SCIENTIFIC REPORT

Results of the Czech National Ring Tests of Disease Resistance in Wheat

Jana CHRPOVÁ[1], Václav ŠÍP[1], Pavel BARTOŠ[1], Alena HANZALOVÁ[1], Jana PALICOVÁ[1], Lenka ŠTOČKOVÁ[1], Lubomír ČEJKA[1], Irena BÍŽOVÁ[2], Petr LAML[3], Tomáš NOVÁČEK[4] and Pavel HORČIČKA[5]

[1]*Research Institute of Crop Production, Prague-Ruzyně, Czech Republic,* [2]*SELTON, Ltd., Úhřetice Breeding Station, Czech Republic,* [3]*RAGT Czech, Ltd., Branišovice Breeding Station, Czech Republic,* [4]*Limagrain Central Europe Cereals, Ltd., Hrubčice, Czech Republic,* [5]*SELGEN a.s., Stupice Breeding Station, Czech Republic*

Abstract: In this contribution actual results of the Czech national ring tests of disease resistance in wheat are presented that are performed at 3–5 locations each year. Special attention was paid to possibilities of increasing resistance to rusts, powdery mildew, Fusarium head blight and brown leaf spot diseases. New sources of resistance to the above-mentioned diseases were detected and described. Achievements and prospects of wheat breeding for resistance to these diseases, as well as to other important diseases and pests (common and dwarf bunt, eyespot and stem base diseases, barley yellow dwarf virus, orange wheat blossom midge) are discussed.

Keywords: Czech Republic; diseases and pests; resistance genes; resistance sources; *Triticum aestivum* L.

Wheat breeding for disease resistance is linked with common farming systems aimed at obtaining high productivity and quality of products. Growing of susceptible cultivars that will require many pesticide applications is not undoubtedly cost effective and, besides, it is also too risky due to toxic residues. Breeding for multiple resistance to diseases has become the promising breeding strategy. At present this trend is supported by requirements for reduced production costs through the lowering of inputs, as well as by the demand for the environment and agricultural products unaffected by toxic residues. The aim of modern resistance breeding is to obtain sufficient resistance to all most important diseases rather than high resistance to one disease only, while the cost of resistance is also considered. The research linked with breeding is oriented towards the detection of resistance sources usable as prospective parents, setting of new methodology for resistance testing and effective application of molecular markers.

The aim of this paper is to provide actual information about the results obtained in the Czech national ring tests, paying attention to the most important wheat diseases, and to contribute to better characterization and utilization of wheat germplasm from these aspects.

National ring tests of disease resistance

In 2002 Czech wheat breeders and researchers initiated the establishment of national ring tests (NRT) in which now all breeding stations involved in wheat breeding and Crop Research Institute in Prague-Ruzyně (CRI) participate. Verified methods, which were described in greater detail by Šíp *et al.* (2005), are available for the field testing of resistance to stem rust, yellow rust and leaf rust, powdery mildew, Fusarium head blight and brown leaf spot diseases (caused by *Septoria tritici*, *Stagonospora nodorum* and *Pyrenophora tritici-repentis*). The tests of resistance to these diseases are usually performed at 3–5 sites each year (CRI, Prague-Ruzyně or Humpolec, SELGEN a.s., Stupice and Úhřetice, RAGT Czech Ltd., Branišovice, Limagrain Central Europe Cereals, Ltd. – LCEC, Ltd., Hrubčice). The sets of tested materials include available sources of resistance and advanced breeding lines, together with checks (more than 70 materials are tested each year). The selected cultivars and lines are also tested at 2 sites (Prague-Ruzyně and Stupice) for resistance to the barley yellow dwarf virus and at Prague-Ruzyně for resistance to common and dwarf bunt. Newly (in connection with financial support by the research project), attention is also paid to resistance to eyespot and other stem base diseases, as well as resistance to the orange wheat blossom midge. Promising materials with detected resistance to a certain disease are tested repeatedly (at least for three years) and examined for resistance to other important diseases, because multiple resistance is the major objective. With the exception of powdery mildew, where infection is natural, all other tests are performed under high infection pressure using inoculations with the pathogens. Cultivar response to the infection is usually scored on the 9-point scale basis (1 – high severity, 9 – no symptoms).

Available molecular markers are used for detection of rust resistance genes (newly also *Pch1* and *Sm1*) and the effectiveness of detected genes is evaluated in field conditions.

Genetic aspects and results of disease resistance testing

Rust diseases

Leaf rust (*Puccinia triticina* Eriks.) is an important disease of wheat that is most economically controlled by breeding for resistance. Due to the large number of different pathotypes of leaf rust, resistance breeding is a continuous process. Knowledge of virulence in the leaf rust population is a prerequisite for successful resistance breeding. Importance of international surveillance of wheat rust pathogens was recently underlined by Park *et al.* (2011). The present global status of wheat leaf rust has been newly summarized by Huerta Espino *et al.* (2011). More than 60 resistance genes have been described. Recently recorded genes originate mainly from wild grasses or bread wheat relatives.

At present the most common resistance gene for adult plant resistance in wheat cultivars grown in the Czech Republic is *Lr37*. The level of effectiveness depends upon the combination with other leaf rust resistance genes. Other *Lr* genes determined in the grown cultivars (e.g. *Lr26*, *Lr3a*) are no more effective to the prevailing leaf rust pathotypes. Resistance to leaf rust is particularly important in warmer regions like central and southern Moravia where leaf rust occurs and causes yield losses regularly.

