Neth. J. Pl. Path. 94 (1988) 177-184

A comparative study of resistance to powdery mildew in wild emmer wheat in the seedling and adult plant stage

C.H. VAN SILFHOUT[1] and Z.K. GERECHTER-AMITAI[2]

[1] Research Institute for Plant Protection (IPO), P.O. Box 9060, 6700 GW Wageningen, the Netherlands
[2] Agricultural Research Organization, The Volcani Center, P.O. Box 6, Bet Dagan, Israel

Accepted 14 December 1987

Abstract

In a comparative study of 272 entries of wild emmer (*Triticum dicoccoides*), resistance to powdery mildew (*Erysiphe graminis* f.sp. *tritici*) was determined both in the seedling and the adult plant stage. The performance of the entries was evaluated with two methods, scoring of infection types and noting the uppermost leaf which had become affected. With the first method, 133 entries were resistant both in the seedling stage and the adult plant stage, while with the second method 134 entries were resistant in the seedling stage and free of infection or affected only on the lower leaves in the adult plant stage. Moreover, 26 entries which were susceptible in the seedling stage, became moderately resistant or resistant in the adult plant stage. In general, there was good agreement between seedling and adult plant reactions. Screening for resistance to powdery mildew in the seedling stage was shown to be a reliable method to secure selections for wheat breeding programmes. By screening in the adult plant stage and comparing with the seedling reaction, four different types of resistance were found, namely true seedling resistance, overall resistance, adult plant resistance and partial resistance.

Additional keywords: Erysiphe graminis f.sp. *tritici, Triticum dicoccoides.*

Introduction

The importance of finding new sources of resistance to the powdery mildew fungus of wheat, *Erysiphe graminis* DC. ex Merat f.sp. *tritici* [E. Marchal], has been stressed by various workers. Already two decades ago it was realized that in cultivated wheat the few known genes for resistance successively were matched by virulence genes in the pathogen when cultivars with those genes were grown commercially (Leijerstam, 1965). Therefore, the search was extended to the wild and semi-wild species related to cultivated wheat, and in particular to wild emmer, *Triticum dicoccoides* Körn., a new potential source of resistance (Lehmann, 1968; Filatenko, 1969; Leijerstam, 1972; Krivchenko et al., 1979; Moseman et al., 1984; Gerechter-Amitai and Van Silfhout, 1984).

In a collection of wild emmer from ten sites in Israel, Moseman et al. (1984) found that 49% of the entries were resistant to powdery mildew when they were inoculated in the seedling stage with American cultures of the pathogen. Studying a different collection of wild emmer from 73 sites in Israel and other Middle East countries, Gerechter-Amitai and Van Silfhout (1984) showed that in field nurseries 62% and 48% of the

entries were resistant in the adult plant stage to the local populations of powdery mildew in Israel and in the Netherlands, respectively. Comparing the performance of 47 wild emmer entries which were tested in all six nurseries, they discerned 11 markedly different reaction patterns, indicating the presence of several different resistance genes.

Thus, it has been established by two teams, studying two collections of wild emmer with powdery mildew of different origin, that resistance to the pathogen is rather common in the seedling stage (Moseman et al., 1984) and in the adult plant stage (Gerechter-Amitai and Van Silfhout, 1984). However, it is not known whether the same entry which is resistant to the local powdery mildew population in the seedling stage, will also be resistant to this inoculum in the adult plant stage. In wild cereals, it is often found that seedling resistance is not effective in the adult plant stage. In studies by the second author (unpublished data), seedlings of *Avena barbata* and *A. sterilis* resistant to *Puccinia graminis* f.sp. *avenae* and of *Hordeum spontaneum* resistant to *P. graminis* f.sp. *tritici* and to *P. graminis* f.sp. *secalis*, as well as juvenile plants of *Triticum dicoccoides* resistant to *P. recondita*, were found to be susceptible to the respective pathogens in the adult plant stage.

The main objective of the present investigation is to study the relation between seedling and adult plant resistance to powdery mildew in wild emmer wheat.

