Effect of Freezing Injury on Head Rot and Spot of Cabbage

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ABSTRACT

The cabbage cultivar Market Prize was transplanted in September and October and inoculated with several bacteria with or without artificial wounding in November, December, and January. Temperatures of −5 to −8 C occurred 6 times during the winter. Heads were harvested as they matured in December to April. The percentage of nonwounded plants producing saleable heads was significantly reduced by inoculations with *Pseudomonas cichorii* and *P. maculicola* in November, but not in later months. Wounding significantly increased damage caused by *P. maculicola* but not by *P. cichorii*. Frequently, heads had severe internal damage but no external discoloration similar to head rot observed in commercial fields. Tan to brown target lesions were caused by *P. cichorii*, and purplish-black to black lesions by *P. maculicola*. An isolate of *Erwinia* caused a soft, gray rot with a putrid odor. No appreciable damage was caused by *P. marginalis*. Younger plants were more severely damaged than older plants. The percentage of plants killed or damaged with multiple heads, hollow stems, or bolting was significantly increased by *P. cichorii* and *P. maculicola*. When the remaining nondamaged young plants began rapid growth in the warm spring months, the discolored tissue was usually confined to the exterior of the heads.

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Additional key words: Brassica oleracea var. *capitata*, wind-chill index.

Cabbage head rot is periodically a problem in the Georgia Coastal Plain. Several bacteria are known to cause head disfiguration (4, 5, 8), and they are usually more severe with artificial wounding. Winter cabbage is transplanted in the Georgia Coastal Plain from August to October, and harvested from November to April. The plants grow slower during the winter than in the spring. Therefore, growers can leave heads in the field longer after they mature, and pick them according to availability of labor and markets. This study was run to determine if natural wounding of cabbage caused by freezing increases damage by bacterial pathogens.

MATERIALS AND METHODS.—Seed of *Brassica oleracea* var. *capitata* L. 'Market Prize' from a commercial lot was planted in a greenhouse in methyl bromide-fumigated soil. Six- to eight-week-old plants were transplanted to a field of Tifton loamy sand in September and October 1970. A randomized complete block design with four replications was used. Ten plants were used in each treatment in each replication. The oldest plants were transplanted into two blocks in September, and younger plants were used in two additional blocks in October. Despite frequent overhead irrigation, many transplants died in September during hot, dry weather, and were replaced with younger plants in October. Temperatures above 25 C may be detrimental to cabbage (1). Most plants in the first two blocks were 2 to 4 weeks older than plants in the second two blocks. All data were based on the number of surviving plants when treatments were started in November.

Plants were inoculated 10 November, 10 December, and 8 January with *Pseudomonas cichorii*, *P. maculicola*, *P. marginalis*, or *Erwinia* sp. Cultures of *P. cichorii* from endive and *P. maculicola* from cabbage were provided by Cornelius Wehlburg, Division of Plant Industry, Florida Department of Agriculture, Gainesville. The isolate of *P. marginalis* from lettuce was obtained from David Sands, Connecticut Agriculture Experiment Station, New Haven. The *Erwinia* sp. was a virulent soft rot pathogen isolated from cabbage in Georgia. Cells from 1- to 2-day-old cultures on nutrient agar were used. Suspensions of each bacterium were prepared in sterile distilled water and adjusted to ca. 5×10^6 cells/ml. Sterile distilled water was used for controls. Plants were inoculated 1 to 3 hr after suspensions were prepared. All bacteria used survived well in distilled water, and were pathogenic after 5 hr at 25 to 30 C. In some treatments, each plant was wound-inoculated (W) with a syringe by the injection of 1 ml, 1 to 5 mm deep, into the top of the head or growing point, parallel to the stem. In other treatments, ca. 0.6 ml each was sprayed on nonwounded (NW) plants with an atomizer. All instruments were autoclaved before using. Plants ranged from 10 to 45 cm high, with heads up to 10 cm in diam in November and 20 cm in diam in December and January. Heads weighing 400 to 1,600 g were harvested and evaluated 18 December, 22 January, 25 February, and 8 April. Each head was cut and examined for internal damage. A head was considered nonsaleable when more than 10% of the tissue was discolored, and plants were considered severely damaged when more than 25% of the tissue was discolored.

Meteorological data was taken from National Weather Service Office instruments 3 km from the field.

RESULTS.—A light frost occurred 17 November, 7 days after the first inoculations, but no head injury was noted. On 23 November, there was no damage on the NW plants. However, six plants injected with *Erwinia* sp. and three with *P. maculicola* were dead or

