Efficacy of Fungicides for Control of Sclerotinia Stem Rot of Canola

C. A. Bradley and H. A. Lamey, Department of Plant Pathology, North Dakota State University, Fargo 58105; G. J. Endres and R. A. Henson, Carrington Research Extension Center, North Dakota State University, Carrington, 58421; B. K. Hanson, Langdon Research Extension Center, North Dakota State University, Langdon 58249; K. R. McKay and M. Halvorson, North Central Research Extension Center, North Dakota State University, Minot 58701; and D. G. LeGare and P. M. Porter, Department of Agronomy and Plant Genetics, University of Minnesota, St. Paul 55108

ABSTRACT

Bradley, C. A., Lamey, H. A., Endres, G. J., Henson, R. A., Hanson, B. K., McKay, K. R., Halvorson, M., LeGare, D. G., and Porter, P. M. 2006. Efficacy of fungicides for control of Sclerotinia stem rot of canola. Plant Dis. 90:1129-1134.

Sclerotinia stem rot (SSR), incited by *Sclerotinia sclerotiorum*, causes yield reductions to canola (*Brassica napus*) grown in North Dakota and Minnesota. Field trials were conducted in North Dakota and Minnesota from 2000 to 2004 to evaluate the effect of foliar fungicides on SSR and canola yield. Levels of SSR varied among years and location. In general, fungicides that consistently reduced SSR incidence compared with an untreated control were azoxystrobin, benomyl, boscalid, iprodione, prothioconazole, tebuconazole, thiophanate-methyl, trifloxystrobin, and vinclozolin. Significant reductions in SSR incidence with fungicides did not always translate into differences in canola yield, however. Inconsistent results were observed with different timings of applications based on percent bloom. This indicates that application timing should be based on factors in addition to percent bloom.

Additional keywords: Benlate, Blocker, Endura, Folicur, Gem, JAU6476, Omega, Quadris, rape-seed, Ronilan, Rovral, Topsin M, white mold

Sclerotinia stem rot (SSR), caused by *Sclerotinia sclerotiorum* (Lib.) de Bary, is a major disease of canola (rapeseed, *Brassica napus* L.) grown in North Dakota and Minnesota. SSR incidence has ranged from 7 to 19% in North Dakota from 1991 to 2002 (4,5) and 11 to 19% in Minnesota from 1996 to 2002 (4).

Because no commercial canola cultivars currently have complete resistance to *S. sclerotiorum* (1), use of fungicides is the primary method of controlling SSR. Historically, benomyl fungicide (trade name: Benlate; DuPont Agricultural Products, Wilmington, DE) had been used effectively for controlling SSR in canola in Canada (2,11), and was in the process of becoming registered on canola in the United States; however, DuPont terminated manufacturing and sale of Benlate in 2001. Other fungicides such as iprodione and vinclozolin also have been used for SSR control in Canada (2, 11), and newly registered and experimental fungicides have the potential for providing excellent control of SSR. Although canola growers in Minne-

sota and North Dakota have access to a Sclerotinia risk forecasting system (6) which helps with fungicide application decisions, it does not provide help in choosing which fungicide to apply. Canola growers in North Dakota currently have four fungicide active ingredients registered for control of SSR on canola (azoxystrobin, boscalid, thiophanate-methyl, and vinclozolin; 7). If a fungicide application is warranted, the use of the most effective economical fungicide product will give growers the greatest return on their investment. The objective of this research was to evaluate the efficacy of

several fungicides for control of SSR of canola.

MATERIALS AND METHODS

In all, 16 field environments which consisted of several locations and years between 2000 and 2004, were used to evaluate the efficacy of several fungicides on SSR, (Table 1). Trials that were located on commercial fields relied on natural rainfall and disease pressure, whereas trials located on research farms were mist irrigated and relied on both natural disease pressure and augmented inoculum (*S. sclerotiorum* ascospores provided by M. Boosalis, University of Nebraska, Lincoln). At each environment, an untreated control was included, but fungicide treatments varied by year and location and were azoxystrobin (trade name: Quadris; Syngenta Crop Protection, Greensboro, NC), benomyl (Benlate; DuPont Agricultural Products), boscalid (Endura; BASF Ag Products, Research Triangle Park, NC), fluazinam (Omega; Syngenta Crop Protection), iprodione (Rovral; Bayer CropScience, Research Triangle Park, NC), prothioconazole (JAU6476; Bayer CropScience), pentachloronitrobenzene (PCNB, Blocker; AMVAC Chemical Corp., Los Angeles), tebuconazole (Folicur; Bayer CropScience), trifloxystrobin (Gem; Bayer CropScience), thiophanate-methyl (Topsin M; Cerexagri, King of Prussia, PA), V-10116 (Valent Agricultural Products, Walnut Creek, CA), and vinclozolin (Ronilan;