Materials and methods

The wild emmer material used in the present study consisted of 272 entries, collected by the second author. This collection included for the greater part the same entries which were placed at the disposal of Moseman et al. (1984) for their seedling experiments, but differed from that used in our previous adult plant studies (Gerechter-Amitai and Van Silfhout, 1984). For the present investigation, seeds were obtained from 158 collection sites representing the major distribution area of *T. dicoccoides* in Israel, both geographically and ecologically. The sites range from −180 m alt. near Lake Kinneret (Sea of Galilee) to approximately 1500 m alt. on Mt. Hermon. The entries showed a wide range of variation for morphological traits and colour characteristics.

The experiment was carried out at the Zelder Breeding Station, Ottersum, the Netherlands. A local field collection of powdery mildew, isolated from wheat, served as inoculum. The inoculum was multiplied in a greenhouse at 20-25 °C, protected from direct sunlight by a cheese cloth screen. During cloudy days, light was supplemented by SONT lamps supplying approximately 400 Wm^{-2}. The same field collection was used both in the seedling tests and in the field trials.

For seedling tests, about 12 seeds were sown in 5 × 5 cm plastic pots, the seedlings were inoculated ten days after sowing, when the second leaf had appeared. Inoculations were made by brushing the seedlings evenly with sporulating plants. The inoculated seedlings were maintained under the same conditions as used for the multiplication of the inoculum. Infection types were scored ten days after inoculation, using a scale from 0 (immunity) to 9 (complete susceptibility), (Moseman et al., 1984).

For the field trial, plants were sown in 4 × 4 cm pots, one seed per pot. For germination of the seeds, the pots were placed in a heated greenhouse. After germination they were kept out of doors and protected from frost at night, for 3 weeks during February. Finally they were planted out in the field in rows of one meter length, ten plants per row, spacing between the rows 40 cm. When the plants were in the tillering stage, pots

with sporulating seedlings were transplanted into the field to serve as spreaders of the inoculum. In order to ensure good infection, the plants in the trial were also inoculated by brushing them with sporulating leaves from the seedling experiment approximately three weeks after the spreaders were set out.

In the adult plant stage, ratings for powdery mildew reaction were made twice, first on June 18 when most entries were in the boot to heading stages and the disease had reached the highest leaf layer, and secondly 15 days later, when the plants were in the heading to milky ripe stages and the disease had developed optimally, with up to 50% severity on the flag leaves. In field readings, reactions were recorded as O = very resistant (no sporulation), R = resistant (small sporulating areas), M = moderately resistant (intermediate size sporulating areas) and S = susceptible (large sporulating areas). In order to facilitate a comparison between seedling and adult plant reactions, the infection types (IT) recorded in the seedling tests were grouped into the same four categories: O (IT 0-2), R (IT 3), M (IT 4-6) and S (IT 7-9).

In the present study, a simplified version of the scale devised by Saari and Prescott (1975) was also used for scoring powdery mildew infection. In this scale, which is based on the position of the highest diseased leaf, a plant is considered more susceptible when higher leaf layers are affected. In this version, disease development was assessed as absent (O), low (L), intermediate (I) or high (H), when no symptoms were visible or when the symptoms were visible on the lower, middle or upper leaves, respectively.

Results

The reactions of the 272 wild emmer entries tested for powdery mildew resistance are summarized in Table 1a, listing the observed reaction patterns and the number of entries displaying each of these patterns.

In the seedling tests, 136 of the entries (50.0%) were non-sporulating (highly resistant), 19 (7.0%) were resistant and 54 (19.8%) were moderately resistant whereas 63 (23.2%) proved to be susceptible (Table 1b). In the adult plant stage, considering the higher of the two readings only, 138 entries (50.7%) were non-sporulating, 54 (19.8%) were resistant, 35 (12.9%) were moderately resistant and 45 (16.6%) were susceptible (Table 1a). The combined results of the seedling and adult plant tests showed that 151 of the 272 entries were immune or resistant (O or R) in all stages of growth (Table 1c).

