Variety Trials

Influence of Watermelon Mosaic Virus on Slicing Cucumber Farm-gate Revenues

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Summary. **Watermelon mosaic virus (WMV) is often the most limiting factor to cucumber (*Cucumis sativus*) production in the midwestern U.S. The influence of WMV on farm-gate revenues for nine slicing cucumber (or fresh market cucumber) cultivars was determined under high WMV disease incidence during 2000 and 2001. Over the two growing seasons, most cucumber cultivars produced excessive amounts of unmarketable WMV symptomatic fruit; however, no WMV symptoms were observed on any fruit produced by 'Daytona' or 'Indy'. 'Thunder' produced some WMV symptomatic fruit but was significantly ($P \leq 0.05$) less than that produced by all other cucumber cultivars, except for 'Daytona' and 'Indy.' Consistent high total farm gate-revenues over both years were produced by 'Daytona' and 'Indy' compared to other cucumber cultivars evaluated with the exception of 'Thunder'. 'Daytona,' 'Indy,' and 'Thunder' tended to produce greater early-season farm-gate revenues. However, late-season revenues of 'Thunder' were reduced compared to 'Daytona' and 'Indy'. 'Dasher II,' 'General Lee,' 'Greensleeves,' 'Marketmore 76,' 'Speedway,' and 'Turbo' produced excessive amounts of unmarketable WMV symptomatic fruit which led to reduced farm-gate revenues. Cucumber cultivars without some level of resistance to WMV produced substantially less cumulative farm-gate revenues than those that had some level of resistance. 'Daytona,' 'Indy,' and 'Thunder' were not the highest yielding cucumber cultivars evaluated in this study, but produced the highest farm-gate revenues due to higher levels of genetic resistance to WMV.**

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Watermelon mosaic virus is the most prevalent virus on cucurbits (*Cucurbitaceae*) in southern Illinois and will often severely reduce the production of slicing cucumbers (or fresh market cucumbers) in this region (Walters et al., 2003). The pathogen suppresses yield and shortens the harvest season of cucumber cultivars that do not have resistance. Symptoms include distortion and discoloration of the fruit and foliage as well as plant stunting (Robinson and Decker-Walters, 1997; Schultheis et al., 1998; Zitter et al., 1996). Other viruses including cucumber mosaic virus (CMV), papaya ringspot virus (PRSV), and zucchini yellows mosaic virus (ZYMV) can also be found in southern Illinois cucumber fields, but are not as widely distributed as WMV (Walters et al., 2003). Although virus diseases reduce total yield in slicing cucumbers (Fletcher et al., 1969; Strider and Konsler, 1967; Zitter et al., 1996), associated fruit discoloration and distortion reduce marketable yield as high fruit quality must be maintained for market acceptance (Schultheis et al., 1998).

High incidence of WMV in Illinois cucumber fields leads to reduced yield, quality, and farm-gate revenues. Under high cucurbit virus disease incidence, transgenic virus resistant squash (*Cucurbita pepo*) provided a $1,761/acre ($4,350/ha) return compared to $0 for susceptible squash (Fuchs et al., 1998). To be financially successful, cucumber growers need to maximize marketable yields while minimizing fruit discoloration associated with WMV infection.

Over 75 years ago, CMV resistance in cucumbers became available to growers throughout the U.S. (Porter, 1928) and the single dominant gene responsible for resistance (Wasuwat and Walker, 1961) is still a viable management option for cucumber growers with CMV disease problems (Zitter et al., 1996). However, only recently have WMV resistant cucumber cultivars been available to growers (Zitter, 2002). The objective of this study was to measure the impact of WMV on yield and farm-gate revenues of WMV susceptible and resistant slicing cucumber cultivars.

