Vol. 20 (2011): 62–73.

The emergence of cereal fungal diseases and the incidence of leaf spot diseases in Finland

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Fungal plant pathogens causing cereal diseases in Finland have been studied by a literature survey, and a field survey of cereal leaf spot diseases conducted in 2009. Fifty-seven cereal fungal diseases have been identified in Finland. The first available references on different cereal fungal pathogens were published in 1868 and the most recent reports are on the emergence of *Ramularia collo-cygni* and *Fusarium langsethiae* in 2001. The incidence of cereal leaf spot diseases has increased during the last 40 years. Based on the field survey done in 2009 in Finland, *Pyrenophora teres* was present in 86%, *Cochliobolus sativus* in 90% and *Rhynchosporium secalis* in 52% of the investigated barley fields. *Mycosphaerella graminicola* was identified for the first time in Finnish spring wheat fields, being present in 6% of the studied fields. *Stagonospora nodorum* was present in 98% and *Pyrenophora tritici-repentis* in 94% of spring wheat fields. Oat fields had the fewest fungal diseases. *Pyrenophora chaetomioides* was present in 63% and *Cochliobolus sativus* in 25% of the oat fields studied.

Key-words: Plant disease, leaf spot disease, emergence, cereal, barley, wheat, oat

Introduction

Plant diseases are an outcome of the long-term interaction between plants and pathogens. Plants have evolved defence mechanisms while pathogens have evolved effectors to overcome plant defences (Stukenbrock and McDonald 2009). Changes in cropping systems and in climate are likely to maintain the plant-pathogen interactions (Gregory et al. 2009) and are assumed to play a key role in the emergence of infectious plant diseases (Anderson et al. 2004).

The term ‘emerging disease’ refers to a recent disease on a new host and/or in a new area, or it is

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Vol. 20(2011): 62–73.

a disease that has recently become important due to an increase in virulence (Giraud et al. 2010). A recent example of a new disease is Ramularia leaf spot on barley (Walters et al. 2008). Examples of pathogens with increased virulence are the Ug99 pathotype of wheat stem rust (Singh et al. 2008) and a new type of *Puccinia striiformis* (causal agent of stripe rust) adapted to warmer climates (Hovmøller et al. 2008). A change in virulence may result from plant disease control methods as in the case of the rapid emergence and spread of QoI resistance in *Mycosphaerella graminicola* populations (Torriani et al. 2009) or *Puccinia triticina* isolates able to overcome the resistance gene *Lr9* (McCallum et al. 2010).

Cereal cultivation has a long history in Finnish agriculture. There are records of barley, oat, rye, and wheat cultivation from the 14th century. Barley was the main cereal until the end of the 19th century, when it was replaced by oat (Grotenfelt 1922). The acreage of barley cultivation began to increase rapidly again at the end of 1950 (Figure 1) (Tike 2010). The total agricultural area in Finland in 2010 was 2.3 million hectares, of which cereals were cultivated on almost half the area (1.0 million ha), barley being the main one (0.45 million ha) (Matilda 2010a). A total of 4.2 milliard kilos of grain were produced in 2008, over half of which was used to feed livestock (Matilda 2010b).

Plant diseases cause significant yield losses in cereal crops and reduce grain quality, threatening food safety (Gregory et al. 2009). Oerke (2006) estimated that despite current crop protection practices, the average global yield loss in wheat attributable to plant pathogens is about 10%. In Finland, the average yield increase from fungicide treatments in field trials over four years was 11% in barley, and 13% in spring wheat (Laine et al. 2009). However, environmental conditions, amount of inoculum, host susceptibility, host physiological growth stage and timing of the epidemic, all affect the degree of damage significantly (Duveiller 2007).

