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Genetics of and Breeding for Resistance to BaYMV

R. Götz[1], B. Foroughi-Wehr[2], R. Kaiser[1] and W. Friedt[1]

[1] Institute of Agronomy and Plant Breeding, Justus-Liebig-University, D-6300 Gießen Ludwigstr. 23, Germany F. R.

[2] Institute of Resistance Genetics, BBA, Grünbach, D-8059 Bockhorn, Germany F. R.

Yellow mosaic disease of barley is one of the most important cereal virus diseases in the Federal Republic of Germany and other European countries, like France, Belgium, England and the German Democratic Republic. The present area of distribution in Germany mainly covers the central and northern parts of the country, however, soil of some smaller areas in the south are infested, too (Huth, 1984).

This soil-borne disease is caused by barley yellow mosaic virus (BaYMV), which is transmitted by a fungus, *Polymyxa graminis.* The disease was first discovered in Japan in 1940 (Inouye and Saito, 1975) and became subsequently one of the major diseases of Japanese two-rowed malting barley (Usugi, 1987). Barley yellow mosaic virus frequently causes severe damage to susceptible winter barley crop with corresponding substantial reductions of grain yield (Table 1; see also Friedt and Götz 1987; Huth, 1984). Because of its soil-transmission, chemical measures against this virus disease are either inefficient or uneconomic. So far, yield losses can only be prevented by growing resistant cultivars.

Sources of resistance to BAYMV

After the virus had been discovered in the Federal Republic of Germany (Huth and Lesemann, 1978), many entries of various barley collections have been screened recently and numerous stocks from different parts of the world were found to be resistant or immune to BaYMV (Takahashi, 1983; Friedt et al., 1985), for example high-lysine barley 'Hiproly' from Ethiopia, 'Turkey Naked 2' (naked, black kernel) from Turkey, 'Anson Barley' (awnless) from the U.S.A. or the two-rowed barley cv. 'Palomino' from England (Table 2). But most of the identified, immune genetic stocks are descending from East Asia, like 'Mokusekko 3', 'Mihori Hadaka 3', 'Muju covered 2', and 'Asahi 9' (Table 2).

In Germany, several released, BaYMV-resistant cultivars are available now, i.e. 'Banjo', 'Brunhild', 'Birgit', 'Franka', 'Ogra' (six-rowed) and 'Diana', 'Sonate' (two-rowed). According to the nomenclature recommended by Cooper and Jones (1983), these cultivars may be considered as being immune to the virus.

Tests for resistance to BaYMV are carried out by mechanical inoculation in the greenhouse and laboratory respectively; details of inoculum preparation, plant inoculation and subsequent maintenance of inoculated plants have already been described earlier (Friedt, 1983; 1984). It is necessary to mention that only

Table 1

Grain yield of BaYMV-resistant as compared to susceptible winter barley cultivars in Northern Hesse, 1987

Cultivar	BaYMV-reaction	Grain yield*	
		dt/ha	relative
Six-row			
Franka	resistant or immune	48.2	100
Mammut	susceptible	19.8	41
Two-row			
Sonate	resistant or immune	46.1	100
Danilo	susceptible	24.9	54

* Gipper's Farm, Bellnhausen/Gilserberg: 10 m^2 plots, 3 replications; LSD 5% = = 7.8 dt/ha.

Table 2

Sources of resistance to BaYMV (FRIEDT & FOROUGHI-WEHR, 1987)

Variety	Origin	Reference (s)
Mokusekko 3	China	Takahashi et al., 1973
Resistant Ym No. 1	Japan	Muramatsu, 1976
Kanto nijo 19	Japan	Kitahara et al., 1982
Tochigi-strains	Japan	Kitahara et al., 1982
Mihori hadaka 3	Japan	Takahashi et al., 1973
Chikurin Ibar. 'Ea52'	Japan	Ukai, 1984
Hiproly (CI 3947)	Ethiopia	Yoshikawa & Kato, 1983
Kagoshima Kobai	Japan	Friedt et al., 1985
Muju covered 2	Japan	Friedt et al., 1985
Senbon hadaka	Japan	Kawada et al., 1982
Asahi 9	Japan	Sanada, pers. comm.
Nirasaki-strains	Japan	Sanada, pers. comm.
Iwate Mensury 2	Japan	Friedt et al., 1985
Miyako A	Japan	Friedt et al., 1985
Taisho-mugi	Japan	Kato, pers. comm.
Anson barley	USA	Murphy, 1983
Turkey Naked 2	Turkey	Friedt et al., 1985
Birgit, Franka, Ogra	FRG	Friedt et al., 1985
Diana, Gloria, Sonate	FRG	Friedt et al., 1985
Palomino	England	Friedt et al., 1985