Stem rust (*Puccinia graminis* Pers. f.sp. *tritici*). Since the last decade worldwide attention has been paid to race Ug99 endangering large areas under wheat in Africa and Asia. It is one of the most important topics in the Borlaug Global Rust Initiative (McIntosh & Pretorius 2011). New sources of resistance are searched for and lines resistant to Ug99 and its derivatives are being developed. Though stem rust was not economically important in the last decades in the Czech Republic, the devastating effect of race Ug99 shows that stem rust remains a very dangerous pathogen. At present research on stem rust is going on also in countries with a low stem rust risk like the UK or Germany. In the course of the last 40 years stem rust resistance genes *Sr31*, *Sr11*, *Sr29* and *Sr38* were recorded in the grown wheat cultivars in the Czech Republic. At present the most important gene is *Sr38*. However, virulence to that gene can be found in the collection of stem rust isolates of the Crop Research Institute. Gene *Sr38* is derived from *Aegilops ventricosa* and is possessed together with the gene *Lr37* for leaf rust resistance and *Yr17* for yellow rust resistance by a number of wheat cultivars grown in Europe. In the Czech Republic gene *Sr31* remains the most effective gene. It is derived from rye together with *Lr26* and *Yr9*. Virulence to *Sr31* (race Ug99) is still limited to Africa and Asia. In addition to the abovementioned genes, stem rust resistance in several recommended wheat cultivars is governed by genes undetermined till now.

Yellow rust (*Puccinia striiformis* Pers. f.sp. *tritici*) can play a very important role particularly in colder regions. It is a major wheat disease in Western Europe controlled by resistance breeding. The last epidemic of yellow rust was in the years around 2000, since that time its incidence has been low. However, this situation can change if yellow rust in Europe becomes adapted to higher temperatures as it happened in the central part of the USA in the last decade. Because of the introduction of wheat cultivars from Western Europe to the Czech Republic yellow rust resistant cultivars prevail among the recommended cultivars. Very frequent gene *Yr17*, ineffective in Western Europe, seems to be still relatively effective in our country. Field resistance (adult plant resistance) is the most important type of yellow rust resistance.

Cultivars and lines with detected multiple resistance to all three rust species are listed in Table 1. In the framework of all tested materials 17 lines possessing multiple resistance to all three rust species on wheat have been detected. Besides the phenotypic assessment of resistance genes, molecular markers have been applied to determine resistance genes. Markers for leaf rust resistance genes *Lr10*, *Lr24 Lr26*, *Lr34* and *Lr37* have been applied till now. Marker for the gene *Lr26* reveals also the presence of other linked genes on the 1BL/1RS translocation (*Sr31*, *Yr9*, *Pm8*); marker for *Lr37* detects linked genes *Sr38* and *Yr17* derived from *Aegilops ventricosa* as well. Molecular markers for APR (adult plant resistance) genes *Lr34* and *Lr37* are particularly useful because these genes cannot be identified by phenotypic analysis at the seedling stage. Though genes for specific resistance that can be determined by molecular markers have played an important role in the disease resistance breeding, at present much attention is paid to APR and QTL analyses are applied to study loci conditioning APR. Genetic background (plant genotype) is important for the expression of resistance genes. Marker-assisted selection can speed up the breeding process, however, disease resistance manifested in the field is crucial for successful rust resistance breeding.

Fusarium head blight

Fusarium head blight (FHB) is one of the most dangerous diseases worldwide. The protection against this serious disease is based on a complex approach involving management practices, fungicide application and growing of cultivars possessing at least moderate resistance to FHB. The resistance against FHB in small grain cereals is determined quantitatively by several quantitative trait loci (QTL). A recent meta-analysis based on 101 QTL for FHB resistance from 30 mapping populations suggested the presence of 19 independent meta-QTL derived exclusively from the adapted European germplasm (Löffler *et al.* 2009). FHB resistance breeding with the use of traditional methods (and also MAS) is difficult because resistance is quantitative in nature and has different components. In addition, the most resistant sources are not adapted to these environmental conditions of Central Europe and they are often susceptible to other diseases and have a poor combining ability (Chen *et al.* 2003). Obtaining resistance to the accumulation of mycotoxins is undoubtedly of crucial importance. Deoxynivalenol (DON) is the most frequent toxin reaching the highest concentration levels also in the conditions of Central Europe.

Resistance to Fusarium head blight (FHB) was evaluated in selected resistance sources and breeding lines after inoculation with *Fusarium culmorum*. Cultivar response to *F. culmorum* was not found different from the response to *F. graminearum* (Šíp *et al.* 2008), which is now a highly prevalent species in this region. As shown in Table 2, the lowest deoxynivalenol (DON) content and also the lowest symptomatic reaction were detected in materials that were examined in the European Fusarium Ring Tests, such as A 17-15-1-2 (AT), 20817-3 (AT), Fg 437 (HU), 98710 A (AT) (all four lines were obtained after crossing with Sumai 3), F01302GP3-1 (RO), and HUS 692 (DE). It is delightful that also breeding lines developed by Czech wheat breeders (SG-U3018 F-A, BR 07-009 – Cimrmanova raná, SG-S930-08, SG-U6014 B, SG-U3007 B, HE 7812 – Dagmar, and SG-U 641A-B – spring wheat) showed a higher resistance level.

