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Smallholder Farmer Perceptions of Postharvest Loss and Its Determinants in Fijian Tomato Value Chains

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Abstract: The Fiji Islands, like many small Pacific island nations, are thought to incur high rates of postharvest loss. Little work has been undertaken to quantify the amount of loss within Pacific horticultural value chains, or identify the key determinants. This study sought to quantify postharvest loss within Fijian smallholder tomato value chains and to examine the relative importance of current on-farm practices as possible contributors to this loss. A semi-structured survey of 115 smallholder tomato farmers in Sigatoka Valley and eastern Viti Levu was undertaken, covering socio-economic and demographic parameters, production and postharvest handling practice, and postharvest loss based on farmer recall. On-farm postharvest loss for smallholder farmer tomato value chains was between 26.1% in Sigatoka Valley and 27.6% in eastern Viti Levu. This finding was consistent with quantification of postharvest loss in Fijian tomato chains by direct determination, but is relatively high when compared to smallholder tomato value chain loss in Sub-Saharan Africa. When Fijian tomato value chains were segregated according to specific postharvest handling practice, the contributors to postharvest loss were often associated with on-farm decision-making. Those value chains that only harvested once a week, or in the early morning (before 7 am) or mid-day onwards, stored harvest product in the field for more than three hours, did not sort or grade prior to on-farm ripening, or used packing sheds that had relatively open designs, all had consistently higher levels of postharvest loss. The prevalence of specific postharvest handling practice in both locations is further reported. While this study highlights the impact of current on-farm postharvest handling practices on tomato value chain loss, what remain unclear are the underlying drivers associated with current postharvest handling behaviour and the decision-making that shapes quality and logistic control activities.

Keywords: food security; smallholder farmer; Fiji; agribusiness; postharvest; Pacific; food loss; tomato

1. Introduction

The Fiji Islands, like many developing countries, are thought to incur high rates of horticultural postharvest loss [1–6]. Quantifying this loss at a national level, while useful in terms of providing a basis for wider regional comparisons, is often compromised due to variable production practice, crop-type, seasonality, and socio-economic factors [7–9]. How postharvest horticultural loss is determined, either by farmer recall (i.e., survey-based methodologies) or by direct determination (i.e., physical measurement methodologies), can also influence findings [10]. In the absence of larger longitudinal and multi-sectoral studies that might address such variability, more can be potentially achieved through developing a better appreciation of the determinants of postharvest loss within commodity-specific value chains [7,11].

There have been few published studies of postharvest horticultural loss in Fiji, or the wider South Pacific region. Often, researchers attribute horticultural loss to a series of generic factors such as a lack

of on-farm postharvest infrastructure, limited or discontinuous access to labour, poor transport systems, a lack of a cool chain, and general supply chain dysfunction [1,12–14], reflecting wider thematic challenges experienced by smallholder horticultural farmers elsewhere [12]. There is also a perception that smallholder farmers are often disconnected from the market and consumers, and as a result are poorly informed as to the extent and causes of loss [15]. However, horticultural value chains in the South Pacific tend to be associated with very short transport distances (commonly less than 50 km) [9], involve small volumes of supply [6], with farmer access to good telecommunications services [16,17], and value chains that are often linked to a large network of road-side vendors and regional fruit and vegetable markets [6]. While underlying postharvest practice may be poor, this fast-to-market and possibly rapid market throughput, has the potential to lessen postharvest loss vulnerability. A recent study of postharvest loss in the Solomon Islands reported a range of value chain strategies to reduce potential loss, with farmers and vendors regulating supply volume, avoiding sourcing perishable product from supply chains with challenging transport logistics, and adopting various in-market strategies (such as whole-of-market price discounting periods and local value-adding) to enhance fast market throughput [9]. In the case of Fijian horticultural value chains, the nexus between possible poor postharvest practice and chain operations that are likely to reduce postharvest loss vulnerability is unclear.

This study aims to examine current postharvest handling practices and associated loss for smallholder tomato value chains in Fiji, based on farmer perception. Given that horticultural postharvest handling remediation in Fiji is rarely based on a detailed understanding of existing value-chain operations, the information gleaned from this study should assist in developing more targeted and possibly more effective on-farm postharvest interventions. This study will also aid smallholder farmer's decision making by presenting anticipated levels of postharvest loss associated with various handling practice options. Tomato was selected as the study crop because it is an important commercial horticultural crop in Fiji, and the subject of several prior value chain studies [5,18,19].

