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Post-harvest dynamics of canker-affected acid lime: Implications for shelf life and market value

Bholanath Mondal[1*], Uttam Mondal[1] and Palash Mondal[2]

[1]Department of Plant Pathology, [2]Department of Agricultural Entomology, Palli-Siksha Bhavana (Institute of Agriculture), Visva-Bharati, Sriniketan, West Bengal, India

** E-mail: bholanath.ppvb@gmail.com*

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ABSTRACT

Citrus canker, caused by Xanthomonas axonopodis pv. citri (Hasse) Vauterin et al., represents a major threat to acid lime (Citrus aurantifolia (Christm.) Swingle) production, significantly impairing fruit quality and reducing marketability. Throughout the year, monthly average market prices for acid lime were recorded across five quality grades (0 to IV). The percentage decrease in market price for grades I to IV, relative to grade 0, was calculated. Standard procedures were used to estimate cultivation costs, and the Benefit-Cost Ratio (BCR) was calculated to assess profitability. Post-harvest keeping quality is crucial for storage, transportation, and obtaining higher market prices. The presence of visible citrus canker symptoms on the fruit surface led to reduced quality and lower prices, with heavily infected fruits fetching the lowest market values. Fluctuations in market prices over the months appeared to correlate with fruit availability, size, and the extent of canker-related lesions. Fruits not infected by the disease exhibited no signs of rotting after 8 days of storage at room temperature. In contrast, infected fruits demonstrated varying levels of deterioration based on their grade. The potential market price loss could be lowered by 14.26% through effective disease management practices, considering only grade 0 fruits in the BCR calculations. This study underscores the post-harvest challenges posed by citrus canker and highlights the need for effective disease management strategies to maintain fruit market value.

Keywords: Acid lime, citrus canker, keeping quality, post-harvest loss.

INTRODUCTION

Citrus crops are susceptible to various diseases caused by fungi, bacteria, viruses, and phytoplasmas. Among bacterial and phytoplasma-related diseases, the most significant include citrus canker (*Xanthomonas axonopodis* pv. *citri*), citrus greening (*Candidatus liberibacter* spp.), blast or black pit (*Pseudomonas syringae*), citrus variegated chlorosis (*Xylella fastidiosa*), Australian citrus dieback (an unidentified prokaryote), stubborn disease (*Spiroplasma citri*), witches' broom of lime (phytoplasma) and abiotic stresses (Anonymous, 2012a; Anonymous, 2012b; Das *et al.*, 2025). Citrus canker is particularly notorious due to its global significance and destructive nature. The disease affects citrus production severely, with intensity influenced by cultivar susceptibility and climatic conditions. It is prevalent in various parts of Africa, Asia, Australia, South America, and recently in some regions of Florida, USA. In India, citrus canker was initially reported in Punjab (Kalita *et al.*, 1996), with subsequent observations in Tamil Nadu, Andhra Pradesh, Karnataka, Rajasthan, Madhya Pradesh, Assam, Uttar Pradesh (Kalita *et al.*, 1996), and later in West Bengal. Among commercial citrus cultivars, acid lime (*Citrus aurantifolia*) is particularly susceptible (Das *et al.*, 2014), and orchards free from infection are exceedingly rare. Yield losses of up to 50–60% have been reported globally due to the disease (Das, 2003). The citrus leaf miner (*Phyllocnistis citrella* Stainton) plays a significant role in spreading and intensifying the severity of citrus canker (Das *et al.*, 2012). In West Bengal, citrus canker has emerged as a major issue, inflicting serious damage particularly on lime and lemon crops. However, limited data exist on its impact in the Red and Lateritic Agro-climatic Zone of West Bengal. This study investigates how varying levels of citrus canker infection impact acid lime's shelf life and market price.

MATERIALS AND METHODS

Assessment of loss caused by the disease: The economic loss due to the disease was assessed by conducting market surveys across various locations, including Bolpur, Sriniketan, Illambazar, Nalhati, Bankura Bazaar, and Manbazar-I. The survey focused on the price received by farmers for marketable acid lime fruits across different seasons. In fruits, citrus canker is recognized by small, raised, corky lesions with a distinct yellow halo and a characteristic crater-like appearance. In severe cases, lesions may coalesce, leading to rough, cracked surfaces and blemishes that lower market quality. Infected fruits may also drop prematurely. Fruits were categorized into five grades based on disease incidence: Grade 0 (no incidence), Grade I (1–5%), Grade II (6–30%), Grade III (31–60%), and Grade IV (61–100%) (Das *et al.*, 2012). During 2013–14 and 2014–15, monthly average market prices for each grade were obtained through unstructured interviews with sellers across various markets, and grade-wise market prices of individual fruits were then calculated. The percentage decrease in market price for Grades I to IV was calculated in comparison to Grade 0. Additionally, the cost of cultivation was estimated using standard procedures, and the Benefit-Cost Ratio (BCR) was calculated to determine the actual profitability.