Materials and methods

Nine cucumber cultivars were evaluated in a randomized complete block design with four replications located at Rendleman Orchards in Alto Pass, Ill. The cultivars evaluated were 'Dasher II' [Seminis Vegetable Seeds (SVS), Oxnard, Calif.], 'Daytona'(SVS), 'General Lee' [Harris Moran Seed Co. (HMS), Modesto, Calif.], 'Greensleeves' (HMS), 'Indy' (SVS), 'Marketmore 76' (Cornell University, Ithaca, N.Y.), 'Speedway' (SVS), 'Thunder' (SVS), and 'Turbo'(SVS). Experimental plots were 10 ft (3.0 m) in length with a 5-ft (1.5-m) alley between plots. Center-to-center row spacing was 4 ft (1.2 m) with in-row spacings of 0.5 ft (0.15 m) allowing 20 plants per plot. 'Marketmore 76' [CMV resistant, but susceptible to most cucurbit viruses including WMV (Zitter, 2002)] was planted on the two outside rows of the test as a border.

The soil was an Alford silty clay loam soil, which is a fine-silty, mixed, mesic typic Hapludalf (Miles, 1979).

Standard cultural practices for cucumber production in Illinois were followed (Foster et al., 2000, 2001). Thirty lb/acre (33.6 kg·ha^{-1}) nitrogen (N), 37 lb/acre (41.4 kg·ha^{-1}) phosphorus (P), and 71 lb/acre (79.5 kg·ha^{-1}) potassium (K) were applied to plots before planting; plots were side-dressed with 25 lb/acre (28.0 kg·ha^{-1}) N 4 weeks after planting. Recommended pest control was used, consisting of spraying a tank mixture of carbaryl (Sevin; Rhone-Poulenc Ag Company, Research Triangle Park, N.C.) and chlorothalonil (Bravo; Zeneca, Inc., Wilmington, Del.) at 7- to 10-d intervals for the duration of the test. Weeds were controlled by mechanical or hand cultivation. No supplemental irrigation was provided.

Cucumbers were direct seeded on 14 July and 16 July in 2000 and 2001, respectively. Harvest began when first fruit reached marketable size [34 d after planting (DAP) for both years], and continued at 3- to 4-d intervals with a total of eight harvests (ending 63 and 61 DAP in 2000 and 2001, respectively). Fruit at each harvest were graded into super select [no more than 2 inches (5.1 cm) in diameter and no less than 6 inches (15.2 cm) in length], select [no less than 1.5 inches (3.81 cm) or more than 2 inches in diameter with no length requirement], cull (unmarketable – misshapened, off-color, or decaying fruit), and cull with WMV symptoms (green blotched skin). Standard packaging units for the industry are 22-lb (9.9-kg) boxes for super select and 24-lb (10.8-kg) boxes for select. Gross returns of cucumbers were estimated by using the actual mean commercial price received in southern Illinois (Brumleve Farms, Cobden, Ill.) for the Chicago terminal market during each production year with $9.33 and $7.73 for 22-lb boxes of super select and $4.11 and $3.70 for 24-lb boxes of select, respectively, for the 2000 and 2001 season.

At 4 and 7 weeks after planting, the number of plants in each plot exhibiting typical virus symptoms were determined and a rating was conducted to determine the severity of virus symptoms expressed on plants with 0 = no foliage symptoms, 1 to 3 = few foliar symptoms, 4 to 6 = moderate amount of foliar symptoms, and 7 to 9 = severe foliar symptoms including excessive leaf mottling and mosaic over the entire plant. Virus data were collected on 13 Aug. and 3 Sept. 2000, and on 12 Aug. and 4 Sept. 2001. At least one cucumber foliage sample symptomatic of virus infection was randomly collected from all plots that had visible symptoms at each sampling date to determine the specific virus(es) present. Samples were evaluated utilizing alkaline phosphatase enzyme-linked immunosorbent assay (ELISA) kits (Agdia Pathoscreen kits; Agdia, Inc., Elkhart, Ind.) for the presence of five viruses: CMV, PRSV, SqMV, WMV, and ZYMV. Samples were considered positive if absorbance readings equaled or exceeded 3× the absorbance of negative controls (healthy cucumber leaves).

Data were subjected to analysis of variance procedures appropriate for a randomized complete block design using SAS (SAS Inst., Cary, N.C.). Fisher's least significant difference (LSD) tests were used to separate differences among cucumber cultivar means at $P \leq 0.05$.

