Effects of Fungicides Applied During Bloom on Yield, Yield Components, and Storage Rots of Cranberry

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ABSTRACT

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Captafol, chlorothalonil, and mancozeb were applied to the same plots, which were established in commercial cranberry (cv. Searles) beds at two locations in central Wisconsin, for three consecutive years to manage postharvest storage rots of fresh fruit. Applications were initiated progressively earlier each year in relation to bloom (late bloom in 1986, 70% bloom in 1987, and 14% bloom in 1988) and were made three times at 14-day intervals each year. Compared with the untreated control, one or more of the fungicide treatments reduced yield (i.e., marketable berry weight per unit area) in all 3 yr at both locations. Chlorothalonil reduced yield most consistently (63% at location 1 in 1987 and 1988 and 20% at location 2 over all 3 yr). Fruit-set was reduced whenever yield was reduced; other components of yield that were routinely affected by fungicides were the proportion of the upright shoots that produced flowers and the number of flowers produced per flowering shoot. Weights of individual berries and the total number of upright shoots per unit area were not affected by the treatments. Incidence of rot was assessed after berries were stored 3 mo at 2 C. Only captafol consistently reduced the incidence of soft, rotted berries and increased the percentage of berries that was marketable. This increase ranged from 4 to 10% over the 3 yr. Chlorothalonil increased the percentage of marketable berries and decreased storage rots in 1986 only when applications were initiated at late bloom. Mancozeb was ineffective at managing storage rots. The incidence of black rot was not affected by fungicide treatments. From isolations conducted with berries harvested in 1988, *Apostrasseria lunata* consistently was recovered from berries with black rot symptoms. The four most common fungi recovered from soft, rotted berries were *Godronia cassandrae*, *Penicillium* spp., *A. lunata*, and *Coleophoma empetri*. Frequently, berries from which no fungus was isolated (i.e., sterile breakdown) occurred at each location (57% of the berries at location 1 and 10% of the berries at location 2). This research suggests that a thorough investigation of the costs and benefits of fungicides applied for cranberry storage rot disease management in Wisconsin is needed.

Cranberries (*Vaccinium macrocarpon* Aiton) are the most important fruit crop grown in Wisconsin based both on economic value and total acreage planted. Postharvest fruit rots, caused by various fungi, develop in storage while cranberries are being held for sale as fresh fruit and are one of the most important disease problems affecting this crop (1,2,6,13,21,23). In the past, end rot caused by *Godronia cassandrae* Peck (anamorph = *Fusicoccum putrefaciens* Shear) has been predominant among these storage rot diseases in Wisconsin (2,21,23,24); recently, however, black rot caused by *Apostrasseria lunata* (Shear) Nag Raj (= *Ceuthospora lunata* Shear) has also been recognized as an important storage rot disease (11,19).

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Fungi that cause storage rots can infect cranberry fruit very early in the season, either during or shortly after bloom (1,3, 22). Consequently, fungicide applications to manage storage rots have been initiated at this time (1,3,10). For cranberry storage rot management in Wisconsin, three fungicide applications at 14-day intervals are currently recommended with applications beginning during bloom (15). In fact, other than applications to manage the cottonball disease caused by *Monilinia oxycocci* (Woronin) Honey, no other fungicide applications are recommended in Wisconsin (15) because of an absence of other economically important diseases (6,15,21,23). However, numerous fungi are capable of colonizing cranberry, and minor diseases affecting stems, leaves, and fruit are known (1,2,11,21). Consequently, many believe that fungicides are beneficial in most years, despite a lack of obvious disease symptoms occurring on plants in the field. This belief has caused many Wisconsin growers to make needless fungicide applications to cranberries that are to be processed immediately after harvest and not stored as fresh fruit. These applications could amount to a sizeable and unnecessary cost to the state's cranberry industry because 85–90% of the cranberries grown in Wisconsin are processed.

The objective of this research was to determine the effects of fungicides applied for storage rot disease management on cranberry yield, vine productivity, and storage rot incidence. To identify any positive response that may have occurred because of the suppression of chronic diseases that might have been present at low, undetectable levels, the project was conducted for 3 yr.

MATERIALS AND METHODS

Experimental design. The experiment was conducted during the growing seasons of 1986, 1987, and 1988 at two independently owned, commercial cranberry marshes, designated location 1 and location 2, in the principal cranberry-growing region of central Wisconsin. Both experimental sites were in the same township of Wood County; location 1 was in section 34 and location 2 was in section 9. At both locations, fruit was grown primarily for processing, and no fungicides had been applied for at least 10 yr. At each site, plots were established in beds planted with the cv. Searles, the most widely planted cultivar in Wisconsin (2,6); beds were at least 40 yr old at both locations. Corners of plots were permanently marked with wooden stakes so that the same treatments could be applied to the same plots each year. Plots measured 2.0 × 3.5 m, were separated from each other by 1 m on all sides, and were arranged in a completely randomized design because no legitimate grounds for establishing blocks were determined. There were 10 replicate plots for each of the four treatments. At each location, the 40 plots were a contiguous group in an 8 × 5 arrangement at location 1 and in a 20 × 2 arrangement at location 2.

