Common Root Rot of Cereals in California

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ABSTRACT

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Fusarium culmorum, F. graminearum, Bipolaris sorokiniana, and *Microdochium bolleyi* were frequently isolated from crowns and subcrown internodes of wheat and barley showing common root rot symptoms. *M. bolleyi* was also isolated from oat. The frequency of isolation of these fungi varied with the area from which infected plants were obtained. Most isolates of *F. culmorum, F. graminearum,* and *B. sorokiniana* were moderately to highly virulent on the barley cultivar CM72, although a few isolates were not pathogenic. All isolates of *M. bolleyi* were less virulent than isolates of the other fungi. The barley cultivar CM72 was more susceptible than the wheat cultivar Anza to *F. culmorum, F. graminearum,* and *B. sorokiniana* at a relatively low inoculum level (200 propagules per gram of soil); however, differences among wheat and barley cultivars were not as apparent at a higher inoculum level (900 propagules per gram). Isolates of *F. culmorum, F. graminearum,* and *B. sorokiniana* obtained from either wheat or barley showed no evidence of host specificity on wheat or barley.

Additional key words: cereal foot rot, *Fusarium roseum, Helminthosporium sativum*

Common root rot symptoms on cereals may consist of discoloration and rotting of lower leaf sheaths, culms, crowns, subcrown internodes (8), and roots (2,9). Severely infected plants may senesce prematurely and produce small, off-color heads that contain shriveled kernels. Early infections may result in preemergence and postemergence seedling blight (2). The etiology of common root rot is complex and includes a number of fungi. The most important are *Bipolaris sorokiniana* (Sacc. in Sorok.) Shoem. (*Helminthosporium sativum* P. K. & B., *Drechslera sorokiniana* (Sacc.) Subram. & Jam), *Fusarium culmorum* (W.G. Sm.) Sacc., and *Fusarium graminearum* Schwabe (13). In addition, *Microdochium bolleyi* (Sprague) de Hoog and Herm.-Nijhof (*Aureobasidium bolleyi* (Sprague) von Arx, *Gloeosporium bolleyi* Sprague) has been frequently isolated from the roots and subcrown internodes of wheat (4,5). Although some isolates of *M. bolleyi* are saprophytic, others cause a mild root necrosis of cereals and other grasses (13).

Common root rot is widespread and has been reported from most grain-growing areas of the world (11,13); however, the occurrence and frequency of the causal organisms vary from place to place.

Common root rot was first reported in California by Mackie (6) in 1931 as pink root of cereals caused by *F. culmorum* (*F. culmorum* var. *leteuis* Sherb.). Later, Oswald (8) reported the cause to be primarily *B. sorokiniana* and *F. roseum* f. sp. *cerealis* (Cke.) Snyd. et Hans (*F. graminearum*). He also reported *F. culmorum* (*F. roseum* f. sp. *cerealis*) to occur but considered it unimportant except in the Sacramento-San Joaquin delta area. *M. bolleyi* has been reported as a pathogen of wheat in California (11), but no report has been made on barley or oat.

Wood (14) showed 103 isolates of *B. sorokiniana* to differ greatly in their pathogenicity on cereals; some were pathogenic to wheat, barley, and oat, whereas others were only pathogenic to other combinations of these hosts. Although studies on host specificity have been made on isolates of *B. sorokiniana* elsewhere in the United States (14), such studies have not been conducted in California. Reports concerning host specificity among isolates of *F. culmorum* and *F. graminearum* are also lacking. Differences in susceptibility of wheat and barley have been reported (2,7,12), but some reports are conflicting.

Studies on many aspects of common root rot of cereals in California are incomplete. This paper extends previous investigations concerning various aspects of common root rot of cereals in California, including the fungi isolated, their pathogenicity, their host specificity, and host susceptibility.

