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Geographic Differentiation of Barley Powdery Mildew Fungus (*Erysiphe graminis* DC. f. sp. *hordei*)

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Fifteen cultures of barley powdery mildew fungus (*Erysiphe graminis* DC. f. sp. *hordei*) isolated in different regions of the world were inoculated to 120 barley varieties. Infection scores varied among the cultures and barley varieties, and their interactions were observed. Principal component analysis of the infection scores revealed that the cultures could be classified into three groups by the first and second components (contributing 40.2% and 15.6% of the total variance, respectively), and that two Japanese cultures could be distinguished from the others isolated in Europe and North America. This indicates that the fungus is geographically differentiated in the reaction of the barley varieties to the cultures. Furthermore, East Asian barley varieties differed from European ones in their reactions to the cultures, while barley varieties from regions between East Asia and Europe showed a large genetic diversity in their reactions.

Key words: Barley, Powdery mildew, Geographic distribution, Differentiation

INTRODUCTION

Barley (*Hordeum vulgare* L.) widely grown in the world, is distributed with geographic regularity in morphological and physiological characters and their genes (Takahashi 1955, 1963, Takahashi *et al.* 1983). Meanwhile, barley powdery mildew fungus (*Erysiphe graminis* DC. f. sp. *hordei*) is differentiated into a number of physiological races detected by their reactions to differential varieties of barley. For instance, the fungus has been classified into 11 races in Japan (Hiura and Heta 1955), 16 races in Germany

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(Nover 1957), and 19 races in North America (Moseman 1956). Reactions of barley varieties to races of the fungus have been studied extensively, and resistant genes of barley varieties have been determined (e.g. Jorgensen 1992).

Herein, we examined the reactions of barley varieties to cultures of the powdery mildew fungus isolated in different regions of the world, and discuss the geographic differentiation of the fungus, compared with that of barley varieties.

MATERIALS AND METHODS

A total of 120 barley varieties were randomly selected from the World Barley Collection preserved at the Barley Germplasm Center of Okayama University, which consisted of 20 varieties each from Japan, Korea, China, Nepal and India, Southwest Asia and Turkey, and Europe. Table 1 shows the designations and origins of 15 barley podwery mildew cultures examined. The cultures were isolated from barleys grown in different countries; five cultures in Sweden, three in Japan, two each in Denmark and U.S.A., and one each in Ireland, Israel and Canada.

Table 1. Designations and origins of 15 powdery mildew cultures

Designation	Synonym	Origin	Reference
H-1	Race I	Japan	Hiura and Heta (1955)
Hh-4	Race IV	Japan	Hiura and Heta (1955)
h-9	Race IX	Japan	Hiura and Heta (1955)
63.1		Ireland	Moseman (1968)
A 6	290	Sweden	Wiberg (1960)
EmA 30	1488	Sweden	Wiberg (1974)
D 24	1548	Sweden	Wiberg (1974)
58-74		Sweden	Jan Meyer, pers. comm.
K31-74		Sweden	Jan Meyer, pers. comm.
C7-6		Denmark	J. E. Hermansen, pers. comm.
JEH 31	190672-54	Denmark	J. E. Hermansen, pers. comm.
NI-IS−1/1		Israel	E. Schwarzbach, pers. comm.
CR 3	59.1	U.S.A.	Moseman (1968)
59.11		U.S.A.	Moseman (1968)
R70/1	59.21	Canada	Moseman (1968)
CR 3	59.1	U.S.A.	Moseman (1968)

At Riso National Laboratory in Denmark, seedlings of the 120 barley varieties were grown in a growth chamber maintained at 14 to 16°C with a 23 hr illumination per day, and were inoculated in the first leaf stage with each of the cultures multiplied on the variety, 'Carlsberg II', susceptible to all

the cultures. Meanwhile, at the Research Institute for Bioresources of Okayama University in Japan, the seedlings of the barley varieties were grown in a greenhouse, and each of the three Japanese cultures propagated on the other susceptible variety, 'Kuromugi 148', was inoculated on the seedlings in the first leaf stage.