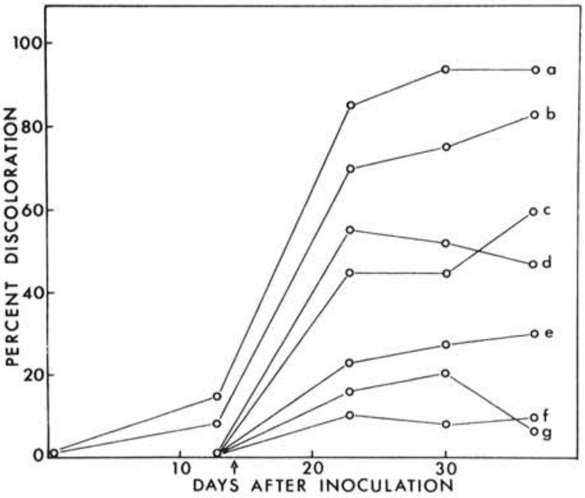

Fig. 1. Effect of a hard freeze of −8 C (arrow) 14 days after inoculation on discoloration of nonwounded (NW) and wounded (W) cabbage plants inoculated with several bacteria. a = *Erwinia* sp.-W; b = *Pseudomonas maculicola*-W; c = *P. cichorii*-W; d = *P. maculicola*-NW; e = *P. cichorii*-NW; f = control-NW; and g = control-W.

severely rotted. The following night, a record freeze of −8 C occurred with wind, and the wind-chill index was ca. −9 to −17 C for 4 hr. Nine days later, NW plants inoculated with *P. maculicola* showed severe injury, whereas the control plants showed very little damage (Fig. 1). In the first harvest on 18 December, none of the heads inoculated with *P. maculicola, P. cichorii,* or *Erwinia* sp. on 10 November was saleable, but only 1 of 17 noninoculated heads was nonsaleable. Typical target lesions (7) were observed on both W and NW heads inoculated with *P. cichorii*, but not on heads in any other treatment. Only purplish-black to black discoloration was seen on heads inoculated with *P. maculicola* and *Erwinia* sp. The putrid odor and complete disintegration of tissues associated with cabbage soft rot was only evident in plants inoculated with *Erwinia* sp. Significantly more plants inoculated with *P. maculicola* or *Erwinia* sp. were killed by 18 December than plants inoculated with *P. cichorii* or noninoculated plants. Noninoculated plants in the prehead stage of retardation of leaf unfolding (2) during the freeze appeared to be no more severely damaged than plants with heads 4 to 12 cm in diam. However, younger, noninoculated, rapidly growing plants of the same variety 10 to 20 cm high in an adjacent field were nearly all killed by the freeze, indicating the susceptibility of the exposed growing point to freezing. Freeze-damaged tissue in noninoculated plants was bleached white to tan.

Frequently, both wounded and nonwounded heads showed no external discoloration, but internal tissue was 10 to 30% discolored. Target spots were observed as much as 7 leaves deep into the head in nonwounded plants inoculated with *P. cichorii*, and purplish-black to gray lesions were seen 6 leaves deep in plants inoculated with *P. maculicola*.

None of the heads inoculated 10 December with *P. marginalis, P. maculicola*, and *P. cichorii* was more than 5% discolored when harvested 18 December. Heads injected with *Erwinia* sp. were nondamaged on the exterior, but had severe internal soft rot.

Between 17 December and 26 February, there were 6 nights when the temperature dropped to −5 to −8 C, and once the wind chill index was −11 C. Ice formed on an electrical resistance sensor on 11 days during this period. In January and February, harvests 6 of 9, 3 of 9, and 5 of 16 NW heads, and 6 of 8, 17 of 29, and 3 of 7 W heads inoculated 10 November or 10 December with *P. cichorii, P. maculicola*, or noninoculated, respectively, were nonsaleable. None of the 11 heads injected with *Erwinia* sp. was saleable. More heads from NW plants inoculated in November with the pseudomonads were nonsaleable than those inoculated in December (83 vs 33%), but the percentage of nonsaleable heads was similar in injected plants (75 vs 59%). Fewer NW plants in November and December inoculations were damaged by *P. maculicola* than by *P. cichorii* (33 vs 67%), but the reverse was true in W plants (73 vs 47%). Some freezing injury was evident in all treatments during January and February, but severe plant damage was only noted in inoculated plants. Plants inoculated with *P. marginalis* on 10 December showed discoloration similar to that in noninoculated plants.

The younger plants in blocks 3 and 4 transplanted on 7 to 8 October were 10 to 20 cm high, and were in the prehead to early head stage until late January. Many of these plants were killed or deformed with brown, hollow stems. On 29 January, 26% of the NW younger plants inoculated with *P. cichorii* and 17% inoculated with *P. maculicola* were dead or showed hollow stems as compared to none in the control plants. In W plants, 31, 40, and 5%, respectively, of the plants were dead or damaged. Damage was similar in NW plants inoculated with *P. cichorii* at all dates, but 42% of the NW plants inoculated with *P. maculicola* 10 November were severely damaged in contrast to only 5% in later inoculations. Often, young plants showed no discoloration except lesions on the exposed growing point before they died or formed multiple heads.

As the temperatures increased in March, the plants began growing more rapidly, and most discolored tissue was confined to outer leaves removed during harvest. Nonwounded plants in two experiments in nearby plots inoculated with the same pathogens 26 January and 29 April were not severely damaged.