Reports on causal agents of cereal fungal diseases in Finland have existed since the end of the 19th century (Karsten 1868). Liro (1917) and Grotenfelt (1922) informed farmers of the importance of destroying smut and other disease-causing fungi from cereal seed. Since then, the methods to control plant diseases have developed considerably

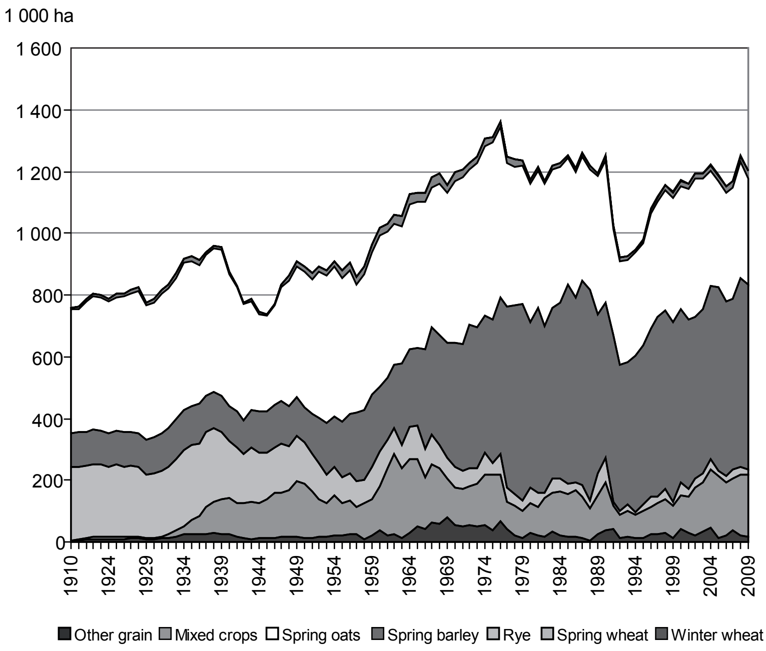

Fig. 1. The area of cereal crops cultivated in Finland in 1910–2009 (Tike 2010).

and have concentrated on various important plant diseases at different times. Currently, 73% of Finnish farmers treat cereal fields with fungicides annually (Mäenpää 2010). The sale of fungicides in agriculture (in active ingredients) increased from 18 tonnes to 158 tonnes between 1953 and 2008 (Evira 2010). At the same time, there has been substantial development in disease resistance breeding (Jalli 2010).

Pest surveys recognise the changes of pest status in time and also identify the indigenous and non-indigenous pest species. In Finland, the pest surveys are made on weeds (Salonen et al. 2011) and on insects (Vappula 1962). Previous survey on cereal leaf spot pathogens in Finland was conducted by Mäkelä (1975a,b). The aim of this study was to evaluate the current state of cereal leaf diseases in Finland with reference to historical and current research data. The questions addressed were: i) which cereal pathogen species have been identified in Finland; and ii) what is the incidence and distribution of the main leaf spot diseases in the Finnish spring cereal fields? The objective was to get a base for better understanding on the possible risks caused by plant pathogens in the Finnish cereal production. The updated information on the incidence of pathogens and their distribution is in the key role in advisory services, in developing novel durable plant protection methods and in disease resistance breeding strategies for future needs.

Material and methods

The first part of this study, based on literature survey, is an evaluation of the earliest records on cereal fungal pathogens diagnosed in Finland. The earliest available references on pathogen occurrence and collection year were surveyed. The literature is published mainly in Finnish. In this study, the pathogen names were changed to common names recommended by Species Fungorum (2010).

In the second part, we studied the incidence and distribution of cereal leaf spot diseases in spring barley, spring wheat and oats in Finland in 2009. The disease survey was co-organized with a weed distribution study (Salonen et al. 2011) and by ProAgria Rural Advisory Centres in order to cover the main cereal production area (Fig. 2). The total number of investigated fields was 107 in barley, 84 in spring wheat, and 64 in oats. The selected fields represented the most common cereal cultivars grown in Finland under both ploughed and reduced tillage systems, as well as for conventional and organic farming.

Leaf samples were collected between flowering and milk ripening growth stages from mid-July till early August. For 10 sites per field, 10 leaves were collected from 10 randomly selected plants; 100 leaves per field in total. The aim was to collect the oldest green leaves, usually the second or third leaf from the apex.

The leaves were dried and pressed between tissues immediately after collection. The visual symptoms were recorded for all dried leaves. The pathogen identifications were made using the agar plate method (barley and oat) or a PCR-test method (wheat). The oat and barley leaf tissues with lesions were surface sterilized in 50% ethanol for 15 s and in 2% NaOCI for 30 s, and then rinsed with distilled water and placed on water agar in sterile Petri dishes. Petri dishes were kept under near UV light and a 12:12 h L:D photoperiod at 18° C for 7–14 days. The pathogens were identified using a light microscope. From wheat samples, *Stagonospora nodorum* (stagonospora leaf blotch), *Pyrenophora tritici-repentis* (tan spot) and *Mycosphaerella graminicola* (septoria tritici leaf blotch) were identified using a specific PCR-test method as described by Jalli et al. (2011).