Comparing the highest reactions of the adult plants with those of the seedlings (Table 1a), more than half of the entries (173 out of 272) displayed reactions which were similar in both growth stages. In the others, a shift towards resistance was observed in 68 entries and towards susceptibility in 31 entries. Most of these shifts were of minor magnitude, major shifts towards susceptibility occurred in three entries and major shifts towards resistance in 41 entries (Table 1c).

To evaluate resistance in the adult plant stage, a comparison was made between the data obtained on reaction to infection and on the highest leaf layer affected (Table 2). On the basis of this table, the Spearman rank correlation coefficient between the two methods was calculated to be 0.72 for the first adult plant scoring. The correlation coefficient for the second scoring appeared to be slightly higher at 0.76. The high correlation indicates that both methods will generally lead to the same conclusions. However the differences between the two methods indicate cases of special interest. The 14 entries with a resistant reaction and symptoms on intermediate leaf layers (Table 2) and

Table 1a. Comparison of seedling and adult plant reaction to powdery mildew in 272 entries of wild emmer and their distribution according to reaction pattern.

Seedling reaction*	Adult plant reaction			Number of entries
	first scoring	second scoring	highest score	
O	O	O	O	113
O	O	R	R	1
O	R	O	R	12
O	R	R	R	7
O	R	M	M	1
O	M	O	M	1
O	S	S	S	1
R	O	O	O	14
R	R	O	R	3
R	R	R	R	1
R	M	O	M	1
M	O	O	O	10
M	O	R	R	1
M	O	S	S	1
M	R	O	R	7
M	R	R	R	10
M	R	M	M	1
M	M	O	M	3
M	M	R	M	6
M	M	M	M	9
M	M	S	S	1
M	S	M	S	3
M	S	S	S	2
S	O	O	O	1
S	O	R	R	1
S	R	O	R	3
S	R	R	R	8
S	R	M	M	2
S	M	R	M	4
S	M	M	M	7
S	M	S	S	4
S	S	R	S	1
S	S	M	S	6
S	S	S	S	26
Total				272

* Reaction classes: O = no visible infection or immune; R = resistant; M = moderately resistant; S = susceptible.

the 12 entries which were moderately resistant and showed symptoms on the higher leaf layers, are considered more susceptible when evaluated with the modified Saari-Prescott scale (fast disease development). Even more interesting are the six entries with

Table 1b. Number of wild emmer entries which were classified as immune (O), resistant (R), moderately resistant (M) or susceptible (S) to powdery mildew at three growth stages.

Growth stage	(DC*)	O	R	M	S	Total
Seedling	(11)	136	19	54	63	272
Boot - heading	(45-55)	142	55	36	39	272
Water ripe - early milk	(71-73)	168	40	29	35	272

* DC = Decimal Code for growth stages (Zadoks et al., 1974).

Table 1c. Seedling reaction and highest adult plant reaction to powdery mildew with postulated type of resistance in 201 wild emmer entries.

Seedling reaction	Adult plant reaction	Type of resistance	Number of entries
O	M or S	seedling	3
O or R	O or R	overall	151
M or S	O or R	adult	41
S	S	partial	26*

* See Table 4.

Table 2. Relation between reaction to powdery mildew and uppermost leaf layer at which symptoms were visible in 130 entries of wild emmer at boot to heading stage.

Leaf layer	Number of entries in reaction class			
	R	M	S	total
L*	41	14	2	57
I	14	10	4	28
H	0	12	33	45
Total	55	36	39	130**

Spearmans r = 0.72.
* L = lower; I = intermediate; H = higher leaf layers.
** Immune plants were excluded.

a susceptible reaction and symptoms on lower or intermediate leaf layers which are considered more resistant when evaluated with the modified Saari-Prescott scale (Table 2 and 4), indicating a slow disease development.

Since in the nursery considerable variation in phenology was observed, notes were taken also on the developmental stage (DC) of each entry (Zadoks et al., 1974). At the time of the first disease reading in the adult plant stage (Table 3), ten entries were in the elongation stage (DC 37), 21 in the flag leaf stage (DC 41), 48 in the boot stage (DC 45), 81 in the awn-peeping stage (DC 49) and 112 in the heading stage (DC 55).