2. Materials and Methods

2.1. Location

This study was undertaken in the western and eastern parts of Viti Levu Island, the Fiji Islands (Figure 1). Sampling in the western region of Viti Levu, occurred in the Sigatoka Valley, Nadroga province, the main vegetable production center on Viti Levu. The Sigatoka Valley is often divided into four zones; east bank, lower Valley, mid Valley and upper Valley. Given the focus on developing a broad understanding of postharvest handling practices, sampling was not segregated within the Sigatoka Valley. However, the upper Valley, was excluded from the study as it is largely subsistence-based community gardens and farms [20]. Sampling in the eastern Viti Levu was in Rewa, Naitasiri, Namosi and Tailevu provinces, where there is a concentration of peri-urban and commercial-scale horticultural farmers.

These two study areas incorporated approximately 80% of the commercial tomato production on the Island of Viti Levu [19,21].

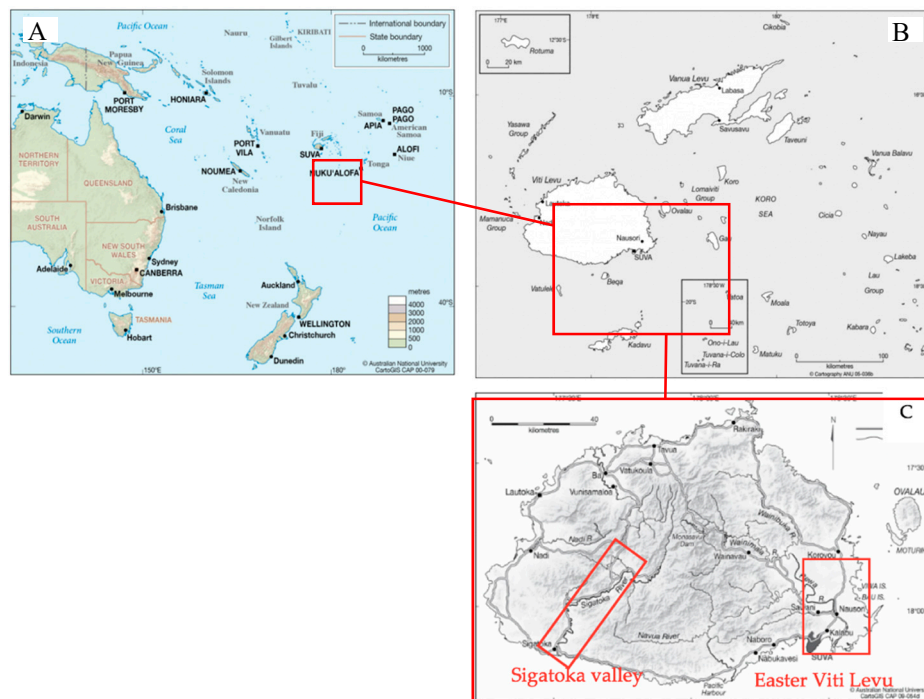


Figure 1. Map of the Fiji Islands. (A) Location of the Fiji Islands relative to countries within close proximity. (B) Map of Viti Levu Island within the Fiji Islands group. (C) Map of the two study sites on Viti Levu where farmer surveys were undertaken. (Map source: CartoGIS Services, College of Asia and the Pacific, The Australian National University, Australia, 2019).

2.2. Survey Design

The survey design was based on a semi-structured questionnaire involving face-to-face interviews consistent with previous reported studies [19]. The study was undertaken between November 2013 and January 2014, with horticultural production volume and on-farm production practices having remained static since this study [21,22]. The sampling period was selected, as it was outside of the normal planting and harvesting cycles. To further reduce external distractions and interference with farmers' routine farm activities, the survey was conducted at midday and during the evenings.

The questionnaire was segregated into 21 components that accounted for all steps associated with production and postharvest handling [23]. Component one involved 28 questions on smallholder farmer socio-economic and demographic parameters. Components two to five had 53 questions concerning production practices, pests and diseases and pre-harvest treatments. Components six to 14 had 79 questions on harvesting, grading, storage, packaging, cooling, transport, and postharvest loss based on farmer recall. The farmers' perception of postharvest loss during each postharvest handling practice was determined. The total postharvest loss was calculated as the sum of pre-harvest loss, harvesting loss, sorting loss, storage loss and grading and packaging loss.

