A Proposed International System for Designating Races of *Plasmopara halstedii*

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Downy mildew caused by *Plasmopara halstedii* (Farl.) Berl. & de Toni is one of the major diseases of sunflower (*Helianthus annuus* L.) (25). It is known to occur almost everywhere in the world where sunflower is grown extensively except in Australia, South Africa, and possibly parts of North Africa (16). Detailed reviews of the disease have been published (12,16). The number of known or postulated genes for resistance to downy mildew has increased from two to nine since 1980, and others are certain to be discovered (11). In order to make the naming of races that can be distinguished in a gene-for-gene system useful to plant breeders, epidemiologists, and others anywhere in the world, we propose that the designations be based on the genes for resistance that the respective races can overcome, and we present information on the genes and races already described.

Resistant varieties have given control of downy mildew in Europe since the widespread adoption of hybrid sunflower carrying the *Pl* and/or *Pk* genes for resistance, and in north-central North America until the occurrence of new races of *P. halstedii* there in 1980 and subsequent years (2,6,7). The number of races that can be distinguished depends on the number of distinct genes for resistance. When the gene-for-gene relationship applies, as it has been shown to do for many obligate parasites, the maximum number of races is 2^n, where n is the number of resistance genes (4,13). The known genes for resistance of sunflower to *P. halstedii* are listed in Table 1.

Only two races of *P. halstedii* had been identified prior to 1980. Race 1, the “European race,” was prevalent in Europe and in a small area in the province of Quebec, Canada. It appears able to affect only those sunflower genotypes with no known genes for resistance. Race 2, the “Red River race,” was prevalent in the Red River Valley of north-central United States and adjacent areas in Canada. Race 2 was also known or suspected to occur in small areas in several countries of Europe, in most cases confined to experiment stations (16). It induces typical systemic infection in sunflowers carrying the *Pl* gene for resistance, but not in those with gene *Pk*.

Race 3, the “new race,” was first recognized in the north-central United States in 1980, affecting sunflowers resistant to race 2, and was considered the dominant race in the Red River Valley of the United States and Canada (2,7). Since the development of sunflower lines carrying both genes *Pl* and *Pk*, conferring resistance to races 2 and 3, races 4 and 5 have been identified in the Red River Valley (6,9). Races 2 and 3, and possibly others, have appeared recently in farm fields in the Indre region of France (18; Gulya and Sackston, unpublished).

Plant breeders attempting to discover and incorporate genes for downy mildew resistance into sunflower lines for production of hybrids must know what races are present in the areas where these hybrid varieties are likely to be grown. Identification of the races by names or numbers may be adequate when only a few resistance genes and races are known. With the recent increase in number of identified and postulated

<table>
<thead>
<tr>
<th>Table 1. Genes for resistance to downy mildew of sunflower</th>
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<tbody>
<tr>
<td><strong>Gene</strong></td>
</tr>
<tr>
<td>---</td>
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<tr>
<td><em>Pl</em></td>
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<tr>
<td><em>Pl</em></td>
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<tr>
<td><em>Pl</em></td>
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<td><em>Pl</em></td>
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</tbody>
</table>

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Table 1. (continued from preceding page)

<table>
<thead>
<tr>
<th>Gene</th>
<th>Source</th>
<th>Description and history</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pl₆ + ?</td>
<td>Encountered in lines HA 335 and 336 derived in North Dakota from backcrosses to cultivated sunflower with crosses of wild <em>H. annuus</em> 423 and 432, respectively (11).</td>
<td>Conferred homozygous resistance to downy mildew races 1, 2, 3, 4, 5, and 6 in tests in North Dakota. Resistance to race 4 is controlled by a single gene (11).</td>
</tr>
</tbody>
</table>