Treatments and application timing. Four treatments were compared—the three most popular fungicides applied for storage rot management in Wisconsin and an untreated control. The fungicides and equivalent rates of application in the amount of formulated product per hectare included: chlorothalonil 6F (Bravo 720, Fermenta ASC Corporation, Mentor, OH), 4.9 L; mancozeb 80WP (Dithane M-45, Rohm and Haas Company, Philadelphia, PA), 4.5 kg; and captafol 80WDG (Difolatan, Chevron Chemical Company, San Francisco, CA), 4.5 kg. Amounts were set at the low end of the range of amounts that are registered for application to cranberries. Appropriate amounts of fungicides were applied to each plot in 1 L of water, equivalent to 1,429 L/ha, by a CO_2-pressurized backpack sprayer with a three-nozzle boom. Each year, three applications were made at 14-day intervals; however, the timing of the first application relative to bloom was progressively earlier in each consecutive year. Treatments were initiated at late bloom (2 July) in 1986, at 70% bloom (17 June) in 1987, and at 14% bloom (17 June) in 1988. Treatments were always applied to both locations on the same day. Host phenology at the two locations was comparable. Other than the fungicide treatments, plots were subjected to the crop management practices routinely performed at each marsh.

Data collection—yield and productivity. To determine treatment effects on yield and productivity, all of the upright shoots (i.e., uprights) and berries were removed from two randomly selected, circular, 363-cm^2 areas in the center portion of each plot just before the time of commercial harvest at each location. Samples from the two areas were combined to provide a larger composite sample (i.e., from 726 cm^2), which was expected to be more representative of each plot, and were stored in polyethylene bags at 2 C for 4–8 wk. For each sample, the following data were collected: 1) number of vegetative uprights (*Uv*), those without flower pedicels; 2) number of flowering uprights (*Up*), those with flower pedicels; 3) number of flower pedicels (*P*), which are persistent on uprights and a direct count of the number of flowers produced; 4) number of marketable berries (*Bm*)—berries without visible decay; 5) number of immature defective berries (*Bdi*)—berries that were rotted or abscised before reaching a mature size; 6) number of mature defective berries (*Bdm*)—berries that were rotted or abscised after reaching a mature size; 7) weight of all marketable berries (*Wb*), which constituted yield; and 8) weight of all uprights (*Wu*).

Cranberry yield, in berry weight per unit area, has been shown to be the product of five components (8,9), which were calculated as follows: total number of all uprights per unit area ($Ut/\text{area} = Uv + Up$); proportion of the uprights that produced flowers (Up/Ut); number of flowers per flowering upright (P/Up); fruit-set (B/P, the ratio of the number of berries to the number of flowers); and individual berry weight (Wb/B). That is, yield = (Ut/area) (Up/Ut) (P/Up) (B/P) (Wb/B) = berry weight per area. In addition, fruit retention (Bm/P, the ratio of the number of marketable berries to the number of flowers) and individual upright weight (Wu/Ut) were calculated.

Data collection—storage rot incidence. To determine treatment effects on storage rot incidence, a 2-L sample of berries was hand-raked from each plot immediately after samples for yield and productivity were collected. To enhance development of storage rot diseases (5,25), each sample was placed in a coarse-mesh nylon bag and immersed for 1–2 hr in a flooded cranberry bed that had been recently harvested. Berries remained wet in nylon bags overnight. Samples were then air-dried at room temperature for 2–3 days and sorted to remove rotted or injured berries, placed in paper bags, and stored at 2 C. Berries routinely were harvested during the first 2 wk of October and were evaluated 3 mo later in January. To evaluate samples, berries were examined and separated into three symptom categories: those without any rot symptoms (i.e., marketable); those that were soft and rotted; and those with typical black rot symptoms. Except for black rot, which has characteristic symptoms (1,6), symptoms of storage rots are similar and, therefore, not diagnostic of the causal agent (1,2,22,26).

In 1988, isolations were made from five berries in each of the two rot categories from each replicate sample to determine which fungi were causing storage rots. Berries were surface-disinfested by constant agitation in 0.5% sodium hypochlorite for 5 min, rinsed in sterile distilled water, and allowed to air-dry. An internal piece of tissue was aseptically removed from each berry and placed on half-strength potato-dextrose agar (PDA) (19 g of Difco PDA, 8 g of Difco agar, and 1,000 ml of distilled water per liter) amended with 100 μg/ml of streptomycin sulfate (added after autoclaving) in 9-cm-diameter plastic petri plates. Plates were placed at room temperature (20–25 C) for 14 days and examined periodically. Fungi growing from cranberry tissue pieces were transferred to unamended half-strength PDA and identified. Data from the different treatments were combined for each location and are reported as the incidence (percentage) of different fungi observed.

Data analysis. Data for individual yield and storage rot variables were analyzed independently by two-way analyses of variance (ANOVAs) with MINITAB (version 6.2) statistical software (Minitab, Inc., State College, PA). Data were analyzed by two approaches: 1) with treatment and location as the main effects for each year in a standard two-way ANOVA, and 2) with treatment and year as the main effects for each location in a two-way ANOVA for split-plots, with individual plots being treated as whole plots and years being treated as subplots. In the split-plot approach, subplots (i.e., years) were not randomly assigned so the calculated F statistics were expected to be liberal. Consequently, critical values to determine the significance of these F statistics were based on those with one-half (i.e., 1/[no. of years − 1]) of the actual degrees of freedom (df) as suggested by Box (16). In all analyses, if the interaction term was not significant ($P \geq 0.05$), data for main effects are presented; otherwise, only data for simple effects of treatments are presented. Data are reported as means and were separated by Fisher's protected least significant difference (LSD) with $P = 0.05$. All proportion data are presented as mean percent values but were analyzed and means were separated by first applying an arcsine-square root transformation. For all data analyses and mean separations performed (Tables 1, 2, and 3), responses were judged significant at the 5% level ($P = 0.05$) unless otherwise noted.

