Epidemiology of Barley Yellow Dwarf in Manitoba and Effect of the Virus on Yield of Cereals

C. C. Gill

Research Scientist, Canada Department of Agriculture, Research Station, 25 Dafoe Road, Winnipeg 19, Manitoba, Canada.

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ABSTRACT

In 1969, barley yellow dwarf virus (BYDV) caused an estimated loss of 1,380,860 bushels of two-rowed Herta barley in an area of approximately 2,700 square miles in Manitoba. Losses on other cereals were also high. In a germination test, seed from infected barley produced seedlings of poor vigor. Two strains of the virus, one transmitted specifically by *Rhopalosiphum maidis* and the other transmitted nonspecifically by three other species of aphids, were chiefly responsible for the epidemic. Early migration of the aphid vectors and the prevalence of late-seeded crops contributed to the severity of the disease. A high proportion of plants in the field carried BYDV without showing symptoms. The proportion was highest for barley infected with the *R. maidis*-specific strain. Phytopathology 60:1826-1830.

Additional key words: wheat, oats.

Barley yellow dwarf virus (BYDV) has infected cereals each year since 1964, when intensive surveys in Manitoba were first begun. In 1964 and 1965 (2), barley yellow dwarf (BYD) was more prevalent than in the subsequent 3 years. In 1969, BYD was again widespread on cereals and in some areas was of epidemic proportions. The low incidence of other diseases on cereals in 1969 enabled a clearer picture of the epidemiology of BYD to be obtained than previously, and afforded an opportunity to determine yield losses caused by the virus on spring barley.

MATERIALS AND METHODS.—Intensive surveys for the incidence of BYDV and populations of the aphid vectors on spring cereals in 1969 were confined to the Red River Valley and the Interlake Area (between Lake Manitoba and Lake Winnipeg). Estimation of the aphid populations was made from insects collected in 200 sweeps/field with an insect net. Sweeping was supplemented by visual examination of the plants for aphids. In special cases, plants were pulled at random within a field and the number of aphids per plant was estimated by counting the individuals.

When determining the proportion of infective aphids in a field population, aphids were taken at random from those caught on spring cereals in 200 sweeps. Each aphid was caged on a seedling of Clintland oats (*Avena sativa* L.) for a 3-day feed and was then killed with tetraethylpyrophosphate (TEPP) spray. The seedlings were then kept in a greenhouse for 4 weeks, when final counts of infected plants were taken.

Some of the virus isolates obtained from aphids caught in the field were characterized by comparing the ability of four species of aphids to transmit the virus. The virus-free clones of the English grain aphid, *Macrosiphum avenae* (Fabricius), the corn leaf aphid, *Rhopalosiphum maidis* (Fitch), the cherry oat aphid, *R. padi* (Linnaeus), and the greenbug, *Schizaphis graminum* (Rondani), used regularly in tests for BYDV since 1964, were maintained on caged Parkland barley (*Hordeum vulgare* L.). The tests for characterization were conducted as outlined previously (2), except that for each aphid species, three lots of 12 aphids each were transferred from the leaves in the petri dishes to individually caged Clintland oat test seedlings.

To discover which strains of BYDV were prevalent, and to determine whether virus could be recovered from plants without symptoms, one field each of six-rowed barley and wheat, about 4 miles apart and approx 20 miles west of Winnipeg, were selected for sampling. Both crops were at the heading stage when samples were taken. An approx equal number of plants with and without symptoms was pulled at random in each field. All plants were taken well within the barley field, but in the wheat field some plants were also taken from near the margin. A few oat plants were sampled from experimental plots at Winnipeg.

Several leaves were detached from the culms of each sampled plant and each leaf was cut into three pieces, one piece being placed in each of three petri dishes. Virus-free apterae or late-instar nymphs of *M. avenae*, *R. padi*, or *R. maidis* were transferred from colonies to separate petri dishes containing the leaf pieces; *S. graminum* was not included in these tests because, up to the time of sampling, this species had not been found in the field and it was thus improbable that *S. graminum*-specific strains (4) were present. The remainder of the testing was similar to that outlined previously for characterization of the virus (2), except that for each aphid species, two lots of 15 aphids each were transferred from the leaves in the petri dishes to individually caged Clintland oat test plants.

