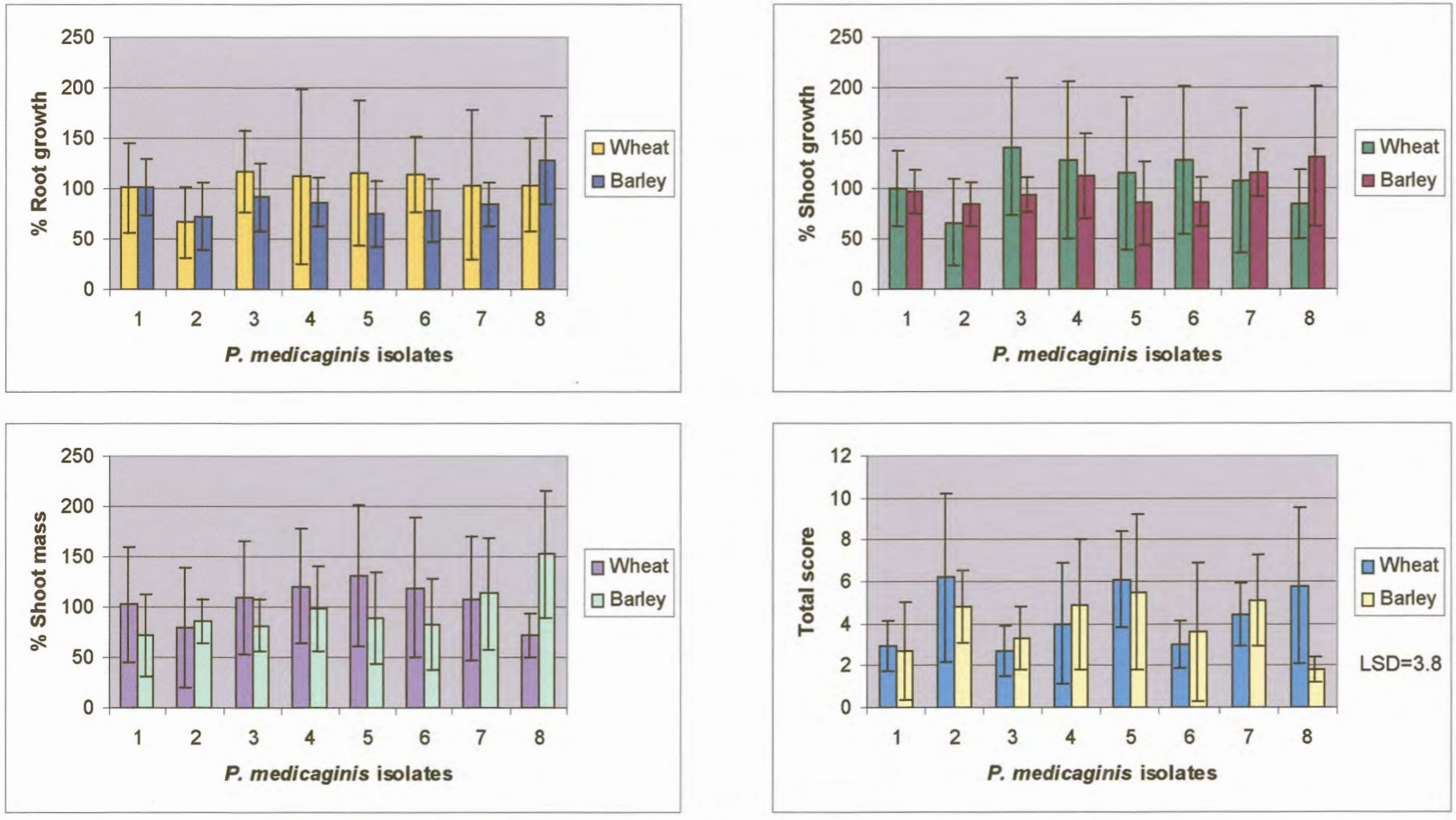



Fig. 11 Percentage root growth, shoot growth and shoot mass of wheat and barley inoculated with different *Phoma medicaginis* isolates and total disease score for each isolate. Error bars indicate standard deviations. (Data for percentage root growth, shoot growth and shoot mass were transformed and LSD values are therefore only indicated for total score).

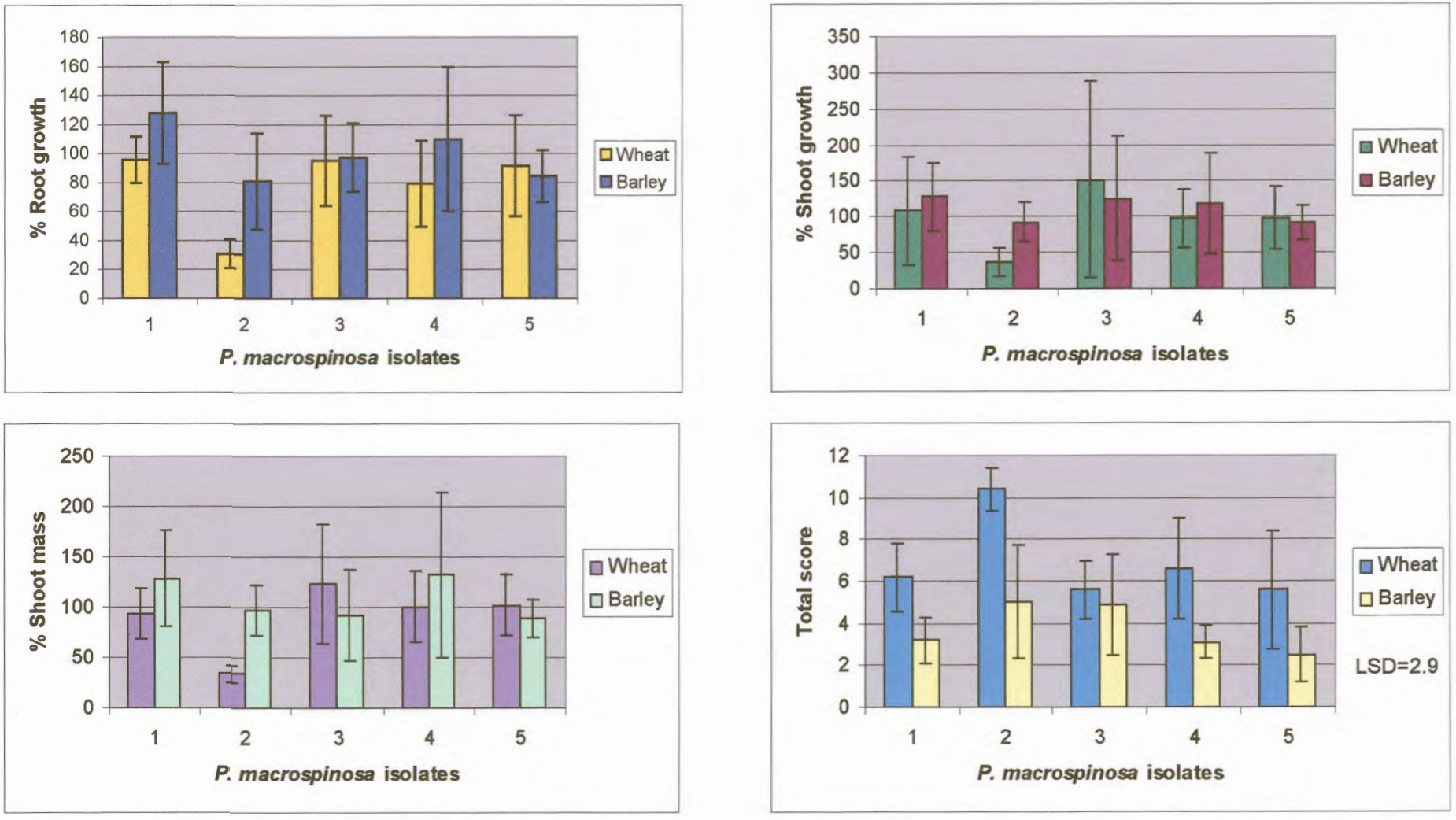



Fig. 12 Percentage root growth, shoot growth and shoot mass of wheat and barley inoculated with different *Periconia macrospinosa* isolates and total disease score for each isolate. Error bars indicate standard deviations. (Data for percentage root growth, shoot growth and shoot mass were transformed and LSD values are therefore only indicated for total score).

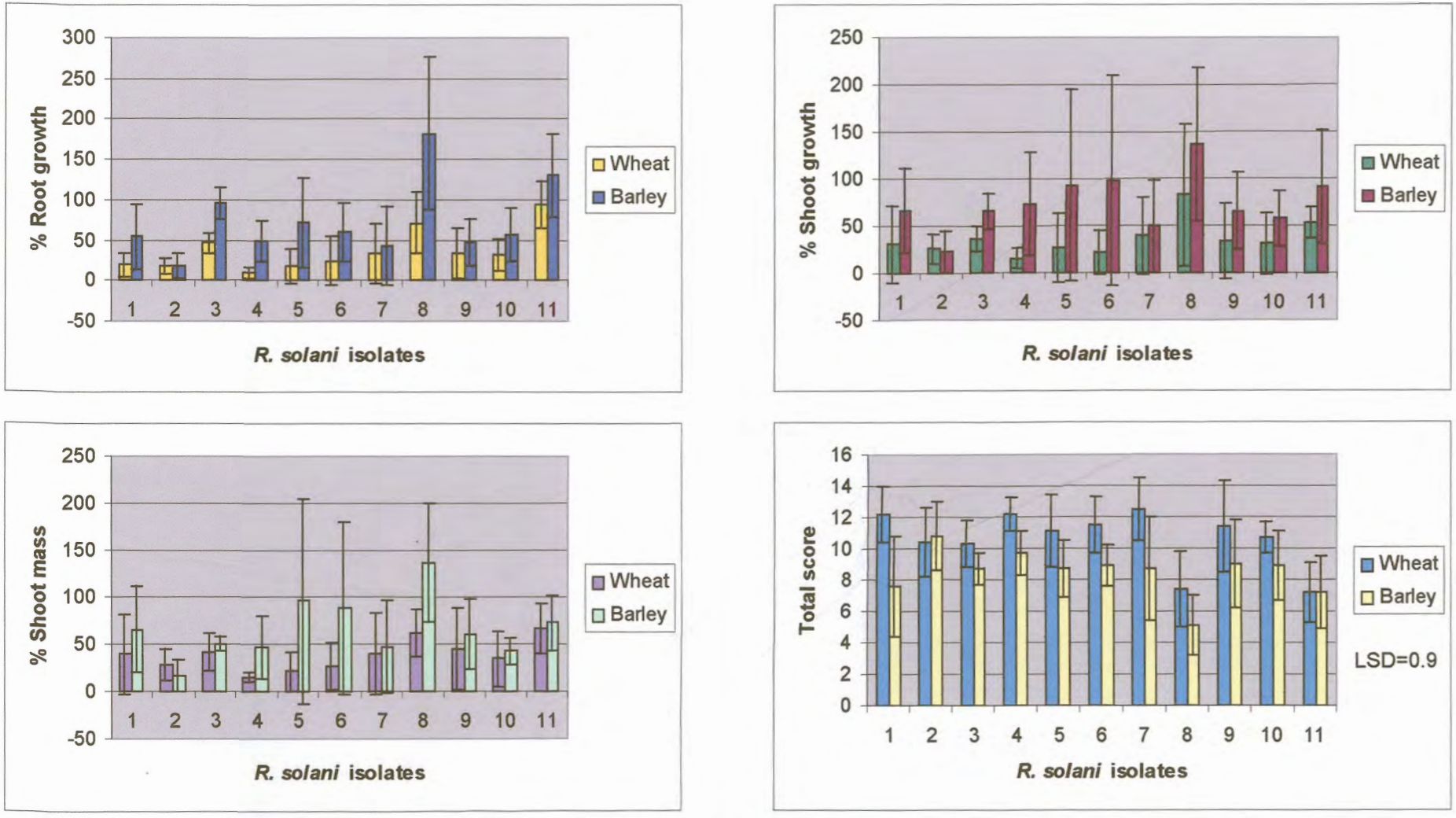



Fig. 13 Percentage root growth, shoot growth and shoot mass of wheat and barley inoculated with different *Rhizoctonia solani* isolates and total disease score for each isolate. Error bars indicate standard deviations. (Data for percentage root growth, shoot growth and shoot mass were transformed and LSD values are therefore only indicated for total score).