RESULTS

Based on observations in the field, there was no evidence of fruit rots or stem and leaf diseases at either location throughout the course of this investigation. Vines and fruit were visibly healthy and vigorous. Climatic conditions for the region varied among years with 1986 being closer to normal for average monthly temperature and precipitation than the other two years (17). In both 1987 and 1988, the blossoming period was early, more so in 1987 than 1988, and temperatures over the summer months were warmer than usual with readings over 32 C not uncommon, especially in 1988. In addition, 1988 was one of the driest years on record for Wisconsin and elsewhere in the midwestern region of the United States.

Yield and productivity. The following comments pertaining to treatment and location effects for individual years are based on data in Table 1. When data were analyzed for treatment and location main effects each year, interactions between these two factors were not significant, except for fruit-set in 1988. This indicated that relative treatment responses at both locations were similar; therefore, data from the two locations were combined with the one exception. Differences between locations for yield and productivity variables were usually highly significant. In general, yield and productivity were lower at location 2 in 1986 and lower at location 1 in 1987 and

1988. In particular, variables directly involving fruit production were very low and those involving vegetative growth were high at location 1 in 1987, presumably in response to excessive fertilization by the grower at this location.

In 1986 when fungicide applications were begun at late bloom (i.e., plants well past full bloom), yield was significantly reduced by captafol; the amount of reduction was 17% compared with the untreated control. Captafol also significantly reduced fruit-set and, therefore, the number of berries produced, which were likely responsible for the observed reduction in yield. Except for a significant reduction in upright weight by captafol, there were no other significant differences among treatments for the other variables in 1986.

Only chlorothalonil significantly reduced yield in 1987, when applications were begun at 70% bloom, and in 1988, when they were begun even earlier at 14% bloom. Yield reduction compared with the untreated control was 34 and 48% in 1987 and 1988, respectively. In these 2 yr, most variables associated with flowering also were reduced in plots treated with chlorothalonil: percentage of uprights flowering, number of berries produced, fruit-set (at least at one location), and fruit retention in both years; number of flowers per flowering upright in 1987; and total number of flowers in 1988. Although not statis-

Table 1. Effects of three fungicides on yield, yield components, and selected productivity variables of cranberry (cv. Searles) at two locations over 3 yr (two-way analysis of treatments and locations for each year)[u]

Yield and productivity variables	Treatment[v]					Location[w]			Interaction
	Chlorothalonil	Mancozeb	Captafol	Control	P^x	1	2	P^x	P^x
1986									
Yield (g)	195 ab	215 b	174 a	209 b	0.032	214 b	182 a	0.003	0.243
No. of uprights	444	433	439	438	0.971	381 a	496 b	0.000	0.669
Uprights flowering (%)	29.3	31.1	26.4	29.3	0.122	31.4 b	26.6 a	0.001	0.424
No. of flowers/flowering upright	3.11	3.05	3.15	3.17	0.504	3.17	3.06	0.090	0.163
Fruit-set (%)	44.7 ab	49.3 c	43.3 a	47.8 bc	0.020	51.7 b	40.9 a	0.000	0.053
Fruit retention (%)	40.4	44.3	40.2	43.4	0.093	46.5 b	37.7 a	0.000	0.131
Individual berry wt. (mg)	1.24	1.22	1.25	1.25	0.694	1.25	1.23	0.399	0.683
No. of flowers	397	406	361	399	0.570	378	404	0.296	0.830
No. of berries	176 ab	196 b	153 a	186 b	0.023	193 b	163 a	0.004	0.218
Defective berries (%)	9.7	9.8	7.4	9.0	0.223	10.0 b	7.9 a	0.010	0.902
Immature (%)[y]	5.5	6.1	4.9	5.4	0.786	7.3 b	3.7 a	0.000	0.774
Mature (%)[y]	4.2	3.6	2.5	3.6	0.159	2.8	4.2	0.113	0.686
Individual upright wt. (mg)	199 b	204 b	183 a	209 b	0.009	211 b	186 a	0.000	0.659
1987									
Yield (g)	100 a	121 ab	161 c	152 bc	0.001	68 a	198 b	0.000	0.082
No. of uprights	471	501	479	477	0.629	452 a	512 b	0.001	0.337
Uprights flowering (%)	25.7 ab	24.7 a	29.3 bc	30.4 c	0.013	17.3 a	37.8 b	0.000	0.098
No. of flowers/flowering upright	2.40 a	2.35 a	2.52 ab	2.61 b	0.031	2.09 a	2.85 b	0.000	0.057
Fruit-set (%)	29.1 a	37.3 b	35.8 b	36.4 b	0.018	37.8 b	31.6 a	0.005	0.326
Fruit retention (%)	26.1 a	32.4 b	33.1 b	32.4 b	0.030	34.7 b	27.3 a	0.000	0.457
Individual berry wt. (mg)	1.21	1.28	1.27	1.25	0.194	1.20 a	1.30 b	0.001	0.112
No. of flowers	334	325	379	392	0.157	164 a	551 b	0.000	0.309
No. of berries	90 a	108 ab	133 bc	140 c	0.001	60 a	175 b	0.000	0.536
Defective berries (%)	10.1 b	13.4 a	7.7 b	11.6 ab	0.049	7.8 a	13.5 b	0.000	0.151
Immature (%)[y]	3.3 a	6.5 b	4.5 ab	4.9 ab	0.023	2.0 a	7.6 b	0.000	0.558
Mature (%)[y]	6.8	6.9	3.2	6.7	0.088	5.8	5.9	0.225	0.181
Individual upright wt. (mg)	200	182	201	178	0.116	248 b	132 a	0.000	0.651
1988									
Yield (g)	97 a	154 b	153 b	185 b	0.000	130 a	165 b	0.007	0.207
No. of uprights	488	473	492	472	0.840	469	494	0.213	0.214
Uprights flowering (%)	24.3 a	27.9 a	28.7 a	35.2 b	0.005	27.7	30.3	0.175	0.369
No. of flowers/flowering upright	2.65	2.94	2.79	2.93	0.054	2.56 a	3.09 b	0.000	0.053
Fruit-set (%)									0.009
Location 1	29.1 a	41.3 b	39.2 b	39.7 b	0.001[z]				
Location 2	43.8	44.4	42.2	46.9	0.305[z]				
Fruit retention (%)	27.8 a	33.8 b	34.4 b	34.4 b	0.018	32.8	32.4	0.849	0.247
Individual berry wt. (mg)	1.15	1.18	1.14	1.21	0.598	1.17	1.17	0.968	0.978
No. of flowers	326 a	399 ab	400 ab	468 b	0.045	345 a	452 b	0.003	0.171
No. of berries	115 a	172 bc	163 b	199 c	0.000	126 a	198 b	0.000	0.262
Defective berries (%)	22.3	20.9	15.1	20.5	0.254	12.5 a	26.9 b	0.000	0.730
Immature (%)[y]	6.5 b	7.0 b	4.1 a	5.7 b	0.042	4.0 a	7.7 b	0.000	0.195
Mature (%)[y]	15.8	13.9	11.0	14.8	0.813	8.5 a	19.2 b	0.001	0.741
Individual upright wt. (mg)	175 b	176 b	190 b	154 a	0.002	175	172	0.661	0.050

