European Journal of Plant Pathology (2006) 116:145–153
DOI 10.1007/s10658-006-9049-9
© Springer 2006

Susceptibility of German spring barley cultivars to loose smut populations from different European origins

Karl-Josef Mueller
Cereal Breeding Research Darzau, Darzau Hof 1, 29490, Neu Darchau, Germany
(Phone: +49-5853-1397; Fax: +49-5853-1394; E-mail: k-j.mueller@darzau.de)

Accepted 29 June 2006

Key words: *Hordeum vulgare*, inspection limits, *Ustilago nuda*, virulence

Abstract

Forty-two registered spring barley cultivars from the German official list were tested under natural infection conditions for susceptibility to loose smut (*Ustilago tritici* f.sp. *hordei*) during two test cycles at two locations. Only cv. Steffi was found to be resistant to the local loose smut population. Cultivar Sigrid showed lowest susceptibility because of flowering inside the leaf sheath. Less than 1% infection at all sites showed up in cvs Auriga, Jacinta and Hendrix. Twenty-one cultivars had an infection rate of less than 2%. Cultivar Danuta displayed the highest susceptibility with an average of 12.6%. Another 23 spring barley accessions with expected loose smut resistance were inoculated artificially with loose smut populations obtained from 11 locations in Germany and neighbouring countries. Only Jet with the resistance Un3/6, CDC Freedom with Un8, CIho9973 with quantitative resistance, as well as Lino and Gang-TuoQuingKeHao1 remained disease-free. In addition to these, another eight accessions in this test group are recommended to become part of a differential tester set to distinguish origins of loose smut. Statistical analysis showed that for scoring of cultivars more importance has to be given to the number of locations for infestation than to the number of test locations to determine the degree of attack. In view of the existing inspection limits for production of certified seed in European countries, the currently registered German barley cultivars put organic seed producers and breeders at high risk in respect to loose smut infection, if the number of generations for multiplication under organic farming increases.

Abbreviations: AT – Austria; CH – Switzerland; CZ – Czech Republic; DE – Germany; DK – Denmark; FR – France; PL – Poland; Un – *Ustilago nuda*.

Introduction

Currently, there is no seed treatment available under certified organic farming in the European Union to combat an infestation with loose smut in barley. According to EU-Regulation 1452/2004 for barley, only the last generation of certified seed has to be produced under organic farming conditions for receiving organic certification approval. Most European countries have strict rejection levels for field or seed inspection of certified seed production regarding tolerance for loose smut (Table 1). For maintenance and multiplication of barley for seed under organic farming it is necessary to estimate the risk for infestation under natural growing conditions. For this reason modern adapted barley cultivars were tested under natural infection, and an additional set of genetic resources were tested artificially using loose smut populations from different locations to find efficient resource materials for further breeding.

Materials and methods

Eleven populations of barley loose smut received from the Czech Republic (1 population), Switzerland (1), France (1), Germany (5), Denmark (1), Austria (1) and Poland (1) were used for inoculations. The origins are marked with internet country code and postal code of suppliers addresses (Table 3). Twenty-three spring barley accessions with documented or expected loose smut resistance (Table 2) were inoculated as described by Poehlman (1945) pricking every flower with a syringe containing a spore suspension of 1 g l^{-1}. Inoculations were carried out during anthesis, as soon as anthers opened. At least four ears per sample and per loose smut origin were inoculated, Cultivar Lawina was used as a susceptible check and to maintain different loose smut strains. After inoculation the ears were protected with a pergamin bag for about 10 days against cross-infestation by any other strain of loose smut. Ears were harvested manually, threshed mechanically and prepared for sowing with magazines in a single-row-plot drilling machine. After initial seed emergence the number of germinated plants was counted and during ear emergence the number of infected plants was counted. All experiments were done in field plots with sandy soil under certified organic growing conditions at Darzau, Lower Saxony, Germany (lat. 53°122′ N, long. 10°52′ E, 60 m above see level).