Loss in the yield of seed on commercially-grown Herta barley, a two-rowed variety, was determined from individual plants in a field of 15 acres about 10 miles north of Winnipeg. The crop was seeded on 5 June and swathed on 11 September. An estimated 55% of the plants were infected. On 19 August, 10 tall stakes were placed at different locations in the field to mark the center of infected groups of plants. At the same time, stakes were also placed at 10 different locations to mark areas of symptomless plants. On 9 September, when the barley was ripe, 20 to 40 infected or symptomless plants were pulled at each location. Each sample of infected material contained plants with symptoms that ranged from marked stunting to no stunting. The seed was threshed, weighed, and counted separately for each sampling location.

RESULTS.—*Aphid populations.*—No aphids were found during May from sweeps on winter rye and in pastures. On 5 June, the first aphids, all *M. avenae*, were found on rye and were chiefly alatae. Populations were low and averaged four aphids/100 sweeps. These small populations persisted until the last week in June, at which time southern Manitoba experienced a period of southerly winds. These winds probably were responsible for a heavy migration of aphids from southerly regions, because during the first week in July the average number of aphids collected from spring cereals rose sharply to 390/100 sweeps.

In the southern part of the Red River Valley, where crops were most advanced, the approx percentage distribution of *M. avenae, R. padi, Sipha kurdjumovi* (Mordvilko), and *R. maidis* caught in the net in the first half of July was as follows: 95, 5, 0, and 0 from six fields of oats; 93, 5, 2, and 0 from four fields of wheat; and 91, 6, 0, and 3 from four fields of barley. From previous studies (C. C. Gill, *unpublished data*) on the relationship between the number of aphids caught in the net and the number of aphids counted on individual plants, it was estimated that there was an average of seven *M. avenae*/oat plant. It is possible that the percentage of *R. padi* in the aphid populations on the plants was higher than that found in the net, as these aphids, in contrast to *M. avenae* and *R. maidis*, are usually found on the lower parts of the plants, an area that is not swept efficiently by the net.

In the northern part of the Red River Valley and in the Interlake Area, a large proportion of all crops, and especially barley and oats, was less advanced than in the southern part of the valley. Aphid populations on late barley in the north were especially large and persisted at high levels for 1 to 2 weeks longer than in the south, and the species composition was different. Thus, in six fields of late barley in the north at the end of July, the average number of aphids counted per plant was: *R. padi*, 21; *R. maidis*, 13; *M. avenae*, 5; and *Acyrthosiphon dirhodum* (Walker), 0.4. The relatively high numbers of *R. padi* and *R. maidis* in these fields was believed to be due to increased opportunity for multiplication, though the young barley plants may also have been more attractive to migrants of these species.

During the second half of July, heavy rains were experienced over much of the area examined, and may have accounted for the drastic reduction in the aphid populations that occurred in most fields of cereals. Large numbers of aphid predators, particularly Coccinellidae, were also present in many fields. With the exception of a few late fields of barley, aphid populations were low on cereals during August and September. *Schizaphis graminum* was found for the first time on 8 August, and then only in low numbers on late-maturing barley.

TABLE 1. The ability of four species of aphids to transmit barley yellow dwarf virus isolated from aphids collected in the field

Original source of virus	*Rhopalosiphum maidis*	*R. padi*	*Macrosiphum avenae*	*Schizaphis graminum*
R. maidis	2[a]	0	0	0
R. maidis	1	0	0	0
R. padi	0	3	1	2
R. padi	0	3	2	2

[a] Number of test plants infected out of three inoculated with 12 aphids/plant. Aphids were allowed a 2-day acquisition feeding followed by a 2-day inoculation feeding.