Significantly more older plants produced saleable heads than younger plants, 52 vs. 35%, but 25% of the total weight harvested from the older plants was nonsaleable compared to only 14% in the younger plants (Table 1). Yields were significantly less from the younger plants because more plants were killed or damaged. In younger plants, 27% bolted or produced multiple nonsaleable heads in contrast to only 11% in older plants, and 21% were killed as compared to 13% in older plants. Nevertheless, only 10% of the younger noninoculated controls bolted or produced

TABLE 1. The effect of head rot and spot bacteria on the yield and quality of cabbage heads on plants subjected to freezing temperatures

Bacterium		Date of inoculation	Plants producing saleable heads (%)	Yields, kg/hectare	
				Total	Saleable
Pseudomonas cichorii	W[a]	10 Nov.	15 cde[b]	3,882 cdef	1,427 cd
	W	10 Dec.	68 a	7,457 abc	7,113 a
	NW	10 Nov.	28 cd	4,034 bcdef	2,126 bcd
	NW	10 Dec.	69 a	7,698 a	7,410 a
	NW	8 Jan.	65 ab	6,010 bcde	6,011 a
P. maculicola	W	10 Nov.	5 de	1,410 f	246 d
	W	10 Dec.	40 bc	5,420 abcde	4,310 abc
	NW	10 Nov.	32 c	2,995 def	2,097 bcd
	NW	10 Dec.	68 a	5,848 abcd	5,577 ab
	NW	8 Jan.	76 a	6,988 abc	6,782 a
P. marginalis	W	10 Dec.	60 ab	5,819 abcd	5,285 ab
	NW	10 Dec.	80 a	7,537 ab	7,267 a
Erwinia sp.	W	10 Nov.	0 e	798 f	0 d
	W	10 Dec.	22 cde	2,107 ef	1,046 c
None	W	10 Nov.	68 a	5,968 abcd	5,646 ab
None	W	10 Dec.	68 a	7,085 abc	6,932 a
None	NW		65 ab	7,032 abc	5,670 ab

[a] W = Wounded. NW = Nonwounded.
[b] Numbers followed by the same letter are not significantly different; $P = .05$.

deformed plants as compared to 30% and 48% of NW plants inoculated 10 November with *P. cichorii* and *P. maculicola*, respectively.

Nonwounded plants inoculated with *P. cichorii* and *P. maculicola* in November had significantly fewer saleable heads than those inoculated in December and January (Table 1). Both total and saleable yields were greatly reduced by all pathogens in NW and W treatments in November, but differences were only significant in W plants. Frequently, saleable weight was much less than total weight because the heads showed no exterior damage when harvested. Wounding significantly increased head discoloration caused by *P. cichorii*, but not by *P. maculicola*. Damage caused by *P. marginalis* was not significantly different from controls, and the bacterium caused only a slight tan discoloration when injected into sections of excised heads. The *Erwinia* sp. was the most virulent pathogen, and caused a soft rot distinctly different from the head rot and spots caused by the pseudomonads.

In a second replicated experiment in an adjacent plot, 2 to 8 NW plants of each of 11 different cultivars were atomized 11 December with the same bacteria used in the first experiment. Plants were cupping or larger. The percentage of plants producing nonsaleable heads was 51, 41, 41, and 27 for *P. cichorii, P. marginalis, Erwinia* sp., and *P. maculicola*, respectively, as compared to 32 in noninoculated plants. Damage varied a great deal among cultivars, and differences were not significant. Some cultivars were entirely killed by cold injury.

DISCUSSION.—This research indicates the importance of keeping plants free of superficial pathogenic bacteria in the winter crop. The subfreezing temperatures from November to February arrested the growth of the plants, and apparently ruptured tissues. This natural wounding allowed the bacteria to invade the plants and cause damage frequently not seen in experiments with nonwounded plants in the spring crop. Cabbage heads enlarge because new leaves are initiated after leaf unfolding has ceased (2). This causes the formation of a tight outer layer as the young leaves on the interior of the head expand until the head is mature. In warm weather, the heads are exposed to surface bacteria for a much shorter time than during the winter. Severe head rot usually only occurred in the spring when bacteria were injected into the heads (Donald R. Sumner, *unpublished data*). Cabbage heads with only interior damage are commonly observed in grower fields, and sometimes losses are sustained (4). Both internal tipburn (6) and black speck (3) are occasionally seen, but those disorders are decidedly different from symptoms caused by the bacterial pathogens. This study also suggests that some of the previously reported "frost-injury" in cole crops (1) may actually be caused by bacteria.

The transplants used in this research were grown in a greenhouse in fumigated soil and protected from external contamination. After the transplanting to a field that had not been in cabbage for several years, no attempt was made to prevent contamination from surface water and soil. Most noninoculated plants were in the field for 3 to 6 months and showed no damage, indicating the importance of clean seed and sanitation in transplant beds (5). No secondary spread among treatments was apparent even though 409 mm of rain fell from December to March.

Unidentified pseudomonads that caused symptoms in injected excised head sections similar to *P. cichorii* and *P. maculicola* have also been isolated in commercial seed lots shipped to Georgia. However, artificially infesting seed by soaking in both cultures of *P. cichorii* and *P. maculicola* has failed to significantly increase head rot in two field experiments.

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