During two test cycles from spring 2002 to summer 2004 forty-two registered spring barley cultivars from the official recommended German list were tested under natural infection conditions using a local population of loose smut (code DE-29490 in Table 3). One cycle includes the vegetation period for infection during flowering followed by the vegetation period for observing the disease infestation as loose smut instead of ears. During summer 2002 every variety was grown on a plot of 3 m^2 between plots of cvs Nackta and Lawina, both previously grown and infected with a population of loose smut occuring at the experimental site at Darzau. From these plots the disease was able to spread during flowering into the cultivars to be tested. Harvesting was done with a plot combine.

In the second year (2003) the infected seeds were planted on plots of 3 m^2 at Darzau and Dottenfelderhof, Bad Vilbel, Hessia, Germany (lat. 50°10′ N, long. 8°45′ E, 143 m above sea level) on plots of 2.25 m^2 in four replications. At Darzau the loose smut infected cv. Lawina was planted every third plot to increase the infection pressure on the plots with cultivars to be tested. After seed emergence the number of germinated plants was counted and during ear emergence the number of diseased plants was counted. In the third year (2004) the tests were repeated at both locations with seeds harvested during the second year at Darzau. Statistical data analysis was done with software PLABSTAT (UTZ 2001).

Table 1. Official tolerance levels for loose smut infection during inspection for basic (certified) seed production in Europe

Country	Limit in field inspection	Limit in seed inspection
Hungary	20 (50) ears 100 m^{-2}	no infection limits
Belgium	5 (25) ears 100 m^{-2}	no infection limits
Latvia	5 (15) plants 100 m^{-2}	no infection limits
Poland	– (3) plants 30 m^{-2}	no infection limits
Switzerland	2 (5) plants 100 m^{-2}	no infection limits
Luxembourg	3 (5) plants 100 m^{-2}	no infection limits
Austria	3 (5) plants 150 m^{-2}	0.8% (2%) infection, > 0.1%: treatment
Germany	3 (5) plants 150 m^{-2}	no infection limits
Netherlands	1 (6) plants 100 m^{-2}	no infection limits
Spain	0,5 (5) plants 100 m^{-2}	2 (5) kernels 500 g^{-1}
Czech Republic	0.8% (2%) plants	no infection limits
Italy	0.4% (0.4%) plants	no infection limits
England/Ireland	0.1% (0.2%) plants	0.1% (0.2%) infection
Estonia	0.0% (0.2%) plants	no infection limits
Finland	seed test recommended	> 1% (> 1%) infection: treatment
Denmark	0.05% (0.1%) plants	0.0% (0.0%) infection

Table 2. Spring barley accessions with expected loose smut resistance

Accession No.	Name/country of origin	Resistance (Author Reference)	c/n
BCC 423	GangTuoQuingKeHao 1/China	unknown	n
BCC 900	Lino/Mexico	unknown	n
Clho 04058	Ulyasutai/Mongolia	unknown	n
Clho 07026	North Carolina26/USA	unknown (Poehlman, 1947)	c
Clho 09973	Shewa/Ethiopia	Un 1 + quantitative (Therrien, 1999)	n
Clho 10877	Keystone/Canada	Un 6 (Moseman and Metcalfe, 1969)	c
HOR 00248	Trebi/Turkey	Un 1 (= Run1a) (Metcalfe, 1969)	c
HOR 02736	Djeddah/Ethiopia	Un 6 (Nover et al., 1976)	c
HOR 03134	MoB475/USA	Un 2 (Metcalfe, 1969)	c
HOR 04014	Kitchin/USA	Un 6 (Nover et al., 1976)	c
HOR 04476	Ogalitsu/Canada	monogene (Nover et al., 1976)	c
HOR 05032	Jet/Ethiopia	Un3/6 (Metcalfe and Johnston 1963)	n
HOR 11363	Steffi/Germany	probably Un6	c
K 08728	–/Ethiopia	Un 11 (Kirdoglo, 1990)	c
K 19907	–/Mongolia	Un 13 (Kirdoglo, 1990)	n
K 22317	Francette/Belgium	probably Un 6 (Hewett, 1979)	c
K 26337	Pervonez/Ukraina	allegedly Un 8 (Kirdoglo, 1990)	c
K 29630	–/Turkey	Un 12 (Kirdoglo, 1990)	c
K 30118	Roland/Belarus	Un 15 (Terentieva et al., 2000)	c
K 30593	Mik-1/Russia	Un 15 (Terentieva et al., 2000)	c
Linz 358150	–/Ethiopia	perhaps Un 6	n
PI 270730	–/Peru	unknown	n
	CDC Freedom/Canada	Un 8 (= Run2a) (Rossnagel, personal communication)	n