Table 3. Relation between reaction to powdery mildew and earliness in 272 wild emmer entries at the first observation in the adult plant stage.

Earliness DC*	O	R	M	S	Total
37	8	1	1	0	10
41	16	2	3	0	21
45	26	7	8	7	48
49	35	17	12	17	81
55	57	28	12	15	112
					272

Spearmans $r = 0.07$.
* DC = Decimal Code for growth stages (Zadoks et al., 1974).

Table 4. Level of partial resistance to powdery mildew estimated by percentage leaf coverage at the flag leaf in 26 wild emmer entries which were susceptible in all growth stages.

Number of entries	Percent coverage	Resistance level
6	0	high
2	< 1	moderate
4	1	moderate
3	5	low
2	10	low
7	25	low
2	50	check

From a cross-tabulation of the frequencies of the five developmental stages and the four reaction classes, a Spearman rank correlation coefficient was calculated. This correlation coefficient was not significantly different from zero, indicating that the differences in earliness of the wild emmer entries at the recording date are not correlated with the level of resistance of the entries.

Although in our studies the resistance of wild emmer was evaluated on the basis of reaction to infection or highest leaf layer affected, notes were taken also on the severity of disease. Differences in severity became most evident in the susceptible group, ranging from mere traces of infection to 50% coverage on the flag leaves (Table 4).

Discussion and conclusions

There was generally a good agreement between seedling resistance and adult plant performance; likely this resistance is based on genes which are effective in all growth stages. This type of resistance is often referred to as 'seedling' resistance, but might better be called 'overall' resistance (Zadoks, 1961). However, there were two groups of entries, in which seedling reaction was not in conformity with adult plant reaction.

In one of these groups, the plants were more resistant in the adult plant stage than in the seedling stage. This shift can be explained by the presence of one or more genes active only in the adult plant stage ('adult plant' resistance). In the other group, in which the plants were more susceptible in the adult plant stage than in the seedling stage, most entries showed only a minor shift in reaction. In a few entries a major shift towards susceptibility was observed; the resistance of these entries could be due to true 'seedling' resistance. In these entries also another mechanism of resistance became evident. Whereas these plants displayed a high infection type in the adult plant stage, and therefore would be classified as susceptible, the severity of infection was low. This was also observed in plants which had a high infection type in all growth stages. This phenomenon is called 'partial' resistance (Parlevliet, 1975) or is sometimes referred to as 'slow mildewing', in conformity with 'slow rusting'.

The fact that resistance to powdery mildew found in the seedling stage of wild emmer is expressed nearly always also in the adult plant stage is of great practical importance. Unlike in cultivated cereals, this is not a general feature in wild cereals, as said before.

In conclusion, for the utilization of wild emmer in wheat breeding programmes, screening for resistance to powdery mildew in the seedling stage was proved to be a reliable method. By additional screening in the adult plant stage, four different types of resistance can be detected, namely 'overall' resistance, 'adult plant' resistance, true 'seedling' resistance and 'partial' resistance.

Acknowledgements

Cooperative investigation of the Research Institute for Plant Protection (IPO), the Netherlands, and the Agricultural Research Organization (ARO), Israel. ARO Contribution No. 2093-E, 1987 Israel.

On request of the Netherlands Minister for Development Cooperation, we state the following: 'The research for this publication was financed by the Netherlands Minister for Development Cooperation, who also shares copyright. Citation is encouraged. Short excerpts may be translated and/or reproduced without prior permission, on the condition that the source is indicated. For translation and/or reproduction in whole the Section for Research and Technology of the aforementioned Minister (P.O. Box 20061, 2500 EB The Hague) should be notified in advance. Responsibility for the contents and for the opinions expressed rests solely with the authors; publication does not constitute an endorsement by the Netherlands Minister for Development Cooperation'.

The willingness of Ir L.J.M. Groenewegen of the Zelder Breeding Station to provide greenhouse and field facilities, and his assistance in the inoculation of the plants, are gratefully acknowledged.