Brown leaf spot diseases

The analysis of pathogen spectra in infected wheat leaves showed the growing importance of *Septoria tritici* (ST) and *Pyrenophora tritici-repentis* (PTR), besides *Stagonospora nodorum* (SN), in the territory of the Czech Republic (Figure 1). Therefore, the attention of wheat breeders is mainly paid to these three pathogens and the selected wheat cultivars and lines in ring tests are examined for resistance to each pathogen separately. To avoid the contamination of artificially inoculated experimental plots with other pathogens, protective belts (stand of triticale) are needed. Evaluation of

Table 1. Rust severity scoring under artificial infection in cultivars and lines showing multiple rust resistance (average of 2009–2011) ; (1–9; 9 – without symptoms)

Cultivar/line	Breeding institution	Pedigree	Leaf rust	Stem rust	Yellow rust	Determined rust resistance genes	Other resistances
SG-S316-06	SELGEN a.s.	Estica/WM510//Ludwig	7.8	7.8	9.0	*Lr37*, *Sr38*, *Yr17*	powdery mildew
SG-S469-07	SELGEN a.s.	SG-S2040-97/Rapsodia	7.8	8.0	8.5	*Lr26*, *Lr37*, *Sr38*, *Sr31*, *Yr9*, *Yr17*	powdery mildew, ST
SG-S111-08	SELGEN a.s.	SG-S992-00/NIC99-3637A	6.3	6.4	8.8	*Lr26*, *Lr34*, *Lr37*, *Sr38*, *Yr17*, *Sr31*, *Yr9*,	
SG-U3037 A	SELGEN a.s.	5118D/PBIS 01-1035	6.6	7.3	9.0	*Lr26*, *Lr37*, *Sr38*, *Yr17*, *Lr10*, *Sr31*, *Yr9*,	ST, PTR
BR 05-082 (RW Nadal)	RAGT Czech Ltd.	Hana/Alana//Rapsodia	7.6	8.0	9.0	*Lr37*, *Sr38*, *Yr17*	ST, SN
SG-U3059 A-A	SELGEN a.s.	U7029/F14	6.4	6.0	7.8		
SG-U6014 B	SELGEN a.s.	Appache/Pegassos	6.4	6.8	8.5	*Lr37*, *Sr38*, *Yr17*	FHB, PTR, ST
SG-RU H 26	SELGEN a.s.	Clever/Šárka	6.4	6.5	8.3	*Lr37*, *Sr38*, *Yr17*	PTR
HE 7815	LCEC, Ltd.	Apache/HE 6332	7.7	6.8	8.3		ST, PTR
HE 96072	LCEC, Ltd.	Folio/Bobino	6.9	6.5	7.8		SN
SG-U 3018 F-A	SELGEN a.s.	Hedvika/Caphorn//Armstrong	6.6	7.3	8.5	*Lr26*, *Lr37*, *Sr38*, *Yr17*, *Sr31*, *Yr9*	FHB
HE 8225	LCEC, Ltd.	PBIS 96/80 /Batis	6.5	6.5	8.3	*Lr26*, *Lr37*, *Sr38*, *Yr17*, *Sr31*, *Yr9*	powdery mildew, ST
BR 07-009 (Cimrmanova raná)	RAGT Czech Ltd.	Altos /BR 633 (Boszanova)	6.2	7.0	8.5		FHB
RW 50924	RAGT Czech Ltd.	Cloud /Euro 96-05 3x	7.4	8.8	7.0	*Lr24*	
HE 8352	LCEC, Ltd.	HE 7996/Drifter	7.4	6.0	8.0	*Lr37*, *Sr38*, *Yr17*, *Lr10*	ST
SG-S 1758-09	SELGEN a.s.	Sulamit/MV233-98//Akteur	7.0	6.3	9.0	*Lr37*, *Sr38*, *Yr17*	SN, ST
SG-S 1426-09	SELGEN a.s.	Biscay/SG-U7029	6.8	7.5	8.0		SN
Check varieties							
Claire – resistant (yellow rust, leaf rust)			6.8	–	9.0	*Lr37*, *Sr38*, *Yr17*, *Lr10*	
Estica – resistant (yellow rust, leaf rust)			6.4	5.5	8.6	*Lr13*, *Lr14a*	
Samanta – susceptible			3.7	3.8	5.4	*Lr3a*, *Lr13*, *Yr2*	
SG.S17-03 – resistant (stem rust)				7.2	–	*Lr26*, *Lr37*, *Sr38*, *Yr17*, *Sr31*, *Yr9*	

FHB – Fusarium head blight; ST – *Septoria tritici*; PTR – *Pyrenophora tritici-repentis*; SN – *Stagnospora nodorum*

Table 2. Average data (2007–2011) on symptomatic reaction (visual symptom score – VSS: 1–9; 9 – without symptoms) and deoxynivalenol (DON) content in selected cultivars and lines following artificial infection with *Fusarium culmorum*