c = covered barley; n = naked/hulless barley; BCC = barley core collection; Clho & PI = Genebank Aberdeen, Idaho, USA; HOR = IPK Genebank Gatersleben, Germany; K = Genebank St.Petersburg, Russia; Linz = Genebank Linz, Austria.

Results and discussion

Susceptibility of accessions

Table 3 shows the differentiation for loose smut resistance after inoculation. From the eleven origins of loose smut, the populations DE-29490, AT-01220, DE-90174 and PL-00950 showed a similar pattern of susceptibility on the tested accessions with only one difference for accession K-19907 in both cases. All accessions showing susceptibility to DE-61118 and DE-39398 had less susceptibility to other origins of loose smut. This points to a lower virulence of these last two populations of loose smut (Table 3).

Accessions MoB475 with Un2 from a cross with Missouri Early Beardless and also North Carolina Hooded 26 (Table 3), a selection from Tennesse Beardless 6, could both be traced back to hooded barley introduced from Asia into the United States during early settlements (Poehlman, 1947). These two accessions had similar susceptibility to loose smut from eight locations and differentiation was only possible based on different resistance to loose smut populations DE-90174, PL-00950 and DE-55239.

Susceptibility to CZ-76701 was found in the accessions reportedly carrying the Un6 resistance (Table 3). Keystone was one of the first Canadian cultivars that carried Un6-resistance from Jet (Luk'yanova and Tishkov, 1985) and is no longer effective in Canada (Thomas and Menzies, 1997). Francette and Steffi have cv. Emir in their pedigree, which is also described as a donor of Un6 (Hewett, 1979; Wicke, 1986). Djeddah and Linz 358150 also responded with susceptibility to CZ-76701 and probably the same Un6-resistance occurred in them. Although Kitchin is reported to carry the Un6 resistance (Niemann, 1961), it was susceptible to CH-08048, which suggests that the spores of CZ-76701 in close proximity to Kitchin in the test plots could reach the inoculated ears before or during the treatment with CH-08048.

It is remarkable that Jet, which was often used as a donor for loose smut resistance in early breeding programmes (Thomas and Metcalfe,

Table 3. Susceptibility of spring barley to loose smut populations from different origins after artificial inoculation (number of plants infected with loose smut per total number of plants)

