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Bacterial Spot Resistant Pepper Trials in Florida

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Cultivars and experimental hybrids of bell peppers (*Capsicum annuum* L.) were transplanted in commercial pepper fields during the 2009–10 growing seasons in two locations in South Florida. The objectives of the study were to evaluate horticultural characteristics and resistance to bacterial spot of peppers caused by *Xanthomonas euvesicatoria* (formally *Xanthomonas axonopodis* pv. *vesicatoria* and *Xanthomonas campestris pv. vesicatoria*). Cultivars tested included standard commercial varieties with race 1, 2, 3 bacterial spot resistance and newer cultivars and lines that incorporated additional resistance to bacterial spot races 4, 5 and 6. Both studies were conducted in commercial pepper fields containing naturally occurring levels of *X. euvesicatoria* inoculum. In these trials, it was demonstrated that cultivars containing the added resistance to race 4, 5 and/or 6 significantly reducing bacterial spot infection rates and increased yields compared with varieties with only resistance to bacterial spot races 1, 2 and 3.

Bell pepper (*Capsicum annuum* L) is one of the primary vegetable crops grown in South Florida, with approximately 90% of Florida's production located south of Orlando (Aerts and Nesheim, 1999). Florida has also historically been a leader in the production of bell peppers, second after California in total harvested acres and fresh market production with a value of $183 million during the 2007–08 season (Florida Agricultural and Statistics Service, 2009). During that season 20.2 million bushels were harvested from 18,300 acres, with an average price per bushel of $10.78. Florida farmers produce most of the U.S. grown bell peppers eaten by Americans from October through June.

Bacterial spot (*Xanthomonas euvesicatoria*) is the most serious diseases facing Florida pepper growers (Pernezny et al., 2003). Loss in yield due to bacterial spot can be attributed to both defoliation and spotting or rotting of fruit. Ten races of *X. euvesicatoria* have been identified worldwide. A race (identified by numbers 1, 2, 3, etc.) has been defined by how it can survive and grow on cultivars with or without specific genes for resistance. Over the years, genes resistant to various races of *X. euvesicatoria* have been identified and introduced into commercial bell pepper cultivars.

Following the 1989–90 winter vegetable season in South Florida, when private seed enterprises released horticulturally desirable cultivars with the Bs1 gene (which imparted resistance to bacterial spot race 1), a shift in the prevalent race from race 2 to 1 occurred in South Florida (McAvoy et al., 2009). The race-1 strains defeated the Bs1 gene. As a result, major losses occurred in Florida bell pepper fields among cultivars with and without the Bs1 gene. Following this event, several seed companies released cultivars with the Bs2 gene, which confers resistance to races 1, 2 and 3 *of X. euvesicatoria*. Within a few years, commercial growers were planting a range of bell pepper cultivars available to growers having the Bs2 gene, expressing resistance to races 1, 2, and 3 of *X. euvesicatoria* (McAvoy et al., 2009). In the 1997–98 season in South Florida, the inevitable happened and field surveys identified races 4 and 6 as the dominant races in fields tested. As a result, serious losses occurred throughout the bell pepper industry in Florida. By 2005, commercial seed companies began to release cultivars that were resistant to races 1, 2, 3, 4, and 5 of *X. euvesicatoria* cultivars with resistance to bacterial spot races 1, 2, 3, and 4 or 1, 2, 3, and 5. In 2009, a few bell pepper cultivars with resistance to races 1, 2, 3, 4, 5 and 6 were released. This paper will report on the performance of some of these bacterial spot resistant varieties in the field during the 2009–10 season.

Materials and Methods

Trials were conducted on grower's farms in two locations around South Florida (Delray Beach in Palm Beach County and Immokalee in Collier County) during the 2009–10 growing season. Transplants were started from seed by a commercial transplant producer using commercial potting mix and polystyrene trays. Cultivars tested included standard commercial varieties with race 1, 2, 3 bacterial spot resistance, and newer cultivars and lines that include additional resistance to bacterial spot races 4, 5 and 6. Seedlings were transplanted by hand, with dead or dying transplants replaced within 10 d of transplanting. Green pepper

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entries in each location were planted in a randomized complete block design with four replications. Raised beds were 9 inches high and 36 inches wide. Beds were fumigated with methyl bromide/chloropicrin prior to being covered with polyethylene. Each plot consisted of 10.8 ft long and peppers were planted in double rows 11 inches apart, with in-row plant spacing at 9 and 10, in Immokalee and Palm Beach, respectively. Seedlings were planted in an offset, staggered planting design.