The proportion of infective aphids in natural populations.—Individuals of *M. avenae*, the dominant species in two fields of oats near Isle de Chênes, were collected for testing on 21 July. An average of 3% of the plants in these fields showed symptoms of BYD. Colonies of *R. padi* were also observed on many plants. A total of 340 *M. avenae* were tested, but none of the test seedlings became infected.

On 8 August, aphids were collected from a field of two-rowed barley at Dugald in which 85% of the plants carried BYD symptoms. Five per cent of 213 *R. padi* and 22% of 96 *R. maidis* transmitted virus to test plants. Five individuals of *M. avenae* and one of *S. graminum* that were also tested did not transmit virus. Aphids of the latter two species were rare.

Characterization of BYDV isolated from aphids.—Two BYDV isolates each, from individuals of *R. maidis* and *R. padi* swept from the barley field at Dugald, were tested for transmissibility by four species of aphids. Results (Table 1) indicated that the isolates from *R. maidis* were transmitted only by this aphid, whereas, those isolated from *R. padi* were transmitted by *R. padi*, *S. graminum*, and *M. avenae*, but not by *R. maidis*. Symptoms on oats of the isolates from *R. maidis* and *R. padi* were, respectively, mild and severe. These results pointed to the presence of two strains of BYDV, the one specific for *R. maidis*, the other transmitted nonspecifically by the three other species of aphids (4, 12).

Incidence of BYDV infection on cereals.—Symptoms of BYDV in fields of cereals began to appear about the 1st or 2nd week in July, and were most conspicuous on oats and barley. Surveys for the incidence of infection were made during the last week in July and the first week in August. The area of the highest disease incidence covered about 2,700 sq miles and extended northwards from a line approximately between Portage la Prairie and Steinbach, to Teulon, Libau, and Brokenhead. This area is referred to as the epidemic area. The incidence of infection was also high in parts of the Interlake Area, notably around Arborg. The average proportion of cereals infected in the epidemic area was 52.5% for 16 fields of two-rowed Herta barley examined; 10.5% for 23 fields of six-rowed barley; 7.2% for 39 fields of oats; and 2.5% for 27 fields of wheat. Infection in fields of barley, the crop most affected, ranged from a trace to 86%.

In the Red River Valley south of the epidemic area, the average proportion of plants infected was 2.2% for 10 fields of barley examined, 1.7% for 12 fields of oats, and 0.3% for 12 fields of wheat. The highest infection rate was 14% in a field of six-rowed barley. BYDV was widely distributed in Manitoba west of the Red River Valley, but the incidence was not high.

In the Red River Valley, the pattern of BYDV infection within a field of cereals was characteristic and constant. Infected plants occurred in groups ranging from 2 or 3 to 40 or more. Those in the center of the group usually were the most stunted, indicating, presumably, the focus of infection. In barley, where infection was highest, the individual groups of infected plants usually overlapped. Another notable feature was the relatively low incidence of BYDV in plants growing near the edges of the field.

Isolation of BYDV from naturally infected cereals.—In the two fields of barley and wheat that were intensively sampled, 24% and 15% of the plants, respectively, exhibited symptoms of BYD.

When plants were sampled away from the margins of the fields, BYDV was recovered from 56 out of 59 plants with symptoms, and from 23 out of 53 plants without symptoms. The percentage of successful transfers from symptomless plants was higher for barley than for wheat (49 vs. 29%). No virus was recovered from any of 20 additional wheat plants sampled near the margin of the field, an area in which there were no plants with symptoms.

Of the total of 79 virus isolates obtained from the cereals, 34 were transferred from the field plants by *R. maidis* only (Group 1), 34 by *M. avenae* and *R. padi* only (Group 2), and 7 by *R. padi* only (Group 3). Three isolates were transferred by all three aphid species (Group 4), and one by *R. padi* and *R. maidis* only (Group 5). Symptoms on Clintland oats for groups 1, 2, and 3 were mild, strong, and moderate, respectively. The transmission patterns and symptoms of the isolates in these three groups agree with those of three of the strains that were found in Manitoba previously (4). The isolates in Group 4 produced severe symptoms on Clintland oats, and may represent mixed infections with the R. *maidis*-specific strain and the nonspecific strain transmitted by *M. avenae* and *R. padi.* The single isolate in Group 5 produced mild symptoms on Clintland oats, and probably represents a strain belonging to Group 1, since isolates of this strain are also transmitted by *R. padi* but less efficiently than by *R. maidis* (4, 12).