Accession		Un-Typ	Origins of loose smut (country and postal code of supplier)										
			CZ-76701	CH-08048	FR-63039	DE-61118	DE-39398	DK-04200	DE-29490	AT-01220	DE-90174	PL-00950	DE-55239
CHECK: Lawina	DE	–	113/119	85/125	43/52	23/125	13/97	87/91	74/97	66/72	67/75	79/94	82/91
K 8728	ET	Un11	13/17	13/33	15/19	5/16	2/11	4/11	13/34	7/23	9/14	3/31	4/7
K 29630	TR	Un12	22/71	17/49	14/55	1/81	9/18	10/38	9/45	9/32	17/47	5/30	9/26
MoB475	US	Un 2	33/58	4/47	2/6	4/19	3/6	1/13	4/18	2/7	4/18	3/5	0/52
N.Carolina	US	?	27/38	10/52	6/37	12/50	6/44	1/32	3/55	1/68	0/42	0/53	2/43
Trebi	TR	Un 1	2/2	2/11	2/2	0/54	0/45	0/50	2/6	11/14	9/17	2/3	1/59
Clho 4058	MN	1	10/20	0/55	10/24	0/37	1/45	3/9	10/72	1/36	0/9	0/18	2/56
K 19907	MN	Un13	2/11	5/61	1/24	4/26	1/4	0/34	1/40	0/41	3/28	0/20	0/22
PI 270730	PE	?	30/43	1/60	2/34	2/51	2/40	0/21	0/46	0/55	0/22	0/36	0/20
Ogalitsu	CA	mono.	14/70	0/74	5/57	6/71	0/38	0/72	0/36	0/50	0/23	0/90	0/56
Roland	BY	Un15	5/28	0/63	0/19	2/51	1/66	0/19	0/51	0/30	0/34	0/49	0/45
Mik1	RU	Un15	15/47	16/61	0/24	0/29	0/33	0/32	0/29	0/34	0/36	0/47	0/36
Kitchen	US	Un 6	12/18	8/16	0/9	0/28	0/14	0/19	0/29	0/11	0/14	0/13	0/10
Keystone	CA	Un 6	16/49	0/55	0/59	0/38	0/46	0/42	0/50	0/33	0/28	0/49	0/41
Djeddah	ET	Un 6	9/22	0/29	0/29	0/26	0/14	0/17	0/19	0/7	0/2	0/16	0/26
LINZ 358150	ET	(Un6)	27/35	0/55	0/66	0/34	0/31	0/29	0/47	0/34	0/35	0/64	0/52
Francette	BE	(Un6)	11/14	0/9	0/16	0/10	0/28	0/11	0/14	0/12	0/11	0/5	0/12
Steffi	DE	(Un6)	19/23	0/32	0/13	0/33	0/21	0/18	0/32	0/30	0/12	0/19	0/24
Pervonez	UA	?	15/18	0/14	0/3	0/31	0/17	0/3	0/18	0/17	0/3	0/3	0/17
CDC Freedom	CA	Un 8	0/21	0/16	0/7	0/30	0/30	0/12	0/17	0/5	0/20	0/14	0/19
Clho 9973	ET	quant	0/57	0/51	0/47	0/65	0/49	0/45	0/62	0/22	0/43	0/19	0/41
Jet	ET	Un3/6	0/37	0/35	0/29	0/31	0/35	0/19	0/26	0/26	0/36	0/24	0/24
Gang TuoQuing.	CN	?	0/16	0/60	0/50	0/32	0/40	0/44	0/33	0/35	0/45	0/40	0/23
Lino	MX	?	0/36	0/30	0/31	0/41	0/40	0/36	0/57	0/42	0/29	0/14	0/38

Eleven populations of barley loose smut received from Czech Republic(CZ, 1 population), Switzerland (CH,1),France (FR, 1), Germany (DE, 5), Denmark (DK, 1), Austria (AT, 1) and Poland (PL, 1) were used for inoculations. Un. = type of *Ustilago* resistance.

1984), remained free from infection after inoculation with loose smut from all 11 different locations. Jet passes the two monogenic dominant resistances Un3 and Un6 onto descendants (Moseman and Metcalfe, 1969). CDC Freedom with Un8 (Rossnagel, personal communication) showed no plants with loose smut, but always showed a reduced germination in comparison with other resistant accessions after artificial inoculation. Pervonez, which is supposed to carry Un8-resistance (Kirdoglo, 1990), was susceptible to CZ-76701. Accession K-29630 with Un12 (Kirdoglo, 1990) always showed a lower number of diseased plants in comparison with other susceptible accessions. Also, accession K-19907 from Mongolia with Un13 (Kirdoglo, 1990) showed a low infection rate, but had a different resistance pattern than CIho 4058, which also has its origin in Mongolia. PI 270730 from Peru showed a similar resistance pattern to K-19907. Ogalitsu, which was reported to have a monogenic resistance different from Un3, Un6 and Un7 (Zeidan, 1955), showed a susceptibility pattern different from all other accessions.