Delray Beach, Bedner Farms (2009–10). Seeds were sown on 15 Sept. 2009 and transplanted into the field on 9 Nov. 2009. All of the cultivars are marketed as having resistance to at least bacterial spot races 1, 2, and 3 and included several that had resistance to races 1, 2, 3, and 4, races 1, 2, 3, and 5, races 1, 2, 3, 4, and 5 or races 1, 2, 3, 4, 5,and 6 (Table 1). The soil type was a Myakka sand. After transplant, fertilization, pest management, and all other cultural practices were managed by the growers (Bedner Farms). Plants were not staked or tied. The first harvest was 85 d after transplant (DAT) on 1 Feb. 2010, with a second harvest on 25 Feb. 2010 (109 DAT).

Immokalee, Pacific Tomato/Spring (2010). Seeds for the second experiment in Immokalee were sown on 1 Dec. 2009 and transplanted into the field on 19 Jan. 2010 using the same varieties as the Delray Beach trial plus the addition of Aristotle (Table 1). The soil type was Immokalee fine sand. The trial was managed by the growers (Pacific Tomato Growers) after transplant. Plants were also staked and tied. The first harvest was on 22 Apr. 2010 (81 DAT) with a second harvest on 30 Apr. 2010 (91 DAT).

At each harvest from all locations, fruit considered mature green or turning (red or yellow) were harvested by hand from the entire plot. Fruit from each plot were placed in field lugs and graded on site. Ten randomly selected fruit samples from each rep where taken to University of Florida Southwest Florida Research and Education Center for quality measurements. Fruit were measured for length and width to evaluate blockiness. Data were expressed as an average length and width ratio per fruit. Number of lobes and wall thickness was recorded.

Foliar bacterial spot ratings were performed on 14 Jan. in Delray and 11 Apr. at the Immokalee trial. Two ratings were assigned per experimental unit on a 0 to 5 scale with 0 = no disease visible, and 5 = severe bacterial spot throughout entire canopy (Table 2). Many plants exhibited leaf dehiscence in the lower canopy and leaf necrosis in the upper canopy. (Richard Raid, personal communication). Temperatures were obtained from the Florida Automated Weather Network (FAWN) for both locations.

Results and Discussion

Delray Beach, Bedner Farms (2009–10). Due to rainy weather in Dec. 2009 and Jan 2010, bacterial spot pressure was extremely high in this trial with some cultivars showing nearly 100% infection at the time of rating (Table 2). There were significant differences in all yield categories except super-jumbo and large fruit at first harvest (Table 3). The highest yielding entry was XPP 6001 (Sakata) with an average yield of 597 bu/

Table 2. Summary of temperatures and total rainfall in Palm Beach and Immokalee, FL during the winter and spring 2009 and 2010 pepper season.

Period	Temp (°F) Avg	Min	Max	Total rainfall (inches)
	Palm Beach			
Nov. 2009	68.5	58.9	79.6	0.96
Dec. 2009	66.9	57.8	77.1	2.94
Jan. 2010	57.1	45.5	69.8	1.10
Feb. 2010	59.7	49.1	70.8	2.17
Avg/total	63.0	52.8	74.3	7.17
	Immokalee			
Jan. 2010	56.7	44.5	71.2	2.08
Feb. 2010	58.0	46.3	71.2	2.68
Mar. 2010	61.7	48.9	75.3	8.62
Apr. 2010	71.3	60.8	83.1	7.21
Avg/total	61.9	50.1	75.2	20.59

Table 1. Cultivars and resistance package.