Results

Literature survey

Based on the literature study, 57 plant pathogens causing cereal diseases in Finland have been reported to date (Table 1). In 25 cases, the data for collection year were not available. Reports were published

Vol. 20(2011): 62–73.

Table 1. Cereal fungal pathogens reported in Finland.

Plant disease	Causal agent		Collection year for the first reported occurence in Finland	First reference of the occurence of the pathogen in Finland
	Anamorph	Teleomorph		
Leaf spot diseases				
Ascochyta leaf spot	*Ascochyta avenae* (Petr.) R. Sprague & Aar.G. Johnson			Liro 1917
Dilophospora leaf spot	*Dilophospora alopecuri* (Fr.) Fr.			Liro 1917
Septoria tritici leaf blotch	*Septoria tritici* Roberge in Desmaz	*Mycosphaerella graminicola* (Fuckel) J. Schröt.	1972	Liro 1917
Stagonospora leaf blotch	*Stagonospora avenae* (A.B. Frank) Bissett*	*Phaeosphaeria avenaria* f.sp. *avenaria* O.E. Erikss.**	1971**	Liro 1917*, Koponen and Mäkelä 1975**
Stagonospora leaf blotch	*Stagonospora nodorum* (Berk.) E. Castell. & Germano*	*Phaeosphaeria nodorum* (E. Müll.) Hedjar.**		Liro 1917*, Mäkelä 1972**
Septoria leaf blotch of rye	*Septoria secalis* Prill. & Delacr			Mäkelä 1975b
Oat leaf spot	*Drechslera avenae* (Eidam) Scharif	*Pyrenophora chaetomioides* Speg.		Liro 1917
Barley stripe	*Drechslera graminea* (Rabenh. ex Schltdl.) Ito	*Pyrenophora graminea* S. Ito & Kurib.		Liro 1917
Barley net blotch (net type)	*Drechslera teres* f. *teres* (Sacc.) Shoemaker	*Pyrenophora teres* f. *teres* Drechsler		Liro 1917
Scald	*Rhynchosporium secalis* (Oudem.) Davis		1965	Talvia 1966
Spot blotch	*Bipolaris sorokiniana* (Sacc.) Shoemaker	*Cochliobolus sativus* (S. Ito & Kurib.) Drechsler ex Dastur	1967-1970	Mäkelä 1971
Tan spot	*Drechslera tritici-repentis* (Died.) Shoemaker	*Pyrenophora tritici-repentis* (Died.) Drechsler	1967-1970	Mäkelä 1971
Ascochyta leaf spot	*Ascochyta hordei* Hara		1970-1971	Mäkelä 1972
Barley net blotch (spot type)	*Drechslera teres* f. *maculata* Smed.-Pet.	*Pyrenophora teres* f. *maculata* Smed.-Pet.	1970-1971	Mäkelä 1972
Cephalosporium stripe	*Hymenula cerealis* Ellis & Everh.			Kurtto 1998
Ramularia leaf spot	*Ramularia collo-cygni* B. Sutton & J.M. Waller		2001	Oxley et al. 2010
Rusts and mildew				
Oat crown rust	*Puccinia coronata* Corda			Lindroth 1898b
Stem rust	*Puccinia graminis* Pers.			Lindroth 1898b
Leaf rust of barley	*Puccinia hordei* G.H. Otth			Lindroth 1898b
Leaf rust of wheat	*Puccinia recondita* Dietel & Holw.			Lindroth 1898b
Stripe rust	*Puccinia striiformis* Westend			Lindroth 1898b
Powdery mildew	*Blumeria graminis* (DC.) Speer			Liro 1917
Black head mold	*Davidiella tassiana* (De Not.) Crous & U. Braun			Liro 1917
Root, stem and head diseases, snow molds				
	Fusarium sp.			Liro 1917
Head blight/root and stem diseases	*Fusarium culmorum* (Wm. G. Smith) Sacc.		1928	Rainio 1930
Head blight/root and stem diseases	*Fusarium graminearum* Schwabe	*Gibberella zeae* (Schwein.:Fr.) Petch	1938	Jamalainen 1943a
Head blight/root and stem diseases	*Fusarium sambucinum* Fuckel	*Gibberella pulicaris* (Fr.) Sacc.	1938	Jamalainen 1943a