The resistance Un15 seemed to be no more efficient than Un6 when exposed to the loose smut populations. Although Roland and Mik-1 carry the same Un15 resistance (Terentieva et al., 2000), Roland was slightly susceptible to DE-61118 and DE-39398. Compared to Roland only 50% of the seeds of Mik-1 survived after artificial inoculation with loose smut from both locations. Similar to Kitchin, the susceptibility of Mik-1 to CH-08048 suggests infection with CZ-76701 is unavoidable. Jet, CDC Freedom, CIho 9973, GangTuoQuingKeHao1 and Lino all showed broad resistance and remained totally free from loose smut infection (Table 3). Because the number of seeds which survived artificial inoculation showed germination in the field ranging from 2 to 125, the conversion into % diseased plants and statistical analysis for this artificial testing was not applied. One of the reasons for bad germination was poor adaptation of foreign accessions to the wet weather conditions during maturation of the seeds. Therefore interpretation of results was done in the context of the broad variation due to this environmental factor.

Susceptibility of cultivars

Susceptibility of marketed cultivars under natural infection is listed in Table 5. Analysis of variance for this experiment showed significant differences among cultivars, but no significant differences for test cycles and locations. Interactions between variables had to be taken into account (Table 4). Differences between the degrees of infestation related to the test cycles could be influenced in particular by different variables during flowering and disease infestation of pistils (i.e. direction of wind, concentration of spores, partial cleistogamic flowering, humidity and temperature). Variation among locations could be influenced only by environmental conditions during germination, depth of seeds in soil or weather conditions during growing, which in turn affected the successful infection of the developing plant by the pathogen.

Table 4. Analysis of variance for testing of natural susceptibility

Item	Sum squares	Degrees of freedom	Middle squares	Refuse zero hypothesis
Variance between cultivars	2747.81	41	67.02	Yes***
Variance between locations	375.14	1	375.14	No
Variance between test cycles	449.35	1	449.351	No
Interaction between cultivars × locations	260.31	41	6.35	Yes**
Interaction between cultivars × cycles	538.02	41	13.12	Yes***
Interaction between locations × cycles	199.85	1	199.85	Yes***
Interaction between cultivars × locations × cycles	146.17	41	3.57	Yes***
Rest	576.69	504	1.14	
Total	5293.32	671		

*with 5% error of likelihood
**with 1% error of likelihood
***with 0.1% error of likelihood

Table 5. Susceptibility of 42 spring barley cultivars to loose smut origin DE-29490 under natural infection conditions (% infection)