the virus-type M (BaYMV-M) can be used for mechanical inoculation, while the other virus-types, which are known now, are not applicable in this test, because their infection-rate is too low.

Results of genetic analyses

Previous genetic studies have indicated, that immunity to BaYMV of German cultivars mentioned above is probably due to one recessive gene (Table 3). Resistance genes of the different adapted cultivars are obviously identical, because their crosses do not segregate in F_2, where all plants are resistant (Table 4). This "German gene" was probably derived from a commonly used cross parent, 'Ragusa', a Dalmatian land-race of spring-barley (Friedt, 1984).

In order to obtain a complete picture of genetic diversity of BaYMV-resistance in barley, the German resistant cultivars were crossed in various combinations to foreign carriers of BaYMV-resistance. By analyzing such crosses, different (non-allelic) resistance genes can be identified.

In earlier genetic analyses carried out in Japan, three different resistance genes were identified. A dominant gene was found in the Chinese spring barley 'Mokusekko 3' (Ym1), and another dominant gene was found in the Japanese naked spring barley 'Mihori Hadaka 3' (Ym2, Takahashi et al., 1973). The resistance gene of 'Mokusekko 3' was introduced into two-rowed malting barley like 'Resistant Ym No. 1', a BaYMV-immune strain with favourable agronomic and malting characteristics (Muramatsu, 1976). Recent investigations in Japan (Kawada et al., 1986) have shown, that other varieties also carry gene Ym1, e.g. 'Hakei I-41', although their resistance-gene was not derived from 'Mokusekko 3'.

Table 3

Genetics of BaYMV-Resistance: Mechanical Inoculation of crosses including "German resistance" as male parent (GÖTZ, 1989)

Female	F_2-Segregation resistant : susceptible	Interpretation
Franka	120 : 0	identical
Birgit	123 : 0	identical
Mokusekko 3	328 : 0	allelic
Hakei I-41	119 : 1	allelic
Iwate Mensury 2	119 : 0	allelic
Kagoshima Kobai 1	120 : 0	allelic
Kanto Nijo 19	116 : 0	allelic
Nirakei 31	119 : 0	allelic
S-1001	120 : 0	allelic
Turkey Naked 2	122 : 0	allelic
Anson barley	55 : 65	7 : 9

Table 4

Genetics of BaYMV-Resistance: Mechanical Inoculation of crosses including "*Yml*" (GÖTZ, 1989)

Female	(Male: *Yml*) resistant : susceptible	Interpretation
Diana	120 : 0	allelic
Franka	120 : 0	allelic
Hakei I-41	120 : 0	allelic
Iwate Mensury 2	120 : 0	allelic
Kagoshima Kobai 1	119 : 1	allelic
Kanto Nijo 19	118 : 0	allelic
Nirakei 31	116 : 0	allelic
S-1001	118 : 0	allelic
Turkey Naked 2	123 : 0	allelic
Anson barley	89 : 30	13 : 3 ?

Ukai (1984) reported that a recessive mutation causes BaYMV-immunity in the early mutant 'Ea52' of the Japanese six-rowed cv. 'Chikurin Ibaraki 1'; its gene was shown to be not allelic to the genes Yml and Ym2. Therefore, Ukai (1984) proposed the symbol Ym3 for this "new" gene. However, it does not provide resistance to BaYMV-strains prevailing in Germany (e.g. BaYMV-M), whereas the original variety 'Chikurin Ibaraki 1' proved to be resistant here (Friedt, 1985).