Studies on keeping quality of canker-infected acid lime fruit: An experiment was conducted in August 2014 and August 2015 at the Laboratory of the Department of Plant Pathology, Palli-Siksha Bhavana (Institute of Agriculture), Visva-Bharati, to evaluate the keeping quality of canker-infected acid lime fruits. Fruits from different disease grades (0 to IV) were collected and stored separately at room temperature (25 ± 1°C). Observations were recorded every two days over an eight-day period, focusing on changes in lesion colour, enlargement of lesions with corky texture, onset of rotting, and fruit decay.

RESULTS AND DISCUSSION

Seasonal and grade-wise fluctuation in acid lime market prices

Table 1 presents a two-year average of monthly market prices (₹ per fruit) for acid lime, categorized by fruit grade (0 to IV). The data revealed significant variation in market prices across both grades and seasons, emphasizing how disease severity and seasonal supply-demand dynamics affect the economic value of the produce.

Grade-wise price variation: As expected, the highest average market price was consistently obtained for Grade 0 fruits (₹3.71), which were free of visual canker symptoms. In contrast, heavily infected fruits classified as Grade IV fetched the lowest average price (₹2.33). The per cent decrease in market price over Grade 0 increases sharply with disease severity: from 6.74% in Grade I to 37.20% in Grade IV (Table 1). These findings align with earlier studies showing that citrus canker significantly reduces fruit quality and marketability due to visible blemishes and consumer rejection (Gottwald *et al.*, 2002; Das, 2003). The presence of external symptoms such as lesions and oozing on the fruit surface appears to influence consumer preference and pricing more than internal quality, particularly in fresh produce markets where visual appeal is critical (Behlau *et al.*, 2010). This highlights the economic importance of managing citrus canker effectively at both pre- and post-harvest stages.

Seasonal price fluctuation*:* Market prices also showed clear seasonal trends, with the highest prices recorded in June (₹4.25) and lowest in November–February (₹2.60) (Table 1). The early summer months (May to July) reflect peak pricing, likely due to increased demand and relatively lower supply of disease-free fruits. In contrast, prices drop during the winter months, possibly due to increased market availability and higher incidence of infected fruits, as disease severity may accumulate post-monsoon. The main fruiting season extends from April to July, with peak harvesting season for mature fruits spans from mid-August to February. Storms during summer promote the spread of citrus canker, which causes visible surface symptoms on fruits. Although the infection does not affect internal fruit quality, visible lesions reduce both market value and consumer appeal, as reflected in the price drop with increased disease severity. These seasonal trends reflect the interplay between supply, disease dynamics, and consumer demand, as also reported by Timmer *et al.* (2000). The market is likely more competitive in off-peak seasons, and fruits showing even minor symptoms are heavily penalized in price. The data show that both fruit grade and season significantly influence acid lime pricing, with citrus canker being a major economic determinant. Effective disease control strategies, along with improved post-harvest grading and storage, are essential to sustain profitability and market competitiveness.

Estimation of cost of cultivation and profitability in citrus Canker-affected acid lime

Table 2 & 3 outlines the economic implications of citrus canker by presenting the estimated cost of cultivation, fruit yield, potential market returns based solely on Grade 0 pricing, and associated profit and loss. This focused analysis isolates the economic impact of disease-induced fruit downgrading.

Cost analysis and yield: The total production cost per 10 acid lime plants per year was ₹9,700.00, including ₹4,300.00 as input costs (e.g., manure, fertilizers, micronutrients, irrigation, herbicides, and plant growth regulators) and ₹5,400.00 as management costs, mostly labour-related activities such as pruning, spraying, and disease monitoring. This investment yielded 7,230 fruits, with the potential for high economic return if all fruits were free from disease symptoms (i.e., Grade 0) (Table 2).

Profit potential based on grade 0 pricing*:* Using the Grade 0 market price of ₹3.71 per fruit (from Table 1), the total potential revenue was ₹26,823.30. Subtracting the production cost of ₹9,700.00, the maximum possible profit would be ₹17,123.30, assuming the entire harvest was of Grade 0 quality (Table 3). However, this is a theoretical maximum. When compared with actual revenue from Table 2 (₹22,997.08), the data reveal a 14.26% loss in potential market value due to the presence of lower-grade (infected) fruits. This loss is directly attributable to citrus canker infection, which affects fruit quality and downgrades market prices significantly (Gottwald *et al.*, 2002; Das, 2003).