Ten days after the inoculation, the infection types produced by interactions of the 120 varieties with the 15 cultures were scored as follows:

0: Completely resistant, without any mycelium growth and sporulation
2: Highly resistant, with a small amount of mycelium growth
4: Slightly resistant, with moderate mycelium growth and weak sporulation
6: Slightly susceptible, with strong mycelium growth and moderate growth
8: Completely susceptible, with strong mycelium growth and strong sporulation

Intermediate type between the above-mentioned ones was scored as 1, 3, 5 and 7, respectivety.

The scores of the 120 barley varieties inoculated with the 15 cultures of powdery mildew were treated by principal component analysis.

RESULTS

As shown in Table 2, the infection scores of the barley varieties differed with the cultures. Culture NI-IS−1/1 of Israel highly infected to the barley

Table 2. Mean infection scores of barley varieties collected from different regions after inoculation with 15 powdery mildew cultures

Culture	Origin	Barley variety						
		Japan	Korea	China	Nepal India	SW Asia Turkey	Europe	Mean
H-1	Japan	7.4	7.5	7.6	4.7	3.5	2.3	5.5
Hh-4	Japan	7.3	7.4	7.9	4.7	5.1	5.4	6.3
h-9	Japan	6.0	5.9	6.9	6.5	5.1	6.5	6.1
63.1	Ireland	6.8	6.6	5.1	7.2	6.9	7.1	6.6
A 6	Sweden	6.9	6.1	6.4	7.2	5.5	6.6	6.4
EmA 30	Sweden	7.9	7.8	6.2	6.6	6.9	7.1	7.1
D 24	Sweden	6.1	6.6	5.2	6.5	7.0	7.1	6.4
58-74	Sweden	5.8	5.9	5.6	6.9	7.2	7.4	6.5
K31-74	Sweden	6.9	7.2	5.8	6.6	6.6	7.2	6.7
C7-6	Denmark	3.8	4.0	4.4	6.0	6.6	6.6	5.3
JEH 31	Denmark	7.5	7.6	5.8	6.1	6.5	6.4	6.6
NI-IS−1/1	Israel	8.0	7.7	7.8	7.9	7.6	6.8	7.6
CR 3	U.S.A.	6.3	6.6	6.5	7.6	5.0	7.1	6.5
59.11	U.S.A.	5.7	7.2	6.0	7.1	7.0	7.6	6.7
R70/1	Canada	5.4	6.2	6.7	7.2	5.6	6.9	6.3

varieties, while two cultures, H-1 of Japan and C7-6 of Denmark, were significantly lower than the others in the infection score. Interactions of scores between cultures and barley varieties were observed. For instance, H-1 and Hh-4 of Japanese cultures strongly attacked the Japanese, Korean and Chinese varieties, whereas EmA 30 and JEH 31 of Nordic cultures more highly infected the Japanese and Korean varieties than those of other regions. Meanwhile, D 24 and 58-74 of Swedish cultures were more aggressive to barley varieties of Southwest Asia, Turkey and Europe. These interactions suggest that powdery mildew fungus has been geographically differentiated.

The principal component analysis revealed that the first, second, third and fourth components accounted for 40.2%, 15.6%, 13.4% and 6.8% of the total variance in the infection scores of the 120 barley varieties with the 15 cultures, and that the cumulative contribution of the first and second components was more than 55% of the total variance, as shown in Table 3. The first vectors of the cultures except H-1 were positive, suggesting that the first component indicated the agressiveness of the cultures. The second vectors seemed to express a difference in the reaction of the cultures to