Cultivar	Company	Resistance to races
ACR283	Abott and Cobb	
ACR75311	Abott and Cobb	1,2,3
Allegiance	Harris Moran	1,2, 3
Aristotle*	Harris Moran	1,2,3,4, 5
E-41-0591	Enza Zaden	1,2,3
E-41-1023	Enza Zaden	1,2,3
E-41-3041	Enza Zaden	1,2,3
E-41-3088	Enza Zaden	1,2,3,4,5
Excursion	Abott and Cobb	1,2,3,4,5
Hunter	Rogers	1,2,3
Myakka	Enza Zaden	1,2,3,4,5
PT9-56	Pepper Research	1,2,3,4
PT7-12	Pepper Research	1,2,3,4,5,6
Red Bull	Sakata	1,2,3,4,5
Regiment	Harris Moran	1,2,3
Tom Cat	Rogers	1,2,3,4,5
XPP6001	Sakata	1,2,3,4,5
2815	Seminis	1,2,3,4,5,6
7141	Seminis	1,2,3,4,5
8302	Seminis	1,2,3,4,5

*Immokalee trial only.

Table 3. Bacterial spot evaluation at two South Florida locations.

Variety	Company	Delray	Immokalee
Myakka	Enza Zaden	1.8	2.9
E41-1023	Enza Zaden	3.3	4.6
TomCat	Rogers	0.1	3.3
Excursion II	Abbott and Cobb	4.6	4.4
PT 9-56	Pepper Research	0.0	0.1
E41-0591	Enza Zaden	3.0	2.9
Red Bull	Sakata	2.8	3.6
8302	Seminis	0.0	2.9
Hunter	Rogers	0.0	2.9
E41-3041	Enza Zaden	1.5	3.9
7141	Seminis	0.0	2.0
ACR 283	Abbott and Cobb	4.3	4.5
E41-3088	Enza Zaden	0.5	2.1
2815	Seminis	0.5	0.9
PT 7-12	Pepper Research	1.0	1.4
Regiment	Harris Moran	1.3	2.9
Allegiance	Harris Moran	1.9	3.1
XPP6001	Sakata	0.0	2.0
ACR 75311	Abbott and Cobb	1.9	3.6

Rating: 0 = no disease, immune; 1 = highly resistant; 2 = moderately resistant; 3 = moderately susceptible; 4 = susceptible; 5 = highly susceptible.

Table 4. Marketable and non-marketable yield categories of first harvest for selected pepper varieties at Palm Beach, FL, grown in Winter 2009.

Variety	Super-Jumbo	Jumbo	X-Large	Large	Medium	Culls	Total marketable
				Yield (bu/acre)			
ACR 283	0	88 bc	133	140 bcde	0	41	361 bcde
ACR 75311	0	35 c	88	12 e	66	69	201 f
Allegiance	0	194 a	66	93 cde	47	26	399 bcd
E41-0591	0	35 c	239	188 bcd	0	42	462 ab
E-41-1023	0	0 c	85	144 bcde	36	22	265 def
E-41-3041	0	30 c	83	165 bcd	0	26	278 cdef
E-41-3088	0	24 c	35	233 bc	0	26	291 cdef
Excursion	0	81 bc	94	119 bcde	51	28	345 bcdef
Hunter	0	44 c	118	239 bc	0	29	400 bcd
Myakka	0	80 bc	87	102 bcde	0	31	270 def
PT9-56	0	0 c	74	161 bcd	36	24	270 def
PT7-12	0	0 c	89	139 bcde	0	42	228 ef
Red Bull	0	12 c	185	181 bcd	35	43	413 bcd
Regiment	0	201 a	106	63 de	28	51	398 bcd
Tom Cat	0	48 c	93	245 b	41	17	426 bc
XPP 6001	0	36 c	175	386 a	0	43	597 a
2815	0	96 bc	93	72 de	0	22	262 def
7141	9	178 ab	102	109 bcde	94	33	492 ab
8302	0	83 bc	160	123 bcde	0	30	366 bcde
P value	0.47	0.0001	0.07	0.0001	0.53	0.06	0.0001
Significance	NS	**	NS	**	NS	NS	**

NS, *, ** Nonsignificant or significant at $P \leq 0.05$ or 0.01.

Table 5. Marketable and non-marketable yield categories for selected pepper varieties at Delray Beach, FL. Winter 2009–10.