Cultivar/line	Origin	Breeding institution	Pedigree	VSS (1–9)	DON (mg/kg)	Other resistances
98710 A	DE	LfL-Bayern	Atlantis//Tambor/Z14///CM82036*	7.1	6.4	
Fg 437	HU	GK Szeged	Sumai 3/81.60//Kincsö	6.0	7.1	
20817-3	AT	BOKU, Vienna	Capo/Sumai 3	7.1	12.8	
A 17-15-1-2	AT	BOKU, Vienna	Capo///Sumai 3/81.60//Kincsö	6.9	14.1	
SG-U 3018 F-A	CZ	SELGEN a.s.	Hedvika/Caphorn//Armstrong	6.4	14.3	brown leaf spots
BR 07-009 (Cimrmanova raná)	CZ	RAGT Czech Ltd.	Altos/BR 633 (Boszanova)	5.4	18.4	stem rust, leaf rust
SG-S930-08	CZ	SELGEN a.s.	SG-S1456-99/Apache	5.3	21.7	powdery mildew, yellow rust
F01302GP3-1	RO	NARDI-Fundulea	508U3-2FZ2/F135U3-1	6.4	22.3	
SG-U6014 B	CZ	SELGEN a.s.	Apache/Pegassos	4.8	24.6	yellow rust, stem rust
SG-U3007 B	CZ	SELGEN a.s.	Transit/UH 442	5.0	27.3	powdery mildew
HE 7812 (Dagmar)	CZ	LCEC, Ltd.	Apache/Nela	4.8	27.8	stem rust
HUS 692	DE	LfL-Bayern	G16-92**/Hussar	6.0	28.3	ST
SG-U 641A-B (SW)	CZ	SELGEN a.s.	U236C/U773C	4.9	30.9	
Check varieties						
Sumai 3 – resistant (SW)	CH			7.5	8.7	
Petrus – moderately resistant	DE			6.6	25.6	
Arina – moderately resistant	CH			6.3	15.3	
Complet – susceptible	DE			3.9	55.5	

*CM82036 = Sumai 3/Thornbird (Buerstmayr *et al.* 1999); **G16-92 = Arina/Tőring 5//Cariplus/Mex. landrace; ST – *Septoria tritici*

symptomatic reaction on 1–9 scale (9 – without symptoms) considered both the disease progress and the infected leaf area.

Based on evolutionary, taxonomic and genetic studies, systems of genetic control are evidently different. Genes and QTL loci responsible for resistance to these foliar pathogens have been identified, but genetic relations between pathogen and host plant are complicated due to high genetic diversity of pathogen populations. Resistance may often be found isolate specific or quantitative (Chartrain *et al.* 2004). Though marker-assisted selection is at disposal, Czech breeders still rely mainly on results of field infection tests. Inoculation with pathogen populations prevalently occurring in the examined territory is undoubtedly an important prerequisite of success.

Correlation analysis between the percentages of leaf area infected with ST, SN and PTR (causing leaf blotch, glume blotch and tan spot, respectively) showed that it was particularly difficult to obtain combined resistance to *Septorias* and *Pyrenophora tritici-repentis*, and the differential cultivar response to infections with *Septoria tritici* and *Stagonospora nodorum* was not exceptional, either (Šíp *et al.* 2005). Gurung *et al.* (2012) found a positive association between STB (Septoria tritici blotch) and SNB (Septoria nodorum blotch), but tan spot was positively associated only with STB. Therefore, the detection of sources of combined resistance to all pathogens causing brown leaf spots is highly valuable.

As shown in Table 3, the highest resistance to all pathogens (on average exceeding level 6) was detected in the Czech advanced breeding lines SG-U 3018 F-A, RUB 70 (Raduza), HE 8502, SG-U 3037 A, HE 8225, BR 05-082 (RW Nadal), SG-U6014 B and RW10815, similarly like in the resistant checks Senat, Arina and SG-U 7029 (characterized also by Šíp *et al.* 2005). It is advantageous that the German line HUS 692 with resistance to FHB, detected in the International Fusarium Ring Tests as well as in NRT, has demonstrated an acceptable combined resistance to brown leaf spot diseases.

There are also useful data on resistance obtained with modern commercially grown winter wheat cultivars under conditions favourable for natural infection in the chemically untreated variant. The 2009–2012 tests at the Humpolec location (potato-growing region) showed relatively higher resistance to brown leaf spot diseases (> 5.5) in the modern cultivars Aladin (DE), Bagou (FR), Fermi (FR), Henrik (FR), Hybery (FR), Hyland (FR), Chevalier (DE), Sultan (CZ) and Bohemia (CZ), but it is obvious (also according to the classification of CISTA) that many cultivars still suffer from insufficient resistance to these diseases and substantial improvement is needed.

Powdery mildew

Although powdery mildew, caused by *Blumeria graminis* DC. f.sp. *tritici*, can now be effectively controlled by fungicides, this disease may be a serious problem in certain regions and years, because continuous protection, increasing the costs, cannot often be provided. Partial or field resistance to such a variable pathogen as powdery mildew is undoubtedly of great importance (Bartoš *et al.* 2002). Genes for resistance (*Pm*) have been identified on more than 35 loci and molecular marker-aided accumulation or pyramiding of several resistance genes aims at achieving more durable and broad-spectrum resistance (Landjeva *et al.* 2007). Šíp *et al.* (2005) reported that the level of resistance to powdery mildew in presently grown wheat cultivars was not mostly satisfactory and, therefore, an increase in the resistance level by breeding became highly desirable. However, because high resistance to