Results

The data were combined over the 2 years and analyzed. The 2 years provided distinctly different growing seasons (primarily due to soil moisture differences) as indicated by the differences ($P \leq 0.05$) between years for the variables studied (data not presented). Drought conditions during 2000 suppressed cumulative yields and thus total farm-gate revenues compared to 2001 (Tables 1 and 2). Although years were different, symptom and severity rating data were combined over the 2 years since no year by cultivar interactions ($P \leq 0.05$) were observed for these variables. However, a significant year by cultivar interaction ($P \leq 0.05$) was observed for cucumber yields and farm-gate revenues indicating that cultivar performance depended on year (data not presented). Therefore, yield and farm-gate revenue results will be presented by year.

WATERMELON MOSAIC VIRUS SYMPTOM AND SEVERITY DEVELOPMENT. For both years, WMV was the only virus identified from the foliage samples that were analyzed by ELISA. WMV disease incidence and symptom severity ratings increased as the growing season progressed (Figs. 1 and 2). 'Daytona' and 'Indy' are resistant to WMV (Zitter, 2002) and neither had WMV foliage symptom development at any time during the growing season. The small number of 'Thunder' plants per plot with foliar WMV symptoms and low symptom severity ratings indicated that this cultivar also has some level of resistance to WMV (Figs. 1 and 2). All other cucumber cultivars had >60% WMV disease incidence in plots by the seven week rating. Cultivars with moderate susceptibilty to WMV were 'Dasher II,' 'Speedway,' General Lee,' and 'Greensleeves'. 'Turbo' and 'Marketmore 76' had the greatest amount of WMV symptom development and highest severity ratings of the cultivars evaluated.

For both years at the 7-week rating, cull fruit with WMV symptoms were correlated with WMV disease incidence ($r = 0.58$, $P = 0.0001$) and severity of the WMV symptoms produced on plants ($r = 0.54$, $P = 0.0001$). In contrast, WMV disease incidence and symptom severity on plants were inversely related with total marketable fruit weight ($r = -0.72$, $P = 0.0001$ and $r = -0.73$, $P = 0.0001$, respectively).

WATERMELON MOSAIC VIRUS AND FARM-GATE REVENUES. For the 2000 growing season, high early-season revenues were similar among several cucumber cultivars including those with WMV resistance (Table 1). However, only 'Indy,' 'Daytona,' and 'Thunder' had high late season revenues [>$1500/acre ($3705/ha)]. This revenue increase during the late season resulted in high total season revenues [>$3800/acre ($9386/ha)] for these three cultivars, although 'Thunder' [$3871/acre ($9561/ha)] did not differ ($P \leq 0.05$) from 'General Lee' [$3118/acre ($7701/ha)]. Most cultivars had suppressed late season revenues [<$1000/acre ($2470/ha)] due to the production of excessive WMV symptomatic fruit (Tables 1 and 3). 'Daytona' and 'Indy' did not produce WMV symptomatic fruit throughout the production season and 'Thunder' produced only a small amount (<10%) (Table 3). Considering total season production, all WMV susceptible cultivars (except 'Thunder') produced >40% fruit with WMV symptoms.

During 2001, high total farm-gate revenues [>$5500/acre ($13,585/ha)] were achieved with 'Indy,' 'Daytona,' and 'Thunder' (Table 2), although the revenues of 'Dasher II' and 'Turbo' did not differ ($P \leq 0.05$) from 'Thunder'. The revenues generated by 'Indy,' 'Daytona,' and 'Thunder' were significantly ($P \leq 0.05$)

Table 1. Slicing cucumber farm-gate revenues ($/acre) and yields (tons/acre) during summer 2000 at Rendleman's Orchard in Alto Pass, Ill.[z]