Variety	Super-Jumbo	Jumbo	X-Large	Large	Medium	Culls	Total marketable
				Yield (bu/acre)			
ACR 283	0	88 bc	133 bcde	295 bc	4	76 abc	520 abcd
ACR 75311	0	35 c	111 bcde	178 c	217	123 a	541 abcd
Allegiance	0	194 a	66 de	233 bc	47	42 c	539 abcd
E41-0591	0	43 c	290 a	334 bc	0	79 abc	667 abc
E-41-1023	0	0 c	88 bcde	196 c	39	41c	322 d
E-41-3041	0	30 c	124 bcde	243 bc	97	85abc	495 abcd
E-41-3088	0	24 c	38 e	335 bc	54	56bc	451 bcd
Excursion	0	81 bc	109 bcde	202 c	51	53bc	444 bcd
Hunter	0	44 c	227 ab	440 ab	17	67bc	728 ab
Myakka	0	99 bc	87 bcde	202 c	11	76abc	399 cd
PT9-56	249	0 c	74 cde	201 c	87	57bc	611 abcd
PT7-12	0	0 c	101 bcde	222 bc	52	97ab	375 cd
Red Bull	0	12 c	185 abcd	252 bc	54	62bc	503 abcd
Regiment	0	201 a	138 bcde	111 c	70	81abc	519 abcd
Tom Cat	0	48 c	93 bcde	295 bc	66	40c`	502 abcd
XPP 6001	0	36 c	215 abc	558 a	23	89abc	832 a
2815	36	96 bc	121 bcde	169 c	11	56bc	434 bcd
7141	9	213 a	167 abcde	267 bc	101	78abc	759 ab
8302	0	149 ab	227 ab	295 bc	0	59bc	671 abc
P value	0.52	0.0001	0.006	0.01	0.26	0.01	0.03
Significance	NS	**	**	*	NS	*	*

NS, *, ** Nonsignificant or significant at $P \leq 0.05$ or 0.01.

acre followed by 7141 (Seminis) with an average yield of 492 bu/acre. Both varieties were resistant to bacterial spot races 1, 2, 3, 4, and 5. Early yield was important to growers as early peppers frequently attract a premium price.

Yields of all varieties were much below those achieved in past years primarily due to cold conditions over an extended period of time. Bacterial spot disease rating varied widely ranging from 0 to 4.6 (Table 3). There were significant differences in total marketable yield categories except super-jumbo and medium fruit categories (Tables 4 and 5). The highest yielding entry was XPP 6001 (Sakata) with an average yield of 832 bu/acre followed by Hunter with an average yield of 788 bu/acre and 7141 (Seminis) with an average yield of 759 bu/acre. Both varieties were resistant to bacterial spot races 1, 2, 3, 4, and 5. In general, the varieties that had the lowest incidence of bacterial spot infection tended to produce the highest yields with the two highest yielding varieties

Table 6. Marketable and non-marketable yield categories of first harvest for selected pepper varieties grown in Spring 2010 at Immokalee, FL.

Variety	Super-Jumbo	Jumbo	X-Large	Large	Medium	Culls	Total marketable
				Yield (bu/acre)			
ACR 283	5	21 de	57 cdef	99 cdef	8 b	0	189 efg
ACR 75311	0	51 bcde	43 cdef	30 f	2 b	4	126 g
Allegiance	0	78 bcd	106 abc	48 ef	0 b	18	232 efg
Aristotle	5	82 bc	86 bcde	97 cdef	13 b	131	284 cdef
E41-0591	0	0 e	49 cdef	87 cdef	29 b	3	165 fg
E-41-1023	0	0 e	14 f	64 def	38 b	0	116 g
E-41-3041	0	0 e	27 ef	65 def	24 b	6	117 g
E-41-3088	18	50 bcde	135 ab	189 ab	24 b	5	416 ab
Excursion	0	18 e	45 cdef	90 cdef	27 b	0	180 efg
Hunter	0	41 bcde	53 cdef	165 abc	11 b	9	269 cdef
Myakka	0	47 bcde	107 abc	81 cdef	2 b	6	236 defg
PT9-56	11	36 bcde	94 abcd	230 a	39 b	0	410 ab
PT7-12	0	3 e	32 def	144 bcd	26 b	3	205 efg
Red Bull	0	12 e	77 bcdef	93 cdef	44 b	0	225 efg
Regiment	0	87 b	66 cdef	62 def	5 b	2	219 efg
Tom Cat	0	33 bcde	57 cdef	107 bcdef	91 a	9	288 cdef
XPP 6001	0	29 cde	86 bcde	161 abc	18 b	2	293 cde
2815	48	174 a	136 ab	132 bcde	20 b	0	510 a
7141	0	89 b	156 a	126 bcde	11 b	11	381 bc
8302	15	83 bc	98 abc	138 bcd	23 b	6	356 bcd
P value	0.09	0.0001	0.0001	0.0001	0.03	0.37	0.0001
Significance	NS	**	**	**	*	NS	**

NS, *, ** Nonsignificant or significant at $P \leq 0.05$ or 0.01.