Table 3. Component vectors of 15 powdery mildew cultures

Culture	Origin	Component vector			
		I	II	III	IV
H-1	Japan	-0.043	0.547	0.157	0.253
Hh-4	Japan	.056	.542	.062	.301
h-9	Japan	.232	.256	-.346	-.201
63.1	Ireland	.327	-.171	.172	.288
A 6	Sweden	.318	.128	-.136	-.065
EmA 30	Sweden	.252	.093	.439	-.001
D 24	Sweden	.268	-.139	.213	-.359
58-74	Sweden	.333	-.191	-.063	.104
K31-74	Sweden	.306	-.089	.305	.303
C7-6	Denmark	.293	-.220	-.158	-.055
JEH 31	Denmark	.165	.131	.394	-.520
NI-IS-1/1	Israel	.142	.302	.159	-.247
CR 3	U.S.A.	.276	.182	-.394	-.013
59.11	U.S.A.	.312	-.121	-.018	.368
R70/1	Canada	.295	.138	-.327	-.126
Contribution (%)		40.2	15.6	13.4	6.8

barley varieties. Some of the cultures possessed positive vectors, whereas the others had negative vectors.

The cultures could be classified into three groups (A, B and C) by the scattering diagramme of the first and second components as illustrated in

Fig. 1. Group A consisted of cultures H-1 and Hh-4 in Japan, group B included seven cultures of h-9 (Japan), NI-IS−1/1 (Israel), CR 3 (U.S.A.), R 70/1 (Canada), A 6 and EmA 30 (Sweden) and JEH 31 (Denmark), and group C contained six cultures of K31-74, D 24 and 58-74 (Sweden), C7-6 (Denmark), 63.1 (Ireland) and 59.11 (U.S.A.), respectively.

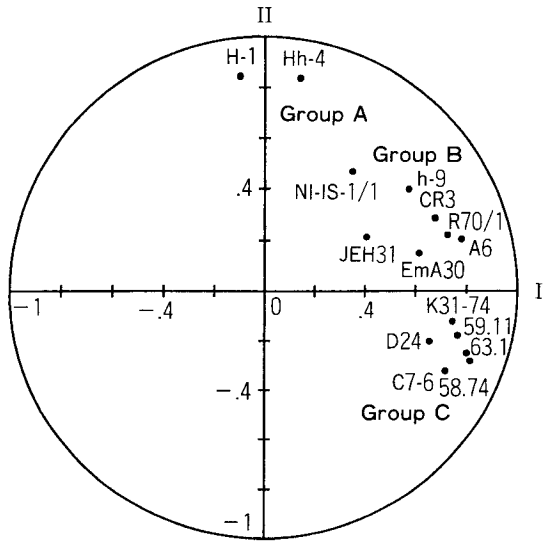

Fig. 1. Fifteen powdery mildew races scattered by the first and second components of principal component analysis.

From the principal component analysis, the first and second component scores of each barley variety were calculated, and their scattering diagram was illustrated in Fig. 2. Most of the barley varieties from East Asia (Japan, Korea and China) were distributed in the upper side of the figure (the first and second quadrants), while all the European varieties scattered in the lower side (the third and fourth quadrants). Varieties of Nepal, India, Southwest Asia and Turkey were found on both sides. These results indicate that East Asian varieties were clearly different from European ones in their reactions to powdery mildew cultures, and that the barley varieties from regions between East Asia and Europe showed a large genetic diversity.

DISCUSSION

The reaction of barley varieties to powdery mildew fungus is useful for studies of the interaction between host and parasite, since the fungus is an obligate parasite and the reaction can be detected in the juvenile stage of the

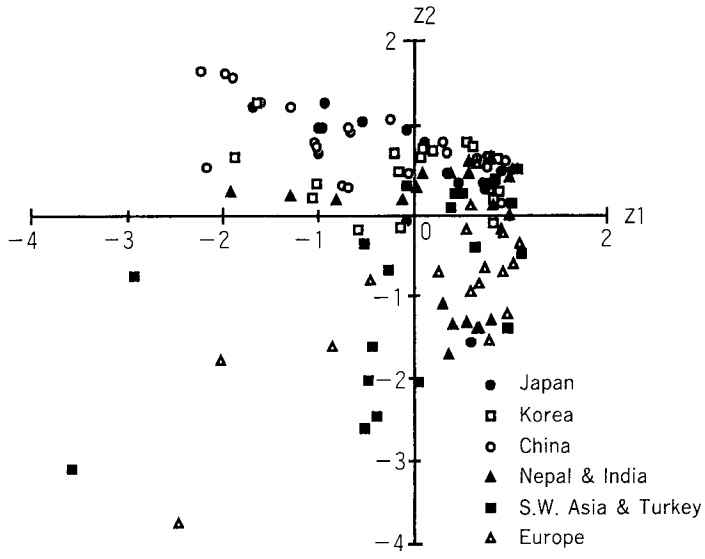

Fig. 2. Barley varieties from different regions of the world scattered by the first and second scores.