These varieties and numerous other resistant genetic stocks were used in the crossing programme mentioned above. Hybrid plants (F_1) from crosses of German cultivars like 'Ogra' to Asian resistant parents, which carry the gene Yml, like 'Mokusekko 3', 'Resistant Ym No. 1' or 'Hakei I-41', were all resistant and the respective F_2-populations did not segregate susceptible individuals (Table 3). Since German varieties possess a recessive resistance gene, segregation into 3 susceptible and 13 resistant F_2-plants would be expected, provided that the genes were unlinked. The fact, that no one susceptible individual occurred among almost 4,000 F_2-plants indicates therefore, that the respective resistance genes are either allelic or very tightly linked.

Several other resistant stocks like 'Iwate Mensury 2', 'Nirakei 31' and 'Turkey Naked 2' were crossed to German cultivars. These crosses also did not segregate susceptible plants in F_2 and therefore, the respective resistance-genes must be allelic to the "German gene", too.

The cross between 'Diana' and 'Anson Barley' was the first one between a German cultivar and a foreign resistant variety which has segregated susceptible plants in the F_2-generation. The observed segregation (7 : 9) indicates that the resistance-genes are unlinked and that both act recessively.

Progeny of crosses of several resistant genetic stocks to either Yml or German cultivars lead to identical results, e.g. the F_2-generation did not segregate in both cases (Table 4). This confirms the conclusion mentioned above, that the "German gene" and Ym1 are either allelic or very tightly linked. The observed F_2-segregation of the cross of Ym1 to 'Anson Barley' (Table 4, Table 5) confirms this conclusion. Finally, segregation in the F_2-generation of crosses of the "German gene" and Ym1, respectively, to 'Anson Barley' clearly indicates that the resistance of the latter variety is inherited independently from the former genes.

Table 5

Anther-culture results of crosses including donors of dominant BaYMV-resistance derived from 'Mokusekko 3'

(*'Mokusekko' x 'Igri'*) x	Anthers cultured	Callus-format. (%)		Green plants (%)		BaYMV-React. inocul.	susc.
Strain 106/1430-2						A_1	
x Alraune	20,907	1,309	(6.3)	188	(0.9)	156	64
x Cosima	21,265	1,102	(5.2)	120	(0.6)	102	36
x Danilo	20,444	1,072	(5.2)	114	(0.6)	99	40
x Marinka	21,366	1,252	(5.9)	126	(0.6)	126	53
Stamm 106/1431-1							
x Harmonika	5,379	444	(8.3)	51	(0.9)	38	19
x Interbell	6,487	322	(5.0)	35	(0.5)	28	13
x Posaune	8,628	801	(9.3)	238	(2.8)	231	55
x Tamara	5,097	664	(13.2)	145	(2.8)	131	87
Total/Average	109,673	6,966	(6.4)	1,017	(0.9)	911	367

Breeding for BAYMV-resistance

Since various sources of monogenically inherited resistance or immunity are available (Table 2), rapid progress in breeding for BaYMV-resistance has already been made in recent years and can further be expected in the near future. Many of the resistant cultivars or stocks exhibit inferior agronomic performance, due to susceptibility to lodging or various diseases or, in total insufficient grain yield (Friedt and Götz, 1987). Therefore, extensive breeding activities are required for an improvement of agronomic value of these resistant materials.

In self-pollinating barley, new breeding lines and cultivars can either be developed by conventional selfing over several generations, i.e. pedigree-, bulk- or family-selection procedures or by using haploidy-techniques (e.g. via androgenesis, i.e. anther- or microspore-culture) for the production of dubled-haploid, i.e. homozygous lines. In the case of monogenic-recessive immunity, as many as 50% of homozygous resistant doubled haploids can be expected from an F_1-hybrid derived from an immune and a susceptible parent, whereas the selfed F_1-progeny yields only 25% homozygous recessive, i.e. BaYMV-immune plants in F_2. The results obtained from culturing anthers of various F_1-hybrids including

Yml is given in Table 5. Numerous doubled haploid lines have already been tested in field trials for agronomic performance. Many of them have already been handed over to breeding companies for further propagation and testing.