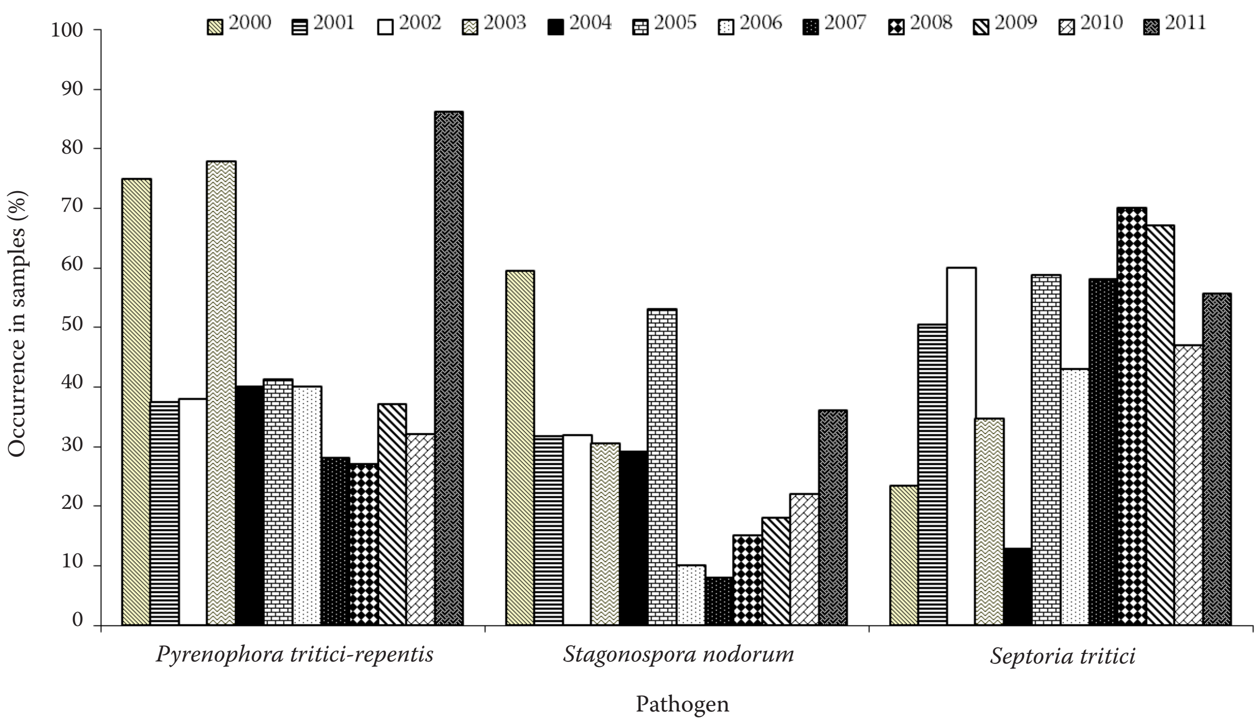

Figure 1. Occurrence (%) of three pathogens causing brown leaf spot diseases in wheat leaf samples collected over 12 year period in different locations in the Czech Republic

Table 3. Average symptom scores (1–9; 9 – without symptoms) for 11 selected winter wheat cultivars and lines showing combined resistance to brown leaf spot diseases obtained in the five-year period (2007–2011) after artificial infection with *Septoria tritici* (ST), *Stagonospora nodorum* (SN) and *Pyrenophora tritici-repentis* (PTR)

Cultivar /line	Breeding institution	Pedigree	ST	SN	PTR	Average	Other resistances
SG-U 3018 F-A	SELGEN a.s.	Hedvika/Caphorn// Armstrong	7.5	6.3	6.7	6.7	yellow rust, stem rust, FHB
RUB 70 (Raduza)	SELGEN a.s.	RU 23/Alveor	7.3	5.9	6.7	6.7	leaf rust, yellow rust
HE 8502	LCEC, Ltd.	Clarus/Complet	6.8	5.8	6.9	6.9	yellow rust
SG-U 3037 A	SELGEN a.s.	5118D/PBIS 01-1035	6.9	5.9	6.4	6.4	yellow rust, stem rust
HE 8225	LCEC, Ltd.	PBIS 96/80/Batis	6.7	5.9	6.2	6.2	yellow rust
BR 05-082 (RW Nadal)	RAGT Czech Ltd.	Hana/Alana// Rapsodia	6.5	6.3	5.8	5.8	rust diseases
SG-U6014 B	SELGEN a.s.	Apache/Pegassos	6.4	5.8	6.2	6.2	yellow rust, stem rust
RW10815	RAGT Czech Ltd.	Carenius/Boomer	6.1	6.2	5.9	5.9	yellow rust, stem rust
SG-U 4092 D-b	SELGEN a.s.	U5140/Batis	5.9	6.3	5.6	5.6	yellow rust
SG-S1850-08	SELGEN a.s.	Sakura/Ilias	5.6	6.1	6.0	6.0	powdery mildew, yellow rust
HUS 692	LfL-Bayern	G16- 92/Hussar	6.5	5.6	5.3	5.3	FHB
Check varieties							
Senat – resistant			6.8	6.2	7.1	7.1	
Arina (ST, PTR) – resistant			6.8	5.2	6.7	6.7	
SG-U 7029 – resistant			6.5	6.6	6.5	6.5	
MV Marshall – susceptible			4.3	3.9	4.4	4.4	

FHB – Fusarium head blight

this disease is undoubtedly conferred by large gene complexes and accumulation of different genes may be very time-consuming and costly, selection under conditions of high infection pressure in different locations (with different pathogen populations) can still be reckoned as a predominant breeding method.