Table 1. Canola cultivar and irrigation information for each year and location

Year	Location ^a	Cultivar	Mist irrigation used
2000	Langdon, ND, REC	Pioneer 44A89	Yes
2000	Langdon, ND, commercial field	Golden Boy	No
2001	Red Lake Falls, MN	Pioneer 44A89	Yes
2001	Langdon, ND, REC	Minot RR	Yes
2001	Langdon, ND, commercial field	Minot RR	No
2001	Carrington, ND, REC	Minot RR	Yes
2001	Newburg, ND, commercial field 1	Li-Bred 449	No
2001	Newburg, ND, commercial field 2	Pioneer 45A55	No
2002	Langdon, ND, REC	LG 3455	Yes
2003	Langdon, ND, REC	Hyola 357 Magnum	Yes
2003	Carrington, ND, REC	Hyola 357 Magnum	Yes
2003	Minot, ND, REC	Invigor 2663	Yes
2003	Red Lake Falls, MN	Invigor 2663	Yes
2004	Langdon, ND, REC	Invigor 2663	Yes
2004	Carrington, ND, REC	Hyola 357 Magnum	Yes
2004	Red Lake Falls, MN	Invigor 2663	Yes

^a REC = research extension center.

Corresponding author: C. A. Bradley
E-mail: carl.bradley@ndsu.edu

Accepted for publication 1 May 2006.

DOI: 10.1094/PD-90-1129

© 2006 The American Phytopathological Society

BASF Ag Products). Fungicide applications were made with CO₂-pressurized backpack sprayers calibrated to deliver between 131 and 188 liters/ha at 207 to 276 kPa of pressure. Plot sizes varied with location and year and ranged from 1.5 to 1.8 m wide by 4.9 to 7.6 m long. Plots were arranged in a randomized complete block design with four replications.

Data from each location and year were analyzed separately due to differences in cultivars used and fungicide treatments

tested. Data were statistically analyzed using the general linear model procedure (PROC GLM) in SAS (SAS Institute, Inc., Cary, NC). Fisher's protected least significant difference test was used to compare means, where $\alpha = 0.05$.

RESULTS

2000. Significant differences among fungicide treatments were detected for SSR incidence and yield at the Langdon Research Extension Center (REC) in 2000 (Table 2). All fungicides except fluazinam

significantly reduced SSR incidence compared with the untreated control. Most fungicide treatments provided a significant yield increase over the untreated control; however, fluazinam, trifloxystrobin, and vinclozolin at 420 g a.i./ha applied at 30 to 50% bloom did not.

Significant differences among fungicide treatments were detected for SSR incidence and yield at the commercial field in Langdon in 2000 (Table 2). All fungicide treatments significantly reduced SSR incidence compared with the untreated control.

Table 2. Effect of fungicides on Sclerotinia stem rot (SSR) incidence and canola yield at a field located on the research extension center (REC) and in a commercial field in Langdon, ND in 2000

Fungicide	Rate (g a.i./ha)	Timing (% bloom)	REC		Commercial field ^a	
			SSR incidence (%)	Yield (kg/ha)	SSR incidence (%)	Yield (kg/ha)
Untreated	...	...	17	2,322	27	2,424
Azoxystrobin	175	10–20	10	2,542	5	2,791
Azoxystrobin ^b	175	10–20	10	2,578	3	2,673
Benomyl	489	20–30	2	2,714	2	2,677
Boscalid	249	20–30	6	2,622	1	2,571
Boscalid	249	30–50	3	2,791	7	2,743
Fluazinam	248	10–20	14	2,494	18	2,410
Fluazinam	496	10–20	14	2,341	8	2,553
Iprodione ^c	504	20–30	5	2,739	3	2,816
Tebuconazole	126	20–30	5	2,567	14	2,659
Tebuconazole	190	20–30	11	2,604	9	2,857
Trifloxystrobin	175	10–20	6	2,472	10	2,382
Trifloxystrobin	245	10–20	11	2,424	4	2,652
Vinclozolin	375	30–50	8	2,545	3	2,692
Vinclozolin	420	30–50	7	2,465	2	2,655
Vinclozolin	420	20–30	10	2,571	NI	NI
Vinclozolin	420	50–60	5	2,813	NI	NI
Vinclozolin ^b	420	30–50	5	2,663	1	2,857
LSD 0.05 ^d	...	...	5	210	5	303

^a NI = treatment was not included in this trial.