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MATERIALS AND METHODS

Isolation and maintenance of cultures. Diseased wheat, barley, or oat plants were collected from a total of 93 fields in 15 counties in 1977–1978. Crown and subcrown internode tissues were immersed in 0.05% sodium hypochlorite for 5–10 min, cut into small pieces, and placed on acidified potato-dextrose agar (aPDA). Culture dishes were incubated 1–2 wk under continuous cool white fluorescent light at room temperature (24 ± 2 C). Conidia of the *Fusarium* spp. and *B. sorokiniana* produced on aPDA were spread over fresh PDA in plates, and single conidia were selected and transferred to cornmeal agar "+" slants (17 g of cornmeal agar, 0.1 g of yeast extract, 0.1 g of Casamino Acids, and 1 L of distilled water). Single conidia of *M. bolleyi* were selected and transferred to PDA slants. All single conidial stock cultures were incubated for 2–3 wk under continuous cool white fluorescent light at room temperature (24 ± 2 C) and stored at 1–2 C thereafter. Original stock cultures, with the exception of some *Fusarium* isolates, were maintained as a source of cultures for identification and inoculum preparation.

Preparation and application of inoculum. Inoculum of *Fusarium* isolates was produced from single conidia and grown on cornmeal agar + in plastic petri plates, whereas inoculum of *B. sorokiniana* and *M. bolleyi* was produced by mass transfer of conidia onto V-8 juice agar and PDA, respectively. All were incubated under cool white fluorescent light at room temperature (24 ± 2 C) for 2–3 wk. Plates were then flooded with tap water, and the agar surface was scraped with a glass slide. The resulting suspension was strained through two layers of cheesecloth, stirred, and the conidial concentration determined. Conidial suspensions were adjusted to the desired number of propagules and applied to U.C. mix (1) or soil in containers 1 wk before planting. The upper 10–12 cm of U.C. mix or soil was then mixed to ensure an even distribution of inoculum.

Disease severity rating. Disease severity was rated on a scale of 0–4, with 0 = no symptoms, plant healthy; 1 = light symptoms, discoloration of the leaf sheath; 2 = moderate symptoms, discoloration of the culm or the subcrown internode; 3 = severe symptoms, discoloration and rotting of the crown; and 4 = plant killed, postemergence seedling blight. A mean disease rating (MDR) was calculated by multiplying the number of plants in each category by their numerical rating, adding the ratings, and dividing by the total number of plants rated. An MDR of 0 represents all plants healthy, whereas 4 represents all plants killed.

Pathogenicity of isolates. Pathogenicity of *Fusarium, Bipolaris*, and *Microdochium* isolates was tested in seven separate experiments on barley (*Hordeum vulgare* 'CM72'). Seeds were surface-sterilized with 0.05% sodium hypochlorite for 5–10 min and sown in infested U.C. mix (1,000 propagules per gram) at a depth of 2.5–3.8 cm. Treatments were replicated four times with six plants per pot. After 5 wk, plants were rated for disease and isolations made to verify the pathogenicity of each isolate. The average maximum and minimum temperatures during the experiments were 23.7 and 16.3 C.

Seedling blight. The susceptibility of wheat (*Triticum aestivum* 'Anza') and barley (CM72) to seedling blight was compared when grown in unsterile Yolo loam infested with isolates *F. graminearum* or *F. culmorum*. Two isolates of *F. graminearum* and nine of *F. culmorum* were individually tested, with each treatment consisting of four replicates. In another experiment, the susceptibility of barley (CM72) to seedling blight was compared when grown in pasteurized U.C. mix or in unsterile Yolo loam infested with an isolate of *F. culmorum*. Treatments were replicated twice. In both experiments, infested treatments received 100 ml of a conidial suspension containing 1.2×10^4 conidia per milliliter. Fifty seeds that were not surface sterilized were sown in each replicate flat. Plants were evaluated for seedling blight 5 wk after planting.

Host susceptibility and pathogen specificity. In two separate experiments, isolates of *F. culmorum*, *F. graminearum*, and *B. sorokiniana* obtained from wheat or barley were selected to study the susceptibility of wheat, barley, and oat to seedling blight and common root rot. In the first experiment, nine isolates of *F. culmorum*, two isolates of *F. graminearum*, and nine isolates of *B. sorokiniana* were tested on wheat (Anza) and barley (CM72). Infested (200 propagules per gram of U.C. mix) and noninfested treatments were replicated five times with six seeds planted per 2-gal container.

In the second experiment, three cultivars each of wheat and barley and one cultivar of oat were grown in U.C. mix infested with two isolates of *B. sorokiniana*, two isolates of *F. graminearum*, and one isolate of *F. culmorum*. Infested (900 propagules per gram of U.C. mix) and noninfested treatments for wheat, barley, and oat were completely randomized within each cereal and replicated five times with six plants per 2-gal container. Final counts of blighted seedlings and disease ratings for both experiments were made when plants were mature, except oat plants, which did not mature.