host grown under controlled conditions. Furthermore, the gene-for-gene hypothesis proposed by Flor (1955) is acceptable in barley mildew fungus as far as major genes for pathogenicity of mildew cultures and for resistance of barley varieties are concerned (Hiura 1964).

Geographic differentiation of barley powdery mildew fungus is controlled by genotypes of barley varieties grown in different regions. Limpert and Schwarzbach (1981) found striking differences in the virulence pattern of barley powdery mildew between regions in Europe, relating to the spread of barley varieties with corresponding resistance genes. For instance, virulence for 'Carina' carrying one of the resistant genes, *Mla6*, frequently occurred in Germany, whereas in other regions it was considerably low. This resulted from the fact that 'Carina' was the leading variety for many years in Germany, while the variety and its derivatives possessing the *Mla6* gene were not so popular in other parts of Europe. Molina-Cano *et al.* (1992) found that virulence genes of barley powdery mildew fungus were distributed with geographical regularity in Spain, resulting from the introduction of new cultivars carrying resistance genes to the fungus.

In Japan, from the pathogenicity and the frequency of powdery mildew races, Hiura and Heta (1955) demonstrated that races I, IV and VI were fundamental and principal physiological races among 11 races isolated from Japanese populations, and that race IX sampled in Hokkaido, the northern-

most district of Japan, showed a different pathogenicity compared to any other race. In Hokkaido, most of the barley varieties grown in the 1950's were introduced mainly from Europe, suggesting that the race IX might be similar to European races in virulence. In fact, the culture h-9 derived from a single conidium subculture of race IX was close to European cultures of group B in its reaction to the barley varieties, as illustrated in Fig. 1. Two Japanese cultures, H-1 and Hh-4, were markedly different from others in their reactions to barley varieties; they were more susceptible to barley varieties in East Asia (Japan, Korea and China) than those in other regions (Nepal to Europe). This resulted from the fact that East Asian barley varieties were slightly more resistant to most of the European and North American cultures, compared with the European varieties.

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オオムギうどんこ病菌(*Erysiphe graminis* DC. f. sp. *hordei*)の地理的分化

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オオムギは世界的に広く栽培され，形態的・生理的特性を支配する遺伝子が地理的に規則性をもって分布している．そこで，本研究ではオオムギに罹病するオオムギうどんこ病菌の地理的分化を知るために，世界の異なる地域から採集した15菌系をオオムギ120品種に接種し，それらの反応を調査した．病原性は菌系によって，また，感受性はオオムギ品種によって著しく異なり，菌系と品種との相互作用が認められた．そこで，15菌系に対する120品種の反応を肉眼観察によって8階級に分け，その値を主成分分析法によって解析した．第1主成分と第2主成分で全体の分散の55%以上を説明することが可能であり，これらの菌系は第1および第2主成分によって3群に分類することができた．供試した菌系についてみると，日本の3菌系のうち2菌系は他のものと明らかに異なり，残りの1菌系はイスラエルや欧米の菌系と類似していた．さらに，欧米の菌系は2群に細分することができた．このことから，うどんこ病菌にも地理的な分化が生じているとみることができる．さらに，オオムギ品種をうどんこ病菌系に対する反応から分類してみると，東アジアの品種は欧州のものと明らかに異なり，オオムギの起源地である西南アジアの品種は極めて多様性に富んでいた．

キーワード：オオムギ，うどんこ病，地理的分布，分化