	Early season [$/acre (ton/acre)]			Late season [$/acre (ton/acre)]			Total season [$/acre (ton/acre)]		
Cultivar	SSEL	SEL	Total	SSEL	SEL	Total	SSEL	SEL	Total
Indy[y]	1185 (1.4)	510 (1.5)	1695 (2.9)	2031(2.4)	584 (1.7)	2615 (4.1)	3216 (3.8)	1094 (3.2)	4310 (7.0)
Daytona[y]	1539 (1.8)	472 (1.4)	2011 (3.2)	1313 (1.5)	721 (2.1)	2034 (3.6)	2852 (3.3)	1193 (3.5)	4045 (6.8)
Thunder[x]	1970 (2.3)	390 (1.1)	2360 (3.4)	1047 (1.2)	464 (1.4)	1511 (2.6)	3017 (3.5)	854 (2.5)	3871 (6.0)
General Lee	1642 (1.9)	514 (1.5)	2156 (3.4)	780 (0.9)	182 (0.5)	962 (1.4)	2422 (2.8)	696 (2.0)	3118 (4.8)
Dasher II	1498 (1.8)	406 (1.2)	1904 (3.0)	513 (0.6)	207 (0.6)	720 (1.2)	2011 (2.4)	613 (1.8)	2624 (4.2)
Greensleeves	1252 (1.5)	456 (1.3)	1708 (2.8)	718 (0.8)	182 (0.5)	900 (1.3)	1970 (2.3)	638 (1.8)	2608 (4.1)
Speedway	964 (1.1)	323 (0.9)	1287 (2.0)	267 (0.3)	174 (0.5)	441 (0.8)	1231 (1.4)	497 (1.4)	1728 (2.8)
Turbo	554 (0.7)	124 (0.4)	678 (1.1)	769 (0.9)	186 (0.5)	955 (1.4)	1323 (1.6)	310 (0.9)	1633 (2.5)
Marketmore 76[w]	0 (0.0)	98 (0.3)	98 (0.3)	144 (0.2)	25 (0.1)	169 (0.3)	144 (0.2)	123 (0.4)	267 (0.6)
LSD ($P \leq 0.05$)	828 (1.0)	251 (0.8)	905 (1.3)	711 (1.0)	259 (1.0)	416 (0.8)	1128 (1.6)	353 (1.1)	1074(1.7)

[z]Data are means of four replications. Early-season harvest is the sum of the harvests 1 to 4, and late-season harvest is the sum of harvests 5 to 8, and total harvest is the sum of harvests 1 to 8. Cultivars are ranked according to total total-season farm-gate revenues obtained per acre. SSEL = super select grade and SEL = select grade. Total is the sum of SSEL and SEL. Price per 22-lb (9.9-kg) super select box ($9.33) and 24-lb (10.8-kg) select box ($4.11) are based on the average price obtained by vegetable growers in southern Illinois for the 2000 production season; $1/acre = $2.47/ha; 1.0 ton/acre = 2.24 Mg·ha^{-1}; LSD = Fisher's least significant difference.
[y]Cucumber cultivars with cucumber mosaic virus (CMV), papaya ringspot virus (PRSV), watermelon mosaic virus (WMV), and zucchini yellows mosaic virus (ZYMV) resistance.
[x]Cucumber cultivar with only CMV and ZYMV resistance.
[w]Cucumber cultivar with only CMV resistance.

Table 2. Slicing cucumber farm-gate revenues ($/acre) and yields (tons/acre) during summer 2001 at Rendleman's Orchard in Alto Pass, Ill.[z]