# CHAPTER 5

# DISCUSSION

During the course of this study 37 fungal taxa were isolated from wheat and barley. While most are known to be associated with wheat and/or barley (Table 1), the majority represent first recordings on these crops in Tanzania. Indeed, of the taxa isolated, only *Alternaria, B. sorokiniana, Cladosporium, F. oxysporum, F. solani, Periconia* and *Rhizoctonia* spp., including *R. solani* AG-6, have previously been reported from wheat in the country (Ebbels & Allen, 1979; Kuwite *et al.*, 1996; Meyer *et al.*, 1996).

*Fusarium* spp., mainly *F. oxysporum* and *F. nygamai,* dominated the fungi isolated from roots, whereas *F. equiseti* was the predominant *Fusarium* species isolated from crowns. Fedel-Moen & Harris (1987) found the frequency of *F. oxysporum* to be similar on wheat and barley and regarded it as a predominantly root-infecting species. Findings of the present study confirm *F. oxysporum* to primarily infect roots but are in conflict with the reported non-selectivity of the species as it was isolated at significantly higher frequencies from wheat than barley roots. Fedel-Moen & Harris (1987) also isolated *F. equiseti* at similar frequencies from both crops, though the incidence on culm bases of barley was double that on wheat. Once again results of this study both contradict and support their findings. Wheat roots showed a significantly higher incidence of *F. equiseti* than those of barley, but overall incidence on crowns of barley was five times higher than on wheat. *F. nygamai* has previously been associated with roots and crowns of wheat (Van Wyk *et al.*, 1987; Lubbe *et al.*, 1992; Opperman & Barnard, 1992; Ravanlou & Banihashemi, 1999; Meyer & Wehner, 2000; Meyer & Van Dyk, 2002), but has not been reported from barley. Although isolated from crowns, it was found to infect mainly roots and showed a similar incidence on wheat and barley. *F. nygamai* furthermore predominated in wheat fields at HWC where *F. oxysporum* and, to a lesser extent, *F. equiseti* also prevailed, thus contradicting the view of Marasas *et al.* (1988a) that *F. nygamai* does not compete well with species such as the latter two in cultivated soils. The relative infrequent isolation of the remaining fusaria is in accordance with their reported behaviour (Gordon, 1960; Booth, 1971; Burgess *et al.*, 1975; Van Wyk *et al.*, 1987;

Windels & Holen, 1989). Because *Fusarium* infections comprised multiple species, it is difficult to relate disease ratings to actual isolation data. However, disease ratings seem to indicate that barley was more severely affected by *Fusarium* spp. than wheat, whereas isolation frequencies generally indicate the opposite, particularly for the Karatu and West-Kilimanjaro areas.

In artificial inoculation studies most isolates of the *Fusarium* spp. tested, viz. *F. chlamydosporum, F. equiseti, F. nygamai, F. oxysporum* and *F. subglutinans*, impeded seedling root growth, and shoot growth and mass of wheat and barley. Ability of the fusaria to retard seedling growth was not surprising considering their capacity to produce phytotoxic compounds such as fusaric acid, fusarubin, isomarticin, javanicin, marticin and moniliformin (Domsch *et al.*, 1980; Marasas *et al.*, 1991; Capasso *et al.*, 1996). The most virulent species, as indicated by total disease score, were *F. nygamai* and *F. chlamydosporum*. *F. nygamai* has previously been described as a pathogen of wheat and grain sorghum (Burgess & Trimboli, 1986; Lubbe et al., 1992). Recently, five pasture crops were also shown to be significantly affected by it (Meyer & Van Dyk, 2002). Establishment of pathogenicity of *F. nygamai* towards barley thus expands its list of susceptible graminaceous hosts to eight. The ability of *F. chlamydosporum* to impede seedling growth of barley and particularly wheat, has not been documented before. Tinline *et al.* (1988) isolated this species from wheat subcrown internodes showing symptoms of common root rot with increasing frequency as the season progressed, but regarded it as a secondary invader. Although *F. oxysporum* is commonly accepted as weakly pathogenic to small-grains (Chambers, 1972; Burgess *et al.*, 1975; Sturz & Bernier, 1991), it has been implicated in development of root and crown rot of both wheat (Maric, 1981; Fouly *et al.*, 1996) and barley (Fedel-Moen & Harris, 1987; Sturz & Carter, 1995). *F. equiseti* is often considered non- or slightly pathogenic (Oswald, 1949; Chambers, 1972; Burgess *et al.*, 1975; Burgess, 1981; Sturz & Bernier, 1991; Gonzalez & Trevathan, 2000). However, according to Booth (1971) it is known as a root and stem rot pathogen of cereals. The opinion of the latter author is supported by findings of Maric (1981), Maas & Kotzé (1985) and Lubbe *et al.* (1992) for wheat and by Fedel-Moen & Harris (1987) for barley. *F. subglutinans* and *F. solani* were generally less virulent than the above species. This is in accordance with reports by

Specht & Rush (1988), Chen *et al.* (1996) and Gonzalez & Trevathan (2000). Burgess *et al.* (1975), on the other hand, considered both to be non-pathogenic to wheat.

*B. sorokiniana* was predominantly isolated from crowns of wheat and barley, with only a low rate of infection in roots. This is in agreement with the findings of Fedel-Moen & Harris (1987) and Wildermuth & McNamara (1987). However, infection of roots by this pathogen tends to increase progressively during the host's growing season (Chinn *et al.*, 1962; Verma *et al.*, 1974). A somewhat different situation may therefore have existed if isolations were made at a later stage. Disease ratings and subsequent isolations corroborate the greater susceptibility of barley to *B. sorokiniana* (Piening *et al.*, 1976; Tinline & Ledingham, 1979; Scardaci & Webster, 1982; Fedel-Moen & Harris, 1987), but only for the Karatu and West-Kilimanjaro areas. In these two areas barley rated significantly higher for symptoms of infection by *B. sorokiniana*, particularly in the moderate to severe categories and the pathogen was isolated at higher frequencies from crowns of barley than from those of wheat. The opposite was observed with wheat and barley planted to soil from HWC. Conner & Atkinson (1989) reported that repeated cropping to susceptible cultivars of wheat or barley resulted in selection of *B. sorokiniana* strains that were more damaging to the host being grown continuously. *B. sorokiniana* isolates were shown to be highly virulent on their original host but weakly virulent on the alternative host. Likewise, El-Nashaar & Stack (1989) reported that long-term continuous cropping appeared to shift the population of *B. sorokiniana* towards more aggressive types. A similar situation apparently existed at HWC where wheat has been mono-cropped for many years. Pathogenicity screening of *B. sorokiniana* supports this theory as all isolates tested originated from HWC and proved to be more virulent on wheat than on barley.

*P. macrospinosa* showed a similar incidence on wheat and barley but was isolated significantly more frequently from HWC soil than from the other two areas. Its higher incidence at HWC can probably also be attributed to the practice of wheat monoculture. Rufenacht (1980) found *P. macrospinosa* not to cause necrosis of wheat roots or shoots but noted a considerable reduction in root and shoot growth which was ascribed to toxin production. Toxins produced by this fungus were initially

also implicated in CD (Scott *et al.*, 1979). Sturz & Bernier (1991) described *P. macrospinosa* as a minor pathogen of wheat. With the exception of one isolate on wheat, *P. macrospinosa* did not reduce root growth, shoot growth or mass of wheat or barley, but was significantly more virulent on wheat than on barley. Isolate differences, as observed in the artificial inoculation study, could explain the discrepancies in literature regarding the virulence of *P. macrospinosa*.

Of the fungal species isolated less frequently, only *S. rolfsii,* binucleate *Rhizoctonia* spp. and *Macrophomina phaseolina* (Tassi) Goid. are known to infect roots or crowns of wheat and barley. *S. rolfsii* is an aggressive plurivorous, albeit opportunistic, facultative parasite (Aycock, 1961) and its pathogenicity towards wheat and barley was therefore not surprising. It is likely that secretion of oxalic acid and enzymatic compounds by *S. rolfsii* (Agrios, 1997) contributed to its high virulence in the pathogenicity tests. Binucleate *Rhizoctonia* isolates vary in their pathogenicity towards wheat and barley and although most are considered non- or slightly pathogenic (Roberts & Sivasithamparam, 1986; Yang *et al.*, 1994; Demirci, 1998), species such as *R. cerealis* and *R. oryzae* have been associated with root and crown rot of these crops (Lipps & Herr, 1982; Mathre, 1982; Wiese, 1987; Ogoshi *et al.*, 1990). Pathogenicity of binucleate *Rhizoctonia* spp. found in this survey could not be determined as none of the isolates survived storage. *M. phaseolina* was implicated as a possible minor pathogen of wheat by Harris & Moen (1985a), whereas greenhouse tests by Fouly *et al.* (1996) showed it to aggressively rot wheat roots, with some isolates capable of killing plants. However, in the present study *M. phaseolina* was isolated too sporadically to be considered of significance.

Most of the remaining taxa probably were opportunistic secondary invaders present in the various soil samples. *P. macrostroma* and *P. medicaginis,* although isolated from wheat and barley in soil from all three regions, are not known to be pathogenic to either crop. A close relative of *P. medicaginis*, *P. medicaginis* var. *pinodella* (L.K. Jones) Boerema, has been isolated from wheat roots at Rothamsted in the UK (Bateman & Kwasna, 1999) and is known to occur in Tanzania (Sutton, 1980). The present species, however, could easily be distinguished from the *pinodella* variety by its sparse formation of crystals on malt extract agar (Sutton, 1980). *P. macrostroma*

could likewise not have been confused with any other common *Phoma* species as it characteristically produced fast-growing, felty or wooly colonies with a livid red reverse, changing to purplish-blue with addition of NaOH. Like *P. medicaginis*, it has previously been recorded in Tanzania (Sutton, 1980).

Species in the *Bipolaris/Curvularia/Drechslera/Exserohilum/Helminthosporium* group of fungi, including *Bipolaris cynodontis* (Marignoni) Shoemaker, *B. indica* Rai, Wadhani & Tewari, *B. papendorfii* (Aa) Alcorn, *Drechslera poae* (Baudys) Shoemaker and *Exserohilum rostratum* (Drechs.) K.J. Leonard & E.G. Suggs, are commonly associated with graminaceous crops in Africa (Ellis, 1971, 1976; Sivanesan, 1987), but only *B. cynodontis, B. papendorfii* and *E. rostratum* have been described from wheat or barley on the continent (http://www.ars.usda.gov). None of the above species are associated with CD in South Africa, where the dominant related species appears to be *Bipolaris australiensis* (M.B. Ellis) Tsuda & Ueyama (Meyer & Wehner, 2000). The *Pithomyces* sp. isolated from wheat and barley in soil samples from HWC closely resembled *Pithomyces sacchari* (Speg.) M.B Ellis, but did not produce any conidia with transverse septa and could therefore not be classified as the latter species, which commonly occurs on various substrates, including soil and wheat, in Africa (Ellis, 1971). *Ramichloridium schulzeri* (Sacc.) de Hoog has previously been recorded from dead stems of wheat in Australia and cultivated soil under wheat in Germany (Gams *et al.*, 1969; De Hoog, 1977), and more recently from wheat and barley roots at Rothamsted (Bateman & Kwasna, 1999; Dawson & Bateman, 2001). Its relative frequent occurrence in wheat and barley soils in Tanzania indicates that it may be more commonly associated with these two crops than previously thought. The species has, however, never been isolated from roots of wheat or any related crop on the Springbok Flats in South Africa.