^b Included the adjuvant CL 9831 at 1.25% (vol/vol).

^c Included the adjuvant Aphoil at 1% (vol/vol).

^d Fisher's least significant difference, where $\alpha = 0.05$.

Table 3. Effect of fungicides on Sclerotinia stem rot (SSR) incidence and canola yield at a field located on the research extension center (REC) and in a commercial field in Langdon, ND in 2001

Fungicide	Rate (g a.i./ha)	Timing (% bloom)	REC		Commercial field	
			SSR incidence (%)	Yield (kg/ha)	SSR incidence (%)	Yield (kg/ha)
Untreated	...	...	59	1,433	12	2,004
Azoxystrobin	175	10–20	44	1,712	12	1,795
Benomyl	561	30–40	11	2,097	2	1,899
Boscalid	200	30–40	7	2,243	3	1,814
Boscalid	249	10–20	17	2,072	5	1,960
Boscalid	249	30–40	26	1,990	3	1,986
Boscalid	249	50–60	22	2,243	1	1,916
Boscalid	299	30–40	1	2,433	1	1,822
Boscalid ^a	249	30–40	9	2,195	1	2,052
Iprodione ^b	504	10–20	16	1,872	4	1,968
Iprodione ^b	504	30–40	19	2,058	2	2,008
Iprodione ^b	504	50–60	7	2,199	1	2,019
Tebuconazole	126	10–20	32	1,896	8	1,861
Tebuconazole	126	30–40	41	1,634	14	2,103
Tebuconazole	126	50–60	19	2,014	3	2,055
Tebuconazole	190	30–40	25	1,994	8	2,019
Thiophanate-methyl	785	30–40	6	2,239	0	2,019
Vinclozolin	420	10–20	19	1,707	11	1,931
Vinclozolin	420	30–40	12	2,151	5	1,982
Vinclozolin	420	50–60	11	2,136	1	2,063
Vinclozolin	375	30–40	20	2,126	7	1,825
Vinclozolin ^a	420	30–40	24	1,892	6	2,169
LSD 0.05 ^c	...	...	24	350	6	NS

^a Included the adjuvant LOL 9831 at 1.25% (vol/vol).

^b Included the adjuvant Aphoil at 1% (vol/vol).

^c Fisher's least significant difference, where $\alpha = 0.05$. NS = not statistically significant ($P \leq 0.05$) according to the *F* test.

The fungicide treatments azoxystrobin without an adjuvant, boscalid applied at 30 to 50% bloom, iprodione, tebuconazole at 190 g a.i./ha, and vinclozolin at 420 g a.i./ha applied at 30 to 50% bloom with an adjuvant provided significant yield increases over the untreated control.

2001. Significant differences among fungicide treatments were detected for SSR incidence and yield at the Langdon REC in 2001 (Table 3). All fungicide treatments except azoxystrobin and tebuconazole at 126 g a.i./ha applied at 30 to 40% bloom significantly reduced SSR incidence compared with the untreated control. All fungicide treatments except azoxystrobin, tebuconazole at 126 g a.i./ha applied at 30 to 40% bloom, and vinclozolin at 420 g a.i./ha applied at 10 to 20% bloom provided significant yield increases over the untreated control.

Significant differences among fungicide treatments were detected for SSR incidence but not for yield at the commercial field in Langdon in 2001 (Table 3). All fungicide treatments had significantly lower SSR incidence than the untreated control, except azoxystrobin, tebuconazole at 126 g a.i./ha applied at 30 to 40% bloom, tebuconazole at 190 g a.i./ha applied at 30 to 40% bloom, vinclozolin at 420 g a.i./ha applied at 10 to 20% bloom, and vinclozolin at 375 g a.i./ha applied at 30 to 40% bloom.

Significant differences among fungicide treatments were detected for SSR incidence but not for yield at the Carrington REC in 2001 (Table 4). Fungicide treatments that significantly reduced SSR incidence compared with the untreated control were benomyl, boscalid at 200 g a.i./ha applied at 30 to 40% bloom, boscalid at

294 g a.i./ha applied at 30 to 40% bloom, iprodione applied at 30 to 40% bloom, tebuconazole at 126 g a.i./ha applied at 30 to 40% bloom, and thiophanate-methyl applied at either 30 to 40% or 50 to 60% bloom.