Table 1. Isolation frequency of the principal fungi obtained from wheat, barley, and oat affected with root rot in California

		Isolation frequency (%)			
Host	Number of fields sampled	*Bipolaris sorokiniana*	*Fusarium graminearum*	*F. culmorum*	*Microdochium bolleyi*
Wheat	44	11	18	20	14
Barley	45	36	13	5	16
Oat	4	0	0	0	25
Total	93	23	15	12	15

Table 2. Isolation frequency by county of the principal fungi obtained from wheat, barley, and oat affected with root rot in California

		Isolation frequency (%)			
County	Number of fields sampled	*Bipolaris sorokiniana*	*Fusarium graminearum*	*F. culmorum*	*Microdochium bolleyi*
		Butte Valley-Tulelake			
Modoc	3	100	0	33	0
Siskiyou	9	67	0	33	0
Total	12	75	0	33	0
		Sacramento Valley			
Butte	13	5	0	0	38
Colusa	2	0	100	0	0
Glenn	9	0	11	11	11
Sacramento	1	0	0	100	0
Solano	14	7	36	14	21
Sutter	1	0	0	0	0
Yolo	13	0	15	23	8
Yuba	3	0	0	0	0
Total	56	5	18	13	18
		Salinas Valley foothills			
Monterey	14	38	21	0	21
San Benito	1	100	100	0	0
Total	15	40	27	0	20
		San Joaquin Valley			
Kings	6	50	0	0	17
San Joaquin	3	0	0	0	0
Tulare	1	0	0	0	0
Total	10	30	0	0	10

RESULTS

Occurrence and distribution of isolates. *F. culmorum*, *F. graminearum*, *B. sorokiniana*, and *M. bolleyi*, as well as other *Fusarium* species, were frequently isolated from wheat and barley (Table 1). In addition, *M. bolleyi* was isolated from a single oat field. More than one pathogen was sometimes isolated from plants in the same field.

The isolation frequency of these fungi varied with the area of collection (Table 2). In the Sacramento Valley, *F. graminearum*, *F. culmorum*, and *M. bolleyi* were frequently isolated from wheat and barley, whereas *B. sorokiniana* was isolated less frequently. Isolations from barley collected from the Salinas Valley foothills showed that *F. graminearum*, *B. sorokiniana*, and *M. bolleyi* were common. In the Tulelake area, *F. culmorum* and *B. sorokiniana* were frequently isolated from wheat and barley.

Pathogenicity of isolates. Nearly all isolates of *F. culmorum*, *F. graminearum*, *B. sorokiniana*, and *M. bolleyi* were pathogenic to barley, whereas nine of 10 isolates of other *Fusarium* species were not pathogenic. Isolates of *F. culmorum*, *F. graminearum*, and *B. sorokiniana* were usually moderate to high in virulence (MDR of 2–4), whereas isolates of *M. bolleyi* were less virulent (MDR <1). Most isolates of *F. culmorum* and *F. graminearum* caused a seedling blight on barley, whereas isolates of *B. sorokiniana* and *M. bolleyi* did not. Symptoms on plants infected with isolates of *F. culmorum* or *F. graminearum* consisted of a discoloration and rotting of lower leaf sheaths, culms, crowns, and subcrown internodes. This discoloration and rotting frequently extended up the culm with salmon-colored sporodochia occurring at the nodes. Symptoms on plants infected with isolates of *B. sorokiniana* were similar to those produced by *F. graminearum* and *F. culmorum*, except that the discoloration and rotting did not extend as far up the culm. Symptoms produced by isolates of *M. bolleyi* consisted of a discoloration and necrosis primarily on the subcrown internode, which could be confused with mild symptoms caused by *F. culmorum*, *F. graminearum*, or *B. sorokiniana*.

Seedling blight. Barley (CM72) was

significantly more susceptible to seedling blight ($P = 0.01$) caused by isolates of *F. culmorum* or *F. graminearum* than wheat (Anza) when grown in infested, unsterile Yolo loam. The combined average seedling blight (all isolates) for barley was 3.6%, whereas it was 1.0% for wheat. All isolates caused more seedling blight on barley than wheat, however; the host × isolate interaction was not significant at the 0.05 level.