*Chaetomium spp., Cladosporium cladosporioides* (Fresen.) G.A. de Vries, *Epicoccum nigrum* Link, *Gliocladium catenulatum* Gilm. & Abbott, *Myrothecium verrucaria* (Albertini & Schwein.) Ditmar: Fr., *Paecilomyces lilacinus* (Thom) Samson and *Phoma chrysanthemicola* Hollõs have previously been recorded on wheat and/or barley roots or crowns in other parts of the world (Harris & Moen, 1985b; Sturz & Bernier, 1991; Chen *et al.*, 1996; Bateman & Kwasna, 1999; Gonzalez & Trevathan,

2000; Meyer & Wehner, 2000; Dawson & Bateman, 2001; Lemanczyk & Sadowski, 2002). However, no report describing the isolation of *Chaetomella* spp., *Microsphaeropsis olivacea* (Bonord.) Höhn, *Stachybotrys elegans* (Pidopl.) W. Gams, *Talaromyces trachyspermus* (Shear) Stolk & Samson and *Trichothecium roseum* (Pers.) Link ex Gray from wheat or barley could be traced. The latter five taxa nevertheless are common soil inhabitants (Domsch *et al.*, 1980; Sutton, 1980), with the last two species having been reported from the rhizosphere of wheat and/or barley (Mangan, 1967; Mahmood, 1971; Ranga Rao & Mukerji, 1971).

The take-all pathogen, *G. graminis* var. *tritici,* and *Pythium* spp. could not be isolated. This contradicts findings of a limited survey by the CSIR (unpublished data), at least for barley fields in West-Kilimanjaro. *G. graminis* var. *tritici,* and most *Pythium* spp. are notoriously difficult to isolate from organs showing typical disease symptoms (Vanterpool, 1938; Bateman & Kwasna, 1999; Lemanczyk & Sadowski, 2002). Isolation media used in the present study were also not selective for *Pythium* and it is therefore acknowledged that species of this genus may occur more widespread than suggested by the results. In South Africa, *P. aphanidermatum, P. arrhenomanes*, *Pythium* F-group and *Pythium tracheiphilum* Matta have been associated with wheat roots and soil in CD patches (Meyer & Wehner, 2000). *P. aphanidermatum* was shown to act synergistically with *R. solani* as it aggravated nodule formation induced by the latter pathogen. *G. graminis* var. *tritici* does not readily sporulate in culture and routine identification of putative isolates therefore relies on cultural characteristics (Asher, 1980; Cunningham, 1981). Duffy & Weller (1994) consequently developed a semi-selective diagnostic medium consisting of dilute PDA amended with rifampicin and tolclofos-methyl on which identification of *G. graminis* var. *tritici* is aided based on its ability to alter the colour of rifampicin from orange to purple. Cultures of some of the sterile isolates found in this survey resembled those of *G. graminis* var. *tritici* and its *Phialophora* anamorph, but remained sterile despite various attempts to induce sporulation. However, as ½PDA amended with rifampicin was the primary isolation medium employed during the study and no colour change from orange to purple was observed for any of the above isolates, it is concluded that *G. graminis* var. *tritici* was absent in the soil samples. It is nevertheless interesting to take note of the presence of *Melanospora* in Karatu and West-Kilimanjaro soils. This

genus is best known as a mycoparasite, though some species exist as saprobes producing *Phialophora* anamorphs (Hanlin, 1990; Alexopoulos *et al.*, 1996). The *Melanospora* sp. in the soil samples could therefore have represented the teleomorph of a *Phialophora* sp., though obviously not the anamorph of *G. graminis* var. *tritici*.

Species such as *Fusarium concolor* Reinking, *F. heterosporum* Nees, *F. pseudograminearum* and *M. nivale*, previously recorded from wheat and/or barley in Tanzania (Ebbels & Allen, 1979; Kuwite *et al.*, 1996) were also not isolated in this study. The former two species seem to occur only sporadically on wheat and barley (Table 1). Scardaci & Webster (1981) demonstrated antagonism between *B. sorokiniana* and *F. pseudograminearum* and indicated that pre-colonisation of barley roots by the one precluded establishment of the other. The absence of *F. pseudograminearum* during this survey can therefore be attributed to the high levels of infestation by *B. sorokiniana*. Reference to the occurrence of *M. nivale* in Tanzania by Kuwite *et al.* (1996) is questioned as this species prefers lower temperatures and is therefore more commonly isolated from cereals grown in regions with a cooler, wetter growing season, such as Canada, Europe, Scandinavia and the US (Cassini, 1981; Wiese, 1987; Parry *et al.*, 1994; Rossi *et al.*, 1995).

It is deemed fit to conclude this chapter by elaborating on the situation with soilborne diseases in Tanzania. Fields not affected by PS but where disease was manifested as thinned and uneven stands will be considered first. *B. sorokiniana* has previously been shown to predispose plants to infection by fungi normally considered weak pathogens (Ludwig *et al.*, 1956; Windels & Holen, 1989). Taking into account the high incidence of *B. sorokiniana*, it seems reasonable to assume that this infection predisposed plants to invasion by fungi such as *F. equiseti*, *F. oxysporum*, *F. nygamai* and others not normally considered as primary pathogens of wheat and barley. Co-inoculation studies would obviously have resolved this, but demonstration of pathogenicity of the above species nevertheless adds weight to their importance in the dryland root and crown rot syndrome of wheat and barley in Tanzania.

PS of wheat and barley in Tanzania is both similar to and different from CD of wheat on the Springbok Flats in South Africa and bare patch disease of cereals occurring in various other parts of the world. All three diseases are characterised by patches of severely stunted and chlorotic plants producing little or no grain (Deacon & Scott, 1985; Roberts & Sivasithamparam, 1986; Meyer *et al.*, 1996), but as opposed to girdling, necrosis and rotting of roots associated with bare patch (Weller *et al.*, 1986; Ogoshi *et al.*, 1990), infection by the PS and CD *R. solani* results in production of nodulose swellings and sclerotial sheaths on roots (Deacon & Scott, 1985; Smith & Wehner, 1986; Kuwite *et al.*, 1996; Meyer *et al.*, 1996). CD and PS have furthermore been shown to be caused by *R. solani* AG-6 (Carling *et al.*, 1996; Meyer *et al.*, 1998), whereas bare patch disease has mostly been ascribed to infection by *R. solani* AG-8 (Neate & Warcup, 1985). However, CD is found exclusively on black montmorillonitic clay soils, whereas PS and bare patch occur on different soil types (MacNish & Neate, 1996; Meyer *et al.*, 1996). In the present study, patches of stunted wheat and/or barley were observed at HWC and, to a lesser extent, at West-Kilimanjaro, but not at Karatu. Distribution, size, shape and number of patches are known to vary considerably between seasons (MacNish, 1985). Meyer (1996) also frequently observed CD patches to disappear between seasons with some reappearing later but others vanishing permanently. A similar situation apparently exists in Tanzania where patches were observed at least in some fields in the Karatu area during the 1997 season (Dr C.A. Kuwite, personal communication), but not in the following year when sampling was conducted. Abundant rain in Karatu and West-Kilimanjaro in 1998 probably allowed the seedlings to outgrow infection by *R. solani* AG-6, hence expaining the absence of symptoms in fields infested with the pathogen. Isolation of *R. solani* from all three areas, albeit at low frequencies, confirmed its omnipresence. Anastomosis reactions furthermore substantiated placement of *R. solani* isolates associated with PS in AG-6, whereas artificial inoculation confirmed its pathogenicity and high virulence to wheat. Pathogenicity of *R. solani* AG-6 to barley was also established, although this crop appeared to be affected less than wheat. Observation of patches on different soil types as well as the absence of significant differences in isolation frequencies of *R. solani* AG-6 from the four soils investigated provide conclusive evidence that PS is not limited to a particular soil type in Tanzania.

# CHAPTER 6

# REFERENCES

AGRIOS, G.N. 1997. Plant Pathology. 4th ed. Academic Press, San Diego.

ALEXOPOULOS, C.J., MIMS, C.W. & BLACKWELL, M. 1996. Introductory Mycology. 4th ed. John Wiley & Sons, New York.

ANTAPA, P.L. 1996. Agronomic constraints to sustainable wheat production at the Hanang Wheat Complex in Northern Tanzania. Pages 120-126 in: The Ninth Regional Wheat Workshop for Eastern, Central and Southern Africa. D.G. Tanner, T.S. Payne & O.S. Abdalla, eds. CIMMYT, Addis Ababa, Ethiopia.

ASHER, M.J.C. 1972. Effect of *Ophiobolus graminis* infection on the growth of wheat and barley. *Annals of Applied Biology* 70: 215-223.

ASHER, M.J.C. 1980. Variation in pathogenicity and cultural characteristics in *Gaeumannomyces graminis* var. *tritici*. *Transactions of the British Mycological Society* 75: 213-220.

ASHWORTH, L.J., KEITH, A., LAHR, A. & COLLINS, R.J. 1960. Pathogenic specialization of Helminthosporium sativum (Abstract). *Phytopathology* 50: 627.

AYCOCK, R. 1961. Symposium on *Sclerotium rolfsii*. Summation. *Phytopathology* 51: 107-108.

BAILEY, K.L., GOSSEN, B.D., DERKSEN, D.A. & WATSON, P.R. 2000. Impact of agronomic practices and environment on diseases of wheat and lentil in southeastern Saskatchewan. *Canadian Journal of Plant Science* 80: 917-927.

BATEMAN, G.L. & KWASNA, H. 1999. Effects of number of winter wheat crops grown successively on fungal communities on wheat roots. *Applied Soil Ecology* 13: 271-282.

BELFORD, R.K., KLEPPER, B. & RICKMAN, R.W. 1987. Studies of intact root-shoot systems of field-grown winter wheat. II. Root and shoot developmental patterns as related to nitrogen fertilizer. *Agronomy Journal* 79: 310-319.

BENEDICT, W.G. & MOUNTAIN, W.B. 1956. Studies on the etiology of a root rot of winter wheat in southwestern Ontario. *Canadian Journal of Botany* 34: 159-174.

BOATWRIGHT, G.O. & FERGUSON, H. 1967. Influence of primary and/or adventitious root systems on wheat production and nutrient uptake. *Agronomy Journal* 59: 299-302.

BOEREMA, G.H. & VERHOEVEN, A.A. 1977. Check-list for scientific names of common parasitic fungi. Series 2b. Fungi on field crops: cereals and grasses. *Netherlands Journal of Plant Pathology* 86: 165-204.

BOLKAN, H.A. & RIBEIRO, W.R.C. 1985. Anastomosis groups and pathogenicity of *Rhizoctonia solani* isolates from Brazil. *Plant Disease* 69: 599-601.

BOOTH, C. 1971. The genus *Fusarium*. Commonwealth Mycological Institute, Kew.

BROSCIOUS, S.C. & FRANK, J.A. 1986. Effects of crop management practices on common root rot in winter wheat. *Plant Disease* 70: 857-859.

BRUEHL, G.W. 1951. Rhizoctonia solani in relation to cereal crown and foot rots. *Phytopathology* 41: 375-377.

BURGESS, L.W. 1981. General ecology of the fusaria. Pages 225-235 in: Fusarium: Diseases, Biology and Taxonomy. P.E. Nelson, T.A. Toussoun & R.J. Cook, eds. The Pennsylvania State University Press, University Park.

BURGESS, L.W., WEARING, A.H. & TOUSSOUN, T.A. 1975. Surveys of fusaria associated with crown rot of wheat in Eastern Australia. *Australian Journal of Agricultural Research* 26: 791-799.

BURGESS, L.W., DODMAN, R.L., PONT, W. & MAYERS, P. 1981. Fusarium diseases of wheat, maize and grain sorghum in eastern Australia. Pages 64-76 in: Fusarium: Diseases, Biology and Taxonomy. P.E. Nelson, T.A. Toussoun & R.J. Cook, eds. The Pennsylvania State University Press, University Park.

BURGESS, L.W. & TRIMBOLI, D. 1986. Characterization and distribution of *Fusarium nygamai* sp. nov. *Mycologia* 78: 223-229.