Significant differences among fungicide treatments were detected for SSR incidence and yield at both commercial fields in Newburg in 2001 (Table 5). At commercial field 1, all fungicide treatments significantly reduced SSR incidence compared with the untreated control; however, only boscalid, thiophanate-methyl, and vinclozolin at 420 g a.i./ha provided a significant yield increase over the untreated control. At commercial field 2, all fungicide treatments significantly reduced SSR incidence and increased yield compared with the untreated control, except vinclozolin at 375 g a.i./ha with an adjuvant, which did not provide a significant yield increase over the untreated control.

Significant differences among fungicide treatments were detected for SSR incidence and yield at Red Lake Falls in 2001 (Table 6). All fungicide treatments except thiophanate-methyl at 785 g a.i./ha significantly reduced SSR incidence and increased yield compared with the untreated control.

2002. Significant differences among fungicide treatments were detected for SSR incidence but not yield at the Langdon REC in 2002 (Table 7). Fungicide treatments that significantly reduced SSR incidence compared with the untreated control were boscalid at 249 and 284 g a.i./ha, iprodione applied at 50 to 60% bloom, prothioconazole at 200 g a.i./ha applied at 50 to 60% bloom, thiophanate-methyl at 785 g a.i./ha applied at 50 to 60% bloom, and vinclozolin applied at 50 to 60% bloom.

2003. Significant differences among fungicide treatments were detected for SSR incidence and yield at the Langdon REC in 2003 (Table 8). Fungicide treat-

Table 4. Effect of fungicides on Sclerotinia stem rot (SSR) incidence and canola yield at Carrington, ND in 2001

Fungicide	Rate (g a.i./ha)	Timing (% bloom)	SSR incidence (%)	Yield (kg/ha)
Untreated	...	...	73	1,954
Azoxystrobin	175	10–20	63	1,627
Benomyl	561	30–40	35	2,259
Boscalid	200	30–40	43	2,086
Boscalid	249	10–20	58	1,898
Boscalid	249	30–40	46	2,281
Boscalid	249	50–60	62	2,059
Boscalid	294	30–40	39	2,132
Iprodione ^a	504	30–40	12	2,355
Iprodione ^a	504	50–60	65	1,888
Tebuconazole	126	10–20	94	1,977
Tebuconazole	126	30–40	43	2,178
Tebuconazole	126	50–60	71	2,085
Tebuconazole	190	30–40	76	1,983
Thiophanate-methyl	785	10–20	67	1,953
Thiophanate-methyl	785	30–40	23	1,976
Thiophanate-methyl	785	50–60	35	2,253
Vinclozolin	420	10–20	65	1,912
Vinclozolin	420	30–40	79	2,281
Vinclozolin	420	50–60	65	1,995
Vinclozolin	375	30–40	57	2,164
LSD 0.05 ^b	...	...	29	NS

^a Included the adjuvant Herbimax at 1% vol/vol.

^b Fisher's least significant difference, where $\alpha = 0.05$. NS = not statistically significant ($P \leq 0.05$) according to the *F* test.

Table 5. Effect of fungicides on Sclerotinia stem rot (SSR) incidence and canola yield on two commercial fields located in Newburg, ND in 2001^a

Fungicide	Rate (g a.i./ha)	Commercial field 1		Commercial field 2	
		SSR incidence (%)	Yield (kg/ha)	SSR incidence (%)	Yield (kg/ha)
Untreated	...	34	1,868	39	2,254
Boscalid	249	10	2,075	4	2,858
Iprodione ^b	504	13	1,979	NI	NI
Tebuconazole	126	14	2,021	NI	NI
Tebuconazole ^c	126	NI	NI	19	2,687
Thiophanate-methyl	785	8	2,229	3	2,768
Vinclozolin	420	9	2,102	8	2,896
Vinclozolin	375	14	2,052	10	2,742
Vinclozolin ^d	420	NI	NI	8	2,692
Vinclozolin ^d	375	NI	NI	8	2,496
LSD 0.05 ^e	...	10	190	6	277

^a Fungicides were applied at 20 to 30% bloom in field 1 and at 40% bloom in field 2; NI = treatment was not included in this trial.

^b Included the adjuvant Aphoil at 1% (vol/vol).

^c Included the adjuvant Induce at 0.125% (vol/vol).

^d Included a silicone adjuvant at 0.25% (vol/vol).