	Early season [$/acre (ton/acre)]			Late season [$/acre (ton/acre)]			Total season [$/acre (ton/acre)]		
Cultivar	SSEL	SEL	Total	SSEL	SEL	Total	SSEL	SEL	Total
Daytona[y]	3741 (10.6)	1030 (6.7)	4771 (17.3)	1173 (3.3)	843 (5.5)	2016 (8.8)	4914 (13.9)	1873 (12.2)	6787 (26.1)
Indy[y]	3503 (10.0)	1097 (7.1)	4600 (17.1)	1360 (3.9)	537 (3.5)	1897 (7.4)	4863 (13.9)	1634 (10.6)	6497 (24.5)
Thunder[x]	3656 (10.4)	649 (4.2)	4305 (14.6)	867 (2.5)	388 (2.5)	1255 (5.0)	4523 (12.9)	1037 (6.7)	5560 (19.6)
Turbo	2942 (8.4)	351 (2.3)	3293 (10.7)	1378 (3.9)	515 (3.3)	1893 (7.2)	4320 (12.3)	866 (5.6)	5186 (17.9)
Dasher II	3622 (10.3)	485 (3.1)	4107 (13.4)	561 (1.6)	388 (2.5)	949 (4.1)	4183 (11.9)	873 (5.6)	5056 (17.5)
General Lee	3129 (8.9)	552 (3.6)	3681 (12.5)	544 (1.5)	418 (2.7)	962 (4.2)	3673 (10.4)	970 (6.3)	4643 (16.7)
Greensleeves	2704 (7.7)	649 (4.2)	3353 (11.9)	136 (0.4)	358 (2.3)	494 (2.7)	2840 (8.1)	1007 (6.5)	3847 (14.6)
Speedway	1582 (4.5)	515 (3.3)	2097 (7.8)	1054 (3.0)	224 (1.5)	1278 (4.5)	2636 (7.5)	739 (4.8)	2375 (12.3)
Marketmore 76[w]	102 (0.3)	60 (0.4)	162 (0.7)	507 (1.4)	239 (1.6)	746 (3.0)	609 (1.7)	908 (2.0)	1517 (3.7)
LSD ($P \leq 0.05$)	929 (2.6)	407 (2.6)	849 (3.1)	970 (2.8)	283 (1.8)	601 (2.4)	1418 (3.9)	516 (3.3)	1123 (3.7)

[z]Data are means of four replications. Early-season harvest is the sum of the harvests 1 to 4, and late-season harvest is the sum of harvests 5 to 8, and total harvest is the sum of harvests 1 to 8. Cultivars are ranked according to total total-season farm-gate revenues obtained per acre. SSEL = super select grade and SEL = select grade. Total is the sum of SSEL and SEL. Price per 22-lb (9.9-kg) super select box ($7.73) and 24-lb (10.8-kg) select box ($3.70) are based on the average price obtained by vegetable growers in southern Illinois for the 2001 production season; $1/acre = $2.47/ha; 1.0 ton/acre = 2.24 Mg·ha^{-1}; LSD = Fisher's least significant difference.
[y]Cucumber cultivars with cucumber mosaic virus (CMV), papaya ringspot virus (PRSV), watermelon mosaic virus (WMV), and zucchini yellows mosaic virus (ZYMV) resistance.
[x]Cucumber cultivar with only CMV and ZYMV resistance.
[w]Cucumber cultivar with only CMV resistance.

Table 3. Percentage of total cucumber fruit that had watermelon mosaic virus (WMV) symptoms at early, late, and all harvests at Rendleman's Orchard in Alto Pass, Ill., for the 2000 and 2001 growing seasons.[z]

	2000			2001		
	Fruit with WMV symptoms (%)			Fruit with WMV symptoms (%)		
Cultivar	Early	Late	Total	Early	Late	Total
Daytona[y]	0	0	0	0	0	0
Indy[y]	0	0	0	0	0	0
Thunder[x]	3	12	8	0	11	5
Greensleeves	17	60	41	18	64	38
Turbo	41	53	49	7	45	31
General Lee	40	67	55	19	51	36
Dasher II	42	72	58	23	56	37
Speedway	47	50	48	51	52	52
Marketmore 76[w]	58	83	74	37	57	55
LSD ($P \leq 0.05$)	13	17	16	11	19	21

[z]Data are means of four replications. Early is the sum of harvests 1 to 4, late is the sum of harvests 5 to 8, and total is the sum of harvests 1 to 8. LSD = Fisher's least significant difference.
[y]Cucumber cultivars with cucumber mosaic virus (CMV), papaya ringspot virus (PRSV), watermelon mosaic virus (WMV), and zucchini yellows mosaic virus (ZYMV) resistance.
[x]Cucumber cultivar with only CMV and ZYMV resistance.
[w]Cucumber cultivar with only CMV resistance.