BURTON, R.J., COLEY-SMITH, J.R., WAREING, P.W. & GLADDERS, P. 1988. *Rhizoctonia oryzae* and *R. solani* associated with barley stunt disease in the United Kingdom. *Transactions of the British Mycological Society* 91: 409-417.

CAPASSO, R., EVIDENTE, A., OUTIGNANO, A., VURRO, M., ZONNO, M.C., & BOTTALICO, A. 1996. Fusaric acid and 9, 10-dehydrofusaric acids and their methyl-ester from *Fusarium nygamai*. *Phytochemistry* 41: 1035-1039.

CARLING, D.E., LEINER, R.H. & KEBLER, K.M. 1987. Characterization of a new anastomosis group (AG-9) of *Rhizoctonia solani*. *Phytopathology* 77: 1609-1612.

CARLING, D.E., MEYER, L. & BRAINARD, K.A. 1996. Crater disease of wheat caused by *Rhizoctonia solani* AG-6. *Plant Disease* 80: 1429.

CASSINI, R. 1981. Fusarium diseases of wheat and corn in Europe. Pages 56-63 in: Fusarium: Diseases, Biology and Taxonomy. P.E. Nelson, T.A. Toussoun & R.J. Cook, eds. The Pennsylvania State University Press, University Park.

CHAMBERS, S.C. 1972. Fusarium species associated with wheat in Victoria. *Australian Journal of Experimental Agriculture and Animal Husbandry* 12: 433-436.

CHAMSWARNG, C. & COOK, R.J. 1985. Identification and comparative pathogenicity of *Pythium* species from wheat roots and wheat-field soils in the Pacific Northwest. *Phytopathology* 75: 821-827.

CHEN, C., COLLINS, D.J. & MORGAN-JONES, G. 1996. Fungi associated with root rot of winter wheat in Alabama. *Journal of Phytopathology* 144: 193-196.

CHINN, S.H.F. 1976a. Influence of rape in a rotation on prevalence of *Cochliobolus sativus* conidia and common root rot of wheat. *Canadian Journal of Plant Science* 56: 199-201.

CHINN, S.H.F. 1976b. Cochliobolus sativus conidia populations in soils following various cereal crops. *Phytopathology* 66: 1082-1084.

CHINN, S.H.F., SALLANS, B.J. & LEDINGHAM, R.J. 1962. Spore populations of *Helminthosporium sativum* in soils in relation to the occurrence of common root rot of wheat. *Canadian Journal of Plant Science* 42: 720-727.

CLARKSON, J.D.S. & GRIFFIN, M.J. 1977. Sclerotia of *Rhizoctonia solani* in wheat stems with sharp eyespot. *Plant Pathology* 26: 98.

COLBACH, N., MAURIN, N. & HUET, P. 1996. Influence of cropping system on foot rot of winter wheat in France. *Crop Protection* 15: 295-305.

COLHOUN, J. 1979. Minor pathogens and complex root diseases: concluding remarks. Pages 351-354 in: Soil-Borne Plant Pathogens. B. Schippers & W. Gams, eds. Academic Press, London.

COLHOUN, J. & PARK, D. 1964. *Fusarium* diseases of cereals. I. Infection of wheat plants, with particular reference to the effects of soil moisture and temperature on seedling infection. *Transactions of the British Mycological Society* 47: 559-572.

CONNER, R.L. & ATKINSON, T.G. 1989. Influence of continuous cropping on severity of common root rot in wheat and barley. *Canadian Journal of Plant Pathology* 11: 127-132.

COOK, R.J. 1968. Fusarium root and foot rot of cereals in the Pacific Northwest. *Phytopathology* 58: 127-131.

COOK, R.J. 1980. Fusarium foot rot of wheat and its control in the Pacific Northwest. *Plant Disease* 64: 1061-1066.

COOK, R.J. 1981. The effects of soil reaction and physical conditions. Pages 343-352 in: Biology and Control of Take-all. M.J.C. Asher & P.J. Shipton, eds. Academic Press, London.

COOK, R.J. 2001. Management of wheat and barley root diseases in modern farming systems. *Australasian Plant Pathology* 30: 119-126.

COOK, R.J., SITTON, J.W. & WALDHER, J.T. 1980. Evidence for *Pythium* as a pathogen of direct-drilled wheat in the Pacific Northwest. *Plant Disease* 64: 102-103.

COOK, R.J., SITTON, J.W. & HAGLUND, W.A. 1987. Influence of soil treatments on growth and yield of wheat and implications for control of Pythium root rot. *Phytopathology* 77: 1192-1198.

COOK, R.J. & VESETH, R.J. 1991. Wheat Health Management. APS Press, St. Paul, Minnesota.

CROUS, P.W., PETRINI, O., MARAIS, G.F., PRETORIUS, Z.A. & REHDER, F. 1995. Occurrence of fungal endophytes in cultivars of *Triticum aestivum* in South Africa. *Mycoscience* 36: 105-111.

CUNNINGHAM, P.C. 1981. Isolation and culture. Pages 103-124 in: Biology and Control of Take-all. M.J.C. Asher & P.J. Shipton, eds. Academic Press, London.

DAWSON, W.A.J.M & BATEMAN, G.L. 2001. Fungal communities on roots of wheat and barley and effects of seed treatments containing fluquinconazole applied to control take-all. *Plant Pathology* 50: 75-82.

DEACON, J.W. 1974. Further studies on *Phialophora radicicola* and *Gaeumannomyces graminis* on roots and stem bases of grasses and cereals. *Transactions of the British Mycological Society* 63: 307-327.

DEACON, J.W. & SCOTT, D.B. 1985. *Rhizoctonia solani* associated with crater disease (stunting) of wheat in South Africa. *Transactions of the British Mycological Society* 85: 319-327.

DE HOOG, G.S. 1977. *Rhinocladiella* and allied genera. *Studies in Mycology* 15: 1-140.

DEIGHTON, F.C. 1973. *Pseudocercosporella herpotrichoides* (Fron) Deighton. *Mycological Papers* 133: 46-47.

DEMIRCI, E. 1998. *Rhizoctonia* species and anastomosis groups isolated from barley and wheat in Erzurum, Turkey. *Plant Pathology* 47: 10-15.

DIEHL, J.A. 1979. Common root rot of wheat in Brazil. *Plant Disease Reporter* 63: 1020-1022.

DIEHL, J.A., TINLINE, R.D., KOCHHANN, R.A. SHIPTON, P.J. & ROVIRA, A.D. 1982. The effect of fallow periods on common root rot of wheat in Rio Grande do Sul, Brazil. *Phytopathology* 72: 1297-1301.

DILLON-WESTON, W.A.R. & GARRETT, S.D. 1943. *Rhizoctonia solani* associated with a root rot of cereals in Norfolk. *Annals of Applied Biology* 30: 79.

DIPPENAAR, B.J. 1930. Take-all in wheat. *Farming in South Africa* 4: 639-640.

DOMSCH, K.H., GAMS, W. & ANDERSON, T.-H. 1980. Compendium of soil fungi. Academic Press, London.

DUCZEK, L.J. 1986. Effects of flooding at early stages and mechanical damage of foliage on common root rot of spring wheat and barley. *Canadian Journal of Plant Pathology* 8: 418-421.

DUCZEK, L.J. 1989. Relationship between common root rot (*Cochliobolus sativus*) and tillering in spring wheat. *Canadian Journal of Plant Pathology* 11: 39-44.

DUCZEK, L.J., JONES-FLORY, L.L., REED, S.L., BAILEY, K.L. & LAFOND, G.P. 1996. Sporulation of *Bipolaris sorokiniana* on the crowns of crop plants grown in Saskatchewan. *Canadian Journal of Plant Science* 76: 861-867.

DUFFY, B.K. & WELLER, D.M. 1994. A semiselective and diagnostic medium for *Gaeumannomyces graminis* var. *tritici*. *Phytopathology* 84: 1407-1415.

EBBELS, D.L. & ALLEN, D.J. 1979. A supplementary and annotated list of plant diseases, pathogens and associated fungi in Tanzania. *Phytopathological Paper* 22: 1-89.

ELLIS, M.B. 1971. Dematiaceous Hyphomycetes. Commonwealth Mycological Institute, Kew.

ELLIS, M.B. 1976. More Dematiaceous Hyphomycetes. Commonwealth Mycological Institute, Kew.

EL-MELEIGI, M.A. 1988. Fungal diseases of spring wheat in central Saudi Arabia. *Crop Protection* 7: 207-209.

EL-NASHAAR, H.M. & STACK, R.W. 1989. Effect of long-term continuous cropping of spring wheat on aggressiveness of *Cochliobolus sativus*. *Canadian Journal of Plant Science* 69: 395-400.

ENNOS, R. 1991. The mechanics of anchorage in wheat *Triticum aestivum* L. II. Anchorage of mature wheat against lodging. *Journal of Experimental Botany* 42: 1607-1613.

FEDEL-MOEN, R. & HARRIS, J.R. 1987. Stratified distribution of *Fusarium* and *Bipolaris* on wheat and barley with dryland root rot in South Australia. *Plant Pathology* 36: 447-454.

FOULY, H.M., PEDERSEN, W.L., WILKINSON, H.T. & ABD EL-KADER, M.M. 1996. Wheat root rotting fungi in the "old" and "new" agricultural lands of Egypt. *Plant Disease* 80: 1298-1300.

GAMS, W., DOMSCH, K.H. & WEBER, E. 1969. Nachweis signifikant verschiedener pilzpopulationen bei gleicher bodennutzung. *Plant and Soil* 31: 439-450.

GENSTAT FOR WINDOWS. 2000. Release 4.2. 5th ed. VSN International, Oxford.

GILL, J.S., SIVASITHAMPARAM, K. & SMETTEM, K.R.J. 2000. Soil types with different soil textures affects Rhizoctonia root rot of wheat seedlings. *Plant and Soil* 221: 113-120.

GILL, J.S., SIVASITHAMPARAM, K. & SMETTEM, K.R.J. 2001a. Effect of soil moisture at different temperatures on Rhizoctonia root rot of wheat seedlings. *Plant and Soil* 231: 91-96.

GILL, J.S., SIVASITHAMPARAM, K. & SMETTEM, K.R.J. 2001b. Soil moisture affects disease severity and colonisation of wheat roots by *Rhizoctonia solani* AG-8. *Soil Biology and Biochemistry* 33: 1363-1370.

GILL, J.S., SIVASITHAMPARAM, K. & SMETTEM, K.R.J. 2002. Size of bare-patches in wheat caused by *Rhizoctonia solani* AG-8 is determined by the established mycelial network at sowing. *Soil Biology and Biochemistry* 34: 889-893.

GODFREY, G.H. 1918. *Sclerotium rolfsii* on wheat. *Phytopathology* 8: 64-66.

GONZALEZ, M.S. & TREVATHAN, L.E. 2000. Identity and pathogenicity of fungi associated with root and crown rot of soft red winter wheat grown in the upper coastal plain land resource area of Mississippi. *Journal of Phytopathology* 148: 77-85.

GORDON, W.L. 1960. The taxonomy and habitat of *Fusarium* species from tropical and temperate regions. *Canadian Journal of Botany* 38: 643-658.

GORTER, G.J.M.A. 1943. "Doodgaansiekte", fusarium blight or common root rot of wheat. *Farming in South Africa* 18: 181-183.

GOULDS, A. & POLLEY, R.W. 1990. Assessment of eyespot and other stem base diseases of winter wheat and winter barley. *Mycological Research* 94: 819-822.

HANLIN, R.T. 1990. Illustrated Genera of Ascomycetes. APS Press, St. Paul, Minnesota.

HARDING, H. 1971. Effect of *Bipolaris sorokiniana* on germination and seedling survival of varieties or lines of 14 *Triticum* species. *Canadian Journal of Botany* 49: 281-287.

HARDING, H. 1973. Fungi associated with subcrown internodes of wheat (*Triticum aestivum*). *Canadian Journal of Botany* 51: 2514-2516.

HARRIS, J.R. & MOEN, R. 1985a. Replacement of *Rhizoctonia solani* on wheat seedlings by a succession of root-rot fungi. *Transactions of the British Mycological Society* 84: 11-20.