The strain transmitted specifically by *R. maidis* predominated among those isolated from barley, while from wheat, most of the isolates belonged to the nonspecific strain.

Yield loss on Herta barley.—Table 2 shows that yields of commercially grown Herta barley were adversely affected by infection with BYDV. The reduction in the average wt of seed per infected plant was 65.1%. The mean difference in the wt of seed between the 10 samples each of healthy and infected material was significant at the 1% level ("Student" t-test). The reduction in the number of seeds per plant was 55.4%, and the wt of 1,000 seeds was 21.9% less for infected plants than for healthy plants.

TABLE 2. Effect of barley yellow dwarf virus on yield of seed from commercially-grown Herta barley

Seed source	Plants sampled	Seeds/ plant	Wt of seeds/ plant	Loss in wt of seeds/ plant	Wt of 1,000 seeds
	no.	*no.*	*g*	*%*	*g*
Healthy plants	247	82.9	2.84		34.3
Infected plants	280	37.0	0.99	65.1	26.8

TABLE 3. Germination test on Herta barley seed from healthy plants and from plants infected with barley yellow dwarf virus

Origin of seed	Germination	Avg height seedling	Avg fresh wt, 4-leaf aerial portion
	%	*cm*	*g*
Healthy plants	87	18.7	0.93
Infected plants	84	14.8	0.66

The average size of seed from infected plants was noticeably smaller than that of seed from healthy plants. A germination test in the greenhouse on random samples of seed from healthy and infected Herta showed that only slightly fewer seeds germinated from BYDV-infected plants than from healthy plants (Table 3). The poor vigor of the seedlings grown from seed of infected plants, however, was very apparent. This was reflected in the short average height and low fresh wt of these seedlings.

Estimated losses on Herta barley in the epidemic area.—The estimation of losses on Herta barley was facilitated by data supplied by the Manitoba Department of Agriculture. The epidemic area coincided largely with Manitoba Crop Reporting Districts 4 and 5 (8). About one-third of District 5 lies south of the epidemic area, but very little Herta barley was grown in this southern section. The total acreage of Herta barley harvested in 1969 in Districts 4 and 5, based on reports from 1,000 farms within each district, was estimated by the Statistics Department of the Manitoba Department of Agriculture to be 106,220 acres. Average yields were estimated at 24.7 and 25.4 bu/acre for Districts 4 and 5, respectively.

Our investigations indicated that an average of 52.5% of the Herta barley plants was infected, and that there was an average loss of 65% in the wt of seed per infected plant. The estimated loss, therefore, was 13.0 bu per acre, or a total loss of 1,380,860 bu in Districts 4 and 5. This loss represents 34% of the potential yield. The potential yield is defined here as the yield expected in 1969 had infection with BYDV not occurred.

Estimated losses on other cereals.—It is not possible to estimate the commercial losses on six-rowed barley and oats for 1969 as accurately as for Herta barley. Conquest was the predominant six-rowed barley grown in the epidemic area (Districts 4 and 5). When this variety was inoculated experimentally with BYDV at the two-leaf stage in a field plot trial in 1965, a yield loss of 67% resulted (5). If a loss of 33% is accepted as a conservative estimate resulting from infection at a somewhat later stage of growth, then the estimated loss for six-rowed barley in the epidemic area would amount to 49,000 bu on 3.5% of the potential yield. The yield loss per culm on Kelsey oats in 1969 that resulted from natural infection of BYDV in an experimental plot near Winnipeg was 65% (J. W. Martens, *personal communication*). On this basis, the estimated loss on oats in the epidemic area was 517,000 bu, or 4.6% of the potential yield. Because Kelsey oats are less susceptible to BYDV than are the varieties commonly grown in this area (C. C. Gill, *unpublished data*), the estimated loss on oats is also considered to be conservative.