Cultivar	Average	Cycle 2002/03		Cycle 2003/04	
		Dottenf.	Darzau	Dottenf.	Darzau
Danuta	12.63	18.62	10.69	12.92	8.30
Maresi	5.36	10.64	4.83	3.19	2.80
Annabell	4.49	8.45	3.13	3.95	2.44
Barka	3.93	7.77	2.77	3.39	1.82
Extract	3.92	7.99	4.80	1.72	1.17
Alexis	3.76	9.40	2.55	1.57	1.53
Aspen	3.70	8.54	3.62	1.36	1.27
Madeira	3.51	9.53	2.81	0.72	1.00
Saloon	3.31	7.82	3.16	1.07	1.19
Tunika	3.30	4.69	1.94	3.17	3.41
Taiga	3.23	4.69	2.37	3.63	2.23
Baronesse	3.19	4.89	2.70	2.74	2.42
Chantal	2.99	7.93	2.45	0.72	0.87
Krona	2.95	6.97	2.45	1.23	1.14
Braemar	2.49	2.22	1.29	3.83	2.61
Ricarda	2.46	5.40	2.23	1.36	0.86
Apex	2.30	4.31	1.61	1.72	1.54
Peggy	2.29	4.58	1.97	1.55	1.08
Ria	2.27	4.08	1.41	2.19	1.40
Madonna	2.25	4.19	1.55	2.36	0.90
Chariot	2.20	4.20	2.19	1.54	0.85
Adonis	1.98	2.61	0.88	2.25	2.16
Neruda	1.86	4.16	2.16	0.49	0.62
Baccara	1.73	3.31	1.81	0.95	0.84
Meltan	1.72	3.62	0.72	1.44	1.10
Brenda	1.64	2.94	1.91	0.75	0.94
Hanka	1.64	2.07	1.47	1.46	1.55
Pasadena	1.48	1.57	1.12	1.85	1.39
Pewter	1.42	1.56	0.90	1.89	1.32
Scarlett	1.41	4.19	0.95	0.39	0.12
Cellar	1.40	2.11	0.83	1.71	0.94
Orthega	1.18	2.02	1.07	0.79	0.84
Prestige	1.12	3.00	0.81	0.24	0.42
Marnie	1.05	2.89	0.56	0.40	0.34
Thuringia	0.85	0.69	0.25	1.22	1.26
Eunova	0.78	1.76	0.51	0.37	0.47
Hendrix	0.68	0.99	0.52	0.65	0.57
Havanna	0.64	1.05	0.59	0.60	0.33
Jacinta	0.52	0.97	0.42	0.36	0.31
Auriga	0.42	0.24.	0.19	0.48	0.78
Sigrid	0.14	0.18	0.04	0.10	0.24
Steffi	0.01	0.00	0.03	0.00	0.00

LSD 5% = 2.84% (to compare average of cultivars).

Correlation coefficients ($P < 0.001$) of $r = 0.93$ between the locations in the first cycle and $r = 0.96$ in the second cycle compared to $r = 0.75$ between the two cycles showed there was always more similarity between the two test locations in the second year of one cycle than between the two years of infection of the flowers, which always occurred in the first year of one cycle.

From all officially registered cultivars only Steffi was resistant to loose smut from DE-29490, which was used to test all marketed cultivars (Table 5). Only Steffi remained within the German tolerance limit of five ears in an area of 150 m^2 for certified seed production, which means a disease rate of 0.01% (Table 1). The cultivar Sigrid showed nearly complete cleistogamic flowering with most of the ears remaining in the leaf sheath of the flag leaf. Therefore the susceptibility of Sigrid was the lowest among infested cultivars. However Sigrid did not receive any attention from organic farming since it was released because of its very short plant height, resulting in poor light competitiveness with weeds. With a plant infection rate of < 1% throughout all locations, cvs Auriga, Hendrix and Jacinta deserve attention. Twenty-one of the 42 cultivars had an average infection rate of < 2%. Only Maresi with 5.4% and the highly susceptible Danuta with an average of 12.6% infestation reached values > 5% (Table 5).

Compared to the locations of other loose smut populations, DE-29490 produced smut of only medium virulence (Table 3). Perhaps a higher degree of infestation could be established by using barley infected with loose smut CZ-76701 as an infection source in the experimental design, as this was the most virulent population under artificial inoculation in the parallel experiment with genetic resources.

Vigorous rejection levels for basic and certified seed throughout Europe indicate barley loose smut to be of serious concern. A highly susceptible cultivar such as Danuta reaches a high degree of natural infestation during only two generations after the disease appears in the plots. None of the cultivars available on the German market remained free from attack after inoculation. However, 50% of the tested cultivars did not show more than an average of 2% infestation during two test cycles. This was much less than expected, but too much to avoid the risk of losing approval as certified organic seed. If spring barley for certified seed production is to be multiplied for more than one generation under organic farming conditions, new cultivars with a broad resistance are required.