Implications for profitability and management*:* If only Grade 0 fruits are considered in BCR analysis, the price loss from lower-grade fruits could potentially be reduced by 14.26%. Benefit-Cost ratio (1.63) was calculated on the basis of profit obtained over the total management cost which indicated that the BCR is quite high (Table 2 & 3). This reinforces the need for effective disease management and post-harvest handling practices, such as sorting, grading, and cold storage, to maintain fruit quality and reduce economic losses (Gottwald, 2000; Schubert *et al.*, 2001). Furthermore, ensuring higher proportions of Grade 0 produce can improve profitability for growers by maximizing returns and reducing the proportion of downgraded, low-value fruit in the market channel. The data clearly demonstrate the dual impact of fruit grade and season on acid lime pricing, with citrus canker being a major economic determinant. Effective disease control strategies, along with improved post-harvest grading and storage, are essential to sustain profitability and market competitiveness. The Benefit-Cost Ratio of 1.63 highlights that acid lime cultivation remains profitable under managed citrus canker conditions (Table 2). However, the economic returns can be further improved by enhancing fruit quality through better disease control and grading practices. The data emphasize the need for growers to invest in integrated disease management strategies, which not only reduce disease incidence but also enhance economic returns by increasing the proportion of higher-grade fruits. The findings from Table 3 clearly indicate that citrus canker causes a measurable economic loss of 14.26% due to fruit quality degradation. By aligning production strategies to favour high-grade fruit output, farmers can recover a significant portion of this loss, thereby improving the overall profitability of acid lime cultivation.

This analysis confirms that the presence of citrus canker directly translates into economic loss, not just through reduced yield but more importantly through reduced fruit grade and market value. If effective management strategies can improve the proportion of Grade 0 fruits, the overall profit margin could increase substantially, justifying the investment in inputs and labour. These include the use of copper sprays, resistant varieties, orchard sanitation, and integrated nutrient management (Timmer *et al.*, 2000; Schubert *et al.*, 2001).

Post-harvest keeping quality of citrus canker-infected acid lime fruits

Table 4 presents a comparative observation of the post-harvest keeping quality of acid lime fruits infected with citrus canker, categorized by grade and monitored over 8 days of room temperature storage during August 2014 and 2015. The findings provide clear evidence of progressive deterioration in fruit quality correlated with the severity of canker infection.

Grade 0 (Healthy fruits): These fruits showed minimal degradation during the 8-day storage period. Colour changes were gradual—from green to light brown by the 6th day, and a dirty brown surface by the 8th day. Notably, internal tissues remained unaffected, highlighting good post-harvest shelf life.

Grade I (1–5% Infection): Slight yellowing appeared by day 2, progressing to lesion enlargement and water-soaked patches by day 6. By the 8th day, rotting began, affecting both surface and internal tissues, indicating a notable decline in storability even at low infection levels.

Grades II to IV (6–100% Infection): These categories exhibited rapid and severe deterioration. By day 4, visible discoloration and softening set in. By days 6 and 8, severe oozing, cracking, and tissue decay were recorded. Grade IV fruits (with 61–100% infection) showed complete decay of internal and external tissues by day 8, confirming their unsuitability for storage or market.

The keeping quality of acid lime is drastically compromised in the presence of citrus canker. Fruits with higher grades of infection deteriorate faster due to the breakdown of rind tissues and internal colonization by the bacteria, *Xanthomonas axonopodis* pv. *citri*. This correlates with existing research that suggests pathogen-induced physiological degradation accelerates post-harvest spoilage (Das, 2003; Graham *et al.*, 2004). The progression from colour changes to full tissue rotting aligns with the characteristic symptoms of canker—lesion expansion, water-soaking appearance, cracking, and bacterial oozing (Gottwald *et al.*, 2002; Schubert *et al.*, 2001). Once lesions compromise the fruit's epidermis, moisture loss and microbial invasion accelerate the decay process, particularly under ambient (room temperature) conditions.

The study has significant implications for storage, transportation, and marketing – (a). Grade 0 fruits retained acceptable post-harvest quality and are suitable for longer storage and distant markets. (b). Lower-grade fruits (I–IV) exhibited poor keeping quality, rendering them economically unviable for storage or transport. These should be either processed immediately (e.g., for fresh juice, concentrated juice, pickle, dried lime products, lime oil etc.) or discarded, as their deterioration increases the risk of cross-contamination and post-harvest losses. This aligns with earlier conclusions (Behlau *et al.*, 2010) that emphasize the importance of sorting and grading at harvest, especially under disease stress, to maintain quality and protect market value.