^e Fisher's least significant difference, where $\alpha = 0.05$.

ments that significantly reduced SSR incidence compared with the untreated control were boscalid applied at either 30 to 40% or 50 to 60% bloom and prothioconazole

at either 175 or 200 g a.i./ha applied at 30 to 40% bloom. Fungicide treatments that provided a significant yield increase over the untreated control were boscalid applied

at either 30 to 40 or 50 to 60% bloom, iprodione applied at either 30 to 40% or 50 to 60% bloom, prothioconazole at either 175 or 200 g a.i./ha applied at either 30 to 40% or 50 to 60% bloom, V-10116 applied at 30 to 40% bloom, and vinclozolin applied at 50 to 60% bloom.

Significant differences among fungicide treatments were detected for SSR incidence but not yield at the Carrington REC in 2003 (Table 8). Fungicide treatments that significantly reduced SSR incidence compared with the untreated control were boscalid applied at 50 to 60% bloom and prothioconazole at either 175 or 200 g a.i./ha applied at 50 to 60% bloom.

Significant differences among fungicide treatments were detected for SSR incidence but not yield at the Minot REC in 2003 (Table 8). All fungicide treatments significantly reduced SSR incidence compared with the untreated control, except PCNB applied at 30 to 40% bloom and V-10116 applied at 30 to 40% bloom.

Significant differences among fungicide treatments were detected for SSR incidence but not yield at Red Lake Falls in 2003 (Table 8). All fungicide treatments significantly reduced SSR incidence compared with the untreated control.

2004. Significant differences among fungicide treatments were detected for SSR incidence but not yield at the Langdon REC in 2004 (Table 9). No significant differences were detected among fungicide treatments for either SSR incidence or yield at the Carrington REC and Red Lake Falls in 2004. At the Langdon REC, all fungicide treatments significantly reduced SSR incidence compared with the untreated control.

Table 6. Effect of fungicides on Sclerotinia stem rot (SSR) incidence and canola yield at Red Lake Falls, MN in 2001^a

Fungicide	Rate (g a.i./ha)	SSR incidence (%)	Yield (kg/ha)
Untreated	...	61	1,403
Benomyl	561	9	1,715
Thiophanate-methyl	1,176	23	1,742
Thiophanate-methyl	785	48	1,586
Vinclozolin	420	35	1,673
LSD 0.05 ^b	...	17	234

^a Fungicides were applied at 30% bloom.

^b Fisher's least significant difference, where $\alpha = 0.05$.

Table 7. Effect of fungicides on Sclerotinia stem rot (SSR) incidence and canola yield at Langdon, ND in 2002

Fungicide	Rate (g a.i./ha)	Timing (% bloom)	SSR incidence (%)	Yield (kg/ha)
Untreated	...	...	51	2,107
Boscalid	249	30–40	20	2,550
Boscalid	284	50–60	9	2,575
Iprodione ^a	504	30–40	39	2,221
Iprodione ^a	504	50–60	25	2,388
Iprodione ^b	504	30–40	40	2,410
Prothioconazole ^c	151	30–40	37	2,217
Prothioconazole ^c	151	50–60	34	2,407
Prothioconazole ^c	200	30–40	35	2,341
Prothioconazole ^c	200	50–60	21	2,615
Thiophanate-methyl	785	30–40	39	2,206
Thiophanate-methyl	785	50–60	19	2,583
Thiophanate-methyl	1,175	30–40	46	2,429
Thiophanate-methyl ^b	785	30–40	31	2,429
Vinclozolin	420	30–40	49	2,180
Vinclozolin	420	50–60	24	2,440
LSD 0.05 ^d	...	...	22	NS

^a Included the adjuvant Aphoil at 1% (vol/vol).

^b Included the adjuvant Prime Oil at 1% (vol/vol).

^c Included the adjuvant Induce at 1.25% (vol/vol).

^d Fisher's least significant difference, where $\alpha = 0.05$. NS = not statistically significant ($P \leq 0.05$) according to the F test.