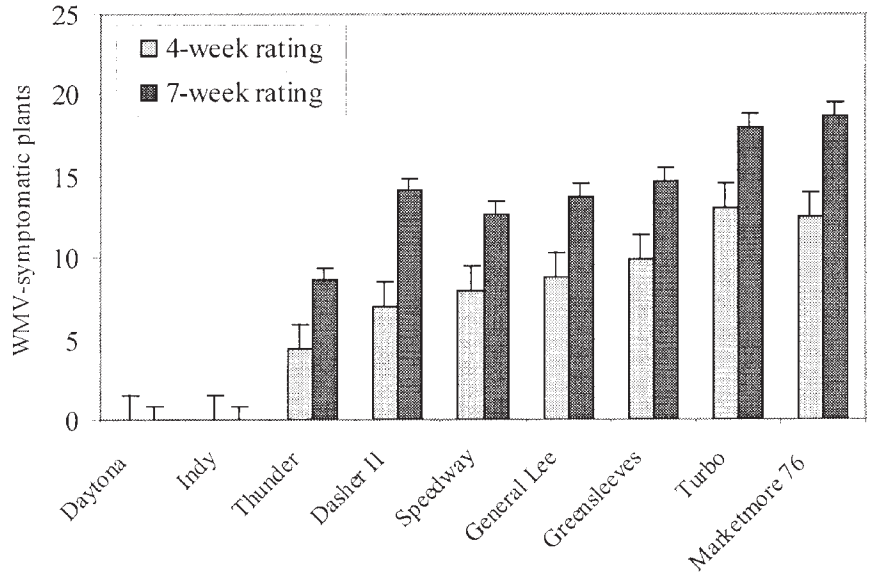

Fig. 1. Number of cucumber plants per plot (out of 20) with foliage showing watermelon mosaic virus (WMV) symptoms at 4 and 7 weeks after planting for the nine cucumber cultivars evaluated at Rendleman's Orchard in Alto Pass, Ill. Data were combined over the 2000 and 2001 growing seasons.

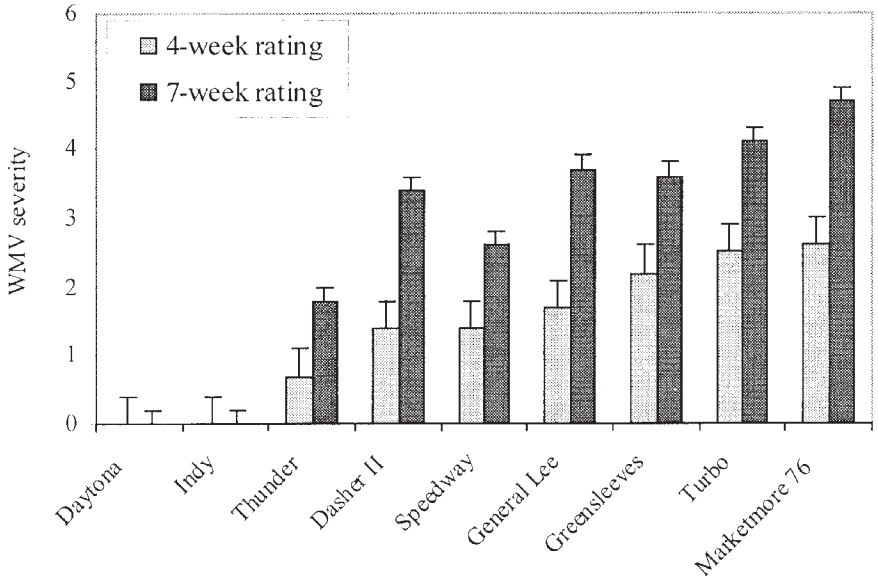

Fig. 2. Watermelon mosaic virus (WMV) foliage symptom severity ratings at 4 and 7 weeks after planting for the nine cucumber cultivars evaluated at Rendleman's Orchard in Alto Pass, Ill. Data were combined over the 2000 and 2001 growing seasons. WMV severity was rated from 0 = no foliage symptoms, 1 to 3 = few foliar symptoms, 4 to 6 = moderate amount of foliar symptoms, and 7 to 9 = severe foliage symptoms including excessive leaf mottling and mosaic over the entire plant.