The Un8 resistance such as that in CDC Freedom, which is used in Canada, seems to be also suitable for central Europe. The lower germination rate after artificial inoculation was expected because of the type of embryo resistance in Un8, which is based on cell necrosis after penetration by the fungal hyphae. The high concentration of fungal spores from inoculation could result in seed atrophy with a total loss of germination (Gabor and Thomas, 1987). The effect on seed viability of CDC Freedom from inoculation was probably caused by high inoculum pressure, very different from natural disease conditions. Reduced germination after infection should not be a problem under organic farming conditions. However, if Un8 is to be widely used in Canada and Europe, the demand for different resistances to loose smut will soon arise, because the current resistance may well break down.

The reasons for Jet remaining free from disease infestation whilst carrying Un3 and Un6 cannot be explained; resistance to smut from CZ-76701, which did not occur in accessions with Un6, may have been due to Un3 or a combination of Un3 with Un6, but no accession with Un3-resistance only was available for testing. For this reason it was impossible to decide whether a resistance based upon Un3 only might be sufficient. But Jet could still be a source for resistance breeding in Europe.

CIho 9973, which remained free from loose smut infection, carries quantitative loose smut resistance, but this cannot yet be integrated into a new cultivar (Therrien, 1999). Therefore CIho 9973 will not be the first choice for resistance breeding. Further work should be carried out to prove if the two barley accessions Lino and GangTuoQuingKeHao1, both of which withstood all disease attacks and not previously known to carry broad resistance, have different genetic backgrounds than Jet or CDC Freedom, before they are recommended for further breeding.

From all tested accessions it is more likely that the sample of Pervonez, which should have Un8, carried Un6, because of its susceptibility to CZ-76701. The original loose smut population, which was used during development of Pervonez, was probably not virulent to Un6. Perhaps this should be the reason for establishing Un6 resistance in this cultivar. Otherwise it is suggested that the tested sample of K-26337 was not identical to that described by Kirdoglo (1990).

The low disease infestation rate of K-29630 indicates the Un12 resistance to be a partial resistance. This also agrees with Kirdoglo (1990), that Un12 is effective under dry growing conditions. Dry conditions, in particular during flowering, reduce susceptibility to loose smut, because germination of spores needs high humidity (Oertel, 1955). For dry environments a partial resistance could be sufficient. However, it may be possible that higher temperatures increase the level of Un12 resistance. The differing resistance patterns of the

Mongolian K-19907 and CIho 4058 indicate that they carry different partial resistances and the unique pattern of susceptibility of Ogalitsu makes it useful as a differential line to identify loose smut population locations.

The following nine accessions could be used as a differential set to distinguish loose smut populations: HOR 248 = Trebi (Un1); HOR 3134 = MoB475 (Un2); HOR 11363 = Steffi (Un6); CDC Freedom (Un8); K-29630 (Un12); K-19907 (Un13); K-30593 = Mik-1 (Un15); CIho 4058 = Ulyasutai; HOR 4476 = Ogalitsu.

For further testing under natural disease infestation it should be recognized that during testing of cultivars the correlation between the two test cycles was much lower than between the locations; this suggests that more different locations for disease infestation during flowering are required than a higher number of second year locations for testing the degree of infestation, in order to estimate the natural susceptibility of cultivars. With a growing market for products from organic agriculture the demand for certified organic seed increases. To avoid shortages, breeding for loose smut resistance is urgently required. The other option would be to increase the tolerance level for loose smut to 2% natural infestation in seed certification. As a first step, the information about loose smut resistance could be reported in official cultivar recommendations to help seed multipliers estimate the infection risk in continued multiplication in organic farming.

Acknowledgements

The trials were supported by the German Federal Ministry of Consumer Protection, Food and Agriculture under project number 01HS027. With the help of breeders and scientists from Germany and related countries it was possible to collect the loose smut populations from different locations. Hartmut Spiess was in charge of the second test location, Dottenfelderhof. Irina Terentieva from St.Petersburg, Helmut Knuepffer from Gatersleben, Harold Bockelman from Aberdeen/Idaho and Brian Rossnagel from Saskatoon made available the genetic resources, and participants of EU COST Action 860 (SUSVAR) collated data on seed inspection rejection levels from many European countries. I would like to thank them all for their assistance.

