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The occurrence and severity of rust diseases of winter rye in Estonian climatic conditions

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Abstract. This paper presents a six-year study (2000–2005) of rusts on 11 winter rye varieties in Estonian conditions. Environmental factors may be related to occurrence of different pathogens causing rye diseases. The aim of the study was to analyse the influence of environmental factors on the occurrence of rust diseases on rye. Visual assessments of *Puccinia recondita* at inflorescence emergence (GS 50) and *Puccinia graminis* at milk ripening stage (GS 75) under natural infection conditions were carried out. As to average of the years, trial results demonstrated quite moderate infection level in the field conditions at the Jõgeva Plant Breeding Institute (PBI). The year's climatic conditions had significant influence on the occurrence of stem rust. The impact of year to leaf rust was insignificant. Genotype had an insignificant effect on stem and leaf rust. Stem rust correlated highly with year and variety – R^2 = 70.3%, $p < 0.001$. Neither year nor variety had any impact on the occurrence of leaf rust (R^2 = 40.6%).

Key words: winter rye, disease severity, leaf rust, stem rust

INTRODUCTION

In Estonia, winter rye (*Secale cereale* L.) is sown every year, and the main users of the grain are bakeries and spirit producers. For several reasons, the area under rye decreased from 28.9 thousand hectares in 2000 to 7.4 thousand hectares in 2005. At the same period, the average yield of winter rye fluctuated between 1530 and 2750 kg ha^{-1} (Statistcs Estonia).

The presence and severity of a plant disease is determined by the dynamic interaction of the host, pathogen and environment (Cook et al., 1999; Krupinsky et al., 2002). Disease control of rye depends mainly on the genetic resistance of the variety and the agro-technical practices, including crop rotation and tillage to bury crop residue (Starzycki, 1976; Lõiveke, 2004). Increasing use of reduced-tillage and cereal-rich crop rotations in Estonia may influence the development of residue-born pathogens. According to Krupinsky et al. (2002), using disease-free seeds of more resistant varieties reduces the impact of diseases because the incidence and severity of a disease in the field decreases significantly. In general, experts agree that foliar diseases are an important cause of the yield losses of winter rye (Hardwick et al., 2001; Krupinsky et al., 2002). The occurrence and severity of major rye pathogens, *Puccinia recondita* causing leaf rust and *Puccinia graminis* causing stem rust varies from year to year in Estonia. These diseases are the most infectious during heading and grain filling stages of rye development.

Winter rye varieties are generally found to be susceptible to leaf rust (Miedaner, 2007). Air-borne urediospores of leaf rust survive the harvest period on late tillers, which are the main source of infection. Spreading from there or from volunteer plants, they infect rye already in autumn, after sowing. Leaf rust infection is related to sowing time. In Finland for example, rye sown in the beginning of September (compared to sowing in the second part of August) is less infected by leaf rust (Serenius et al., 2005). Tupits (2007) recommends the same sowing time for Estonia. At the end of the vegetation period, telia develop and fungus hibernates on rye plants (Nyvall, 1979; Zillinsky, 1983). In spring, leaf rust develops fast in dewy conditions. Optimum temperature for rust sporulation is around 15–20ºC. In Estonia, yield loss caused by high infection rate may reach 5–10% (Lõiveke, 1999).

Stem rust develops fastest at the air temperature of 20ºC and high humidity. Pustules of stem rust usually begin to appear in June and increase in number until the grain is ripe. Rust symptoms develop most commonly on stems and leaf sheaths but leaf blades and spikes may also be infected (Starzycki, 1976). Heavy dew in the evenings that dries up during the day favours the infection and spreading of the pathogen (Zillinsky, 1983; Mathre, 1997). The main hosts of stem rust fungus are grasses and barberry (Starzycki, 1976). Where stem rust is severe, rye seeds are shrivelled and lightweight compared to healthy seeds from rust-free plants, although the number of seeds is the same (Stem Rust…, 1991). In Estonia, early infection may cause the reduction of yield by about 5–10% (Lõiveke, 1999).