Table 8. Effect of fungicides on Sclerotinia stem rot (SSR) incidence and canola yield at Langdon, Carrington, and Minot, ND and Red Lake Falls, MN in 2003^a

Fungicide	Rate (g a.i./ha)	Bloom (%)	Langdon		Carrington		Minot		Red Lake Falls	
			SSR (%)	Yield (kg/ha)	SSR (%)	Yield (kg/ha)	SSR (%)	Yield (kg/ha)	SSR (%)	Yield (kg/ha)
Untreated	...	...	89	1,668	69	1,687	8	2,936	25	1,970
Boscalid	284	30–40	65	2,176	58	1,752	1	2,893	9	1,925
Boscalid	284	50–60	66	2,410	44	1,865	1	3,119	5	2,006
Iprodione ^b	504	30–40	77	2,286	64	1,694	5	3,167	5	1,866
Iprodione ^b	504	50–60	92	2,446	57	1,613	3	2,732	5	2,002
PCNB	1,680	30–40	99	1,785	59	1,530	8	2,968	12	1,905
PCNB	1,680	50–60	NI	NI	63	1,636	NI	NI	NI	NI
PCNB + thiophanate-methyl	1,680 + 393	30–40	98	1,844	63	1,563	4	2,979	15	1,943
Prothioconazole ^c	175	30–40	50	2,520	55	1,920	3	3,292	5	1,998
Prothioconazole ^c	175	50–60	73	2,688	49	1,928	2	2,732	5	2,065
Prothioconazole ^c	200	30–40	54	2,366	57	1,892	1	2,954	7	2,010
Prothioconazole ^c	200	50–60	79	2,681	47	1,826	2	3,188	4	2,060
Thiophanate-methyl	393	30–40	93	2,048	NI	NI	3	3,308	5	1,663
Thiophanate-methyl	785	30–40	94	2,102	75	1,739	2	3,238	5	1,923
Thiophanate-methyl	785	50–60	81	1,877	65	1,680	2	3,218	5	1,848
V-10116	141	30–40	93	2,231	59	1,932	6	3,480	-	-
V-10116	141	50–60	89	1,957	58	1,955	4	3,018	12	2,068
Vinclozolin	420	30–40	83	2,147	77	1,734	2	3,134	9	1,931
Vinclozolin	420	50–60	72	2,289	66	1,830	2	3,237	7	1,888
LSD 0.05 ^d	...	...	23	495	15	NS	3	NS	7	NS

^a PCNB = pentachloronitrobenzene and NI = treatment was not included in this trial.

^b Included either crop oil concentrate or Aphoil as an adjuvant at 1% (vol/vol).

^c Included the adjuvant Induce at 0.125% (vol/vol).

^d Fisher's least significant difference, where $\alpha = 0.05$. NS = not statistically significant ($P \leq 0.05$) according to the F test.

DISCUSSION

Fungicide active ingredients currently registered in the United States for control of SSR on canola are azoxystrobin, boscalid, thiophanate-methyl, and vinclozolin, in which each represents a distinct chemical group: quinone outside inhibitors (QoI), carboxamides, methyl benzimidazole carbamates (MBC), and dicarboximides, respectively. When applied at labeled rates, all of these fungicides significantly reduced SSR incidence compared with the untreated control on a consistent basis. The reductions in SSR incidence sometimes resulted in a significant increase in yield over the untreated control as well. Vinclozolin previously was reported to control SSR effectively in rapeseed (2). Fungicide recommendations to canola growers should include rotation among the registered active ingredients to slow down the selection for fungicide-resistant isolates. Although fungicide-resistant populations of *S. sclerotiorum* have not yet been observed in North Dakota, *S. sclerotiorum* isolates resistant to MBC fungicides have been reported in Canada and China (3,15). Mueller et al. (8) reported that several isolates of *S. sclerotiorum* from Illinois and other states had reduced sensitivity to thiophanate-methyl, thus showing that the potential of developing resistance to this MBC fungicide could be realized. Even though *S. sclerotiorum* populations resistant to QoI, carboxamide, and dicarboximide fungicide groups have not been identified thus far, resistance management practices still should be recommended because the fungicide chemical groups registered on canola for SSR control in the United States are classified as either medium risk, medium to high risk, or high risk by the Fungicide Resistance Action Committee.

In addition to the fungicide active ingredients currently registered on canola, some of the nonregistered fungicides provided significantly better SSR control than the untreated control on a relatively consistent basis. These fungicides included iprodione, prothioconazole, tebuconazole, and trifloxystrobin. Iprodione previously has been reported to provide control of SSR on rapeseed in Canada (2,11). Tebuconazole

was reported to reduce SSR severity on soybean (*Glycine max*) in the greenhouse (8), but its efficacy against SSR on canola in the field does not appear to have been reported previously. Trifloxystrobin did not improve marketable yield of snap bean (*Phaseolus vulgaris*) over an untreated control under white mold (*S. sclerotiorum*) pressure in New York (10). Conversely, trifloxystrobin did significantly reduce SSR incidence in our canola trials, although it was tested in 1 year only. If registered on canola in the United States, these fungicide active ingredients would provide canola growers with more products to choose from which could help drive down the price, making fungicides more economical to apply. Prothioconazole and tebuconazole both belong to the demethylation inhibitors fungicide group. If registered, this would give canola growers one more fungicide group to rotate with that would help with fungicide resistance management.