HARRIS, J.R. & MOEN, R. 1985b. Secondary infection and fertilizer response of wheat initially infected with *Rhizoctonia solani*. *Transactions of the British Mycological Society* 84: 307-315.

HENDRIX, F.F. & CAMPBELL, W.A. 1973. Pythiums as plant pathogens. *Annual Review of Phytopathology* 11: 77-98.

HERING, T.F., COOK, R.J. & TANG, W.-H. 1987. Infection of wheat embryos by *Pythium* species during seed germination and the influence of seed age and soil matric potential. *Phytopathology* 77: 1104-1108.

HILL, J.P., FERNANDEZ, J.A. & McSHANE, M.S. 1983. Fungi associated with common root rot of winter wheat in Colorado and Wyoming. *Plant Disease* 67: 795-797.

HOES, J.A. 1962. Dynamics of the mycoflora of subterranean parts of winter wheat in the dryland area of Washington (Abstract). *Phytopathology* 52: 736.

HUBER, D.M. 1981. The role of nutrients and chemicals. Pages 317-341 in: Biology and Control of Take-all. M.J.C. Asher & P.J. Shipton, eds. Academic Press, London.

HUBER, D.M. & McCAY-BUIS, T.S. 1993. A multiple component analysis of the take-all disease of cereals. *Plant Disease* 77: 437-447.

JOOSTE, W.J. 1965. Crown rot in wheat. *Farming in South Africa* 41: 13-15.

KANE, R.T., SMILEY, R.W. & SORRELLS, M.E. 1987. Relative pathogenicity of selected *Fusarium* species and *Microdochium bolleyi* to winter wheat in New York. *Plant Disease* 71: 177-181.

KILPATRICK, R.A. & MERKLE, O.G. 1967. Seedling disease of wheat caused by Sclerotium rolfsii. *Phytopathology* 57: 538-540.

KLEIN, T.A., BURGESS, L.W. & ELLISON, F.W. 1991. The incidence and spatial patterns of wheat plants infected by *Fusarium graminearum* group 1 and the effect of crown rot on yield. *Australian Journal of Agricultural Research* 42: 399-407.

KLEPPER, B. 1991. Root-shoot relationships. Pages 265-286 in: Plant Roots: The Hidden Half. Y. Waisel, A. Eshel & U. Kafkafi, eds. Marcel Dekker, New York.

KUWITE, C.A., PIENING, L. & BRAUN, L. 1996. Patchy stunting of wheat in the Hanang Wheat Complex, Tanzania: a mycological aspect. Pages 447-451 in: The Ninth Regional Wheat Workshop for Eastern, Central and Southern Africa. D.G. Tanner, T.S. Payne & O.S. Abdalla, eds. CIMMYT, Addis Ababa, Ethiopia.

LAWN, D.A. & SAYRE, K.D. 1989. Effects of crop rotation, tillage and straw management on common root rot of wheat (Abstract). *Phytopathology* 79: 1142.

LAWN, D.A. & SAYRE, K.D. 1992. Soilborne pathogens on cereals in a highland location of Mexico. *Plant Disease* 76: 149-154.

LEDINGHAM, R.J., ATKINSON, T.G., HORRICKS, J.S., MILLS, J.T. PIENING, L.J. & TINLINE, R.D. 1973. Wheat losses due to common root rot in the prairie provinces of Canada, 1969-71. *Canadian Plant Disease Survey* 53: 113-122.

LEMANCZYK, G. & SADOWSKI, C.K. 2002. Fungal communities and health status of roots of winter wheat cultivated after oats and oats mixed with other crops. *Biocontrol* 47: 349-361.

LEYVA, G.M. & VILLASEÑOR, E.M. 1993. Fungi associated with root rot of non-irrigated wheat in the high Valleys of Mexico (Abstract). *Phytopathology* 83: 1387.

LIPPS, P.E. & HERR, L.J. 1982. Etiology of *Rhizoctonia cerealis* in sharp eyespot of wheat. *Phytopathology* 72: 1574-1577.

LUBBE, E.M., WEHNER, F.C., MARASAS, W.F.O. & KOTZÉ, J.M. 1992. *Fusarium* spp. associated with crown and root rot of wheat in Transvaal (Abstract). *Phytophylactica* 24: 115.

LUDWIG, R.A., CLARK, R.V., JULIAN, J.B. & ROBINSON, D.B. 1956. Studies on the seedling disease of barley caused by *Helminthosporium sativum* P.K. & B. *Canadian Journal of Botany* 34: 653-673.

MAAS, E.M.C. & KOTZÉ, J.M. 1981. Fungi associated with root diseases of wheat in South Africa. *Phytophylactica* 13: 155-156.

MAAS, E.M.C. & KOTZÉ, J.M. 1985. *Fusarium equiseti* crown rot of wheat in South Africa. *Phytophylactica* 17: 169-170.

MacNISH, G.C. 1983. Rhizoctonia patch in Western Australian grain belt. *Australasian Plant Pathology* 12: 49-50.

MacNISH, G.C. 1984. The use of undisturbed soil cores to study methods of controlling rhizoctonia patch of cereals. *Plant Pathology* 33: 355-359.

MacNISH, G.C. 1985. Mapping rhizoctonia patch in consecutive crops in Western Australia. *Plant Pathology* 34: 165-174.

MacNISH, G.C., CARLING, D.E., SWEETINGHAM, M.W. & BRAINARD, K.A. 1994. Anastomosis group (AG) affinity of pectic isozyme (zymogram) groups (ZG) of *Rhizoctonia solani* from the Western Australian cereal-belt. *Mycological Research* 98: 1369-1375.

MacNISH, G.C. & NEATE, S.M. 1996. Rhizoctonia bare patch of cereals: an Australian perspective. *Plant Disease* 80: 965-971.

MAHMOOD, T. 1971. A qualitative and quantitative study of the soil mycoflora of a barley field. *Acta Botanica Neerlandia* 20: 624-626.

MAJANGA, B.D. & ANTAPA, P.L. 1996. Operational and economic sustainability of the Hanang wheat farms in Northern Tanzania. Pages 238-244 in: The Ninth Regional Wheat Workshop for Eastern, Central and Southern Africa. D.G. Tanner, T.S. Payne & O.S. Abdalla, eds. CIMMYT, Addis Ababa, Ethiopia.

MANGAN, A. 1967. Studies on wheat rhizosphere soil fungi. *Irish Journal of Agricultural Research* 6: 9-14.

MARASAS, W.F.O., BURGESS, L.W., ANELICH, R.Y., LAMPRECHT, S.C. & VAN SCHALKWYK, D.J. 1988a. Survey of *Fusarium* species associated with plant debris in South African soils. *South African Journal of Botany* 54: 63-71.

MARASAS, W.F.O., VOIGT, W.G.J., LAMPRECHT, S.C. & VAN WYK, P.S. 1988b. Crown rot and head blight of wheat caused by *Fusarium graminearum* groups 1 and 2 in the southern Cape Province. *Phytophylactica* 20: 385-389.

MARASAS, W.F.O., THIEL, P.G., SYDENHAM, E.W., RABIE, C.J., LÜBBEN, A. & NELSON, P.E. 1991. Toxicity and moniliformin production by 4 recently described species of *Fusarium* and 2 uncertain taxa. *Mycopathologia* 113: 191-197.

MARIC, A. 1981. *Fusarium* diseases of wheat and corn in Eastern Europe and the Soviet Union. Pages 77-93 in: Fusarium: Diseases, Biology and Taxonomy. P.E. Nelson, T.A. Toussoun & R.J. Cook, eds. The Pennsylvania State University Press, University Park.

MARLEY, P.S. & ADEOTI, A.A. 1995. Effect of seed treatment chemicals on seedling emergence, establishment and control of foot and root diseases of wheat in Nigeria. *Crop Protection* 14: 271-274.

MATHIESON, J.T. & RUSH, C.M. 1991. Influence of temperature and five fungicides on Rhizoctonia root rot of hard red winter wheat. *Plant Disease* 75: 983-986.

MATHRE, D.E. 1982. Compendium of Barley Diseases. APS Press, St. Paul, Minnesota.

MCHOMVU, P.M. & ANTAPA, P.L. 1996. Research on prospective rotational crops at Hanang wheat farms in Northern Tanzania. Pages 252-260 in: The Ninth Regional Wheat Workshop for Eastern, Central and Southern Africa. D.G. Tanner, T.S. Payne & O.S. Abdalla, eds. CIMMYT, Addis Ababa, Ethiopia.

MEYER, L. 1996. Characteristics and ecology of *Rhizoctonia solani* causing crater disease in wheat. PhD thesis. University of Pretoria, Pretoria.

MEYER, L., WEHNER, F.C., KUWITE, C.A. & PIENING, L. 1996. Crater disease and patchy stunting of wheat caused by the same strain of *Rhizoctonia solani*. *Plant Disease* 80: 1079.

MEYER, L. WEHNER, F.C., NEL, L.H. & CARLING, D.E. 1998. Characterization of the crater disease strain of *Rhizoctonia solani*. *Phytopathology* 88: 366-371.

MEYER, L. & WEHNER, F.C. 2000. Involvement of fungi other than *Rhizoctonia solani* in crater disease of wheat. *African Plant Protection* 6: 45-53.

MEYER, L. & VAN DYK, K. 2002. Susceptibility of pasture crops to *Rhizoctonia solani* and other fungi associated with crater disease of wheat on the Springbok Flats, South Africa. *African Plant Protection* 8: 57-63.

MILUS, E.A. & ROTHROCK, C.S. 1989. Yield constraints in wheat due to soilborne pathogens (Abstract). *Phytopathology* 79: 1142.

MOEN, R. & HARRIS, J.R. 1985. The Rhizoctonia disease complex of wheat. Pages 48-50 in: Ecology and Management of Soilborne Plant Pathogens. C.A. Parker, A.D. Rovira, K.J. Moore, P.T.W. Wong & J.F. Kollmorgen, eds. American Phytopathological Society, St. Paul, Minnesota.

MURRAY, D.I.L. 1981. *Rhizoctonia solani* causing barley stunt disorder. *Transactions of the British Mycological Society* 76: 383-395.

MURRAY, D.I.L. & NICOLSON, T.H. 1979. Barley stunt disorder in Scotland. *Plant Pathology* 28: 200-201.

MURRAY, D.I.L. & GADD, G.M. 1981. Preliminary studies on *Microdochium bolleyi* with special reference to colonization of barley. *Transactions of the British Mycological Society* 76: 397-403.

NEATE, S.M. 1985. *Rhizoctonia* in South Australian wheat fields. Pages 54-56 in: Ecology and Management of Soilborne Plant Pathogens. C.A. Parker, A.D. Rovira, K.J. Moore, P.T.W. Wong & J.F. Kollmorgen, eds. American Phytopathological Society, St. Paul, Minnesota.

NEATE, S.M. & WARCUP, J.H. 1985. Anastomosis grouping of some isolates of *Thanatephorus cucumeris* from agricultural soils in South Australia. *Transactions of the British Mycological Society* 85: 615-620.

NELSON, K.E. & BURGESS, L.W. 1995. Effect of rotation with barley and oats on crown rot of wheat in the northern wheat belt of New South Wales. *Australian Journal of Experimental Agriculture* 35: 765-770.

NICHOLSON, P. & PARRY, D.W. 1996. Development and use of a PCR assay to detect *Rhizoctonia cerealis*, the cause of sharp eyespot in wheat. *Plant Pathology* 45: 872-883.

OGOSHI, A., COOK, R.J. & BASSETT, E.N. 1990. *Rhizoctonia* species and anastomosis groups causing root rot of wheat and barley in the Pacific Northwest. *Phytopathology* 80: 784-788.

OSWALD, J.W. 1949. Cultural variation, taxonomy and pathogenicity of *Fusarium* species associated with cereal roots. *Phytopathology* 39: 359-375.

OPPERMAN, L. & BARNARD, R.O. 1992. Improved growth and grain yield of wheat in deep mouldboard ploughed crater disease and disease-free soil on the Springbok Flats. *Phytophylactica* 24: 335-338.