Discussion.—In 1969, several factors appear to have accounted for the higher incidence of BYDV on barley than on wheat or oats. The aphid vectors reached peak populations on the cereals about 1 to 2 weeks earlier than in previous years. Reproduction of the aphids was favored by a relatively large proportion of late-sown oats and barley. Colonies of *R. maidis* formed readily on barley, but not on oats or wheat. Therefore, the strain carried specifically by this aphid was spread rapidly on barley, but not on the other cereals. *Rhopalosiphum padi,* however, colonized barley as well as oats and, consequently, the nonspecific and specific strains carried by *R. padi* supplemented the infection on barley. Sampling of the virus from aphids caught in the field, and the testing of naturally infected barley and wheat, seemed to indicate that more individuals of R. *maidis* carried the virus than did those of *R. padi.* This view was supported by the fact that, although *R. padi* was evenly distributed within fields of oats, the circular groups of infected plants in some of these fields were spaced well apart from each other.

The pattern of infection within fields in 1969, consisting of scattered circular patches of infected plants, and the almost total absence of infection around the margins, indicates that the aphids carried the virus from relatively long distances. Studies on the ecology of those cereal aphids that are important vectors of BYDV in Manitoba have shown that *M. avenae, R. maidis,* and *S. graminum* do not overwinter in this province (11), whereas *R. padi* does overwinter here (10, 11). The pattern of BYD infection in fields of cereals and our observations of aphid populations during the past 6 years suggest that overwintering aphids may play only a minor role in distributing this virus on the cereals. BYDV has been found in many samples of wild grasses in Manitoba (C. C. Gill, *unpublished data*); hence, local sources of virus are available for infection of the spring cereals should the aphid vectors move into these crops from adjacent grass. In previous years, only a few fields have been found in Manitoba with a heavy infection along the margins. This effect was usually associated with the movement of *S. graminum* from grass borders into the crop, when these aphids arrived before the spring cereals had germinated. In most years, large increases in aphid populations on cereals in Manitoba have coincided with southerly winds that were responsible, presumably, for carrying the migrants. Although aphids are found on cereals in Manitoba as early as the first week in May, populations usually reach their peak during the second half of July. In 1969, the main migration occurred at the beginning of July, earlier than usual.

The recovery of BYDV from a high proportion of symptomless barley plants is of considerable importance. Because most of these isolates were of the strain specific for *R. maidis,* this strain may be even more common and responsible for more damage on barley than is apparent. Based on previous work in field plots with controlled inoculation, BYDV can cause appreciable yield losses on some varieties of barley and wheat with only limited symptom expression (1, 3, 5). This is believed to be the first report of symptomless BYDV-infection of commercially-grown barley and wheat. A similar type of investigation in England (7) revealed the possibility of symptomless infection with BYDV in spring barley, but only the flag leaf and the leaf below this on one culm of each plant were sampled and examined. All the leaves on a plant were examined in our samples, because in some plants symptoms occurred only on one tiller or on the lower leaves of the main culm.

When Herta barley was inoculated at the two-leaf stage in the greenhouse with an isolate of BYDV transmitted specifically by *M. avenae,* the loss in yield was 94% (5). This loss was higher than that on four other commercial varieties included in the same test. The loss found in the field for Herta in 1969, therefore, confirms that this variety is highly susceptible to BYDV. Losses of similar severity were found on susceptible barley varieties infected naturally with BYDV in California (9). Our work also shows that BYDV may have an adverse effect on the yield of a subsequent crop if seed from infected plants is used.

Although cultivation of tolerant varieties is the best method of avoiding losses from BYDV, no two-rowed barley variety with this tolerance is currently available for commercial use in western Canada. Losses on most cereals, however, may be reduced by seeding early, because a late infection is usually less severe than an early infection (9, 13). Thus, although the wheat varieties grown in Manitoba were very susceptible to BYDV when inoculated at early growth stages (3, 6), losses on commercial wheat from this virus have been less than on either oats or barley because wheat is usually seeded first.

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