[u] Individual plots at each location received the same treatment in each of three consecutive years. Data were collected from samples obtained at harvest by removing all upright shoots and berries from two 363-cm^2 areas (726 cm^2 total) in each of 10 replicate plots per treatment at each location. Yield is the weight of all marketable berries.

[v] Data are means of 20 replicates for both locations combined or 10 replicates for an individual location. Values for each variable within a row followed by different letters are significantly different (Fisher's protected LSD, $P = 0.05$). Percentage data were transformed to arcsine-square root values before analysis and mean separation.

[w] Data are means of 40 replicates for all treatments combined. Pairs of means for each variable within a row followed by different letters are significantly different based on $P < 0.05$ for the calculated F statistic (1 and 72 df) from a two-way analysis of variance (ANOVA).

[x] Significance levels of F statistics from two-way ANOVAs for treatment (3 and 72 df), location (1 and 72 df), and the treatment × location interaction (3 and 72 df).

[y] Defective berries were separated into two categories based on size at harvest: undersized (immature) or normal-sized (mature).

[z] Significance level of the F statistic (3 and 36 df) from a one-way ANOVA for each location.

tically significant, mancozeb reduced yield in both 1987 and 1988 (20 and 17%, respectively) and captafol reduced yield in 1988 (17%). Associated with these reduced yields were consistent, significant reductions in the percentage of the uprights that flowered and occasional reductions in the numbers of flowers per flowering upright and berries produced. Captafol consistently reduced the amount of defective berries present in samples in both 1987 and 1988, although the reduction was significant in only one instance. Interestingly, all three fungicides significantly increased the weight of individual upright shoots compared with the control treatment in 1988.

The following comments pertaining to treatment and year effects for each location are based on data in Table 2. In this analysis, treatment effects were combined over all 3 yr and year effects were combined for all four treatments for each location, except where a significant interaction between treatment and year occurred. Interactions were significant only at location 1 for four variables—yield, percentage of uprights flowering, number of berries, and individual upright weight—indicating that the relative effectiveness of the individual treatments on these variables varied among years. Consequently, simple effects of treatments are presented separately for the individual years.

There was a significant difference among years for all but one of the variables at both locations. Yield and productivity at location 1 tended to be low in 1987 compared with 1986 and 1988, probably because of overfertilization. At location 2, yield was low in 1988 compared with the other 2 yr, most likely because of berry weight. At both locations, the percentage of berries that were defective was greatest in 1988 and significantly so at location 2.

Treatments had a greater effect at location 1 than at location 2. At location 1, yield and the number of berries produced were reduced significantly by

Table 2. Effects of three fungicides on yield, yield components, and other selected productivity variables of cranberry (cv. Searles) at two locations over 3 yr (two-way analysis of treatments and years for each location)[u]