PARMETER, J.R., SHERWOOD, R.T. & PLATT, W.D. 1969. Anastomosis grouping among isolates of *Thanatephorus cucumeris*. *Phytopathology* 59: 1270-1278.

PARRY, D.W., PETTITT, T.R., JENKINSON, P. & LEES, A.K. 1994. The cereal *Fusarium* complex. Pages 301-320 in: Ecology of Plant Pathogens. J.P. Blakeman & B. Williamson, eds. CAB International, Wallingford.

PIENING, L.J., ATKINSON, T.G., HORRICKS, J.S., LEDINGHAM, R.J., MILLS, J.T. & TINLINE, R.D. 1976. Barley losses due to common root rot in the prairie provinces of Canada, 1970-72. *Canadian Plant Disease Survey* 56: 41-45.

PIENING, L.J. & ORR, D. 1988. Effect of crop rotation on common root rot of barley. *Canadian Journal of Plant Pathology* 10: 61-65.

PITT, D. 1964. Studies on sharp eyespot disease of cereals. I. Disease symptoms and pathogenicity of isolates of *Rhizoctonia solani* Kühn and the influence of soil factors and temperature on disease development. *Annals of Applied Biology* 54: 77-89.

POUPARD, P., SIMONET, P., CAVELIER, N. & BARDIN, R. 1993. Molecular characterization of *Pseudocercosporella herpotrichoides* isolates by amplification of ribosomal DNA internal transcribed spacers. *Plant Pathology* 42: 873-882.

RANGA RAO, V. & MUKERJI, K.G. 1971. Fungi in the root zone of four cultivars of wheat. *Annals of the Pasteur Institute, Paris* 121: 533-544.

RAVANLOU, A. & BANIHASHEMI, Z. 1999. Taxonomy and pathogenicity of *Fusarium* spp. associated with root and crown rot of wheat in Fars. *Iranian Journal of Plant Pathology* 35: 12-14.

REED, H.E. 1952. Cereal root-rot studies in Tennessee (Abstract). *Phytopathology* 42: 287.

REIS, E.M., COOK, R.J. & McNEAL, B.L. 1982. Effect of mineral nutrition on take-all of wheat. *Phytopathology* 72: 224-229.

REIS, E.M., COOK, R.J. & McNEAL, B.L. 1983. Elevated pH and associated reduced trace-nutrient availability as factors contributing to take-all of wheat upon soil liming. *Phytopathology* 73: 411-413.

RHOADS, M.L., ROTHROCK, C.S. & MILUS, E.A. 1993. Incidence and identification of *Pythium* spp. pathogenic on soft red winter wheat in Arkansas (Abstract). *Phytopathology* 83: 1387.

RICHARDSON, M.J. & COOK, R.J. 1985. *Rhizoctonia* on small-grain cereals in Great Brittian. Pages 63-65 in: Ecology and Management of Soilborne Plant Pathogens. C.A. Parker, A.D. Rovira, K.J. Moore, P.T.W. Wong & J.F. Kollmorgen, eds. American Phytopathological Society, St. Paul, Minnesota.

RIVERA, J.E. & BRUEHL, G.W. 1963. Inoculation of winter wheat with *Cephalosporium gramineum*. *Plant Disease Reporter* 47: 622-623.

ROBERTS, F.A. & SIVASITHAMPARAM, K. 1986. Identity and pathogenicity of Rhizoctonia spp. associated with bare patch disease of cereals at a field site in Western Australia. *Netherlands Journal of Plant Pathology* 92: 185-195.

ROBERTS, F.A. & SIVASITHAMPARAM, K. 1987. Effect of interaction of *Rhizoctonia* spp. with other fungi from cereal bare patches on root rot of wheat. *Transactions of the British Mycological Society* 89: 256-259.

ROSSI, V., CERVI, C., CHIUSA, G. & LANGUASCO, L. 1995. Fungi associated with foot rots of winter wheat in Northwest Italy. *Journal of Phytopathology* 143: 115-119.

ROVIRA, A.D. 1986. Influence of crop rotation and tillage on Rhizoctonia bare patch of wheat. *Phytopathology* 76: 669-673.

ROVIRA, A.D. & WILDERMUTH, G.B. 1981. The nature and mechanism of suppression. Pages 385-415 in: Biology and Control of Take-all. M.J.C. Asher & P.J. Shipton, eds. Academic Press, London.

ROVIRA, A.D., OGOSHI, A. & McDONALD, H.J. 1986. Characterization of isolates of *Rhizoctonia solani* from cereal roots in South Australia and New South Wales. *Phytopathology* 76: 1245-1248.

RUFENACHT, E.M.C. 1980. Fungi associated with root rot of wheat in South Africa. MSc dissertation. University of Pretoria, Pretoria.

RUSH, C.M., CARLING, D.E., HARVESON, R.M. & MATHIESON, J.T. 1994. Prevalence and pathogenicity of anastomosis groups of *Rhizoctonia solani* from wheat and sugar beet in Texas. *Plant Disease* 78: 349-352.

SAARI, E.E. & WILCOXSON, R.D. 1974. Plant disease situation of high-yielding dwarf wheats in Asia and Africa. *Annual Review of Phytopathology* 12: 49-68.

SALLANS, B.J. 1965. Root rots of cereals. III. *The Botanical Review* 31: 505-536.

SALLANS, B.J. & TINLINE, R.D. 1965. Resistance in wheat to *Cochliobolus sativus*, a cause of common root rot. *Canadian Journal of Plant Science* 45: 343-351.

SALT, G.A. 1979. The increasing interest in "minor pathogens". Pages 289-312 in: Soil-Borne Plant Pathogens. B. Schippers & W. Gams, eds. Academic Press, London.

SAMUEL, G. & GARRETT, S.D. 1932. Rhizoctonia solani on cereals in South Australia. *Phytopathology* 22: 827-836.

SCARDACI, S.C. & WEBSTER, R.K. 1981. Antagonism between the cereal root rot pathogens *Fusarium graminearum* and *Bipolaris sorokiniana*. *Plant Disease* 65: 965-967.

SCARDACI, S.C. & WEBSTER, R.K. 1982. Common root rot of cereals in California. *Plant Disease* 66: 31-34.

SCOTT, D.B. 1978. Take-all of wheat in the eastern Free State. *Phytophylactica* 10: 123-126.

SCOTT, D.B., VISSER, C.P.N. & RUFENACHT, E.M.C. 1979. Crater disease of wheat in African drylands. *Plant Disease Reporter* 63: 836-840.

SCOTT, D.B. & DEACON, J.W. 1983. *Magnaporthe rhizophila* sp.nov., a dark mycelial fungus with a *Phialophora* conidial state, from cereal roots in South Africa. *Transactions of the British Mycological Society* 81: 77-81.

SCOTT, P.R. 1981. Variation in host susceptibility. Pages 219-236 in: Biology and Control of Take-all. M.J.C. Asher & P.J. Shipton, eds. Academic Press, London.

SHARP, E.L. 1959. Two previously unreported fungi on cereals in Montana. *Plant Disease Reporter* 43: 12-13.

SIVANESAN, A. 1987. Graminicolous species of Bipolaris, Curvularia, Drechslera, Exserohilum and their teleomorphs. *Mycological Papers* 158: 1-261.

SMILEY, R.W. & WILKINS, D.E. 1993. Annual spring barley growth, yield, and root rot in high- and low-residue tillage systems. *Journal of Production Agriculture* 6: 270-275.

SMILEY, R.W. & PATTERSON, L.-M. 1996. Pathogenic fungi associated with *Fusarium* foot rot of winter what in the semiarid Pacific Northwest. *Plant Disease* 80: 944-949.

SMITH, E.M., WEHNER, F.C. & KOTZÉ, J.M. 1984. Effect of soil solarization and fungicide drenches on crater disease of wheat. *Plant Disease* 68: 582-584.

SMITH, E.M. & WEHNER, F.C. 1986. Induction of crater disease of wheat in the field by artificial infestation of the soil with *Rhizoctonia solani*. *Phytophylactica* 18: 127-130.

SPECHT, L.P. & RUSH, C.M. 1988. Fungi associated with root and foot rot of winter wheat and populations of *Cochliobolus sativus* in the Texas Panhandle. *Plant Disease* 72: 959-963.

SPRAGUE, G. 1948. Gloeosporium decay in Graminae. *Phytopathology* 38: 131-136.

STERNE, R.E. & JONES, J.P. 1978. Sharp eyespot of wheat in Arkansas caused by Rhizoctonia solani. *Plant Disease Reporter* 62: 56-60.

STURZ, A.V. & BERNIER, C.C. 1991. Fungal communities in winter wheat roots following crop rotations suppressive and nonsuppressive to take-all. *Canadian Journal of Botany* 69: 39-43.

STURZ, A.V. & CARTER, M.R. 1995. Conservation tillage systems, fungal complexes and disease development in soybean and barley rhizospheres in Prince Edward Island. *Soil and Tillage Research* 34: 225-238.

SUTTON, B.C. 1980. The Coelomycetes. Commonwealth Mycological Institute, Kew.

THONGBAI, P., HANNAM, R.J. GRAHAM, R.D. & WEBB, M.J. 1993. Interaction between zinc nutritional status of cereals and *Rhizoctonia* root rot severity. I. Field observations. *Plant and Soil* 153: 207-214.

TINLINE, R.D. & LEDINGHAM, R.J. 1979. Yield losses in wheat and barley cultivars from common root rot in field tests. *Canadian Journal of Plant Science* 59: 313-320.

TINLINE, R.D., WILDERMUTH, G.B. & SPURR, D.T. 1988. Inoculum density of *Cochliobolus sativus* in soil and common root rot of wheat cultivars in Queensland. *Australian Journal of Agricultural Research* 39: 569-577.

VAN LEUR, J.A.G., ALAMDAR, M.Z. & KHAWATNI, S. 1997. Effect of common root rot (*Cochliobolus sativus*) on yields of barley under experimental conditions in northern Syria. *Australian Journal of Agricultural Research* 48: 351-357.

VAN LEUR, J.A.G. & BAILEY, K.L. 2000. The occurrence of barley root diseases in different agri-ecological zones of Syria. *Canadian Journal of Plant Pathology* 22: 61-69.

VANTERPOOL, T.C. 1938. Some species of *Pythium* parasitic on wheat in Canada and England. *Annals of Applied Biology* 25: 528-543.

VANTERPOOL, T.C. & SPRAGUE, R. 1942. *Pythium arrhenomanes* on cereals and grasses in the Northern Great Plains. *Phytopathology* 32: 327-328.

VAN WYK, P.S., LOS, O. & KLOPPERS, F.J. 1986. Crown rot of wheat caused by *Fusarium crookwellense*. *Phytophylactica* 18: 91-92.

VAN WYK, P.S., LOS, O., PAUER, G.D.C. & MARASAS, W.F.O. 1987. Geographic distribution and pathogenicity of *Fusarium* species associated with crown rot of wheat in the Orange Free State, South Africa. *Phytophylactica* 19: 271-274.

VAN WYK, P.S., LOS, O. & MARASAS, W.F.O. 1988. Pathogenicity of a new *Fusarium* sp. from crown rot of wheat in South Africa. *Phytophylactica* 20: 73-75.

VERMA, P.R., TINLINE, R.D. & MORRALL, R.A.A. 1974. The epidemiology of common root rot in Manitou wheat: disease progression during the growing season. *Canadian Journal of Botany* 52: 1757-1764.

VERMA, P.R., MORRALL, R.A.A. & TINLINE, R.D. 1976. The effect of common root rot on components of grain yield in Manitou wheat. *Canadian Journal of Botany* 54: 2888-2892.

WARREN, H.L. & KOMMEDAHL, T. 1972. Fertilization and wheat refuse effects on *Fusarium* species associated with wheat roots in Minnesota. *Phytopathology* 62: 103-108.