Field resistance to this pathogen has recently improved very much through breeding worldwide. Also in the Czech Republic thanks to the availability of resistance sources, among which the Czech cultivar Vlasta, derived from a cross with *Triticum monococcum,* dominated the assortment of cultivated wheats for many years. The latest results of ring tests showed that different materials (SG-S1774-04, SG-U5223 E, BR 05-010 – Idyla, SG-S316-06, SG-S1194-08, RW10815 and SG-U3007 B) were developed that possess the resistance level higher than 7 (Table 4). These results are mainly based on the evaluation of powdery mildew resistance at the Humpolec location with high natural infection occurring every year, though the examination of powdery mildew infestation was carried out at three to five locations each year. Among the modern cultivars commonly grown in the Czech Republic high resistance (7–8) was detected in Pitbull (DE), Avenue (FR), Jindra (CZ), Hyland (FR), Hybery (FR), Caroll (NL), Arktis (DE) and Pepino (AT).

Barley yellow dwarf virus (BYDV)

The *Barley yellow dwarf virus*, which is transmitted by several species of aphids, causes an important virus disease of cereals. In winter wheat the high level of resistance was not detected and crossing with resistant spring wheat materials was recommended as a promising strategy (Bartoš *et* *al.* 2002). Relatively higher, moderate resistance was detected in the Czech winter wheat cultivars Simila and Raduza and spring wheat cultivar Izzy.

Common and dwarf bunt

The level of resistance to bunt is low in commercial cultivars. Tested cultivars are very susceptible (Raduza, Sakura, Bakfis, Baletka and Federer with bunt incidence > 50%) or slightly less susceptible (Elly, Cimrmanova raná and Dagmar with bunt incidence 20–50%). Out of the earlier registered winter wheat cultivars Globus displayed high resistance (infection levels below 10%), similarly to the cultivar Bill (Šíp *et al.* 2005). Unfortunately, these cultivars show only medium resistance to dwarf bunt.

Prospects of obtaining multiple disease resistance in wheat

It is obvious also from these results that wheat breeding made enormous progress in the last years and high-yielding cultivars possessing acceptable field resistance to the majority of diseases can be included in hybridization programmes. In Table 5 there are listed ten wheat cultivars bred by the Czech breeding companies (Simila, Raduza, Sakura, Bakfis, Baletka, Seance, Federer, Elly, Izzy and Cimrmanova raná) possessing combined resistance to diseases determined in the National Ring Tests. Under conditions of high infection pressure it was very difficult to find high or moderate resistance to all examined important diseases, however, it can be expected that the materials in which medium resistance (M) was detected in trials with artificial inoculations could also provide sufficient protection under natural conditions. Based on the results of ring tests presented here it was possible to select promising winter wheat cultivars and lines for their use in wheat breeding for multiple resistance. An overview of the last decade showed that the greatest progress was made in breeding for resistance against rusts, powdery mildew and FHB, however, it is obvious from data provided by the Central Institute for Supervising and Testing in Agriculture (http://www.ukzuz.cz/ChangeLang.aspx?Lang=EN) that wheat cultivars that suffer from insufficient resistance also to these diseases are still grown while a great attention should be permanently paid to pathogen development (occurrence of new races) which is highly actual especially in rusts. The obtained results indicated that it was difficult to obtain multiple resistance to leaf spot diseases. The latest study of Gurung *et al.* (2012)

Table 4. Average symptom scores (VSS; 1–9; 9 – without symptoms) for 9 selected winter wheat cultivars and lines showing resistance to powdery mildew obtained in the five-year period (2007–2011) after natural infection

Cultivar/line	Breeding institution	Pedigree	VSS (1–9)	Other resistances
SG-S1774-04	SELGEN a.s.	Svitava/Batis	8.0	
SG-U5223 E	SELGEN a.s.	U5140/Ebi//Charger	7.6	
BR 05-010 (Idyla)	RAGT Czech Ltd.	Apache/Alana	7.5	
SG-S316-06	SELGEN a.s.	Estica/WM510//Ludwig	7.5	yellow rust, leaf rust, stem rust
SG-S 1194-08	SELGEN a.s.	Sulamit/Rapsodia//Mladka	7.4	
RW10815	RAGT Czech Ltd.	Carenius/Boomer	7.4	brown leaf spots
SG-U3007 B	SELGEN a.s.	Akteur/U5066C	7.2	FHB
SG-S1850-08	SELGEN a.s.	Sakura/Ilias	7.0	brown leaf spots
SG-S930-08	SELGEN a.s.	SG-S1456-99/Apache	7.0	FHB , yellow rust, stem rust
Check varieties				
Pitbull – resistant			7.9	
Vlasta – resistant			7.5	
Kanzler – susceptible			4.8	

FHB – Fusarium head blight

Table 5. Czech multiple disease resistance wheat cultivars developed upon the support of national ring tests (NRT)