Seedling blight of barley (CM72) caused by an isolate of *F. culmorum* was significantly more severe ($P = 0.05$) when plants were grown in infested, pasteurized U.C. mix than in infested, unsterile Yolo loam. The incidence of seedling blight of plants grown in infested U.C. mix was 46%, compared with 2% in infested, unsterile Yolo loam. Plants grown in noninfested U.C. mix or Yolo loam remained healthy.

Host susceptibility and pathogen specificity. Barley (CM72) was more susceptible than wheat (Anza) to seedling blight and root rot caused by *F. culmorum* and *F. graminearum* isolates infested at 200 propagules per gram (Table 3). In addition, barley (CM72) was generally more susceptible than wheat (Anza) to root rot caused by *B. sorokiniana* isolates infested at 200 propagules per gram. Barley cultivars grown in U.C. mix infested with isolates of *F. graminearum* at 900 propagules per gram were more susceptible than wheat cultivars to seedling blight and root rot; however, these differences were not evident with isolates of *F. culmorum* or *B. sorokiniana* at 900 propagules per gram (Table 4). Wheat cultivars were relatively equal in their susceptibility to root rot, as were barley cultivars. However, wheat cultivars differed in their susceptibility to seedling blight caused by *F. culmorum* and *F. graminearum*, whereas barley cultivars did not. No seedling blight was observed on wheat, barley, or oat when grown in U.C. mix infested with isolates of *B. sorokiniana* at either 200 or 900 propagules per gram. Oat was comparable to wheat and barley in its susceptibility to the *F. culmorum* isolate tested, but was less susceptible to isolates of *F. graminearum* and *B. sorokiniana* (Table 4).

Isolates of *F. culmorum*, *F. graminearum*, and *B. sorokiniana* were pathogenic on wheat and barley cultivars without relation to their original host, whether wheat or barley (Tables 3 and 4).

DISCUSSION

All fungi shown in Table 1 (with the exception of *M. bolleyi*, which Sprague [11] reported on wheat in California) were also reported on wheat and barley by Oswald (7,8). In addition, Oswald described a *Colletotrichum* sp., possibly *C. graminicola*, but no positive identification was made. He may have been describing *M. bolleyi*, which is difficult to identify and is often confused with *C. graminicola* (10). Results reported here are the first report of *M. bolleyi* as a pathogen on barley in California.

Oswald reported *F. culmorum* to be prevalent primarily in the Sacramento-San Joaquin delta area (8), whereas results reported here show that this pathogen is more widespread and important than previously reported. Oswald also reported *B. sorokiniana* to be widespread in California (8), although the present study shows it to occur less frequently in the Sacramento Valley. The frequent isolation of *F. graminearum* in areas previously mentioned is generally in agreement with the findings of Oswald (8). More extensive surveys are needed to improve our understanding of the distribution and frequency of these fungi.

Cook and Christen (3) pointed out the difference in ecologic preference of *F. culmorum* and *F. graminearum* in the state of Washington. They reported that, although both fungi are found in warm, dry climates, *F. graminearum* is found in the hotter, drier areas. The distribution of these pathogens in California is not so easily explained. Cultural practices, climate, and season in which cereals are grown vary in the different grain-growing areas of the state. *F. culmorum* was isolated from the cooler Tulelake area where wheat and barley are spring grown and irrigated, whereas *F. graminearum* was not. In the warm Sacramento Valley, where wheat and barley are winter grown and irrigated when necessary, *F. graminearum* and *F. culmorum* were commonly isolated. In the warm, unirrigated areas of the Salinas Valley foothills, *F. graminearum* was frequently isolated from winter-grown barley, whereas *F. culmorum* was not.

Isolates of *F. culmorum*, *F. graminearum*, and *B. sorokiniana*, unlike *M. bolleyi*, have the capability to cause moderate to severe levels of common root rot. However, with few exceptions, common root rot on wheat and barley plants collected in the field was not as severe as that observed in the greenhouse. Furthermore, the disease level on barley grown in unsterile Yolo loam was lower than that on barley grown in pasteurized U.C. mix. These differences may be caused by microbial antagonism in unsterile soils.