Literature

Cooper, J. I. and Jones, A. T. (1983): Responses of plants to pathogens: Proposals for the use of terms. Phytopathology 73, 127–128.

Friedt, W. (1983): Mechanical transmission of soil-borne barley yellow mosaic virus. Phytopath. Z. 106, 16–22.

Friedt, W. (1984): Frühselektion auf Resistenz gegen Barley Yellow Mosaic Virus durch mechanische Inokulation. Nachrichtenbl. Deut. Pflanzenschutzd. 36, 179–182.

Friedt, W. (1985): Genetic studies of resistance to barley yellow mosaic virus of German winter barley cultivars. Barley Genet. Newsl. 15, 58–61.

Friedt, W. and Foroughi-Wehr, B. (1987): Genetics of resistance to barley yellow mosaic virus. Barley Genetics V, Proc. 5th Int. Barley Genet. Symp., Okayama, Japan (in press).

Friedt, W. and Götz, R. (1987): Perspektiven des Wintergerstenanbaues bei zunehmender Gefährdung durch das Gelbmosaikvirus. Ergebnisse landw. Forschung 18, 31–40.

Friedt, W., Huth, W., Mielke, H. and Züchner, S. (1985): Resistenzträger gegen Barley Yellow Mosaic Virus. Nachrichtenbl. Deut. Pflanzenschutzd. 37, 129–135.

Götz, R. (1989): Genetische Untersuchungen zur Diversität der BaYMV-Resistenz. Diss. Univ. Gießen (in prep.).

Huth, W. (1984): Die Gelbmosaikvirose der Gerste in der Bundesrepublik Deutschland — Beobachtungen seit 1978. Nachrichtenbl. Deut. Pflanzenschutzd. 37, 129–135.

Huth, W. and Lesemann, D.-L. (1978): Eine für die Bundesrepublik Deutschland neue Virose der Wintergerste. Nachrichtenbl. Deut. Pflanzenschutzd. 36, 184–185.

Kawada, N., Sasaki, A. and Tsuru, M. (1982): Selection of resistance varieties to barley yellow mosaic disease and their agronomic characters. Jap. J. Breed. 32 (Supp. 2), 158–159 (jap.).

Kawada, N. and Tsuru, M. (1986): Genetics and Breeding of the Resistance to Barley Yellow Mosaic Virus. Barley Genetics V, Proc. 5th Int. Barley Genet. Symp., Okayama, Japan (in press).

Kitahara, S., Fujii, T., Kobayashi, S. and Seko, H. (1982): Studies on breeding of malting barley which is resistant to barley yellow mosaic. 2. Yields of resistant lines in the infected field. Jap. J. Breed. 32, (Suppl. 2), 34–35 (jap.).

Muramatsu, M. (1976): Breeding of malting barley variety which is resistant to barley yellow mosaic. In: Barley Genetics III, 476–485. Proc. 3rd Int. Barley Genet. Symp., Garching, 1975.

Murphy, R. P. (1983): Registration of Anson barley (Reg. No. 182). Crop Sci. 23, 181.

Takahashi, R. (Adv. Ed.) (1983): Catalogue of Barley Germplasm preserved in Okayama University. Inst. Agric. Biol. Sci., Okayama University, Kurashiki, Japan, 217 p.

Takahashi, R., Hayashi, J., Inouye, T., Moriya, I. and Hirao, C. (1973): Studies on resistance to yellow mosaic disease in barley. I. Tests for varietal reactions and genetic analysis of resistance to the disease. Ber. Ohara Inst. 16, 1–17.

Ukai, Y. (1984): Genetic analysis of a mutant resistant to barley yellow mosaic virus. Barley Genet. Newsl. 14, 31–33.

Usugi, T. (1987): Epidemiology of soil-borne filamentous viruses in Japan. Proc. AAB-Meeting, St Andrews, Scotland, 1987.

Yoshikawa, R. and Kato, I. (1983): Inheritance of barley yellow mosaic resistance in naked barley (*Hordeum vulgare* L. emend. Lam.). Jap. J. Breed. 33 (Suppl. 1), 232—233 (jap.).