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Effectiveness of Harvesters at Identifying and Removing Citrus Fruit with Canker Symptoms in the Field

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During the 2008–10 citrus seasons, experiments were conducted to evaluate the ability of harvesters to identify and remove grapefruit with canker symptoms. The harvesting methods evaluated included: 1) current harvest practices without field grading, 2) harvester grading after picking, and 3) harvester grading before picking. The fruit used in this research were collected from commercial 'Ray Ruby' grapefruit groves. Some experiments were harvested by trained laboratory personnel, whereas others were harvested by professional harvesters. Compared to current practices, removing fruit with canker lesions during harvest was not effective. While laboratory personnel tended to be more accurate at distinguishing symptomatic and asymptomatic fruit than professional harvesters, they took more than twice the time to harvest the same amount of fruit. On the other hand, between 29% to 68% of the fruit that professional harvesters thought had canker lesions were actually asymptomatic, while between 8% and 38% of the fruit that they thought were asymptomatic, actually were not. This substantial amount of fruit incorrectly identified as symptomatic represents lost revenue, whereas fruit with canker lesions that were not detected must still be removed at the packinghouse. The extra effort of identifying fruit with canker lesions during harvest would also increase harvesting costs by perhaps 33% to 67% and could increase the time required to harvest the fruit by up to 65%. Results from this research suggest that removing fruit with citrus canker lesions during harvest would not be effective or economic under current Florida conditions.

The establishment of citrus canker (caused by *Xanthomonas citri* subsp. *citri*) in Florida and the iterations of canker rules, including the latest major change to the rule in Oct. 2009, have impacted how Florida's $400 million fresh industry grows, packs, and ships fruit (Ritenour et al., 2008; USDA APHIS, 2009). Fortunately for Florida's industry, the 2009 canker rule now allows even fruit with canker lesions to be shipped to domestic markets, including citrus-producing states, as long as they do not substantially affect the visual quality of the fruit.

However, over 40% of Florida's fresh citrus is exported outside the United States and those shipments are governed by the receiving countries, several of which still require fruit to be inspected and found free of canker before shipment. For example, about 34% of Florida's exported citrus was sent to countries of the European Union (EU) during the 2007–08 season (Florida Department of Citrus, 2010), and all of these countries still require groves to be inspected and found free of canker before harvest, and require postharvest fruit decontamination treatments and inspection to verify the fruit is free of canker lesion before shipping. Extensive training has equipped packinghouse personnel to accurately identify and remove fruit with citrus canker lesions, such that inadvertent misidentification and removal of healthy fruit is minimized. Florida growers and shippers, working with federal and state regulators and inspectors, have an excellent track record for effectively adhering to these regulations. In fact, no fresh Florida citrus exhibiting canker symptoms have ever been found in destination markets when regulations prohibited it.

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Besides grading and removal at the packinghouse, another potential approach is to identify and remove fruit with canker symptoms during harvest. While it was believed effective grading during harvest would be difficult under commercial conditions, it was unknown if such capabilities might actually be possible and, if so, at what cost. To address this, experiments were conducted over two seasons (2008–10) to determine if harvesters could effectively and economically separate fruit with canker lesions from marketable fruit. The objectives of the current study were to 1) compare the efficacy of two different grading methods during harvest at correctly identifying fruit with canker lesions (symptomatic fruit), and 2) understand the extra time and/or expense those methods might require.

Materials and Methods

Fruit used in this research was collected from 'Ray Ruby' grapefruit trees located in two commercial groves about 2 miles north of the Indian River Research and Education Center (IRREC) in Fort Pierce. For all experiments, the following three harvesting methods were evaluated:

1. **Current harvest practices without field grading (control)**—fruit were harvested from each tree and placed directly into the harvest bag.
2. **Harvester grading after picking**—fruit were detached from the tree, with the harvester quickly inspecting and placing fruit with canker lesions (symptomatic) into nearby crates on the ground, and fruit without lesions (asymptomatic) into the harvest bag.

3. **Harvester grading before picking**—harvesters quickly looked at each fruit before picking and only harvested those without canker lesions, leaving fruit with lesions on the tree. Afterwards, all remaining fruit were assumed to be symptomatic, removed from the tree, and placed into separate crates.

Two separate experiments were conducted on 24 Nov. 2008 and 26 Feb. 2009. For the experiment conducted in November, a total of 3,300 fruit were harvested by a group of four laboratory personnel who were previously trained in identifying canker lesions on fresh citrus. Each harvesting method described above included five replicates (two trees per replicate).

In Feb. 2009, a total of 6,500 fruit were harvested by four commercial harvesters with an average experience of 20 years each harvesting fruit for the fresh market. These and all subsequent harvests were conducted in a separate 'Ray Ruby' grapefruit grove near the first one and included 12 replicates (one tree per replicate).