WELLER, D.M., COOK, R.J., MacNISH, G., BASSETT, E.N., POWELSON, R.L. & PETERSEN, R.R. 1986. Rhizoctonia root rot of small grains favored by reduced tillage in the Pacific Northwest. *Plant Disease* 70: 70-73.

WIESE, M.V. 1987. Compendium of Wheat Diseases. 2nd ed. APS Press, St. Paul, Minnesota.

WILDERMUTH, G.B. 1986. Geographic distribution of common root rot and *Bipolaris sorokiniana* in Queensland wheat soils. *Australian Journal of Experimental Agriculture* 26: 601-606.

WILDERMUTH, G.B. & McNAMARA, R.B. 1987. Susceptibility of winter and summer crops to root and crown infection by *Bipolaris sorokiniana*. *Plant Pathology* 36: 481-491.

WILDERMUTH, G.B., TINLINE, R.D. & McNAMARA, R.B. 1992. Assessment of yield loss caused by common root rot in wheat cultivars in Queensland. *Australian Journal of Agricultural Research* 43: 43-58.

WILDERMUTH, G.B., THOMAS, G.A., RADFORD, B.J., McNAMARA, R.B. & KELLY, A. 1997. Crown rot and common root rot in winter wheat grown under different tillage and stubble treatments in southern Queensland, Australia. *Soil and Tillage Research* 44: 211-224.

WINDELS, C.E. & HOLEN, C. 1989. Association *of Bipolaris sorokiniana*, *Fusarium graminearum* group 2 and *F. culmorum* on spring wheat differing in severity of common root rot. *Plant Disease* 73: 953-956.

WINDELS, C.E. & WIERSMA, J.V. 1992. Incidence of *Bipolaris* and *Fusarium* on subcrown internodes of spring barley and wheat grown in continuous conservation tillage. *Phytopathology* 82: 699-705.

WOOD, L.S. 1962. Relation of variation in Helminthosporium sativum to seedling diseases of small grains. *Phytopathology* 52: 493-498.

YAMAMOTO, D.T. & UCHIDA, J.Y. 1982. Rapid nuclear staining of *Rhizoctonia solani* and related fungi with acridine orange and with safranin O. *Mycologia* 74: 145-149.

YANG, H.A., SIVASITHAMPARAM, K., ALEMOHAMMAD, J., BARTON, J.E. & O'BRIEN, P.A. 1994. Association of *Rhizoctonia* strains with bare patch disease of wheat in Western Australia. *Plant Pathology* 43: 878-884.

YANG, H.A., SIVASITHAMPARAM, K., BARTON, J.E. & O'BRIEN, P.A. 1995. Characterization of cereal bare patch isolates of *Rhizoctonia solani* by random amplified polymorphic DNA analysis. *Plant Pathology* 44: 811-818.

# APPENDIX 1

Table A1. Probabilities of pair-wise differences between various fungal isolates and wheat and barley for percentage root growth.

| | Isolate[a] - Crop[b] | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Isolate[a] - Crop[b] | I1-C1 | I1-C2 | I2-C1 | I2-C2 | I3-C1 | I3-C2 | I4-C1 | I4-C2 | I5-C1 | I5-C2 | I6-C1 | I6-C2 | I7-C1 | I7-C2 | I8-C1 | I8-C2 | I9-C1 | I9-C2 | I10-C1 | I10-C2 | I11-C1 | I11-C2 |
| I1-C1 | - | | | | | | | | | | | | | | | | | | | | | |
| I1-C2 | 0.000* | - | | | | | | | | | | | | | | | | | | | | |
| I2-C1 | 0.000* | 0.574 | - | | | | | | | | | | | | | | | | | | | |
| I2-C2 | 0.000* | 0.364 | 0.781 | - | | | | | | | | | | | | | | | | | | |
| I3-C1 | 0.842 | 0.000* | 0.000* | 0.000* | - | | | | | | | | | | | | | | | | | |
| I3-C2 | 0.004 | 0.200 | 0.137 | 0.087 | 0.042 | - | | | | | | | | | | | | | | | | |
| I4-C1 | 0.000* | 0.313 | 0.517 | 0.636 | 0.001 | 0.101 | - | | | | | | | | | | | | | | | |
| I4-C2 | 0.000* | 0.000* | 0.001 | 0.002 | 0.000* | 0.000* | 0.037 | - | | | | | | | | | | | | | | |
| I5-C1 | 0.000* | 0.241 | 0.166 | 0.094 | 0.004 | 0.668 | 0.131 | 0.000* | - | | | | | | | | | | | | | |
| I5-C2 | 0.000* | 0.035 | 0.243 | 0.382 | 0.000* | 0.014 | 0.957 | 0.008 | 0.007 | - | | | | | | | | | | | | |
| I6-C1 | 0.003 | 0.000* | 0.000* | 0.000* | 0.045 | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | - | | | | | | | | | | | |
| I6-C2 | 0.026 | 0.000* | 0.001 | 0.000* | 0.228 | 0.220 | 0.006 | 0.000* | 0.029 | 0.000* | 0.000* | - | | | | | | | | | | |
| I7-C1 | 0.000* | 0.332 | 0.632 | 0.801 | 0.000* | 0.089 | 0.800 | 0.008 | 0.108 | 0.659 | 0.000* | 0.001 | - | | | | | | | | | |
| I7-C2 | 0.000* | 0.003 | 0.025 | 0.044 | 0.000* | 0.001 | 0.321 | 0.156 | 0.001 | 0.167 | 0.000* | 0.000* | 0.127 | - | | | | | | | | |
| I8-C1 | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.012 | 0.802 | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.063 | - | | | | | | | |
| I8-C2 | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.052 | 0.399 | 0.000* | 0.000* | 0.000* | 0.000* | 0.003 | 0.286 | 0.211 | - | | | | | | |
| I9-C1 | 0.000* | 0.000* | 0.002 | 0.006 | 0.000* | 0.000* | 0.226 | 0.138 | 0.000* | 0.045 | 0.000* | 0.000* | 0.050 | 0.893 | 0.018 | 0.200 | - | | | | | |
| I9-C2 | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.015 | 0.786 | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.085 | 0.956 | 0.294 | 0.036 | - | | | | |
| I10-C1 | 0.000* | 0.006 | 0.015 | 0.006 | 0.014 | 0.855 | 0.040 | 0.000* | 0.356 | 0.000* | 0.000* | 0.100 | 0.017 | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | - | | | |
| I10-C2 | 0.000* | 0.000* | 0.031 | 0.069 | 0.000* | 0.001 | 0.608 | 0.021 | 0.000* | 0.376 | 0.000* | 0.000* | 0.271 | 0.376 | 0.000* | 0.001 | 0.142 | 0.000* | 0.000* | - | | |
| I11-C1 | 0.264 | 0.054 | 0.038 | 0.025 | 0.411 | 0.400 | 0.032 | 0.000* | 0.205 | 0.005 | 0.014 | 0.992 | 0.026 | 0.001 | 0.000* | 0.000* | 0.000* | 0.000* | 0.394 | 0.001 | - | |
| I11-C2 | 0.000* | 0.006 | 0.025 | 0.038 | 0.000* | 0.002 | 0.206 | 0.410 | 0.002 | 0.114 | 0.000* | 0.000* | 0.087 | 0.640 | 0.397 | 0.799 | 0.674 | 0.428 | 0.000* | 0.230 | 0.001 | - |

[a]I1 = *Bipolaris sorokiniana*, I2 = *Fusarium equiseti*, I3 = *F. chlamydosporum*, I4 = *F. solani*, I5 = *F. oxysporum*, I6 = *F. nygamai*, I7 = *F. sublglutinans*, I8 = *Phoma medicaginis*, I9 = *Periconia macrospinosa*, I10 = *Rhizoctonia solani*, I11 = *Sclerotium rolfsii*.

[b]C1 = wheat, C2 = barley

*$P$=0.000 ≡ $P$<0.0001

Table A2. Probabilities of pair-wise differences between various fungal isolates and wheat and barley for percentage shoot growth.

| | Isolate[a] - Crop[b] | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Isolate* - Crop[b] | I1-C1 | I1-C2 | I2-C1 | I2-C2 | I3-C1 | I3-C2 | I4-C1 | I4-C2 | I5-C1 | I5-C2 | I6-C1 | I6-C2 | I7-C1 | I7-C2 | I8-C1 | I8-C2 | I9-C1 | I9-C2 | I10-C1 | I10-C2 | I11-C1 | I11-C2 |
| I1-C1 | - | | | | | | | | | | | | | | | | | | | | | |
| I1-C2 | 0.000* | - | | | | | | | | | | | | | | | | | | | | |
| I2-C1 | 0.000* | 0.216 | - | | | | | | | | | | | | | | | | | | | |
| I2-C2 | 0.000* | 0.832 | 0.411 | - | | | | | | | | | | | | | | | | | | |
| I3-C1 | 0.087 | 0.000* | 0.020 | 0.003 | - | | | | | | | | | | | | | | | | | |
| I3-C2 | 0.000* | 0.734 | 0.269 | 0.663 | 0.003 | - | | | | | | | | | | | | | | | | |
| I4-C1 | 0.000* | 0.068 | 0.021 | 0.072 | 0.000* | 0.182 | - | | | | | | | | | | | | | | | |
| I4-C2 | 0.000* | 0.122 | 0.040 | 0.124 | 0.000* | 0.273 | 0.836 | - | | | | | | | | | | | | | | |
| I5-C1 | 0.000* | 0.008 | 0.303 | 0.058 | 0.112 | 0.049 | 0.003 | 0.006 | - | | | | | | | | | | | | | |
| I5-C2 | 0.000* | 0.502 | 0.118 | 0.484 | 0.000* | 0.912 | 0.159 | 0.254 | 0.006 | - | | | | | | | | | | | | |
| I6-C1 | 0.907 | 0.000* | 0.000* | 0.000* | 0.106 | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | - | | | | | | | | | | | |
| I6-C2 | 0.000* | 0.131 | 0.898 | 0.320 | 0.021 | 0.212 | 0.015 | 0.030 | 0.339 | 0.073 | 0.000* | - | | | | | | | | | | |
| I7-C1 | 0.000* | 0.346 | 0.103 | 0.336 | 0.001 | 0.648 | 0.335 | 0.469 | 0.012 | 0.664 | 0.000* | 0.073 | - | | | | | | | | | |
| I7-C2 | 0.000* | 0.493 | 0.159 | 0.461 | 0.001 | 0.794 | 0.262 | 0.377 | 0.023 | 0.840 | 0.000* | 0.119 | 0.846 | - | | | | | | | | |
| I8-C1 | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.010 | 0.692 | 0.502 | 0.000* | 0.001 | 0.000* | 0.000* | 0.044 | 0.024 | - | | | | | | | |
| I8-C2 | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.014 | 0.770 | 0.570 | 0.000* | 0.001 | 0.000* | 0.000* | 0.060 | 0.033 | 0.825 | - | | | | | | |
| I9-C1 | 0.000* | 0.001 | 0.000* | 0.006 | 0.000* | 0.078 | 0.884 | 0.902 | 0.000* | 0.029 | 0.000* | 0.000* | 0.222 | 0.146 | 0.311 | 0.411 | - | | | | | |
| I9-C2 | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.005 | 0.526 | 0.367 | 0.000* | 0.000* | 0.000* | 0.000* | 0.025 | 0.014 | 0.632 | 0.500 | 0.177 | - | | | | |
| I10-C1 | 0.000* | 0.000* | 0.020 | 0.001 | 0.392 | 0.003 | 0.000* | 0.000* | 0.213 | 0.000* | 0.000* | 0.018 | 0.000* | 0.001 | 0.000* | 0.000* | 0.000* | 0.000* | - | | | |
| I10-C2 | 0.000* | 0.359 | 0.067 | 0.402 | 0.000* | 0.883 | 0.145 | 0.239 | 0.001 | 0.969 | 0.000* | 0.032 | 0.655 | 0.846 | 0.000* | 0.000* | 0.012 | 0.000* | 0.000* | - | | |
| I11-C1 | 0.624 | 0.001 | 0.012 | 0.003 | 0.521 | 0.002 | 0.000* | 0.000* | 0.054 | 0.000* | 0.604 | 0.013 | 0.001 | 0.001 | 0.000* | 0.000* | 0.000* | 0.000* | 0.167 | 0.000* | - | |
| I11-C2 | 0.000* | 0.562 | 0.641 | 0.956 | 0.038 | 0.721 | 0.143 | 0.208 | 0.269 | 0.629 | 0.000* | 0.580 | 0.466 | 0.568 | 0.019 | 0.025 | 0.081 | 0.012 | 0.072 | 0.599 | 0.019 | - |

[a]I1 = *Bipolaris sorokiniana*, I2 = *Fusarium equiseti*, I3 = *F. chlamydosporum*, I4 = *F. solani*, I5 = *F. oxysporum*, I6 = *F. nygamai*, I7 = *F. sublglutinans*, I8 = *Phoma medicaginis*, I9 = *Periconia macrospinosa*, I10 = *Rhizoctonia solani*, I11 = *Sclerotium rolfsii*.