Tested as	Name of cultivar	Year of registration	Breeding institution	Rusts	Powdery mildew	Brown leaf spot diseases	FHB	Other resistances
SG-S 1875-01	Simila	2006	SELGEN a.s.	R – yellow rust, MR – leaf rust	MR	M	MR	MR – BYDV
SG-RU B70	Raduza	2006	SELGEN a.s.	R – leaf rust, M – yellow rust	M	M	M	MR – BYDV
SG-S 1800-01	Sakura	2007	SELGEN a.s.	MR – leaf rust	M	MR – SN	MR	MR – OWBM
BR 03/067	Bakfis	2008	RAGT Czech Ltd.	R – yellow rust, M – leaf rust, M – stem rust	M	M	MR*	R-eyespot
BR 03/008	Baletka	2008	RAGT Czech Ltd.	R – leaf rust (*Lr34*), M – yellow rust	MR	M	MR	
SG-S17-03	Seance (SW)	2008	SELGEN a.s.	R – yellow rust, MR – leaf rust	MR	MR	M	
BR 04-080	Federer	2009	RAGT Czech Ltd.	MR – yellow rust, M – leaf rust	R	M	MR	
SG-S 1029-05	Elly	2010	SELGEN a.s.	MR – leaf rust (*Lr37*), MR – yellow rust	M	M	M	
SG-S136-06	Izzy (SW)	2011	SELGEN a.s.	R – yellow rust, MR – stem rust	MR	M	M	MR – BYDV
BR 07-009	Cimrmanova raná	2012	RAGT Czech Ltd.	R – stem rust, R – yellow rust, M – leaf rust	MR-M	M	M	

R – resistant; MR – moderately resistant; M – medium response; SN – *Stagonospora nodorum*; *very low DON accumulation; OWBM – orange wheat blossom midge; BYDV – *Barley yellow dwarf virus*; SW – spring wheat

showed that commercial wheat cultivars are often resistant to one pathogen but susceptible to the others. Valuable are without doubt detections of multiple resistance to different pathogens causing brown leaf spot diseases (Table 3). It is also necessary to increase the resistance to common and dwarf bunt which is very low in commercial cultivars. A number of sources of resistance originating from other countries is available to wheat breeding (Dumalasová & Bartoš 2006, 2007). Unfortunately, these foreign resistant cultivars are mostly unsuitable for local conditions. The transfer of effective genes for bunt resistance to commercial cultivars with good agronomic traits may be facilitated using linked molecular markers.

As already mentioned above, a greater attention is now paid also to other important diseases or pathogens such as eyespot and other stem base diseases and orange wheat blossom midge.

Moderate or severe eyespot infections can cause yield losses of 10–30%, even in the absence of lodging. In the UK the resistance of winter wheat to eyespot was derived mainly from the cultivar Cappelle Desprez carrying the *Pch 2* gene. This gene confers a degree of tolerance rather than total resistance to the disease. The introduction of the winter wheat cultivar Rendezvous in the 1980's brought a new source of resistance derived from a grass species, *Aegilops ventricosa*, which is now used in many breeding programmes. Cultivars carrying high levels of resistance (based on the *Pch 1* gene) are now available.

The orange wheat blossom midge (*Sitodiplosis mosellana*) is found in most areas around the world wherever wheat is grown. Infestations of the wheat midge can reduce crop yields and lower the grade of harvested grain. The midge may exist at low population levels for several years before it becomes a significant problem. But if conditions become favourable, populations can reach epidemic proportions quickly. Resistance against this disease is linked with the presence of *Sm 1* gene. According to tests in the UK it is believed that the Czech cultivar Sakura also possesses resistance to the orange wheat blossom midge.

Evaluation of resistance to BYDV has a long tradition in CRI. The evaluation showed that among the registered cultivars of winter and spring wheat no cultivar had a high resistance to BYDV (with VSS lower than 3.5). The present analyses of available sources suggest that the nature of BYDV resistance for wheat is clearly polygenic. Analyses of populations segregating for the *Bdv1* gene (Ayala *et al.* 2002) brought similar results. It is evident that the introduction of a single gene is not sufficient for achieving the required level of resistance while marker-assisted selection is not very well justified for the time being without a focus on detecting a larger number of QTLs (Veškrna *et al.* 2009).

Molecular techniques offer new possibilities of resistance breeding intensification (pyramiding resistance genes). However, it follows from many studies that the most described resistance genes (QTL loci) have only a limited and variable (often not durable) impact on field resistance. Landjeva *et al.* (2007) saw the main reasons for delay in broad exploitation of MAS in inadequate quality of markers (regarding their predictive and/or diagnostic values), high costs of DNA assays and in the complexity of quantitative traits. Because multiple genes need to be transferred to achieve complex resistance, the time advantage of marker-assisted selection may be lost and breeding costs increased. Recently, Miedaner and Korzun (2012) have shown that in the future, chip-based, high throughput genotyping platforms and the introduction of genomic selection will reduce the current problems of integrating MAS in practical breeding programmes. The results of Chrpová *et al.* (2011) confirmed that marker-based introgression of FHB resistance QTLs on chromosomes 3B and 5A in traditional breeding materials can enrich populations with resistance types, but it was also shown that the effect of marker-based selection need not be large in all crosses and a similar effect can probably be reached by indirect selection for some FHB-related traits.

Nonetheless, the most advantageous strategy is still to detect a germplasm possessing acceptable resistance to the majority of the most important diseases (at the best in combination with high productivity, grain quality, resistance to abiotic stresses, etc.) and to improve single characters using appropriate crossing schemes or deliberate gene transfer (backcrossing), for which molecular markers may be helpful. In spite of the availability of advanced molecular techniques it will undoubtedly remain advantageous to integrate the marker-based approach with additional phenotypic selection (Wilde *et al*. 2007).