During the 2009–10 fresh citrus season, two additional experiments were conducted on 28–29 Jan. 2010 and 1 Apr. 2010. The first experiment utilized two trained laboratory personnel harvesting a total of 5,486 fruit, and the second utilized four professional, commercial harvesters and a total of 5,691 fruit. The commercial harvesters had an average of 5 years of experience harvesting fruit for the fresh market and were led by a supervisor with 18 years of experience.

All trees chosen contained fruit with ample visible canker infections. Professional harvesters were previously trained to detect canker lesions by their supervisor who had been trained by the U.S. Department of Agriculture (USDA) personnel. Only fruit within reach were harvested so that no ladders were used. Only one person harvested each replicate and the time to harvest each replicate was recorded. After completing the experiment, the crew was interviewed to assess how well they thought the methods would work in a practical, commercial setting.

After harvest, the fruit was transported the same day to the postharvest facility at IRREC and stored in crates at 50 °F until washed and coated with carnauba wax containing 1,000 ppm thiabendazole (JBT Corporation, Lakeland, FL). Fruit were evaluated again to determine what fruit were misidentified at harvest. ImmunoStrips® specific for *Xanthomonas citri* subsp. *citri* were used to confirm questionable lesions (Agdia, Elkhart, IN).

The general linear model procedure (PROC GLM, SAS Institute, 2001) was used to analyze the proportion of correctly identified fruit, and means were separated using the least significant difference (LSD). Data were compared using one-way analysis of variance (ANOVA; $P < 0.05$; SAS Institute 2001).

Results and Discussion

Laboratory personnel. Experiments utilizing trained laboratory personnel resulted in significantly greater correct identification of symptomatic fruit both seasons when the fruit was graded after picking, compared to grading before picking (Table 1). This was expected because of the inability to view all fruit surfaces while the fruit was still attached to the tree. Conversely, no significant differences were found in the percentage correct identification of asymptomatic fruit regardless of harvesting method. This could be a case of harvesters erring on the side of catching any potential canker lesions and, thus, being fooled by blemishes resembling canker. In addition, since about 80% of the fruit often were actually asymptomatic, then if the harvester was unable to thoroughly evaluate the fruit, guesses they were asymptomatic were more likely to be correct than guesses they were symptomatic.

Professional harvesters. Laboratory personnel usually had higher percentages of correct identification of symptomatic and asymptomatic fruit for both harvesting methods than was obtained using professional harvesters (Tables 1 and 2). However, the improved discrimination came at a cost, as commercial harvesters completed the tasks in less than half the time required by laboratory personnel (data not shown).

With respect to harvesting method, only during the second season did experiments utilizing professional harvesters result in significantly greater correct identification of symptomatic fruit when grading took place after picking compared to before picking (Table 2). Again, correct identification of asymptomatic fruit was not significantly affected by harvesting method.

Difficulty of correctly classifying fruit during harvest. The percentage of fruit classified during harvest as either symptomatic or asymptomatic during the 2008–09 and 2009–10 seasons are shown in Tables 3 and 4, respectively. The fruit were re-inspected after washing/waxing and the actual percentage of symptomatic and asymptomatic fruit also presented.

Overall, misidentification of symptomatic and asymptomatic

Table 1. Percent correct identification of canker lesions on symptomatic fruit compared to canker-free, asymptomatic 'Ray Ruby' grapefruit by laboratory personnel using two harvesting methods. Fruit "grading after picking" were evaluated for canker after detaching from the tree, whereas "grading before picking" involved evaluating the fruit while hanging on the tree and picking only the fruit with no obvious symptoms of canker.

	Correct identification (%)	
Harvesting method	Symptomatic fruit	Asymptomatic fruit
	Laboratory personnel 2008–09	
Grading after picking	93.1	71.2
Grading before picking	77.2	77.6
Significance	**	NS
	Laboratory personnel 2009–10	
Grading after picking	79.0	92.3
Grading before picking	20.6	94.2
Significance	**	NS

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

Table 2. Percent correct identification of canker lesions on symptomatic fruit compared to canker-free, asymptomatic 'Ray Ruby' grapefruit by professional harvesters using two harvesting methods. Fruit "grading after picking" were evaluated for canker after detaching from the tree, whereas "grading before picking" involved evaluating the fruit while hanging on the tree and picking only the fruit with no obvious symptoms of canker.

	Correct identification (%)	
Harvesting method	Symptomatic fruit	Asymptomatic fruit
	Professional harvesters 2008–09	
Grading after picking	70.8	62.1
Grading before picking	61.4	61.9
Significance	NS	NS
	Professional harvesters 2009–10	
Grading after picking	67.6	90.5
Grading before picking	31.6	92.1
Significance	**	NS

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

Table 3. Percentage of fruit classified during 2008–09 as either having canker lesions (symptomatic) or without lesions (asymptomatic) at harvest and after washing/waxing. Fruit "grading after picking" were evaluated for canker after detaching from the tree, whereas "grading before picking" involved evaluating the fruit while hanging on the tree and picking only the fruit with no obvious symptoms of canker.