Yield and productivity variables	Treatments[v]					Years[v]				Interaction
	Chlorothalonil	Mancozeb	Captafol	Control	P[w]	1986	1987	1988	P[x]	P[y]
Location 1										
Yield (g)										0.012
1986	221 b	233 b	172 a	232 b	0.018					
1987	40 a	52 ab	75 b	107 c	0.000					
1988	71 a	132 b	125 b	191 c	0.000					
No. of uprights	438	439	436	423	0.916	381 a	452 b	469 b	0.000	0.564
Uprights flowering (%)										0.043
1986	32.6	33.0	27.1	33.0	0.079					
1987	13.2 a	15.1 a	18.2 ab	22.6 b	0.011					
1988	22.5 a	24.0 a	28.1 ab	36.3 b	0.009					
No. of flowers/flowering upright	2.52 a	2.47 a	2.63 a	2.81 b	0.002	3.17 c	2.09 a	2.56 b	0.000	0.115
Fruit-set (%)	37.1 a	47.0 c	40.4 ab	44.4 bc	0.003	51.7 b	37.8 a	37.3 a	0.000	0.242
Fruit retention (%)	33.0 a	41.2 b	37.6 b	40.0 b	0.009	46.5 b	34.7 a	32.8 a	0.000	0.218
Individual berry wt. (mg)	1.18	1.22	1.19	1.23	0.481	1.25 b	1.20 ab	1.17 a	0.021	0.570
No. of flowers	269 a	269 a	280 a	365 b	0.013	378 b	164 a	345 b	0.000	0.206
No. of berries										0.008
1986	203 b	212 b	150 a	207 b	0.018					
1987	37 a	46 ab	66 b	91 c	0.000					
1988	71 a	130 b	120 b	185 c	0.000					
Defective berries (%)	11.1 b	12.5 b	6.9 a	9.9 b	0.026	10.0 b	7.8 a	12.5 b	0.001	0.234
Immature (%)[z]	4.4 ab	5.7 b	3.1 a	4.4 ab	0.014	7.3 c	2.0 a	4.0 b	0.000	0.096
Mature (%)[z]	6.7	6.8	3.8	5.5	0.176	2.7 a	5.8 b	8.5 c	0.000	0.564
Individual upright wt. (mg)										0.027
1986	209 ab	218 b	192 a	226 b	0.016					
1987	265	237	261	229	0.271					
1988	171 a	168 a	206 b	156 a	0.002					
Location 2										
Yield (g)	151 a	187 b	201 b	188 b	0.044	182 ab	198 b	165 a	0.035	0.170
No. of uprights	498	499	504	502	0.989	496	512	494	0.402	0.180
Uprights flowering (%)	30.2	31.7	31.8	32.6	0.747	26.6 a	37.8 c	30.3 b	0.000	0.216
No. of flowers/flowering upright	2.91	3.09	3.01	3.00	0.256	3.07 b	2.85 a	3.09 b	0.011	0.350
Fruit-set (%)	36.4 a	39.2 b	39.5 b	40.6 b	0.012	40.9 b	31.6 a	44.3 c	0.000	0.119
Fruit retention (%)	29.8	32.4	34.2	33.5	0.093	37.7 c	27.3 a	32.4 b	0.000	0.547
Individual berry wt. (mg)	1.22	1.23	1.25	1.24	0.916	1.23 a	1.30 b	1.17 a	0.008	0.358
No. of flowers	436	485	480	474	0.594	404 a	551 b	452 a	0.000	0.382
No. of berries	150 a	188 b	187 b	189 b	0.045	163 a	175 a	198 b	0.021	0.413
Defective berries (%)	16.8	16.8	13.3	17.5	0.471	7.9 a	13.5 b	26.9 c	0.000	0.547
Immature (%)[z]	5.7	7.4	5.9	6.2	0.588	3.7 a	7.6 b	7.7 b	0.000	0.632
Mature (%)[z]	11.1	9.4	7.4	11.3	0.441	4.2 a	5.9 a	19.2 b	0.000	0.570
Individual upright wt. (mg)	168	167	163	157	0.513	186 c	132 a	172 b	0.000	0.115

[u] Individual plots at each location received the same treatment in each of three consecutive years. Data were collected from samples obtained at harvest by removing all upright shoots and berries from two 363-cm^2 areas (726 cm^2 total) in each of 10 replicate plots per treatment at each location. Yield is the weight of all marketable berries.

[v] Treatment values are means of 30 replicates for all years combined or 10 replicates for individual years. Year values are means of 40 replicates for all treatments combined. Values for each variable within a row under each analysis factor followed by different letters are significantly different (Fisher's protected LSD, $P = 0.05$). Percentage data were transformed to arcsine-square root values before analysis and mean separation.

[w] Significance levels of F statistics with 3 and 36 df from two-way analyses of variance (ANOVAs) for split-plots for main effects or from one-way ANOVAs for simple effects.

[x] Significance levels of F statistics with 1 and 36 df from two-way ANOVAs for split-plots; degrees of freedom were reduced by one-half.

[y] Significance levels of F statistics with 3 and 36 df for the treatment × year interaction from two-way ANOVAs for split-plots; degrees of freedom were reduced by one-half.

[z] Defective berries were separated into two categories based on size at harvest: undersized (immature) or normal-sized (mature).

captafol in 1986 and by all three fungicides in 1987 and 1988 compared with the untreated control treatment. Captafol reduced yield by 26% in 1986, 30% in 1987, and 35% in 1988 for an average reduction of 30%. Mancozeb reduced yield by an average of 41% over 2 yr (51% in 1987 and 31% in 1988), and chlorothalonil reduced yield by 63% in both 1987 and 1988. Plants treated with either chlorothalonil or mancozeb had a significantly lower percentage of upright shoots that flowered compared with those that were not treated in both 1987 and 1988. Over the 3-yr period, plants treated with all three fungicides had reductions in the total number of flowers produced and, likewise, in the number of flowers produced per flowering upright. Only chlorothalonil significantly reduced fruit-set and fruit retention at location 1.