Table 1. continuing

Plant disease	Causal agent		Collection year for the first reported occurence in Finland	First reference of the occurence of the pathogen in Finland
	Anamorph	Teleomorph		
Head blight/root and stem diseases	*Fusarium avenaceum* (Fr.:Fr.) Sacc.	*Gibberella avenacea* R.J. Cook	1938	Jamalainen 1943b
Head blight/root and stem diseases	*Fusarium poae* (Peck) Wollenw		1938	Jamalainen 1943b
Head blight/root and stem diseases	*Fusarium solani* (Mart.) Sacc.	*Haematonectria haematococca* (Berk. & Broome) Samuels & Rossman	1938	Jamalainen 1943b
Head blight/root and stem diseases	*Fusarium sporotrichioides* Sherb.		1938	Jamalainen 1943b
Head blight/root and stem diseases	*Fusarium tricinctum* (Corda) Sacc.	*Gibberella tricincta* El-Gholl, McRitchie, Schoult. & Ridings	1938	Jamalainen 1943b
Head blight/root and stem diseases	*Fusarium arthrosporioides* Sherb.		1938	Jamalainen 1944
Head blight/root and stem diseases	*Fusarium detonianum* Sacc.		1938	Jamalainen 1944
Head blight/root and stem diseases	*Fusarium oxysporum* Schltdl		1938	Jamalainen 1944
Head blight/root and stem diseases	*Fusarium equiseti* (Corda) Sacc.	*Gibberella intricans* Wollenw	1946-1953	Hårdh 1953
Head blight/root and stem diseases	*Fusarium moniliforme* J. Sheld	*Gibberella fujikuroi* (Sawada) Wollenw.		Korpinen and Ylimäki 1972
Head blight/root and stem diseases	*Fusarium chlamydosporum* Wollenw. & Reinking		1966-1968	Uoti and Ylimäki 1974
Head blight/root and stem diseases	*Fusarium incarnatum* (Desm.) Sacc.		1975-1978	Mäkelä and Mäki 1980
Head blight/root and stem diseases	*Fusarium langsethiae* Torp & Nirenberg		2001	Yli-Mattila et al. 2004
Take-all	*Phialophora* sp.	*Gaeumannomyces graminis* (Sacc.) Arx & D.L. Olivier	1910	Reuter 1912
Eyespot	*Pseudocercosporella herpotrichoides* (Fron) Deighton	*Oculimacula yallundae* (Wallwork & Spooner) Crous & W. Gams	1946-1953	Hårdh 1953
Rhizoctonia root rot	*Rhizoctonia solani* J.G.Kühn	*Thanatephorus cucumeris* (A.B. Frank) Donk	1963-1968	Talvia 1970
Root rot	*Wojnowicia hirta* Sacc		1975-1977	Mäkelä 1979
Rhizoctonia root rot	*Rhizoctonia cerealis* E.P. Hoeven	*Ceratobasidium cereale* D.I. Murray & Burpee	1979-1983	Hannukkala 1985
Typhula blight	*Typhula idahoensis* Remsberg / *Typhula ishikariensis* S. Imai			Karsten 1868
Snow mold	*Microdochium nivale* (Fr.:Fr.) Samuels & I.C. Hallet	*Monographella nivalis* (Schaffnit) E. Müll.	1938	Liro 1917
Typhula blight	*Typhula incarnata* Lasch			Liro 1917
Sclerotinia snow mold	*Sclerotinia borealis* Bubák & Vleugel			Maatalouskoelaitos 1951
Ergot	*Sphacelia segetum* Lév.	*Claviceps purpurea* (Fr.) Tul.		Lindroth 1899
Anthracnose	*Colletotrichum graminicola* (Ces.) G.W. Wilson	*Glomerella graminicola* D.J. Politis	1975-1978	Mäkelä and Parikka 1980
Smuts				
Rye stalk smut	*Urocystis occulta* (Wallr.) Rabenh.		1887	Lindroth 1898a
Common bunt	*Tilletia caries* (DC.) Tul. & C. Tul.			Liro 1914
Common bunt	*Tilletia laevis* J.G. Kühn			Liro 1914
Oat loose smut	*Ustilago avenae* (Pers.) Rostr.			Liro 1915
Covered smut in barley and oats	*Ustilago hordei* (Pers.) Lagerh.			Liro 1915
Barley loose smut	*Ustilago nuda* f.sp. *hordei* Schaffnit			Liro 1915
Wheat loose smut	*Ustilago nuda* f.sp. *tritici* Schaffnit			Liro 1915