Table 7. Marketable and non-marketable yield categories of for selected pepper varieties grown in Spring 2010 at Immokalee, FL.

Variety	Super-Jumbo	Jumbo	X-Large	Large	Medium	Culls	Total marketable
				Yield (bu/acre)			
ACR 283	5	21 d	57 def	116 cdefg	55 cdefg	30	253 defg
ACR 75311	0	51 bcd	43 def	36 g	11 fg	30	141 g
Allegiance	0	84 bc	132 abc	82 efg	18 efg	30	316 de
Aristotle	5	82 bc	89 bcde	110 cdefg	20 efg	149	306 de
E41-0591	0	9 d	81 cdef	118 cdefg	69 cdef	18	276 def
E41-1023	0	0 d	14 f	70 fg	42 efg	16	126 g
E41-3041	0	0 d	33 ef	77 efg	41 efg	35	151 fg
E41-3088	18	50 bcd	135 abc	224 b	71 cde	42	497 b
Excursion	0	18 d	45 def	96 defg	48 defg	27	207 efg
Hunter	0	41 bcd	53 def	174 bcd	44 efg	42	311 de
Myakka	0	47 bcd	110 bcd	123 cdefg	9 g	29	288 de
PT9-56	11	36 bcd	97 bcde	318 a	280 a	6	742 a
PT7-12	0	3 d	38 def	175 bcd	169 b	33	385 bcd
Red Bull	0	21 d	98 bcde	99 defg	60 cdefg	21	278 def
Regiment	0	87 bc	89 bcde	95 defg	45 efg	51	315 de
Tom Cat	0	33 bcd	57 def	107 cdefg	103 cd	58	301 de
XPP 6001	0	29 cd	86 bcdef	179 bcd	53 defg	53	346 cde
2815	48	174 a	191 a	198 bc	110 c	32	721 a
7141	0	89 b	156 ab	164 bcde	46 efg	56	454 bc
8302	15	86 bc	107 bcde	141 bcdef	42 efg	45	390 bcd
P value	0.09	0.0001	0.0001	0.0001	0.0001	0.23	0.0001
Significance	NS	**	**	**	**	NS	**

NS, *, ** Nonsignificant or significant at $P \leq 0.05$ or 0.01.

XPP 6001, Hunter and 7141 all having a 0 infection rating (Table 3). This did not hold true for all varieties. For example, cv. ACR 283 with 1, 2, and 3 resistances produced good yields despite a disease rating of 4.3. This may be due to its robust growth which enables it to out grow infections to some extent, which may be why growers have adopted it so widely.

Immokalee, Pacific Tomato/Spring (2010). Due to abnormal cold rainy weather in winter and spring, bacterial spot pressure was extremely high in this trial with some cultivars displaying up to 4.6 infection rating (Tables 2 and 3). There were significant differences in all yield categories except super jumbo and cull fruit at first harvest (Table 6). The highest yielding entry was

Table 8. Quality categories for selected peppers varieties grown in Spring 2010 at Immokalee, FL.