greater during the early-season harvest period [>$4300/acre (>$10,621/ha)] compared to the other cultivars evaluated. However, during the late-season harvest period, 'Thunder' provided significantly ($P \leq 0.05$) less revenue than 'Daytona' or 'Indy'. For late-season revenue, 'Turbo' was similar to 'Daytona' and 'Indy', while 'Speedway' was similar to 'Thunder'. For both 'Daytona' and 'Indy', WMV symptomatic fruit were not produced at any time during the production season (Table 3), while 'Thunder' produced only a small amount. The WMV symptomatic fruit produced by 'Thunder' was less ($P \leq 0.05$) than the WMV susceptible cultivars evaluated, but was not greater ($P \leq 0.05$) than either 'Daytona' or 'Indy'. Over the entire production season, all other cultivars produced >30% fruit having WMV symptoms.

Most cultivars produced excessive amounts of unmarketable WMV symptomatic fruit, whereas no WMV symptoms were observed on fruit of WMV resistant 'Daytona' and 'Indy' during the course of the two growing seasons. 'Thunder' produced some WMV symptomatic fruit, but significantly ($P \leq 0.05$) less than that produced by the other WMV susceptible cultivars. The WMV susceptible cultivars produced WMV symptomatic fruit throughout the growing season, but frequency increased toward the end of the growing season (Table 3), which coincided with an increase in WMV disease incidence and symptom severity (Figs. 1 and 2). 'Daytona' and 'Indy' provided consistent high total farm-gate revenues over both years compared to most other cucumber cultivars evaluated except 'Thunder' (Tables 1 and 2), although late-season revenues of 'Thunder' were reduced compared to 'Daytona' and 'Indy'. Cucumber cultivars susceptible to WMV produced substantially less cumulative farm-gate revenues than those having resistance (Tables 1 and 2). Those cucumber cultivars with no level of resistance to WMV generated gross revenues that ranged from 7% to 94% less than 'Daytona,' 'Indy,' and 'Thunder'.

Discussion

Virus diseases do not always cause significant yield losses in vegetable crops, but play more of a role in the marketability of the crop. Thomas (1971) reported that cucumbers infected with WMV resulted in no reduction in overall yield from either early or late season infection. However, consumers will not purchase slicing cucumbers that have green blotches on the skin surface and these fruit must be culled in the grading line.

Although 'Daytona,' 'Indy,' and 'Thunder' were not the highest yielding cucumber cultivars evaluated in this study, they produced the highest farm-gate revenues (Tables 1 and 2). These high farm-gate revenues resulted from these cultivars having some level of WMV resistance, as indicated by the production of little to no WMV symptomatic fruit (Table 3). The farm-gate revenues of WMV susceptible cultivars

were inconsistent, while the three cultivars with some level of WMV resistance sustained their marketable productivity throughout the harvest season. The use of WMV resistant cucumber cultivars increased net returns to the grower not only by providing greater farm-gate revenues but also by eliminating grading costs incurred for removal of fruit having WMV symptoms.

Although 'Thunder' is only resistant to CMV and ZYMV (Zitter, 2002), it showed partial resistance to WMV. It may be that the ZYMV resistance also provides resistance to WMV. ZYMV and WMV are somewhat similar potyviruses with flexuous rods containing a single strand of RNA, whereas CMV is a cucumovirus that is characterized by three functional pieces of single stranded RNA encapsidated in three particles (Zitter et al., 1996). Similar results were reported in summer squash, where virus resistant transgenic lines were found to be an economically viable investment even when cucurbit viruses other than those to which they are resistant were infecting plants (Fuchs et. al, 1998).

In areas where WMV is a major limiting factor to cucumber production, genetic resistance has allowed growers to maintain high revenue levels. If only WMV susceptible cultivars were available, cucumber growers would realize much lower farm-gate revenues. Many slicing cucumber growers in the midwestern U.S. who have WMV problems have switched to cultivars having resistance to WMV, permitting continued production regardless of WMV disease pressures. However, cultivar selection is important when managing WMV, since 'Daytona' and 'Indy' are completely resistant to WMV, while 'Thunder' showed only partial resistance.

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