Vol. 20(2011): 62–73.

between 1917 and 2010 for cereal leaf spot diseases. The most recent report is on *Ramularia collo-cygni*. The rusts, powdery mildew and smuts were all reported between 1898 and 1917. The reports on the occurrence of different root, stem and head diseases, and snow moulds, originate from 1868 to 2004. The most recent pathogens to emerge are *Fusarium langsethiae* and *Ramularia collo-cygni*.

Field survey

The causal agents of fungal leaf spot diseases identified in the 2009 field survey were: *Pyrenophora teres* (net blotch), *Cochliobolus sativus* (spot blotch) and *Rhynchosporium secalis* (scald) in barley, *Stagonospora nodorum*, *Pyrenophora tritici-repentis* and *Mycosphaerella graminicola* in spring wheat and *Pyrenophora chaetomioides* (oat leaf spot), *Cochliobolus sativus,* and *Stagonospora avenae* in oats. Minor powdery mildew infections were identified on wheat and barley, and yellow rust infection was observed in one wheat field.

Two of the 107 barley fields studied had no identified plant pathogens on the sampled leaves, and 46 fields carried all three barley pathogens. Disease symptoms were observed on 95% of the collected leaves. *P. teres* was present in 86 % (Fig. 3a), *C. sativus* in 90% (Fig. 3b) and *R. secalis* in 52% (Fig. 3c) of the investigated fields.

Based on the PCR-test, only one of the studied 84 spring wheat fields had none of the tested pathogens. No visual symptoms were observed in that field either. A positive PCR-result was obtained from 15% of the samples that had no clear visual symptoms. Five of the fields were infected by all three pathogens. Disease symptoms were observed on 92% of the collected leaves. *S. nodorum* was present in 98% (Fig. 3d), *P. tritici-repentis* in 94% (Fig. 3e) and *M. graminicola* in 6% (Fig. 3f) of the investigated fields.

Oat fields had the fewest fungal diseases. 26% of the tested fields had no fungal infection. 27% of the studied oat leaves were totally symptomless. *P. chaetomioides* was present in 63% (Fig. 3g), *C. sativus* in 25% (Fig. 3b), and *S. avenae* in 3% of the investigated fields.

Discussion

The main outcome of the literature study was the list of plant pathogens identified on cereals in Finland. Mention of the first report is missing in most cases, except for the most recently identified diseases, *Fusarium langsethiae* and *Ramularia collo-cygni*. Some of the papers reported the first observation of the sexual stage of the pathogen, including *Phaeosphaeria avenaria* f.sp. *avenaria* and *Phaeosphaeria nodorum*.

The most recently identified cereal pathogens in Finland, *F. langsethiae* on barley and oats, and *R. collo-cygni* on barley, are considered to be emerging pathogens also in Europe (Walters et al. 2008; Torp and Nirenberg 2004). *F. langsethiae* may cause serious problems, mainly because of its toxin production. Since 2004, it has been detected in Finnish barley and oat fields annually (Parikka, P., MTT, personal communication). In contrast, even though *R. collo-cygni* is recognized as an important pathogen of barley in Northern Europe and New Zealand (Walters et al. 2008), and has been identified in Finnish barley field already since 2001, it has not yet caused any epidemics in Finland (Jalli, unpublished data).

As Mäkelä (1975b) concluded, the time of identification of a pathogen on cereals does not correlate with its history on wild plants in Finland. Most of the leaf spot disease causal agents, like *Stagonospora* species and *R. secalis*, have been isolated from numerous cultivated and wild grass species (Mäkelä 1974; Mäkelä 1975b). Plant pathogens are assumed to have co-evolved from their original host to their modern hosts during domestication thousands of years ago. This is shown, for example, with *M. graminicola* (Stukenbrock et al. 2007) and *R. secalis* (Zaffarano et al. 2008). Therefore, caution is needed when drawing conclusions on emergence of a specific pathogen. Instead, based on the literature, we can estimate which plant

Fig. 2. The area for the cereal leaf spot disease survey conducted in Finland.