At location 2, significant effects of fungicide treatments for the 3-yr period were few and could be attributed solely to chlorothalonil. Yield, the number of berries produced, and fruit-set were reduced significantly by this fungicide; yield reduction compared with the untreated control treatment was 20%. Fungicides had no effect on the total number of uprights and little effect on the weight of individual upright shoots at either location. Captafol consistently reduced the proportions of berries that were defective at both locations; however, only the reduction at location 1 was significant. At neither location was the weight of an individual berry significantly affected by the treatments, but it did vary significantly among years at both locations.

Storage rot incidence and etiology. The main effects of treatments and years on storage rot incidence were not evaluated because the split-plot analysis produced significant interactions between treatments and years for each of the three variables analyzed at both locations. Most of these interactions were significant with or without Box's correction (16) for the number of df used to identify a critical F value and indicated that relative efficacy of treatments varied among years. Specifically, treatment ranking did not remain similar from year to year. The relative efficacy of treatments also varied between locations in two of 3 yr (1987 and 1988), based on significant interactions between treatments and locations (Table 3). However, the differences among treatments, whether at both locations combined or at individual locations, were always highly significant, except for those for black rot in 1987 (Table 3).

The following comments are based on data in Table 3. The incidence of storage rots ranged from 7 to 25% for all treatments and from 9 to 21% for berries that were not treated with fungicides. Incidence appears to have been greatest in 1987. There was always a greater proportion of berries that were soft and rotted than of those with black rot symptoms, although this was not confirmed statistically. Compared with the untreated control, only captafol consistently improved the percentage of marketable berries and reduced the occurrence of soft, rotted berries. This increase in percentage of marketable berries averaged 7% for all 3 yr—9% in 1986, 10% in 1987, and 4% in 1988. Whether evaluating the percentage of marketable berries or berries that were soft and rotted, results for berries treated with captafol were always significantly better than for those treated with the other two fungicides, except at location 1 in 1988. In addition, captafol significantly reduced black rot incidence in 1986, which was the only time this disease was reduced over all 3 yr.

Chlorothalonil significantly increased the percentage of marketable berries and reduced the percentage of soft and rotted berries in 1986 (when applications were begun at late bloom) at the locations combined and in 1987 only at location 2; the increases in marketable berries were 3 and 5%, respectively. However, in 1988 when fungicide applications were begun early during the blossom period, samples from plots treated with chlorothalonil exhibited a significant increase in incidence of soft, rotted berries and an associated decrease in marketable berries at location 1, as well as a significant increase in black rot incidence at the locations combined. Mancozeb, on the other hand, had no beneficial effect on storage rot incidence in any year.

From isolations conducted with berries harvested in 1988, only *A. lunata* was recovered from berries with black rot symptoms. Both light- and dark-colored morphological types (11,19) were isolated. In general, dark-colored types were isolated predominantly from black, discolored berries and light-colored types were isolated predominantly from berries with a gray-black mottled discoloration. Occasionally, both types were isolated from a single berry, particularly from those that were mottled.

Four fungi were isolated most often from soft, rotted cranberries in 1988; berries from which no fungi were isolated occurred frequently as well, particularly at location 1 (Table 4). More than one fungus often were isolated from one berry.

Table 3. Effects of three fungicides on the percentage of cranberries (cv. Searles) that were marketable, soft and rotted, or had black rot symptoms after 3 mo in storage at 2 C[v]

Symptom category	Year	Location[w]	Treatment[x]					Interaction
			Chlorothalonil	Mancozeb	Captafol	Control	P^y	P^z
Marketable	1986	1 + 2	87.8 b	82.9 a	92.4 c	84.5 a	0.000	0.492
	1987	1	76.0 a	74.8 a	83.4 b	78.7 a	0.003	0.003
		2	85.6 c	77.2 a	91.1 d	81.0 b	0.000	
	1988	1	86.6 a	91.3 bc	93.0 c	90.7 b	0.000	0.019
		2	84.4 a	82.8 a	90.1 b	85.5 a	0.000	
Soft, rotted	1986	1 + 2	10.6 b	14.7 c	6.2 a	13.3 c	0.000	0.322
	1987	1	17.6 b	20.0 b	11.1 a	17.0 b	0.001	0.027
		2	13.1 b	21.9 d	6.9 a	17.5 c	0.000	
	1988	1	8.6 c	6.1 ab	4.9 a	6.5 b	0.001	0.002
		2	12.0 b	15.5 c	7.7 a	13.2 bc	0.000	
Black rot	1986	1 + 2	1.6 ab	2.4 c	1.4 a	2.1 bc	0.002	0.469
	1987	1	6.4	5.2	5.5	4.3	0.059	0.033
		2	1.3	0.9	1.2	1.5	0.140	
	1988	1 + 2	4.2 b	2.2 a	2.1 a	2.0 a	0.000	0.165

[v] The experiment was conducted at two locations in three consecutive years. Plots at each location received the same treatments all years.
[w] Data for locations were combined if the treatment × location interaction in a two-way analysis of variance (ANOVA) was not significant ($P \geq 0.05$).
[x] Data are means of 10 replicates for individual locations or 20 replicates for combined locations. Values within a row followed by different letters are significantly different (Fisher's protected LSD, $P = 0.05$). Data were transformed to arcsine-square root values before analysis and mean separation.
[y] Significance levels of treatment F statistics with 3 and 72 df from two-way ANOVAs for locations combined or with 3 and 36 df from one-way ANOVAs for individual locations.
[z] Significance levels of F statistics with 3 and 72 df for treatment × location interactions from two-way ANOVAs.