CONCLUSION

Citrus canker causes significant direct and indirect economic losses in acid lime cultivation. This study clearly demonstrates that citrus canker significantly reduces the post-harvest shelf life of acid lime fruits, especially in moderate to heavily infected grades. Maintaining high-grade fruit quality through pre-harvest disease management is critical not only for market pricing but also for preserving post-harvest value. By projecting profitability under ideal Grade 0 conditions, findings of the paper can serve as a benchmark for farmers and policy-makers.

CONFLICT OF INTEREST STATEMENT

The author declare that she has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Table 1: Fluctuation of market price of acid lime in relation to grade and season

Month	Grade					Month wise avg. market price (₹) per fruit
	0	I	II	III	IV	
	Two years average market price (in ₹ per fruit)					
May	4.50	4.25	4.00	3.50	3.00	3.85
June	5.00	4.50	4.25	4.00	3.50	4.25
July	4.50	4.00	3.50	3.00	2.50	3.50
August	4.00	3.50	3.00	2.50	2.00	3.00
September	3.50	3.00	2.75	2.50	2.00	2.75
October	3.50	3.00	2.50	2.50	2.00	2.70
November	3.00	3.00	2.50	2.50	2.00	2.60
December	3.00	3.00	2.50	2.50	2.00	2.60
January	3.00	3.00	2.50	2.50	2.00	2.60
February	3.00	3.00	2.50	2.50	2.00	2.60
March	3.50	3.50	3.25	3.00	2.50	3.15
April	4.00	3.75	3.50	3.00	2.50	3.35
Grade wise average	3.71	3.46	3.06	2.83	2.33	-
% decrease of market price over grade '0'	-	6.74	17.52	23.72	37.20	-

Table 2: Assessment of Benefit-Cost Ratio (BCR)

Production cost/10 plants			Fruit production (Number) /10 plants						Total market value (₹)/10 plants	Profit (₹)/10 plants	BCR/10 plants
Input cost (₹)*	Other cost (₹)**	Total cost (₹)	Grade wise#					Total			
			Grade 0	Grade I	Grade II	Grade III	Grade IV				
4300.00	5400.00	9700.00	1121	2248	1802	1497	562	7230	22997.08	15767.08	1.63

*Input cost means, Manure ₹ 300.00 + Fertilizers and micronutrients ₹ 2000.00 + PGR ₹ 1000.00 + Irrigation ₹ 600.00 and Herbicides ₹ 400.00 (for 10plants/year), **Other cost i.e. labour cost for different activities at various stages of crop growth, total 30 labours/year/10plants @ ₹ 180/-, #Grade wise average market price for Grade 0-₹ 3.71; Grade I-₹ 3.46; Grade II-₹ 3.06; Grade III-₹ 2.83; Grade IV-₹ 2.33 (Table 1)

Table 3: Estimation of cost of cultivation

Production cost/10 plants		**Total cost (₹)/10 plants**	**Total fruit yield (Number) /10 plants**	**Total Market value (₹) for Grade 0/10 plants**	**Profit (₹)/10 plants**	**% loss over grade 0/10 plants**
Input cost (₹)	**Management cost (₹)**					
4300.00	5400.00	9700.00	7230	26823.30	17123.30	14.26
Average market price for grade 0 – ₹ 3.71/- (Table 1) Total Market value of all grades (0, I, II, III, IV) - ₹22997.08 (Table 2)						

Table 4: Studies the keeping quality of canker infected acid lime at room temperature

Grade	**Scale**	**Days after storing (DAS)**	**Variation of keeping quality**
0	No infestation, fresh lime	2 DAS	No much colour change, become light green
		4 DAS	No much colour change, become light green
		6 DAS	Light brown in colour
		8 DAS	Fruit surface becomes dirty brown, internal tissues were not affected
I	1-5 % infection	2 DAS	Colour become yellowish
		4 DAS	Developed yellow colour
		6 DAS	Size of the lesions increased and become brownish and watery
		8 DAS	Fruit surface becomes deep brown and rotting start including internal tissues
II	6-30% infection	2 DAS	Colour become yellow
		4 DAS	Developed yellowish brown colour
		6 DAS	The fruits become brownish with water soaked
		8 DAS	Huge oozing from deep brown cracky fruit surface and start to rot including internal tissues
III	31-60% infection	2 DAS	Colour become yellowish-orange
		4 DAS	Cankerous lesions become watery and yellowish brown in colour
		6 DAS	Softening of fruit surface and starts to rot
		8 DAS	Decaying of both internal and external tissues of fruits
IV	61-100% infection	2 DAS	Colour become deep yellow
		4 DAS	Lesions become yellow watery and soft
		6 DAS	Huge oozing from cracky surface and rotting start
		8 DAS	Decaying of both internal and external tissues of fruits