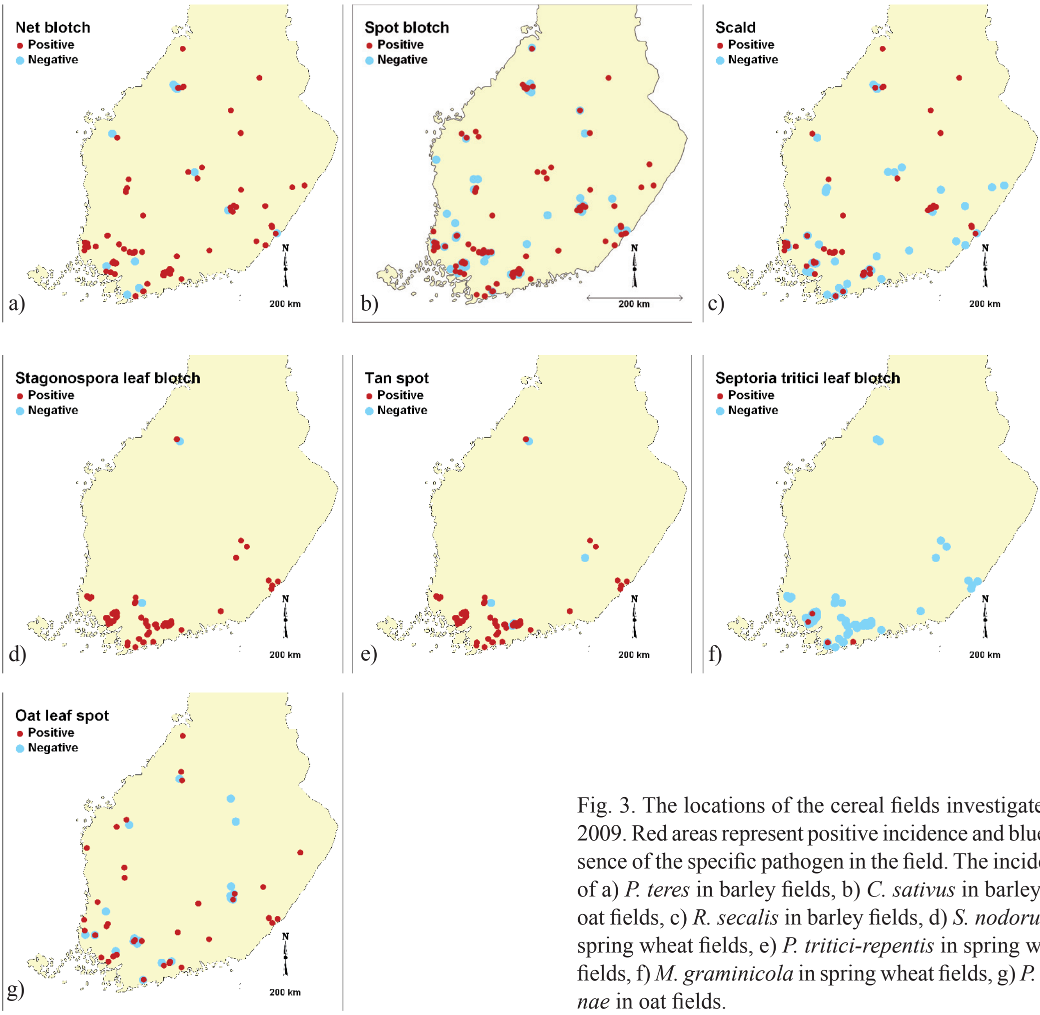

Fig. 3. The locations of the cereal fields investigated in 2009. Red areas represent positive incidence and blue absence of the specific pathogen in the field. The incidence of a) *P. teres* in barley fields, b) *C. sativus* in barley and oat fields, c) *R. secalis* in barley fields, d) *S. nodorum* in spring wheat fields, e) *P. tritici-repentis* in spring wheat fields, f) *M. graminicola* in spring wheat fields, g) *P. avenae* in oat fields.

Vol. 20(2011): 62–73.

pathogens have been significant in Finnish cereal production at different times.