A stratified random sampling technique was adopted which distributes the population into small homogeneous groups (strata), and takes a random sample from each stratum [24,25]. Enumeration areas were based on those used in the Fiji National Agricultural Census [22]. A list sampling frame for commercial smallholder farmers was prepared with the assistance of local crop extension officers and validated with area advisory councilors in each location. List Sampling Frame is one of the three methodologies used for the Fiji National Agricultural Census [22], but this did not identify tomato farmers as a defined sub-group.

To validate responses, interviews were undertaken on-farm to allow for a diagnostic review of potential farm handling practices and infrastructure. Participation was voluntary, undertaken in the local language to ensure participant responses were accurately interpreted, and documented

with prior briefings provided to potential participants outlining the nature and reason for the study. The questionnaire was pre-tested and refined using ten farmers, five from each of the groups.

2.3. Data Collection

A total of 115 smallholder tomato farmers were interviewed in this study, based on 70 farmers in the Sigatoka Valley, and a further 45 farmers in eastern Viti Levu. This sampling represented 60% of the total commercial tomato farmers in the Sigatoka Valley, and 40% of the tomato farmers in eastern Viti Levu [21,22]. Enumerators were used to assist in undertaking surveys. To reduce error and ensure a standard approach was employed in interviewing participants, all enumerators received prior training. All interviews were completed in full compliance with the University of the South Pacific, Faculty Human Research Ethics Approval 6D279-1421.

2.4. Data Analysis

Data was statistically analysed using IBM statistics SPSS 21. Testing for normality using Shapiro–Wilk and Kolmogorov–Smirnov[®] tests was conducted for all the variables to determine whether variables followed a normal distribution. If normally distributed, ($p > 0.05$), analysis of variance (ANOVA) was used for statistical analysis. For variables with more than two groups, a posthoc Tukey test was conducted for multiple comparisons to determine the level of significant difference within the variable group. For one nominal and one ranked variable, if $p > 0.05$, non-parametric (does not meet normality assumptions), a Kruskal–Wallis, Chi square test was used. A Mann–Whitney U test (two independent samples) was conducted to determine statistically significant differences between the variable groups.

3. Results

3.1. Farmer Socio-Demographics and Land Access

Tomato growing in Fiji is dominated by male farmers, representing 62% and 70% of the farms surveyed in the Sigatoka Valley and eastern Viti Levu, respectively (Table 1). This finding is consistent with other studies [19]. The age demographics differed between the two production centers, with most Sigatoka tomato farmers being slightly younger, 35 to 50 years (38%), whereas tomato farmers in eastern Viti Levu, were commonly 51 to 65 years old (47%). Tomato farmers in the Sigatoka Valley had participated in horticultural farming for longer, with 57% of farmers having 21 years or more of experience, and 28% having more than 31 years of experience. In comparison, tomato farmers in eastern Viti Levu had been farming for less time, with only 32% having greater than 21 years of experience. Many of the farmers in eastern Viti Levu identified themselves as being former sugarcane farmers.

Most Fijian tomato farmers resided on or adjacent to their farm, with a mean household size of 4.8 and 4.3 for farms in Sigatoka and eastern Viti Levu, respectively (Table 1). There has been a reduction in household size in the last 30 years, with Chandra [26] previously reporting that the Sigatoka Valley farm households consisted of six to eight persons. A reduced farm household size and aging farmer demographics is anticipated to lead to an increased reliance on hired labour to support farm operations.

The average farm land area was 2.1 and 2.9 ha for Sigatoka Valley and eastern Viti Levu, with those farmers growing tomato allocating 0.8 and 0.4 ha of this land to tomato production, respectively (Table 2).

Table 1. Socio-demographics of Fijian tomato farmers in Sigatoka Valley and eastern Viti Levu.

Socio-Demographic Characteristics	Category	Sigatoka Valley ^z (%)	Eastern Viti Levu ^y (%)
Gender	Male	62	70
	Female	38	30
Age of farmer (years)	<35	23	5
	35–50	38	40
	51–65	37	47
	>66	2	8
Farming experience (years)	<10	22	26
	11–20	23	42
	21–30	29	14
	31–40	22	16
	>41	6	2
Location of place of residence	On-farm	83	88
	Off-farm	17	12
Mean household size		4.8 (2.1) a ^x	4.3 (1.4) b

^z number of farmers surveyed = 65. ^y number of farmers surveyed = 43. ^x Values followed by the same letter within rows were not significantly different ($p < 0.05$) using Levene's test for equality of variances. Values presented in parentheses indicated standard deviation.

Table 2. Land use and access for smallholder tomato farmers in the Sigatoka Valley and eastern Viti Levu, Fiji.