Table 2. Races of the downy mildew pathogen of sunflower

<table>
<thead>
<tr>
<th>North American race designation</th>
<th>Apparently effective resistance genes</th>
<th>Apparently ineffective resistance genes</th>
<th>Proposed international race designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Pl₆, Pl₇, Pl₈, Pl₉, Pl₉₁, Pl₉₃, Pl₉₄, Pl₉₅, Pl₉₆, Pl₉₇, Pl₉₈</td>
<td>None</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2 Pl₆₂ (Pl₇)</td>
<td>Pl₇₁ (Pl₉₃)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>3 Pl₈ + Pl₉₆, Pl₉₇ + ?, Pl₉₈ + ?</td>
<td>Pl₈₁ (Pl₉₃), Pl₉₆ (Pl₉₇)</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>4 Pl₈ + ?, Pl₉₂ + ?</td>
<td>Pl₈₁ (Pl₉₃), Pl₉₂ (Pl₉₄), Pl₉₂ + Pl₉₄ (CL)</td>
<td>1.2,5 (CL)</td>
<td></td>
</tr>
<tr>
<td>5 Pl₉₁ + ?, Pl₉₂ + ?, Pl₉₃ + ?</td>
<td>Pl₉₃₁ (Pl₉₃), Pl₉₃₂ (Pl₉₄), Pl₉₂ + Pl₉₄ (CL)</td>
<td>1.2,5</td>
<td></td>
</tr>
<tr>
<td>6 Pl₉₃ + ?, Pl₉₄ + ?, Pl₉₅ + ?</td>
<td>Pl₉₃₁ (Pl₉₃), Pl₉₄ (Pl₉₄), Pl₉₅ (Pl₉₆)</td>
<td>1.9</td>
<td></td>
</tr>
</tbody>
</table>

* + ? = More than one unidentified gene may be involved.  
* Pl₂ and Pl₆ present in genotype, Pl₉₁ not yet isolated.  
* CL = Cotyledon-limited infection.

resistance genes to nine (11), and the consequent increase in the number of races theoretically distinguishable to 512, a more informative and useful system of designating races is required. A comparable situation with sunflower rust (*Puccinia helianthi* Schw.) led to the adoption of an international system of naming races on the basis of the genes for resistance that they could overcome (1,8,17). We propose that a similar inter-

Table 3. Resistance genes and sources for differentiating "internationally designated" races of *Plasmodara halstedii*

<table>
<thead>
<tr>
<th>Resistance genes</th>
<th>Possible differential lines</th>
</tr>
</thead>
</table>
| 0                | Peredovik, Krasnodar, IS 003,*  
HA 89, HA 300 |
| Pl₁               | CM 5RR, CM 90RR, HA 60, R 18,  
RHA 265, RHA 266 |
| Pl₂               | RHA 274, IS 7600 |
| Pl₂₁ (= Pl₉7)     | HA 671 with Pl₂ |
| Pl₂₂ (= Pl₉₈)    | HIR 34 |
| Pl₅               | With Pl₅ in DM 2, DM 3, IS 2000, IS 3003 |
| Pl₆ + ?           | HA 335, HA 336 |
| Pl₇ + ?           | HA 337, HA 338 |
| Pl₈ + ?           | HA 340 |

* IS genotypes are proprietary lines or hybrids of Interstate Seed Co., Fargo, ND, used by the second author but not available for distribution.  
* + ? = More than one unidentified gene may be involved.

national system be adopted for naming races of *P. halstedii*. Pathologists and plant breeders in any country could continue to use any convenient or familiar designation for the isolates or cultures important in their areas or encountered in a given season. All such isolates, however, should also be identified by listing the genes for resistance that each isolate can overcome in an internationally agreed standard series of differential hosts. Such identification should include also any resistance genes that have been shown to be effective against the particular isolate or culture. The system is flexible. For example, if genes Pl₂ and Pl₆ are confirmed as being distinct from Pl₁ and Pl₂, respectively, designation of the races that attack them would be changed by the addition of the appropriate numbers.

The races we already know, with their current and recommended designations, are listed in Table 2. Some lines currently available and suggested as differentials, and their respective resistance genes, are listed in Table 3. Addition or substitution of differential lines on a continuing basis could be arranged by an ad hoc committee meeting during the International Sunflower Conferences, held every 3 or 4 years. The next is scheduled for Pisa, Italy, in 1992.

The Red River Valley of North Dakota, Minnesota, and Manitoba at present appears to be a center of rapid changes in the population of *P. halstedii*. All but race 1 of the known races have been identified there. The Oilseeds Research Unit of the U.S. Department of Agriculture currently develops and releases germ plasm lines to sunflower breeders throughout the world and identifies and stores new races of the pathogen as they are discovered. It may therefore become a suitable clearinghouse for information on race identification and for distributing seed of differential lines for identifying races of *P. halstedii* elsewhere.

ACKNOWLEDGMENT

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