References

Gabor BK and Thomas PL (1987) Un8 allele for loose smut resistance associated with necrosis in embryos of infected barley. Phytopathology 77: 533–538.

Hewett PD (1979) Reaction of selected spring barley cultivars to inoculation with loose smut, *Ustilago nuda*. Plant Pathology 28: 77–80.

Kirdoglo EK (1990) Breeding barley for resistance to smut and leaf/stem diseases. Vestnik Sel'skochozjajstvennoj Nauki Moskva 10: 98–104.

Luk'yanova MV and Tishkov NI (1985) Basic trends in barley breeding in the steppe zone of the southern Urals. Sbornik Nauchnykh Trudov po Prikladnoi Botanike, Genetike i Selektsii 95: 23–28.

Metcalfe DR (1969) Genetics of host resistance to loose smut of barley. Barley Genetics II. Proceedings of the 2nd International Barley Genetics Symposium Pullman. Washington 1971, 508–512.

Metcalfe DR and Johnston WH (1963) Inheritance of loose smut resistance. II Inheritance of resistance in three barley varieties to races 1,2 and 3 of *Ustilago nuda* (Jens.) Rostr. Canadian Journal of Plant Science 43: 390–396.

Moseman JG and Metcalfe DR (1969) Identification of resistance genes in barley by reactions to *Ustilago nuda*. Canadian Journal of Plant Science 49: 447–451.

Niemann E (1961) Flugbrandresistente Gerstensorten. Zeitschrift fuer Pflanzenzuechtung 45: 8–16.

Nover I, Lehmann CO and Seidenfaden A (1976) Resistenzeigenschaften im Gersten and Weizensortiment Gatersleben. 20. Pruefung des Verhaltens von Gersten gegen Flugbrand, *Ustilago nuda* (Jens.) Rostr. Kulturpflanze 24: 237–247.

Oertel C (1955) Untersuchungen zur Biologie des Gerstenflugbrandes (*Ustilago nuda* (Jens.)Kellerm.et Sw.). Kuehn-Archiv 69: 552–602.

Poehlman JM (1945) A simple method of inoculating barley with loose smut. Phytopathology 35: 640–644.

Poehlman JM (1947) Sources of resistance to loose smut, *Ustilago nuda*, in winter barleys. Journal of American Society of Agronomy 39: 430–437.

Terentieva I, Khohlova A and Kovaleva O (2000) Australian Spring Barley in North-West Russia:Sources of Earliness, Resistance to Loose Smut, Drought Tolerance. In: Logue S (ed) Barley Genetics VIII, Proceedings of the 8th International Barley Genetics Symposium, 22–27 October 2000, Adelaide, 3: 295–296 [ISBN 0086396-680-3].

Therrien MC (1999) The possibility of quantitative inheritance of loose smut in barley. Barley Genetic Newsletter 29: 30.

Thomas PL and Menzies JG (1997) Cereal smuts in Manitoba and Saskatchewan, 1989–95. Canadian Journal of Plant Pathology 19(2): 161–165.

Thomas PL and Metcalfe DR (1984) Loose smut resistance in two introductions of barley from Ethiopia. Canadian Journal of Plant Science 64: 255–260.

Utz HF (2001) PLABSTAT, ein Computerprogramm zur statistischen Analyse pflanzenzuechterischer Experimente. Universitaet Hohenheim.

Wicke H (1986) Vergleichende Untersuchungen zur Resistenz von Sommergerstensorten gegen den Flugbranderreger *Ustilago nuda* (Jens.) Rostr. Dissertation, Rheinische Friedrich-Wilhelms-Universitaet, Bonn.

Zeidan MI (1955) The inheritance of resistance to *Ustilago nuda* (JENS.) K. and W., race 1, in barley. Dissertation Abstracts 15:326.