Variety	Locules (no.)	Length (inches)	Width (inches)	Ratio	Thickness (mm)
ACR 75311	3.8 a	3.6 abcd	3.3 abc	1.13 abcde	0.24 ab
Aristotle	3.2 abcd	3.5 bcd	3.5 a	1.00 efgh	0.24 ab
E41-0591	3.7 ab	3.0 fg	3.2 abcd	0.92 fgh	0.21 b
E41-1023	3.2 abcd	2.9 g	2.8 e	1.03 defgh	0.19 c
E41-3041	3.2 abcd	3.4 bcde	2.9 de	1.20 ab	0.19 c
E41-3088	3.2 abcd	2.8 g	3.1 bcde	0.91 h	0.22 ab
Excursion	3.1 bcd	3.8 ab	3.3 abc	1.18 abc	0.24 ab
Hunter	3.4 abc	3.3 def	3.2 abcd	1.04 cdefg	0.25 a
Myakka	3.6 ab	3.1 efg	3.5 a	0.89 gh	0.24 ab
PT 9-56	3.3 abc	3.7 abc	3.1 bcde	1.21 a	0.24 ab
PT 7-12	3.0 cd	3.3 def	3.0 cde	1.15 abcde	0.23 ab
Red Bull	3.1 bcd	3.6 abcd	3.0 cde	1.24 a	0.24 ab
Regiment	3.4 abc	3.3 def	3.3 abc	1.01 efgh	0.23 ab
Tom Cat	3.6 ab	3.4 cde	3.3 abc	1.03 efgh	0.24 ab
XPP 6001	2.8 d	3.6 abcd	3.2 abcd	1.12 abcde	0.23 ab
7141	3.6 ab	4.0 a	3.4 ab	1.18 abcd	0.23 ab
8302	3.2 abcd	3.4 cde	3.3 abc	1.06 bcdef	0.23 ab
P value	0.02	0.0001	0.0001	0.0001	0.0001
Significance	*	**	**	**	**

NS, *, ** Nonsignificant or significant at $P \leq 0.05$ or 0.01.

cv. 2815, followed by cv. PT 9 -56, but this variety had higher percentage of medium and large instead of super jumbo, jumbo and x-large fruit. Both varieties are resistant to bacterial spot races 1, 2, 3, 4, 5, and 6.

There were also significant differences in total marketable yield (Table 7). In total marketable yield the highest yielding entry were the race 1 - 6 bacterial leafspot resistant cultivars with cv. PT 9 -56 producing the highest yield, followed by cv. 2815. It is important to note that cv 2815 produced significantly more jumbo and extra-large fruit which attract higher prices than did cv. PT9-56 which had more large and medium fruit.

Varieties that demonstrated little or no bacterial spot infection in Delray had higher infection rates indicating that race 6 bacteria spot was present in Immokalee. (Table 2). In both trials, cultivars with advanced levels of bacterial spot resistance tended to produce significantly higher yields under conditions of severe bacterial spot pressure. However low resistance to bacterial spot did not necessarily correlate to decreases in yield and horticultural quality with some entries producing good yields despite having relatively high bacterial spot ratings. Conversely, some entries that had an elevated incidence of bacterial spot did show below average yields. Further research is needed to determine if a correlation between lower yield and bacterial spot exists for these entries.

Performance differences were noted depending on season with some varieties tending to do better in the fall or spring.

While total yield was an extremely important consideration, it was not the only one for choosing pepper cultivars or varieties. Plant architecture, as indicated by fruit placement and set, and fruit size, as indicated by fruit weight, and blockiness (ratio L: W) were also important variables to consider. Another trait deemed important and desirable by the pepper industry was blocky or slightly elongated fruit. Some of the resistant cultivars such as cv. Myakka, E41-0591, and E41-3088 had low ratios of around 90 (Table 8). This indicates a relatively compressed fruit, which was not desired by produce brokers. An ideal ratio of fruit length to width would roughly be between 1.00 and 1.20, a range found in most commercially acceptable varieties. Pepper fruit should also have between three and four lobes, with the preference towards four lobes and distinct indentations at the blossom end. Fruit with two lobes tend to be pointed with little indentations and may or may not be saleable depending on the market. Five-lobed fruit also tend to lose lobe distinction and although they are usually saleable, they were desired less by the industry and the public. Some varieties trialed tended toward three-lobed fruit, which could be a drawback in some markets (Table 8).

Future breeding efforts may make these varieties more reliable and or combine these resistance traits with superior horticultural characteristics. Use of cultivars with of bacterial spot resistance to races1, 2, 3, and 4; 1, 2, 3, 4, and 5; and 1, 2, 3, 4, 5, and 6 did significantly reduce overall bacterial spot ratings and produce significantly higher yield under severe bacterial spot pressure. Resistant cultivars should provide growers with a tool to make a crop with reduced input costs under high bacterial spot pressure. Resistant cultivars should be incorporated into an integrated disease management strategy, which should include tactics aimed at reducing the survival, spread, and reproduction of bacteria and minimizing infection of plants.

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