Different application timings of the fungicides were evaluated in some of the trials, which ranged from 10 to 60% bloom. Dueck et al. (2) reported that effective control of SSR was achieved when fungicides were applied at 25% bloom, and Thomson et al. (11) reported effective control of SSR when fungicides were applied at 20 to 30% or 30 to 50% bloom. In our trials, one specific timing did not necessarily result in the best control for all of the locations and years. The application timing did not appear to make a difference in some years and locations, but in others it did. A specific percent bloom timing may not be the best guide to use to determine when to apply a fungicide for SSR control in canola. Although senescing canola petals need to be present for *S. sclerotiorum* ascospores to infect (9), other factors such as weather and apothecia development also need to be considered for the best time to apply a fungicide. Using disease forecasting such as the Sclerotinia risk forecasting system (6), which predicts the development of apothecia, or measuring petal infestation (12–14) may provide guidance in determining when to apply a fungicide.

Because fungicides are an added expense, the return on the investment of a

fungicide is a major consideration when a canola grower is making a decision whether to spray or not. The four fungicides currently registered for control of SSR in canola are priced quite differently. The current approximate price for each fungicide is \$0.30/g a.i. azoxystrobin (Quadris; registered rate = 113 to 281 g a.i./ha), \$0.28/g a.i. boscalid (Endura; registered rate = 245 to 294 g a.i./ha), \$0.06/g a.i. thiophanate-methyl (Topsin M; registered rate = 785 to 1,570 g a.i./ha), and \$0.10/g a.i. vinclozolin (Ronilan; registered rate = 372 to 560 g a.i./ha). The 10-year average canola marketing price for North Dakota growers is \$0.22/kg (1995 to 2004; National Agriculture Statistics Service). Based on these prices and our results, a grower would have at least a “break-even” return on each fungicide the following number of times (based on the number of times evaluated at registered rates in our trials): 43% of the time (3 of 7 times) for azoxystrobin, 41% of the time (13 of 32 times) for boscalid, 44% of the time (12 of 27 times) for thiophanate-methyl, and 60% of the time (26 of 43 times) for vinclozolin. To stay profitable, canola growers should observe yield potential, disease and weather forecasting systems, and price and efficacy of fungicides before making the decision to spray their canola fields to control SSR.

From the results presented herein, fungicides can be used effectively to control SSR and minimize yield reductions in canola. Fungicides currently registered in the United States for SSR control on canola are effective if applied at labeled rates; however, caution should be taken to rotate among the fungicide groups to slow down the selection for fungicide-resistant isolates. Some of the fungicides not currently registered for application on canola in the United States were efficacious against SSR and would provide canola growers with more management options if they become registered for use on canola in the United States. Although fungicides are effective in reducing SSR incidence, yield reductions still do occur often, especially under heavy disease pressure. More research is needed in evaluating fungicide application technologies for SSR control in

Table 9. Effect of fungicides on Sclerotinia stem rot (SSR) incidence and canola yield at Langdon and Carrington, ND and Red Lake Falls, MN in 2004

Fungicide	Rate (g. a.i./ha)	Bloom (%)	Langdon		Carrington		Red Lake Falls	
			SSR (%)	Yield (kg/ha)	SSR (%)	Yield (kg/ha)	SSR (%)	Yield (kg/ha)
Untreated	...	...	95	1,889	5	2,870	4	2,643
Boscalid	269	30–40	27	2,382	3	2,969	0	2,860
Prothioconazole ^a	151	50–60	50	2,303	2	2,723	1	2,636
Prothioconazole ^a	175	50–60	32	2,576	1	3,066	1	2,602
Thiophanate-methyl	785	30–40	66	2,190	3	2,862	4	2,734
Thiophanate-methyl	785	50–60	50	2,366	3	2,763	1	2,607
V-10116	134	30–40	63	2,472	3	3,291	1	2,924
Vinclozolin	420	30–40	63	2,112	3	2,896	6	2,793
LSD 0.05 ^b	...	...	27	NS	NS	NS	NS	NS

^a Included the adjuvant Induce at 0.125% (vol/vol).