This paper presents the results of the field experiments conducted at the Jõgeva PBI. We studied the effects of two fungal diseases on winter rye varieties over the years (2000–2005) in natural infection conditions. The main objectives of this study were to investigate the winter rye primary field infection, assess the susceptibility of different winter rye varieties, and compare the variability of infection during a time period. The second objective was to get valuable information by assessing the effect of different environmental factors (precipitation, temperature) and examined their correlation to infection level. There is major scope for better exploitation of genetic resources, which should include a constant focus from breeders and scientists in search of new sources of resistance as well as annual testing of all major varieties to provide updates on any change in virulence.

MATERIALS AND METHODS

The field trials made at Jõgeva, involved six growing seasons (2000–2005) and were seeded on podzolized soddy-calcareous soil (pH_{KCl} 6.5) by FAO-UNESCO classification (Kask, 1995). The following 11 varieties were included: the hybrid rye varieties Esprit, Picasso (Germany), and the population varieties Hacada (Germany), Elvi, Tulvi, Vambo and Sangaste (Estonia), Akusti, Riihi, Anna and Kartano (Finland). 290 kg ha^{-1} of complex fertilizer Kemira Skalsa ($N_0P_{12}K_{24}$) was applied according to the soil analyses before sowing. In spring, after the onset of plant growth, depending on the condition of the stand, 100–150 kg ha^{-1} of ammonium nitrate ($N_{34\text{-}51}$) was added. Non-treated seeds were sown after black fallow in four replications in early September, using a completely randomized block design according to the Nearest Neighbour Analyses method (NNA). The optimal sowing time for winter rye is from August 25 to September 10 in Estonia. Sowing rate was 500 germinating seeds per m² and the trial plot size was 10 m². The assessments of diseases' severity were carried out on ten randomly chosen tillers per plot in four replications. Visual scoring was made in 1–9 points (1–no infection, 9–highly infected) by inspecting the whole plant after inflorescence emergence (GS 50) of leaf rust, and at milk ripening stage (GS 75) of stem rust on stems. Phenological growth stages were determined according to BBCH–identification keys of cereals (Zadoks et al., 1974) when > 50% of the plants had reached the target growth stage.

The database management and analysis system Agrobase, software solution for plant breeders, helped to perform the analyses of variance (ANOVA) of the data (Agrobase™ 20, 1999). The impact of years on disease severity in different genotypes was of principal interest. Analyse of variance was used to examine the significance ($LSD_{0.05}$) between the averages for varieties and years. Correlation matrix was used to describe dependency between diseases and weather conditions.

RESULTS AND DISCUSSION

In Estonia, the vegetation period of rye usually begins in the middle of April and the harvest at the end of July or in early August. Field meteorological station Metos Compact recorded the weather data from the beginning of the vegetation period to the harvest. Weather conditions during the trial periods varied considerably (Table 1).

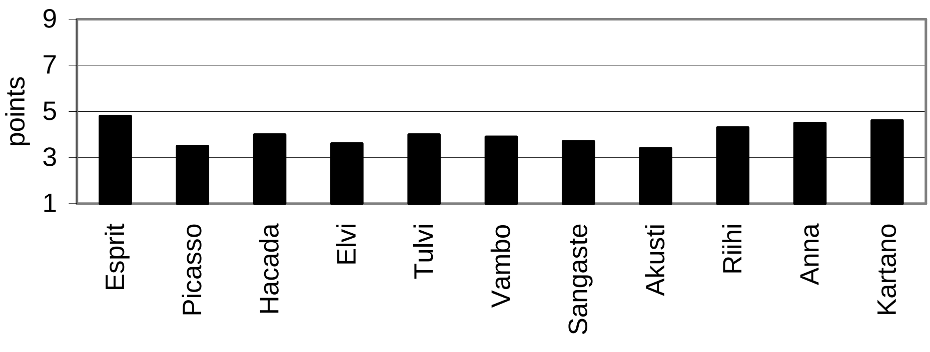
Table 1. Cumulative sum of effective temperatures and precipitation of 2000–2005 by ten-day periods compared to long-term (1922–2005) averages from May to July.