Land Resource	Category	Sigatoka Valley	Eastern Viti Levu
Land use (ha)	Mean area available for cultivation per farm	2.1 (1.3) a ^x	2.9 (2.5) a
	Mean area under tomato production	0.8 (0.3) a	0.4 (0.3) a
Holding (%)	Leased native land	54	45
	Freehold land	38	15
	Leased crown land ^z	8	35
Native land (%)	Leased from i-Taukei land trust ^y	55	67
	Tenancy at will	9	5
	Communal	25	8
	Landowner/tenant arrangement	11	20
	Lease period <5 years	71	63
Crown land (%)	Lease period <5 years	100	40

^z Leased crown land is land owned by the Fijian Government. ^y i-Taukei land trust formally called the Native land trust board. ^x Values followed by the same letter within rows were not significantly different ($p < 0.05$) using Levene's test for equality of variances. Values presented in parentheses indicated standard deviation.

Most of the tomato production in the Sigatoka Valley and eastern Viti Levu was grown on leased native land, 54% and 45%, respectively (Table 2). In the Sigatoka Valley, 38% of tomato production was also sourced from freehold land, with production from crown land (i.e., land owned by the Fijian Government) comparatively minor (8%). This was in direct contrast to eastern Viti Levu where 35% of tomato farmers were sourced from leased crown land. In the last five years only 40% of crown land leases in eastern Viti Levu have been renewed, compared to 100% in Sigatoka Valley. The fact that most of Fiji's tomato production was sourced from short-term native or crown-leased land (i.e., less than 5 years), may have shaped farm demographics, farm practices, and created disincentives for farm infrastructure investment. Challenges in accessing farming land in eastern Viti Levu was anticipated to lead to a further concentration of tomato production in the Sigatoka Valley. In the Sigatoka Valley, especially the mid-Valley region some farmers indicated that they only had one-year

lease agreements, due to non-renewal of long-term leases. A small cohort of Sigatoka farmers (10%) had adopted share-farming with land owners, relatives or friends to ensure commercial farming.

3.2. On-Farm Postharvest Infrastructure

None of the smallholder farmers surveyed had dedicated on-farm postharvest infrastructure (Table 3). Instead, horticultural product was stored or ripened in a range of multiple purpose structures. For tomato farmers, the primary purpose of the postharvest infrastructure was to store product during on-farm ripening. The majority of farmers stored harvested tomato in open sheds (no side walls), with corrugated iron permanent roofs and a concrete floor. Almost a quarter (20 to 25%) of smallholder tomato farmers had no farm infrastructure at all, instead utilizing vacant space within the farm house (often on the verandah). Only 30% to 35% of farmers had multipurpose structures with windows and doors, likely to provide adequate protection to the product during storage.

Table 3. Percentage (n = 108) of Fijian tomato farmers who have on-farm postharvest infrastructure.

Variable	Group	Sigatoka Valley (%)	Eastern Viti Levu (%)
Postharvest infrastructure	Dedicated purpose building ^z	0	0
	Multiple purpose building	100	100
Multiple purpose building			
Structure design	Enclosed shed	20	28
	Open shed	60	47
	Vacant space in farm house	20	25
Roof structure	Corrugated iron (permanent) ^y	91	70
	Corrugated iron (temporary)	9	30
Sidewall structure	No side walls	53	65
	Closed with windows and doors	35	30
	Half-way closed	12	5
Floor structure	Wooden	6	33
	Concrete	82	49
	Bare-ground	12	19

^z Dedicated (sole-use) postharvest building. ^y Roofing material fixed to structure (permanent structure).

3.3. Loss During On-Farm Postharvest Handling Practice

Farmer perception of postharvest loss along the on-farm postharvest handling chain is presented in Table 4. Overall postharvest loss was slightly higher for farmers in eastern Viti Levu compared to those in the Sigatoka Valley, with mean on-farm postharvest loss of 26.1% to 27.6%. Farmers considered that most on-farm postharvest loss was evident during harvesting (7.6% and 8.9%) and following storage (8.6% and 10.1%), for Sigatoka Valley and eastern Viti Levu, respectively. Pre-harvest loss, and loss during harvesting and pre-storage sorting (collectively, 14.1% in Sigatoka Valley and 13.4% in eastern Viti Levu) were likely to be symptomatic of low-intensity and rain-fed production systems. Elevated loss during on-farm storage and packaging (collectively 12.1% in Sigatoka Valley and 14.1% in eastern Viti Levu) were likely to reflect poor harvesting practice and temperature management. Postharvest diseases were particularly prevalent during on-farm ripening and storage, consistent with prior studies [5]. However, the specific postharvest pathogens involved were not determined.