There were significant differences between the isolation frequencies at the two locations for all four fungi, and the relative abundance of the different fungi at each location varied. At location 1, no fungus was isolated from more than half (57%) of the berries; from the remaining 43% of the berries, isolation of *G. cassandrae* and *A. lunata* predominated. At location 2, *G. cassandrae* and *Penicillium* spp. were isolated most often, and only 10% of the berries were void of storage rot fungi. *Coleophoma empetri* (Rostr.) Petr. (= *Sporonema oxycocci* Shear) was recovered at low levels from berries at both locations. Both light- and dark-colored types of *A. lunata* were isolated from soft, rotted berries, but the dark type occurred most often. There were similar proportions of berries at the two locations from which other unidentified fungi were isolated.

DISCUSSION

Cranberry yield was adversely affected by fungicides applied during bloom in all 3 yr at both locations. Of the three fungicides used in this study, chlorothalonil caused reduced yields most consistently. This effect was observed at both experimental sites and in two of the 3 yr that this research was conducted. Although adverse effects from fungicide applications are documented here only for the cv. Searles—the most widely planted cultivar in Wisconsin (2,6)—it is likely that similar effects occur with other cultivars as well. In a recently completed study, yield and yield components of the cv. Bain McFarlin were adversely affected by fungicides, including chlorothalonil, applied during bloom to manage cranberry cottonball (S. N. Jeffers, *unpublished*).

Partitioning yield into its essential components (8,9) was an effective means for determining how yield was being affected. Fruit-set was the yield component affected most consistently; it was reduced whenever yield was reduced. The percentage of the upright shoots that flowered and, occasionally, the number of flowers per flowering upright were components that were also adversely affected by fungicides. Because berry weight tended to be very uniform and unaffected by the treatments, the number of berries produced was reduced every time yield was reduced. Interestingly, fruit retention (i.e., the ratio of marketable berries to flowers) was not affected as often as fruit-set (i.e., the ratio of all berries to flowers). The total number of upright shoots per unit area consistently was not affected by fungicide treatments at either location in all years. In fact, the uniformity of this component among treatments suggests that the 726-cm^2 area sampled per plot was appropriate for this study.

Other reports on the effects of fungicides on cranberry yield are limited in number and inconsistent in their results. In the Pacific Northwest, Shawa et al (20) demonstrated that three or four applications during bloom of a number of different fungicides reduced yield by 19–65% and speculated that the mechanism was a reduction in fruit-set. Most of the fungicides they used are chemically similar or related to the ones used in this study. Later, Bristow and Shawa (4) demonstrated that two applications of triforine as an emulsifiable concentrate during bloom reduced cranberry yield by reducing berry weight and volume but did not significantly affect the number of berries per flowering upright. However, triforine in flowable or wettable powder formulations, mancozeb, or various rates of captafol did not significantly affect yield when applied on a similar schedule. In the latter study, only 10 fruiting uprights were evaluated for each plot, far fewer than were evaluated here. Statistically insignificant reductions in both yield and number of flowers per fruiting upright reported by Bristow and Shawa (4) may have been significant with a larger sample size or more replications. In both of these studies (4,20), results were based on data from only one growing season so the consistency of these results was not demonstrated.

In research conducted in Massachusetts over a 6-yr period (10), two applications of nine different fungicides to two cultivars during bloom consistently did not reduce yield; however, several fungicides adversely affected the anthocyanin pigment content of mature cranberries. In fact, effects of fungicides on cranberry yield in Massachusetts and New Jersey would be difficult to evaluate because of the prevalence of fruit rots that affect berries during the growing season (2,21). On the contrary, the absence of widespread or annual occurrence of fruit rots and other diseases during the growing season makes Wisconsin an ideal location to conduct such research.

The deleterious effects of fungicides on fruit-set may be attributable to a direct phytotoxic influence on pollen germination although such an effect has been demonstrated conclusively only in vitro (4,20). A reduction in the proportion of uprights that produced flowers or in the number of flowers produced per upright would be caused by fewer buds producing flower primordia during the season before flowering. Floral induction in cranberry buds for the following season occurs during and shortly after bloom of the current season (7,14,18). Consequently, a phytotoxic effect from fungicides applied during bloom in 1 yr would become evident the following year. This was the pattern I observed. During this research, fungicides were routinely applied out of necessity during late morning or early afternoon, when daily temperatures were warm. Making applications at times during the day when temperatures were cooler (e.g., early morning or evening) may have alleviated some of the deleterious effects observed.

The two approaches to data analysis employed in this study provided different perspectives on the data and, therefore, a more conclusive interpretation. One approach allowed for treatment and location effects to be evaluated each year. Differences between locations occurred consistently; these were expected and the reason why two locations were included in the study. However, treatments produced relatively similar results at both locations in all 3 yr as indicated by the lack of significant interactions between treatment and location. Much of the variability between locations can be attributed to differences in the cultural management practiced by the two growers and possibly to the tendency of cranberry toward biennial bearing (7,14).