Harvesting method	Field evaluation (%)		Washed/waxed evaluation (%)	
Laboratory personnel				
Grading after picking	Symptomatic	44.8	Symptomatic	93.1
			Asymptomatic	6.9
	Asymptomatic	55.2	Symptomatic	28.8
			Asymptomatic	71.2
Grading before picking	Symptomatic	45.4	Symptomatic	77.2
			Asymptomatic	22.8
	Asymptomatic	54.6	Symptomatic	22.4
			Asymptomatic	77.6
Professional harvesters				
Grading after picking	Symptomatic	16.4	Symptomatic	70.8
			Asymptomatic	29.2
	Asymptomatic	83.6	Symptomatic	37.9
			Asymptomatic	62.1
Grading before picking	Symptomatic	33.2	Symptomatic	61.4
			Asymptomatic	38.6
	Asymptomatic	66.8	Symptomatic	38.1
			Asymptomatic	61.9

Table 4. Percentage of fruit classified during 2009–10 as either having canker lesions (symptomatic) or without lesions (asymptomatic) at harvest and after washing/waxing. Fruit "grading after picking" were evaluated for canker after detaching from the tree, whereas "grading before picking" involved evaluating the fruit while hanging on the tree and picking only the fruit with no obvious symptoms of canker.

Harvesting method	Field evaluation (%)		Washed/waxed evaluation (%)	
Laboratory personnel				
Grading after picking	Symptomatic	8.9	Symptomatic	79.0
			Asymptomatic	21.0
	Asymptomatic	91.1	Symptomatic	7.7
			Asymptomatic	92.3
Grading before picking	Symptomatic	11.3	Symptomatic	20.6
			Asymptomatic	79.4
	Asymptomatic	88.7	Symptomatic	5.8
			Asymptomatic	94.2
Professional harvesters				
Grading after picking	Symptomatic	15.5	Symptomatic	67.6
			Asymptomatic	32.4
	Asymptomatic	88.0	Symptomatic	9.5
			Asymptomatic	90.5
Grading before picking	Symptomatic	10.5	Symptomatic	31.6
			Asymptomatic	68.4
	Asymptomatic	89.8	Symptomatic	7.9
			Asymptomatic	92.1

fruit in the field was common with either group of harvesters. During the 2008–09 season when fruit were graded by laboratory personnel after picking, 55.2% (n = 1,007) were identified as asymptomatic, and 44.8% were identified as symptomatic (Table 3). After cleaning, however, 6.9% of the fruit originally classified as symptomatic were actually found to be canker-free, while 28.8% of the fruit originally identified as canker-free actually had canker lesions. When the fruit were graded before picking, so that only fruit thought to be canker-free were harvested, 54.6% (n = 1,326) of the fruit were identified as asymptomatic and 45.4% were identified as symptomatic and left on the tree. After cleaning, however, 22.8% of the fruit originally classified as symptomatic were actually found to be canker-free, while 22.4% of fruit identified as canker-free actually had canker lesions.

The second grove evaluating professional harvesters had lower canker incidence than the first grove that utilized laboratory personnel (Table 3). When the fruit were graded by professional harvesters after picking, 83.6% (n = 2,017) were found to be canker-free and 16.4% were identified as symptomatic. After cleaning, however, it was determined that 29.2% of those fruit originally considered symptomatic were actually canker-free and 37.9% of fruit originally considered canker free actually had canker lesions. When the fruit were graded before picking, 66.8% (n = 2,188) were identified as canker-free while 33.2% were identified as symptomatic and left on the tree. After cleaning, however, 38.6% of fruit originally identified as symptomatic were actually found to be canker-free while 38.1% of the fruit originally identified as canker-free actually had canker lesions.

Results for the 2009–10 season were similar but with slightly less canker infection rates than found in the same grove the previous season (Table 4). When the fruit were graded by the laboratory personnel after picking, 91.1% (n = 1,484) were identified as canker-free and 8.9% were identified as symptomatic. After cleaning, however, it was determined that 21.0% of fruit originally classified as symptomatic were actually canker-free, while 7.7% of the fruit originally identified as canker-free actually contained canker lesions. When the fruit were graded before picking, 88.7% (n = 1,659) were identified as canker-free and 11.3% were identified as symptomatic. After cleaning, however, it was determined that 79.4% of fruit originally classified as symptomatic were actually canker-free, while 5.8% of fruit identified as canker-free actually had canker lesions.