Acknowledgements. The research was supported by Ministry of Agriculture of the Czech Republic, Projects No. QH81293 and QJ1210189.

References

Ayala L., Henry M., Genkel M., Keller B., Khairallah M. (2002): Identification of QTLs for BYDV tolerance in bread wheat. Euphytica, **128**: 249–259.

Bartoš P., Šíp V., Chrpová J., Vacke J., Stuchlíková E., Blažková V., Šárová J., Hanzalová A. (2002): Achievements and prospects of wheat breeding for disease resistance. Czech Journal of Genetics and Plant Breeding, **38**: 16–28.

Buerstmayr H., Lemmens M., Doldi M.L., Stierschneidr M., Steiner B., Werner K., Hartl L., Rukkenbauer P. (1999): Breeding of wheat for resistance to Fusarium head blight. In: Bericht über die Arbeitstagung 1999 der Vereinigung österreichischer Pflanzenzüchter. Gumpenstein, November 23–25, 1999, 63–67. (in German)

Chartrain L., Brading P.A., Makepiece J.C., Brown J.K.M. (2004): Sources of resistance to septoria tritici blotch and implications for wheat breeding. Plant Pathology, **53**: 454–460.

Chen J., Griffey C.A., Saghai maroof M.A., Winson J.A., Nabati D., Biyashev R.M. (2003): Molecular mapping and marker assisted selection of QTLs for Fusarium head blight resistance in Chinese wheat line W14. In: Canty S.M., Lewis J., Ward R.W. (eds): Proc. National Fusarium Head Blight Forum. December 13–15, 2003, Bloomington, US Wheat & Barley Scab Initiative, Michigan State University, 7–10.

Chrpová J., Šíp V., Sedláček T., Štočková L., Veškrna O., Horčička P. (2011): Effectiveness of marker-based selection for Fusarium head blight resistance in spring wheat. Czech Journal of Genetics and Plant Breeding, **47** (Special Issue): S123–S129.

Dumalasová V., Bartoš P. (2006): Resistance of winter wheat cultivars to common bunt, *Tilletia tritici* (Bjerk.) Wint. and *T. laevis* Kühn. Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz – Journal of Plant Diseases and Protection, **113**: 159–163.

Dumalasová V., Bartoš P. (2007): Reaction of spring wheat cultivars to common bunt *Tilletia tritici* (Bjerk.) Wint. and *T. laevis* Kühn. Czech Journal of Genetics and Plant Breeding, **43**: 82–86.

Gurung S., Hansen J.M., Bonman M., Gironella A.I.N., Adhikari T.B. (2012): Multiple disease resistance to four leaf spot diseases in winter wheat accessions from the USDA National Small Grains Collection. Crop Science, **52**: 1640–1650.

Huerta Espino J., Singh R.P., Germán S., Mccallum B.D., Park R.F., Chen We.Q., Bhardwaj S.C., Goyeau H. (2011): Global status of wheat leaf rust caused by *Puccinia tritici*. Euphytica, **179**: 143–160.

Landjeva S., Korzun V., Bőrner A. (2007): Molecular markers: actual and potential contributions to wheat genome characterization and breeding. Euphytica, **156**: 271–296.

Löffler M., Schön C.-C., Miedaner T. (2009): Revealing the genetic architecture of FHB resistance in hexaploid wheat (*Triticum aestivum* L.) by QTL meta-analysis. Molecular Breeding, **23**: 473–488.

McIntosh R.A., Pretorius Z.A. (2011): Borlaug Global Rust Initiative provides momentum for wheat rust research. Euphytica, **179**: 1–2.

Miedaner T., Korzun V. (2012): Marker-assisted selection for disease resistance in wheat and barley breeding. Phytopathology, **102**: 560–566.

Park R., Fetch T., Hodson D., Jin Y., Nazari K., Prashar M., Pretorius Z.A. (2011): International surveillance of wheat rust pathogenes; progress and challenges. Euphytica, **179**: 109–117.

Šíp V., Bartoš P., Chrpová J., Hanzalová A., Širlová L., Šárová J., Dumalasová V., Čejka L., Hanišová A., Bobková L., Bížová I., Horčička P. (2005): Theoretical bases and sources for breeding wheat for combined disease resistance. Czech Journal of Genetics and Plant Breeding, **41**: 127–143.

Šíp V., Chrpová J., Sýkorová S. (2008): Assessing resistance to head blight in wheat cultivars inoculated with different *Fusarium* isolates. Czech Journal of Genetics and Plant Breeding, **44**: 43–59.

Veškrna O., Chrpová J., Šíp V., Sedláček T., Horčička P. (2009): Reaction of wheat cultivars to infection with barley yellow dwarf virus and prospects of resistance breeding. Czech Journal of Genetics and Plant Breeding, **45**: 45–56.

Wilde G., Korzun V., Ebmeyer E., Geiger H.H., Mieda-ner T. (2007): Comparison of phenotypic and marker-based selection for Fusarium head blight resistance and DON content in spring wheat. Molecular Breeding, **19**: 357–370.

Received for publication September 5, 2012
Accepted after corrections September 19, 2012

Corresponding author:

Ing. Jana Chrpová, CSc., Výzkumný ústav rostlinné výroby, v.v.i., Drnovská 507, 161 06 Praha-Ruzyně, Česká republika
e-mail: chrpova@vurv.cz