Even though the year of emergence of different fungal species on cereals in Finland is usually missing, the significance of different diseases at various times is illustrated in an interesting way in the literature. In the early 20th century, the literature concentrated on smut and rust diseases while towards the end of the century the focus was more on leaf spot diseases. In general, the earliest publications reported most about identification and taxonomy of fungi while the later ones informed on applied research results on the importance and control methods of the diseases. Some of the papers published already at the beginning of the 20th century are relevant today, such as that published by Pesola (1927) on the resistance of spring wheat cultivars to yellow rust. Currently yellow rust and host-plant resistance are again subjects of special interest in Europe and other parts of the world (Hovmøller 2008). There is a similar phenomenon with stem rust. After the heavy stem rust epidemics in Northern Europe in 1951 (Jamalainen 1953) this disease was rare or of minor importance in Finnish cereal fields until recent years (Jalli, unpublished data).

The disease survey, made on spring cereals in 2009, represents an opportunity to compare the changes in incidence and distribution of leaf spot diseases in Finland. Forty years ago, in 1971–1973, a similar type of survey was made for cereals (Mäkelä 1974; Mäkelä 1975a: Mäkelä 1975b). The surveys were made on the same crops covering the same cultivation areas. In barley and in oats, the causal agents were identified with methods comparable to each others.

For barley, the frequency of fields infected by leaf spot diseases increased during the last 40 years. The incidence of *P. teres* infected fields has increased from 60 to 86%, *C. sativus* infected fields from 30 to 90%, and in *R. secalis* infected fields from 30 to 52%. In contrast, *Pyrenophora graminea* that was found in 30% of the fields in 1971–1973 was absent in the fields studied in 2009.

P. teres, *C. sativus* and *R. secalis* survive in straw debris and are favoured by barley monoculture, while *P. graminea* is controlled using healthy or dressed seed (Mathre 1997). During the past 40 years, the barley growing area has increased 50% from 403 500 ha to 600 700 ha. At the same time, the total cultivated area has decreased from 2 526 400 ha to 2 026 800 ha (Matilda 2010a), which means that the possibilities for crop rotation have lessened. Barley monoculture together with the increase in no- or reduced tillage cultivation area in Finland (MAVI 2009) represent a risk for increase in straw-borne pathogen incidence. However, the data presented in this paper illustrate only the incidence, not the severity of different pathogens.

Efficient control methods, the active use of fungicides (Mäenpää 2010) and the moderate resistance level of Finnish barley cultivars (Kangas et al. 2009), all play a role in keeping the level of yield losses to a minimum. However, at the same time, large effective population sizes pose a risk of cancelling out efficient control methods (McDonald and Linde 2002). There is evidence that sexual recombination may also be influenced by climate change and milder winters (Garret et al. 2006). A recombinant pathogen can rapidly assemble new combinations of virulence alleles (McDonald and Linde 2002). In addition to surveys on the incidence of plant pathogens, surveys on virulence are needed when studying the emergence of plant pathogens. In Finland, no change in the virulence of *P. teres* f. *teres* has been observed during the last 15 years (Jalli 2010).

In spring wheat, the frequency of both *S. nodorum* and *P. tritici-repentis* infected fields has increased over 40 years. The number of *S. nodorum* infected fields has risen from 60–70 to 98% and *P. tritici-repentis* infected fields from 30 to 94%. In the study by Mäkelä (1975b), *M. graminicola* was only observed in winter wheat. In this study, *M. graminicola* was identified on spring wheat in Finland for the first time. The positive samples originated from South-West and Southern Finland.

During the last 40 years, the wheat cultivation area has increased by 25%, spring wheat covering 90% of the wheat growing area (Matilda 2010a). *S. nodorum* was considered the main wheat pathogen in Finland till 2004 when the first epidemics of *P. tritici-repentis* were observed (Laine and

Jalli 2005). There is evidence that one reason for rapid increase of *P. tritici-repentis* is the practice of wheat monoculture combined with no-tillage cultivation (Huusela-Veistola et al. 2008). Moreover, *P. tritici-repentis* has been recorded in 50% of the studied Finnish *Agropyron* (*Elymus*) *repens* samples (Mäkelä 1971), a weed present in 30% of the spring cereal fields in Finland (Salonen et al. 2011). *P. tritici-repentis* is a fungus that became pathogenic on wheat only recently in comparison with other leaf spot diseases. Friesen et al. (2006) provided evidence that a gene encoding a virulence factor was transferred from *S. nodorum* to *P. tritici-repentis* probably in the beginning of 1950s. This horizontal gene transfer significantly enhanced virulence and led to the emergence of a new disease of wheat.