Effective temperature sum	May			June			July			
	10	20	31	10	20	30	10	20	31	Σ
2000	42	63	91	68	84	117	104	115	126	810
2001	76	54	37	72	82	120	151	156	168	916
2002	93	69	89	112	117	95	131	148	150	1003
2003	47	59	96	83	68	91	118	143	187	891
2004	103	25	45	78	72	95	98	109	143	769
2005	30	45	106	71	103	97	125	143	128	849
1946–2005	44	60	77	91	95	105	110	115	128	870
Precipitation	May			June			July			
(mm)	10	20	31	10	20	30	10	20	31	Σ
2000	1	7	60	23	13	31	46	45	36	262
2001	16	37	5	23	84	27	31	58	12	293
2002	2	6	0	5	33	70	23	0	36	175
2003	13	65	23	5	43	11	21	28	5	213
2004	3	9	4	33	46	105	14	13	41	267
2005	19	46	19	18	19	13	9	5	46	194
1946–2005	13	17	17	14	26	27	24	28	30	199

The average sum of precipitation of 60 years (1946–2005) from May to the end of July is 199 mm at the Jõgeva PBI. It is important to consider the distribution of precipitation during vegetation period, as well as evaporation. In 2003 and 2005, the sum of precipitation exceeded the long-term average in May, in 2001, 2002 and 2004; it was rainy in June and in 2000 in July. The long-term average cumulative sum of effective (over +5°C) temperatures for the same period is 870 degrees. In general, the vegetation period of 2002 was considerably drier and warmer; weather conditions in 2000, 2001, 2003, 2004 and 2005 favoured the occurrence of the diseases.

The trials demonstrated natural infection level of the rust diseases at the Jõgeva PBI. The disease symptoms observed were associated with pathogens, which occurrence and severity were influenced by weather conditions. The diversity, incidence and spread of fungal diseases increased during more humid growth periods. Visual assessments of the 11 varieties showed that the most common winter rye diseases – rusts – appeared in all growing seasons. The susceptibility of the varieties to the rust diseases varied severely by years. The influence of the diseases to the plants depended on a particular genotype.

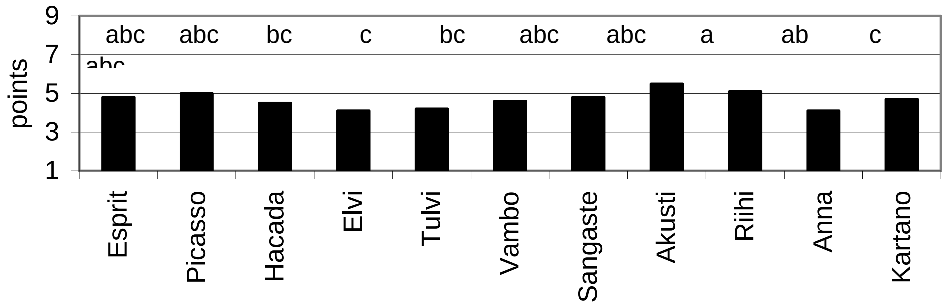
Occurrence of leaf rust. Leaf rust occurred in five years out of six. Leaf infection typically started the end of May (R^2 = 0.75) or in early June (R^2 = 0.59) and progressed during the growing season. Incidence and severity in 2000–2001 and in 2003–2005 demonstrated a very different epidemiological situation in natural conditions. In late spring 2000, before and at heading time of winter rye, there were relatively cool nights and heavy dew covered rye leaves. Also, showers occurred frequently during daytime. Dense and wet foliage provided good conditions for the spread of rust. Infection was moderate in 2001, 2003 and 2004, although conditions for disease spreading were favourable. Conditions for disease development were different in 2005, when the infection occurrence was low until the end of the growing period. Only slight signs of infection were observed during the dry and warm summer of 2002. As to the five years adjusted average, all the varieties were susceptible to leaf rust and there were no significant differences (p > 0.05) between the varieties (Fig. 1).



$LSD_{0.05}$=1.39 (variety)

Figure 1. Adjusted average infection of *P. recondita* on different rye varieties by ANOVA at the Jõgeva PBI in 2000–2005. No significant differences (p > 0.05) between varieties were found.

Occurrence of stem rust. There was a strong but insignificant correlation between precipitation in late May and stem rust ($R^2 = 0.76$) The symptoms extended frequently along the whole length of the stems. The infection was severe in 2000. High level was recorded in 2005. Although the weather was warm and dry, there were foggy nights during the grain formation stage, which favoured development and dispersion. During the droughty and warm vegetation periods of 2002 and droughty spring of 2003, only moderate infection occurred for all the varieties. Stem rust incidence was low in 2004. There was no infection in 2001. The adjusted average infection of the varieties Akusti, Riihi, Picasso, Esprit, Sangaste and Kartano was higher; Vambo, Hacada, Tulvi, Elvi and Anna were less infected during the investigated period. Bars on the figure not sharing a common letter were significantly different at $p < 0.05$ (Fig. 2).