^b Fisher's least significant difference, where $\alpha = 0.05$. NS = not statistically significant ($P \leq 0.05$) according to the *F* test.

canola. Newer application technology may allow for better fungicide coverage, which could result in better control.

ACKNOWLEDGMENTS

This research was supported by the United States Department of Agriculture CSREES National and North Central Canola Research Programs, the Northern Canola Growers Association, and the Minnesota Canola Council.

LITERATURE CITED

- Bradley, C. A., Henson, R. A., Porter, P. M., LeGare, D. G., del Río, L. E., and Khot, S. D. 2006. Response of canola cultivars to *Sclerotinia sclerotiorum* in controlled and field environments. *Plant Dis.* 90:215-219.
- Dueck, J., Morrall, R. A. A., and McKenzie, D. L. 1983. Control of *Sclerotinia sclerotiorum* in rapeseed with fungicides. *Can. J. Plant Pathol.* 5:289-293.
- Gossen, B. D., Rimmer, S. R., and Holley, J. D. 2001. First report of resistance to benomyl fungicide in *Sclerotinia sclerotiorum*. *Plant Dis.* 85:1206.
- Lamey, A., Knodel, J., Endres, G., Andol, K., Ashley, R., Beneda, R., Johnson, N., Knoke, S., Liane, M., Lykken, T., Miller, M., Nyegaard, C., and Peterson, N. 2002. 2002 Canola disease survey in Minnesota and North Dakota. N. D. State Univ. Ext. Rep. No. 80.
- Lamey, H. A. 1995. Blackleg and Sclerotinia disease of canola in North Dakota in 1991 and 1993. *Plant Dis.* 79:322-324.
- McLaren, D. L., Conner, R. L., Platford, R. G., Lamb, J. L., Lamey, H. A., and Kutcher, H. R. 2004. Predicting diseases caused by *Sclerotinia sclerotiorum* on canola and bean—a western Canadian perspective. *Can. J. Plant Pathol.* 26:489-497.
- McMullen, M. P., and Bradley, C. A. 2005. 2005 North Dakota field crop fungicide guide. N. D. State Univ. Ext. Rep. No. PP-622.
- Mueller, D. S., Dorrance, A. E., Derksen, R. C., Ozkan, E., Kurlle, J. E., Grau, C. R., Gaska, J. M., Hartman, G. L., Bradley, C. A., and Pedersen, W. L. 2002. Efficacy of fungicides on *Sclerotinia sclerotiorum* and their potential for control of Sclerotinia stem rot on soybean. *Plant Dis.* 86:26-31.
- Rimmer, S. R., Kutcher, H. R., and Morrall, R. A. A. 2003. Diseases of canola and mustard. Pages 129-146 in: *Diseases of Field Crops in Canada*, 3rd ed. K. L. Bailey, B. D. Gossen, R. K. Gugel, and R. A. A. Morrall, eds. University Extension Press, Saskatoon, SK, Canada.
- Shah, D. A., Dillard, H. R., and Cobb, A. C. 2002. Alternatives to vinclozolin (Ronilan) for controlling gray and white mold on snap bean pods in New York. Online. *Plant Health Progress* doi:10.1094/PHP-2002-0923-01-RS.
- Thomson, J. R., Thomas, P. M., and Evans, I. R. 1984. Efficacy of aerial application of benomyl and iprodione for the control of Sclerotinia stem rot of canola (rapeseed) in central Alberta. *Can. J. Plant Pathol.* 6:75-77.
- Turkington, T. K., and Morrall, R. A. A. 1993. Use of petal infestation to forecast Sclerotinia stem rot of canola: the influence of inoculum variation over the flowering period and canopy density. *Phytopathology* 83:682-689.
- Turkington, T. K., Morrall, R. A. A., and Gugel, R. K. 1991. Use of petal infestation to forecast Sclerotinia stem rot of canola: Evaluation of early bloom sampling, 1985-90. *Can. J. Plant Pathol.* 13:50-59.
- Turkington, T. K., Morrall, R. A. A., and Rude, S. V. 1991. Use of petal infestation to forecast Sclerotinia stem rot of canola: the impact of diurnal and weather-related inoculum fluctuations. *Can. J. Plant Pathol.* 13:347-355.
- Zhiqi, S., Mingguo, Z., Zhongyin, Y., Jianrong, S., Huaigu, C., and Yuzhong, W. 2000. Resistance monitoring of *Sclerotinia sclerotiorum* to carbendazim. *Jiangsu J. Agric. Sci.* 16:226-229.