M. graminicola has been relatively common on winter wheat tillers in early spring, but the disease has rarely developed further under Finnish conditions (Kurtto et al. 2005). However, since 2006, *M. graminicola* has also been observed on the upper leaves of winter wheat later in the growing season (Jalli et al. 2007). Furthermore, in other parts of Europe, the importance of Septoria tritici blotch, caused by *M. graminicola*, has increased particularly during the last decade, being currently the most important wheat disease in Europe (Kema et al. 2008). Contrary to *P. tritici-repentis, M. graminicola* is an ancient pathogen of wheat. The genetic data provide evidence that the domestication of an agricultural crop was accompanied by the domestication of a wheat-adapted fungal pathogen from a population infecting wild grasses in the Middle East approximately 10,500 years ago (Stukenbrock et al. 2007). The recent growth in the incidence of *M. graminicola* may partly be explained by the changes in climate as well as the increase in wheat growing area. Similar phenomenon has been observed with potato late blight epidemics in Finland. Earlier outbreaks of the potato late blight epidemics were associated with a climate more conducive to the disease and the lack of rotation (Hannukkala et al. 2007).

In oats, the incidence of *P. avenae* (observed in about 60% of the oat fields both in 1971–1973 and 2009) has remained stable during the past 40 years. Also *C. sativus* was moderately common in oats already in the previous study. In contrast to wheat and barley, the cultivation of oat has decreased 35% since 1970s (Matilda 2010a).

The information on the incidence of cereal leaf diseases in Finland is based on a survey made in one cropping season and reflects the situation under that season's environmental conditions. The PCR-based diagnostic method to identify wheat pathogen species is very sensitive compared with the agar-plate method used by Mäkelä (1975b). However, it is evident that the cereal leaf spot diseases have more importance today than they had 40 years ago. In Mäkelä's studies both *S. nodorum* and *M. graminicola* were considered to be of minimum importance and were observed most commonly in the southern parts of the country, while in our studies *S. nodorum* and *P. tritici-repentis* were common at all locations. *P. teres*, *C. sativus* and *R. secalis* were of minor significance in barley until the early 1970s while the seed-borne pathogen *P. graminea* was dominant in barley fields (Mäkelä 1972). Now the situation has become reversed. The low incidence of *P. graminea* is related to the increase in barley seed treatment. In 2009, 46% of the cereal seed was fungicide treated in Finland. Approximately 75% of the farmers use fungicide treated barley seed (Markkula, A., Syngenta, personal communication).

As a plant disease is an interaction of several components, the role of different factors in the complex function may only be discussed. A common factor affecting the plant pathogens' environment, besides climatic conditions, is the increased cultivation of susceptible host plants. Huusela-Veistola and Jauhiainen (2006) concluded that the risk of pea moth infestation increases if regional cropping area and frequency of pea cropping increases. Planting large areas of susceptible cultivars would increase the infection pressure exerted on other cultivars (Bingham et al. 2008). The wheat cultivars grown in Finland are only moderately tolerant (Kangas et al. 2009) to leaf spot diseases and the resistance level of barley has increased only during the last 15 years (Jalli 2010).

Our field study concentrated on fungal leaf spot diseases of cereals. However, there is evidence for

Vol. 20(2011): 62–73.

the increased importance of *Fusarium* head blight (Parikka et al. 2010) and rusts (Jalli, unpublished data) on wheat, barley and oats. Stem diseases are important cereal pathogens in Finland (Hannukkala 1985). Also, the insect-transmitted virus diseases are becoming increasing relevant in Finnish cereal production. A recently emerged virus disease is wheat yellow dwarf virus (WYDV) on winter wheat (Lemmetty and Huusela-Veistola 2005). Even though novel pathogen species emerge rarely, the existing hosts and pathogens continuously interact, which may lead to novel virulence if no precautions are taken. Research on pathogen-host interactions, monitoring, risk assessments, multiprotection using cultural practices, crop rotation, durable resistant plants, fungicide used only when needed, and global cooperation among researchers and breeders, are the main strategies to avoid, or to minimize the impact of plant diseases in cereal production.

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Vol. 20(2011): 62–73.

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