$LSD_{0.05}$=0.98 (variety)

Figure 2. Adjusted average infection of *P. graminis* on different rye varieties by ANOVA at the Jõgeva PBI in 2000–2005. Bars not sharing a common letter were significantly different ($p < 0.05$).

The influence of year, variety and joint effect of variety by year (ANOVA) on infection severity are shown in Table 2. Focusing on pathogen data, it was confirmed that the year's climatic conditions had a significant influence on the occurrence of stem rust. The impact of the year to leaf rust was insignificant. Genotype had an insignificant effect on stem and leaf rust. Stem rust correlated highly with year and variety – $R^2 = 70.3\%$ $p < 0.001$. Neither year nor variety had any impact on the occurrence of leaf rust ($R^2 = 40.6\%$).

Table 2. Infections of winter rye varieties by *Puccinia recondita* and *Puccinia graminis* at different variation sources (ANOVA).

Source of variation	*P.recondita*	SED (df)	*P.graminis*	SED (df)
Year	8.85 ns	0.59 (4)	21.76***	0.39 (4)
Variety	6.27 ns	0.87 (10)	6.19 ns	0.58 (10)
Year by variety	25.46 ns	1.95 (40)	42.39*	1.29 (40)
R^2	0.4058		0.7034	

*** – significant at 0.001; * – significant at 0.05; ns – insignificant

Most authors consider climatic factors as being of vital influence on natural infection background (Starzycki, 1976; Priilinn & Peuša, 1993; Lõiveke & Tammaru, 1995; Lõiveke, 1999; Cook et al., 1999; Hardwick et al., 2000; Hovmoller, 2001; Krupinsky et al., 2002; Deacon, 2006). Hardwick et al. (2001) found evident differences in the degree of susceptibility of varieties in response to infections and a positive correlation between the incidence of foliar diseases with the air temperature and amount of precipitation during the period from sowing to yield formation. The results of our tests confirm this assertion, but because of relatively short period of research, the correlation found was insignificant. Each disease can tolerate a wide range of weather conditions, but they may become more severe when the weather conditions are most suitable for their development and spread. Milder winters and increasing amount of precipitation due to climate changes in our region may force appearing of rye diseases during vegetation period. As expected, it was found that the intensity of disease infection depended on the weather conditions of the year more than on the resistance of the variety. Weather conditions during vegetation periods of our trials were diverse. For example, humid and relatively warm weather favoured the development and spread of diseases and a period of hot and dry weather, as in 2002, stopped the development of the diseases.

Goncharenko (2007) claims, as diseases rarely cause substantial economic damage, winter rye usually needs no treatment with fungicides. Cultivation of varieties with high yielding capacity, such as hybrid varieties, is successful in Estonia when chemical treatment is used to prevent plant diseases. By spraying rye with fungicides, it is possible to protect the potential yield of susceptible or moderately resistant varieties. In Estonia, the high price of seeds and poor winter hardiness of hybrid varieties are the main reasons for the non-profitability of cultivation of those varieties. Growers need to develop an integrated approach combining seed quality, variety resistance and use of fungicides. Cultivation of more resistant varieties provides the environmentally most safe, reliable, and cost effective mean of controlling rust diseases. Healthy crop ensures good quality and quantity of grain yield (Starzycki, 1976; Lõiveke & Tammaru, 1995). The data presented in this paper and information obtained on the response of different varieties to pathogenic fungi and evaluation of the varieties' disease intensity are especially valuable, and of prime importance in crop improvement or/and selection of donor varieties for rye breeding.

CONCLUSIONS

The results of six-year (2000–2005) field experiment demonstrated natural infection level of the rust diseases at the Jõgeva PBI. The diversity, incidence and spread of leaf and stem rusts increased during more humid growth periods. The year's climatic conditions had a significant influence on the occurrence of stem rust. All the tested varieties were susceptible to leaf rust.

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