The other approach to analysis evaluated treatments and years as factors at each location. Although there was a consistent difference among years for the different variables quantified, which possibly could be explained by differing environmental conditions and biennial bearing, it was clear that there was no positive effect on yield, yield compo-

Table 4. Incidence of fungi isolated from cranberries grown at two locations that were soft and rotted after being stored 3 mo at 2 C[a]

Fungus species	Isolation frequency (%)[b]		Comparison[c]	
	Location 1	Location 2	χ^2	*P*
Godronia cassandrae	15.0	41.0	33.53	0.000
Apostrasseria lunata	13.5	7.0	4.59	0.032
Coleophoma empetri	2.5	10.5	10.53	0.001
Penicillium spp.	7.0	48.0	84.31	0.000
Other[d]	8.0	5.0	1.48	0.223
None[e]	57.0	10.0	99.16	0.000

[a] Berries were harvested in October 1988 and evaluated in January 1989. Internal pieces from surface-disinfested berries were placed on half-strength potato-dextrose agar supplemented with 100 μg/ml of streptomycin sulfate and incubated at room temperature for 2 wk.
[b] Based on 200 berries from each location: five berries from each of 10 replicate plots for each of four treatments.
[c] Chi-square statistic (χ^2) with 1 df and the probability of a greater chi-square value occurring (*P*) for comparing isolation frequencies at the two locations.
[d] Other miscellaneous fungi that were not identified.
[e] Rotted berries from which no fungus was isolated.

nents, or any other measure of productivity after three consecutive years of fungicide application. Captafol did tend to reduce the incidence of defective berries that occurred during the growing season, implying that fungi may be partially responsible for these defects, but the reductions often were not significant.

Of the three fungicides evaluated in this research, only captafol consistently reduced storage rots characterized by soft, rotted berries, with an increase in the percentage of marketable berries that averaged 7% over 3 yr. Perhaps a more realistic average, though, would be closer to 9–10%, the average for 1986–1987, as storage rot incidence was low in 1988 probably because of the unusually dry weather. Black rot incidence was unaffected by biweekly applications of fungicides initiated during bloom. These data are consistent with other published reports that suggest that infection by *A. lunata* occurs late in the growing season or during harvest (19,25). It is possible that the incidence of storage rots, and particularly black rot, reported herein are low. Storage rot disease incidence increases with the duration of time berries are immersed in water in a harvested bed (5,25), particularly if the duration exceeds 12 hr. In this study, cranberries were immersed for only 1–2 hr, but they did remain wet for 12–24 hr.

In 1988, four fungi were isolated most frequently from cranberries that became soft and rotted in storage. The relative importance of these fungi at two separate locations varied significantly, similar to what has been reported elsewhere (3,12). It was not possible to diagnose the causal agent of soft, rotted berries by symptoms alone, confirming what others have also found (1,2,22,26). The relatively low incidence of *G. cassandrae*, particularly at location 1, was not expected because this fungus has been considered to be the predominant cause of storage rot of cranberries grown in Wisconsin (2,6,15, 21,23,24). Perhaps recovery of *G. cassandrae* would have been better if isolation plates were placed at a temperature more favorable for growth of this fungus, e.g., 15–20 C (2,21); although when *G. cassandrae* was recovered, its growth at room temperature (20–25 C) did not appear affected. Alternatively, the hot, dry conditions that prevailed during the summer of 1988 may have limited the activity of *G. cassandrae*, a fungus normally favored by cooler climates (21).

Also unexpected was the relatively high incidence of *Penicillium* spp. from stored berries at location 2. Species of *Penicillium* have been associated with cranberry storage rots for years, but there is a lack of evidence demonstrating their role as primary pathogens (1,11–13,21, 22,26). The incidence of sterile or physiological breakdown, the term used for deterioration in storage that is not microbiological in nature (6,21), also was high in stored cranberries in this study—57 and 10% of the soft, rotted berries from locations 1 and 2, respectively. This confirms that sterile breakdown continues to be an important cause of storage rots in Wisconsin (21,23,24). It is apparent after the results of isolations from berries with storage rots in 1988 that a more intensive, multi-year project should be undertaken to determine the current etiology of storage rots of cranberry in Wisconsin.

Unfortunately, during the course of this investigation, the registration of captafol was canceled voluntarily by its manufacturer for economic reasons, and this fungicide is no longer available for use on cranberry or any other commodity. Chlorothalonil is now the fungicide of choice for storage rot disease management by most Wisconsin cranberry growers. The deleterious effects on yield and yield components from fungicide treatments, particularly chlorothalonil, seemed to be greater as applications were initiated progressively earlier relative to bloom in each of the 3 yr of this research. In addition, incidence of storage rot diseases was either unaffected or increased compared to the untreated control with earlier initial applications of chlorothalonil. Consequently, if chlorothalonil is to be used to manage storage rots of cranberry in Wisconsin, a thorough investigation on the relationship among application timing, yield, and storage rot incidence needs to be conducted. In light of the sizeable reductions in yield (20–60%) and at best a very modest improvement in percentage of the stored berries that was marketable (3–5%) attributable to chlorothalonil in this study, an assessment of the economic benefits of chlorothalonil applications should be included in such an investigation.

This research has led to the following recommendations for storage rot disease management of cranberries grown in Wisconsin: 1) fungicides should be applied only to cranberries that are to be stored as fresh fruit; 2) if fungicides are applied, applications should begin no earlier than petal fall—after bloom is over; 3) mancozeb should not be used unless additional applications (i.e., more than three) or a higher rate per hectare can be proven to be beneficial; and 4) chlorothalonil should be used with caution and evaluated for economic benefit.

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