The differences in magnitude of disease observed between tests using autoclaved U.C. mix and natural soil emphasize other difficulties encountered with cereal root rot research. For example, extensive effort has been expended at many research centers in attempts to produce cultivars resistant to root rot. Perhaps the lack of substantial progress in this area can be attributed to inadequate disease pressure on selections when plants are grown in natural soils. Screening would be expected to be more severe when carried out in autoclaved or fumigated field soil.

Oswald (7) reported wheat to be

Table 3. Susceptibility of wheat (Anza) and barley (CM72) to common root rot pathogens obtained from wheat or barley

Pathogen[a]	Host source and number of isolates	Seedling blight (%)[b] Wheat	Seedling blight (%)[b] Barley	Mean disease rating[c] Wheat	Mean disease rating[c] Barley
Fusarium culmorum	Wheat (7)	3	21	1.69	3.14
	Barley (2)	3	50	1.61	3.40
F. graminearum	Wheat (2)	3	33	2.27	3.14
Bipolaris sorokiniana	Wheat (3)	0	0	1.46	2.00
	Barley (6)	0	0	1.70	2.30

[a] Inoculum was applied at a rate of 200 propagules per gram of U.C. mix.
[b] Values are means of five replicates for each isolate.
[c] Plants were rated at maturity on a scale of 0 (healthy) to 4 (plants killed).

Table 4. Susceptibility of various cultivars of wheat, barley, and oat to common root rot pathogens obtained from wheat or barley

Pathogen	Host source of isolates	Seedling blight (%) Wheat[b]	Seedling blight (%) Barley[b]	Seedling blight (%) Oat[c]	Mean disease rating[a] Wheat	Mean disease rating[a] Barley	Mean disease rating[a] Oat
Fusarium culmorum	Barley	17 y[d]	20 y	17 z	3.08 y	3.08 y	2.52 y
F. graminearum	Wheat	30 x	76 x	3 z	3.21 y	3.78 x	2.02 yz
F. graminearum	Barley	33 x	76 x	3 z	3.28 y	3.73 x	1.80 yz
Bipolaris sorokiniana	Wheat	0 z	0 z	0 z	2.27 z	2.32 z	1.65 z
B. sorokiniana	Barley	0 z	0 z	0 z	2.25 z	2.18 z	1.67 z

[a] Plants were rated at maturity on a scale of 0 (healthy) to 4 (plant killed).
[b] Values are means of three cultivars, five replicates of six plants each. The wheat cultivars Anza, Sonora, and Yecoro Rojo and the barley cultivars CM72, Numar, and Atlas 46 were used.
[c] Values are means of one cultivar with five replicates of six plants. The oat cultivar California Red was used.
[d] Means in the same column followed by common letters are not significantly different ($P = 0.05$) according to Duncan's multiple range test.

generally more susceptible than barley to *F. culmorum* and *F. graminearum*, but Butler (2) reported them to be equally susceptible to *F. culmorum*. Tinline and Ledingham (12) have shown barley cultivars on the average to be more susceptible to *B. sorokiniana* than wheat cultivars when tested in the field. Oat has also been reported to be susceptible to *F. culmorum* but generally resistant to *F. graminearum* and *B. sorokiniana* (2). Results here are similar to previous findings on the susceptibility of oat to these pathogens and in addition show barley to be more susceptible than wheat to *F. culmorum*, *F. graminearum*, and *B. sorokiniana* under most conditions tested.

Even though the barley cultivar CM72 is more susceptible than the wheat cultivar Anza to these pathogens at a relatively low inoculum level (200 propagules per gram), differences between barley and wheat were not always apparent at a higher inoculum level (900 propagules per gram). This was largely caused by the difference in the level of seedling blight. If only low levels of seedling blight occur, as observed in unsterile Yolo loam, the difference in susceptibility of wheat and barley may not be as discernible.

Fusarium culmorum, *F. graminearum*, and *B. sorokiniana* are generally regarded as nondiscriminating pathogens on most cereals and numerous grasses (13). Results here support this view and show that isolates of these pathogens collected from wheat and barley in California are not host-specific on wheat or barley. Differences of disease severity on wheat and barley infected with different isolates of each pathogen may simply be attributed to differences in host susceptibility and pathogen virulence.

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