Samenvatting

Vergelijkend onderzoek over resistentie tegen meeldauw van wilde emmer tarwe in het kiemplantstadium en volwassenplantstadium

Van 272 wilde emmer (*Triticum dicoccoides*) herkomsten werd de resistentie tegen meeldauw (*Erysiphe graminis* f.sp. *tritici*) bepaald. Waarnemingen werden gedaan in het kiemplantstadium en tweemaal in het volwassenplantstadium. Voor de evaluatie van

de resistentie in het volwassenplantstadium werden twee methoden vergeleken. Bij de ene methode werd gelet op mate van chlorose en puistgrootte, terwijl bij de tweede methode het hoogste bladniveau werd bepaald waarop meeldauwpuistjes werden waargenomen.

Met de eerste methode bleken 133 herkomsten zowel in het kiemplantstadium als in het volwassenplantstadium resistent te zijn, terwijl met de tweede methode 134 herkomsten in het kiemplantstadium resistent waren en in het volwassenplantstadium geen sporulatie vertoonden of slechts op de onderste bladeren.

Bij vergelijking van de kiemplantreactie met de reactie in het volwassenplantstadium kon onderscheid gemaakt worden tussen resistentie die alleen werkzaam is in het kiemplantstadium (echte kiemplantresistentie), resistentie die alleen in het volwassenplantstadium werkt (volwassenplantresistentie) en resistentie die in alle groeistadia bescherming geeft ('overall' resistentie).

Binnen de groep van 26 herkomsten, die zowel in het volwassenplantstadium als in het kiemplantstadium een vatbaar infectietype vertoonden, bleken 6 herkomsten een lage aantastingsgraad te hebben. Dit duidt op het voorkomen van partiële resistentie.

Concluderend kan gesteld worden dat resistentie tegen meeldauw veelvuldig voorkomt in herkomsten van wilde emmer tarwe en dat deze resistentie wordt veroorzaakt door genen met verschillende werkingsmechanismen.

References

Filatenko, A.A., 1969. Hybridization of *Triticum dicoccoides* Körn. with other wheat species. Trudy po Prikladnoj Botanike Genetike i Selekcii 39: 29-51.

Gerechter-Amitai, Z.K. & Silfhout, C.H. van, 1984. Resistance to powdery mildew in wild emmer (*Triticum dicoccoides* Körn.). Euphytica 33: 273-280.

Krivchenko, V.I., Migushova, E.F. & Sukhanberdina, E.Kh., 1979. The role of genomes in the resistance of wheat to powdery mildew. Genetika XV (2): 298-305.

Lehmann, Ch.O., 1968. Investigation of world collections of crops in the German Democratic Republic. Genetika a slechteni 4 (XLI), 1: 69-80.

Leijerstam, B., 1965. Studies in powdery mildew on wheat in Sweden. II. Physiological races in Scandinavia in 1962 and 1963 and the resistance in a number of wheats to Scandinavian races. Meddelanden Statens Växtskyddsanstalt 13: 103, 169-183.

Leijerstam, B., 1972. Studies in powdery mildew on wheat in Sweden. IV. Inventory of sources of resistance to the Scandinavian race population complex. Meddelanden Statens Växtskyddsanstalt 15: 145, 249-270.

Moseman, J.G., Nevo, E., El Morshidy, M.A. & Zohary, D., 1984. Resistance of *Triticum dicoccoides* to infection with *Erysiphe graminis tritici*. Euphytica 33: 41-47.

Parlevliet, J.E., 1975. Partial resistance of barley to leaf rust, *Puccinia hordei*. I. Effect of cultivar and development stage on latent period. Euphytica 24: 21-27.

Saari, E.E. & Prescott, J.M., 1975. A scale of appraising the foliar intensity of wheat diseases. Plant Disease Reporter 59: 377-380.

Zadoks, J.C., 1961. Yellow rust on wheat, studies in epidemiology and physiologic specialization. Netherlands Journal of Plant Pathology 67: 69-256.

Zadoks, J.C., Chang, T.T. & Konzak, C.F., 1974. A decimal code for the growth stages of cereals. Weed Research 14: 415-421.