When the fruit were graded by professional harvesters after picking, 88.0% (n = 1,722) were found to be canker-free and 15.5% were identified as symptomatic (Table 4). After cleaning, however, it was determined that 32.4% of those fruit originally considered symptomatic were actually canker-free while 9.5% of fruit originally considered canker free actually had canker lesions. When the fruit were graded before picking, 89.8% (n = 1,518) were identified as canker-free while 10.5% were identified as symptomatic and left on the tree. After cleaning, however, 68.4% of fruit originally identified as symptomatic were actually found to be canker-free while 7.9% of the fruit identified as canker-free were actually found to have canker lesions. Fruit incorrectly identified as having canker lesions and disqualified for fresh fruit markets represents unnecessary lost revenue, whereas fruit with canker lesions that are not detected or removed could represent a quarantine violation if destined for the EU or other markets with canker restrictions.

Interview of professional harvesters. During the 2008–09 season, the professional harvesters commented that it was not common for them to observe fruit with canker symptoms while harvesting a block, but that the frequency of canker had been increasing over the previous two years. The harvesters interviewed in 2009–10 thought the incidence of canker was even higher. The harvesters of both seasons unanimously thought they could

effectively detect symptomatic fruit in the field, perhaps only missing 1% to 5% of symptomatic fruit. In reality, they missed 38% of the symptomatic fruit during the first season (Table 3), and 8% to 10% in the second season (Table 4).

The harvesters from both seasons preferred to be paid by the hour, especially when grading as they harvested, and thought they could accomplish any of the harvesting methods equally well as long as they were paid between $8 to $10 per hour, representing about a 33% to 67% increase in wages compared to what they currently earned.

Time required to harvest fruit using the tree methods. Harvesters in the first season thought that "grade after picking" was more time consuming than "grade before picking" and, indeed, the data showed the former took significantly more time to harvest than the latter (Table 5). Surprisingly, the time required to harvest using the traditional method was intermediate and not significantly different from the other two harvesting methods. During the second season, harvesting the traditional way took the least amount of time, whereas "grade before picking" and "grade after picking" took 60% and 65% longer, respectively. Thus, evaluating the fruit for canker lesions by the harvesters would both increase the per-hour cost, and also likely reduce the amount of fruit that could be harvested per day. For these analysis, fruit left on the tree after the "grade after picking" method were not included and, thus, additional time would be required to harvest the remaining fruit.

Table 5. Mean time (seconds per fruit) required for professional harvesters to harvest a replicate of each of the three harvesting methods. "Traditional" harvest utilized the normal harvesting method without grading. Fruit "grade after picking" were evaluated for canker after detaching from the tree, whereas "grade before picking" involved evaluating the fruit while hanging on the tree and picking only the fruit with no obvious symptoms of canker.

	Time (seconds/fruit)	
Harvesting method	2008–09	2009–10
Traditional	1.52 ab[z]	1.01 b
Grade after picking	1.86 a	1.67 a
Grade before picking	1.27 b	1.62 a
Significance	*	**

[z]Values within each column followed by unlike letters are significantly different by LSD at $P \leq 0.05$.

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

Conclusions

Overall, attempting to remove fruit with citrus canker lesions during harvest, either before or after picking, was not effective. While laboratory personnel tended to be more accurate at distinguishing symptomatic and asymptomatic fruit, they were relatively slow. On the other hand, between 29% to 68% of the fruit professional harvesters thought had canker lesions were actually asymptomatic, while between 8% and 38% of the fruit that they thought were asymptomatic, actually were not. This substantial amount of fruit incorrectly identified as symptomatic represents lost revenue, whereas the 8% to 38% of fruit with canker lesions that were not detected must still be removed at the packinghouse. The extra effort of identifying fruit with canker lesions during harvest would also increase harvesting costs by perhaps 33% to 67% and could increase the time required to harvest the fruit by up to 65%. Results from this research suggest that grading citrus fruit during harvest would not be effective or economic under current Florida conditions. Furthermore, correct identification of canker lesions is impaired by dirt and sooty mold that accumulates on the fruit as the season progresses but is normally washed off during packinghouse procedures. In the packinghouse, most grading takes place after the fruit is washed and while they are rotated under optimum lighting conditions, making the packinghouse grading line the best place to identify and remove fruit with canker lesions.

Results from this study are likely also applicable to other quarantine diseases, such as citrus black spot (*Guignardia citricarpa*), where even small lesions are grounds for rejection at destination markets that prohibit fruit with the disease. However, these conclusions would likely not apply to removing grossly damaged, deformed, or decayed fruit at harvest, as these defects are easy to detect and any efforts to exclude them from entering the packinghouse will reduce expenses and the potential for contaminating healthy fruit during packinghouse procedures. Further work detailing the benefits and costs of such discriminative harvesting techniques is still needed.

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