[b]C1 = wheat, C2 = barley

*$P$=0.000 ≡ $P$<0.0001

Table A4. F

| Isolate[a] - Crop[b] | I1-C1 |
|---|---|
| I1-C1 | - |
| I1-C2 | 0.000* |
| I2-C1 | 0.000* |
| I2-C2 | 0.000* |
| I3-C1 | 0.361 |
| I3-C2 | 0.000* |
| I4-C1 | 0.000* |
| I4-C2 | 0.000* |
| I5-C1 | 0.000* |
| I5-C2 | 0.000* |
| I6-C1 | 0.251 |
| I6-C2 | 0.000* |
| I7-C1 | 0.000* |
| I7-C2 | 0.000* |
| I8-C1 | 0.000* |
| I8-C2 | 0.000* |
| I9-C1 | 0.000* |
| I9-C2 | 0.000* |
| I10-C1 | 0.002 |
| I10-C2 | 0.000* |
| I11-C1 | 0.568 |
| I11-C2 | 0.006 |

[a]I1 = *Bipola*

I8 = *Phoma*

[b]C1 = whea

**P*=0.000 ≡

Table A3. Probabilities of pair-wise differences between various fungal isolates and wheat and barley for percentage shoot mass.

| | Isolate[a] - Crop[b] | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Isolate[a] - Crop[b] | I1-C1 | I1-C2 | I2-C1 | I2-C2 | I3-C1 | I3-C2 | I4-C1 | I4-C2 | I5-C1 | I5-C2 | I6-C1 | I6-C2 | I7-C1 | I7-C2 | I8-C1 | I8-C2 | I9-C1 | I9-C2 | I10-C1 | I10-C2 | I11-C1 | I11-C2 |
| I1-C1 | - | | | | | | | | | | | | | | | | | | | | | |
| I1-C2 | 0.000* | - | | | | | | | | | | | | | | | | | | | | |
| I2-C1 | 0.000* | 0.592 | - | | | | | | | | | | | | | | | | | | | |
| I2-C2 | 0.000* | 0.974 | 0.686 | - | | | | | | | | | | | | | | | | | | |
| I3-C1 | 0.048 | 0.001 | 0.009 | 0.003 | - | | | | | | | | | | | | | | | | | |
| I3-C2 | 0.000* | 0.856 | 0.611 | 0.858 | 0.007 | - | | | | | | | | | | | | | | | | |
| I4-C1 | 0.000* | 0.378 | 0.277 | 0.406 | 0.005 | 0.527 | - | | | | | | | | | | | | | | | |
| I4-C2 | 0.000* | 0.099 | 0.072 | 0.123 | 0.001 | 0.200 | 0.574 | - | | | | | | | | | | | | | | |
| I5-C1 | 0.000* | 0.003 | 0.061 | 0.022 | 0.232 | 0.043 | 0.024 | 0.003 | - | | | | | | | | | | | | | |
| I5-C2 | 0.000* | 0.916 | 0.594 | 0.914 | 0.002 | 0.921 | 0.434 | 0.132 | 0.011 | - | | | | | | | | | | | | |
| I6-C1 | 0.901 | 0.000* | 0.000* | 0.000* | 0.087 | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | - | | | | | | | | | | | |
| I6-C2 | 0.000* | 0.019 | 0.169 | 0.072 | 0.111 | 0.103 | 0.051 | 0.008 | 0.598 | 0.043 | 0.000* | - | | | | | | | | | | |
| I7-C1 | 0.000* | 0.559 | 0.390 | 0.596 | 0.003 | 0.761 | 0.700 | 0.302 | 0.017 | 0.644 | 0.000* | 0.046 | - | | | | | | | | | |
| I7-C2 | 0.000* | 0.168 | 0.120 | 0.221 | 0.000* | 0.365 | 0.914 | 0.588 | 0.002 | 0.237 | 0.000* | 0.007 | 0.547 | - | | | | | | | | |
| I8-C1 | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.011 | 0.239 | 0.667 | 0.000* | 0.000* | 0.000* | 0.000* | 0.030 | 0.158 | - | | | | | | | |
| I8-C2 | 0.000* | 0.000* | 0.000* | 0.002 | 0.000* | 0.027 | 0.356 | 0.862 | 0.000* | 0.001 | 0.000* | 0.000* | 0.067 | 0.284 | 0.589 | - | | | | | | |
| I9-C1 | 0.000* | 0.002 | 0.005 | 0.017 | 0.000* | 0.085 | 0.541 | 0.909 | 0.000* | 0.016 | 0.000* | 0.000* | 0.173 | 0.520 | 0.310 | 0.586 | - | | | | | |
| I9-C2 | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.006 | 0.163 | 0.502 | 0.000* | 0.000* | 0.000* | 0.000* | 0.017 | 0.095 | 0.625 | 0.334 | 0.173 | - | | | | |
| I10-C1 | 0.000* | 0.000* | 0.008 | 0.002 | 0.353 | 0.010 | 0.008 | 0.001 | 0.596 | 0.000* | 0.000* | 0.251 | 0.003 | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | - | | | |
| I10-C2 | 0.000* | 0.697 | 0.802 | 0.811 | 0.002 | 0.702 | 0.306 | 0.075 | 0.009 | 0.695 | 0.000* | 0.047 | 0.437 | 0.119 | 0.000* | 0.000* | 0.001 | 0.000* | 0.000* | - | | |
| I11-C1 | 0.167 | 0.011 | 0.038 | 0.020 | 0.954 | 0.024 | 0.012 | 0.002 | 0.329 | 0.014 | 0.213 | 0.201 | 0.012 | 0.003 | 0.000* | 0.000* | 0.000* | 0.000* | 0.453 | 0.018 | - | |
| I11-C2 | 0.000* | 0.695 | 0.526 | 0.705 | 0.016 | 0.826 | 0.720 | 0.358 | 0.073 | 0.749 | 0.000* | 0.136 | 0.975 | 0.602 | 0.098 | 0.161 | 0.283 | 0.063 | 0.031 | 0.590 | 0.032 | - |

[a]I1 = *Bipolaris sorokiniana*, I2 = *Fusarium equiseti*, I3 = *F. chlamydosporum*, I4 = *F. solani*, I5 = *F. oxysporum*, I6 = *F. nygamai*, I7 = *F. sublglutinans*, I8 = *Phoma medicaginis*, I9 = *Periconia macrospinosa*, I10 = *Rhizoctonia solani*, I11 = *Sclerotium rolfsii*.

[b]C1 = wheat, C2 = barley

**P*=0.000 ≡ *P*<0.0001

Table A4. Probabilities of pair-wise differences between various fungal isolates and wheat and barley for total disease score.

| | Isolate[a] - Crop[b] | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Isolate[a] - Crop[b] | I1-C1 | I1-C2 | I2-C1 | I2-C2 | I3-C1 | I3-C2 | I4-C1 | I4-C2 | I5-C1 | I5-C2 | I6-C1 | I6-C2 | I7-C1 | I7-C2 | I8-C1 | I8-C2 | I9-C1 | I9-C2 | I10-C1 | I10-C2 | I11-C1 | I11-C2 |
| I1-C1 | - | | | | | | | | | | | | | | | | | | | | | |
| I1-C2 | 0.000* | - | | | | | | | | | | | | | | | | | | | | |
| I2-C1 | 0.000* | 0.856 | - | | | | | | | | | | | | | | | | | | | |
| I2-C2 | 0.000* | 0.114 | 0.157 | - | | | | | | | | | | | | | | | | | | |
| I3-C1 | 0.361 | 0.000* | 0.000* | 0.000* | - | | | | | | | | | | | | | | | | | |
| I3-C2 | 0.000* | 0.449 | 0.436 | 0.707 | 0.000* | - | | | | | | | | | | | | | | | | |
| I4-C1 | 0.000* | 0.334 | 0.324 | 0.926 | 0.000* | 0.727 | - | | | | | | | | | | | | | | | |
| I4-C2 | 0.000* | 0.000* | 0.000* | 0.001 | 0.000* | 0.001 | 0.014 | - | | | | | | | | | | | | | | |
| I5-C1 | 0.000* | 0.012 | 0.070 | 0.001 | 0.006 | 0.024 | 0.035 | 0.000* | - | | | | | | | | | | | | | |
| I5-C2 | 0.000* | 0.007 | 0.026 | 0.457 | 0.000* | 0.325 | 0.717 | 0.005 | 0.000* | - | | | | | | | | | | | | |
| I6-C1 | 0.251 | 0.000* | 0.000* | 0.000* | 0.124 | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | - | | | | | | | | | | | |
| I6-C2 | 0.000* | 0.229 | 0.434 | 0.023 | 0.000* | 0.152 | 0.138 | 0.000* | 0.275 | 0.001 | 0.000* | - | | | | | | | | | | |
| I7-C1 | 0.000* | 0.692 | 0.643 | 0.490 | 0.000* | 0.784 | 0.567 | 0.001 | 0.054 | 0.190 | 0.000* | 0.268 | - | | | | | | | | | |
| I7-C2 | 0.000* | 0.025 | 0.038 | 0.354 | 0.000* | 0.259 | 0.567 | 0.023 | 0.000* | 0.716 | 0.000* | 0.006 | 0.161 | - | | | | | | | | |
| I8-C1 | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.001 | 0.031 | 0.262 | 0.000* | 0.001 | 0.000* | 0.000* | 0.000* | 0.044 | - | | | | | | | |
| I8-C2 | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.010 | 0.483 | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.010 | 0.372 | - | | | | | | |
| I9-C1 | 0.000* | 0.144 | 0.198 | 0.838 | 0.000* | 0.822 | 0.827 | 0.001 | 0.001 | 0.315 | 0.000* | 0.028 | 0.581 | 0.261 | 0.000* | 0.000* | - | | | | | |
| I9-C2 | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.007 | 0.631 | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.007 | 0.245 | 0.703 | 0.000* | - | | | | |
| I10-C1 | 0.002 | 0.000* | 0.000* | 0.000* | 0.485 | 0.000* | 0.000* | 0.000* | 0.001 | 0.000* | 0.001 | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | - | | | |
| I10-C2 | 0.000* | 0.025 | 0.171 | 0.002 | 0.000* | 0.055 | 0.069 | 0.000* | 0.441 | 0.000* | 0.000* | 0.610 | 0.118 | 0.001 | 0.000* | 0.000* | 0.002 | 0.000* | 0.000* | - | | |
| I11-C1 | 0.568 | 0.000* | 0.000* | 0.000* | 0.295 | 0.000* | 0.000* | 0.000* | 0.001 | 0.000* | 0.991 | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* | 0.082 | 0.000* | - | |
| I11-C2 | 0.006 | 0.149 | 0.213 | 0.033 | 0.081 | 0.091 | 0.078 | 0.000* | 0.871 | 0.008 | 0.002 | 0.428 | 0.143 | 0.009 | 0.000* | 0.000* | 0.040 | 0.000* | 0.126 | 0.570 | 0.016 | - |

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[b]C1 = wheat, C2 = barley

*$P$=0.000 ≡ $P$<0.0001