Table 4. Mean percent product loss as a consequence of pre-harvest and postharvest practice.

Product Loss ^z	Sigatoka Valley (%)	Eastern Viti Levu (%)	Reasons for Loss
Pre-harvest	0.4 a ^y	0.1 b	Birds, wind and rain
Harvesting	7.6 a	8.9 a	Pests, diseases, unable to harvest due to rain, soil contact, unsold
Sorting	6.1 a	4.4 a	Insect damage, soft fruits
Storage	8.6 a	10.1 a	Decay, overripe, insect damage
Grading and packaging	3.5 a	4.0 a	Failed to ripe, overripe, blemishes ^x , size
Total loss ^w	26.1 a	27.6 b	

^z Postharvest loss was based on farmer recall. ^y Values followed by the same letter within rows were not significantly different ($p < 0.05$) using Levene's test for equality of variances. ^x The causes of surface blemish (i.e., pest, disease, wind, bird, or poor handling) were not determined. ^w The end-use of product removed from the chain (i.e., possible use as animal feed, compost, family consumption, or refuge) was not determined.

3.4. Postharvest Loss Associated with Specific Types of Postharvest Handling Practice

To examine the potential impact of various postharvest handling practices on overall value chain postharvest loss, all value chains were segregated by location (Sigatoka Valley or eastern Viti Levu) and then by specific postharvest handling practices (i.e., time of harvest, the person undertaking harvest, the number of harvests per week, the amount of time the harvested product remained in the field prior to transport to the packing shed, sorting and grading practices, and packing shed design). Table 4 presents the mean percent postharvest loss, based on farmer recall, experienced by value chains that incorporated specific postharvest handling variables.

The time of harvest was categorized into four periods, early in the morning (before 7 am), morning, midday and afternoon (after 2 pm) (Table 5). Tomato value chains that harvested in the early morning (before 7 am) experienced increased postharvest loss, compared to those harvested after 7 am but before mid-day. This is possibly due to product being harvested wet, as a consequence of early morning dew often experienced in Fiji, increasing the risk of subsequent postharvest diseases. There were no significant differences between very early morning, the middle of the day and late afternoon harvesting. While 38% of the tomato farmers in Sigatoka Valley and 35% of the farmers in eastern Viti Levu harvested in the morning (after 7 am), the majority tended to harvest at times associated with elevated loss (Figure 2A).

The person involved in harvesting the crop had a significant effect on postharvest loss (Table 5). Value chains that used hired labour to harvest the crop experienced significantly greater levels of postharvest loss, compared to those harvested by the farmer-only or farmer and other family members. Interestingly, the inclusion of family members in the harvesting process also increased loss, compared to harvest undertaken solely by the farmer. Most tomato farms in Sigatoka Valley and eastern Viti Levu involved farmer and wider family member participation (Figure 2B). In eastern Viti Levu, only 12% of farmers relied on hired labour (Figure 2B), possibly reflecting smaller land area per farm under tomato cultivation (Table 2).

Value chains that employed more frequent harvesting (two or more harvesting cycles per week), had significantly lower postharvest loss compared to those chains that only harvested once a week (Table 5). This response was consistent for Sigatoka Valley and eastern Viti Levu tomato farmers. Farmers in eastern Viti Levu tended to harvest slightly more frequently (60% of farms harvesting at least two to three times per week), whereas Sigatoka farms tended to harvest weekly (51%) (Figure 2C).

Table 5. Mean percent postharvest loss ^z associated with current postharvest handling practice for Sigatoka Valley and Eastern Viti Levu tomato value chains.

Harvesting and Postharvest Practice	Variable	Mean Percent Postharvest Loss Per Location ^z	
		Sigatoka Valley	Eastern Viti Levu
Time of harvest	Early morning (before 7 am)	30.2 b	31.4 b
	Morning	21.2 c	21.5 c
	Mid-day	28.6 b	28.4 b
	Afternoon (after 2 pm)	29.3 b	32.5 a
Person harvesting	Farmer only	20.1 f	25.1 e
	Hired-labour	30.6 b	36.2 a
	Farmer and family labour	26.0 d	28.8 c
Number of harvests per week	1 harvest per week	9.3 a	10.7 a
	2 harvests per week	7.0 b	7.8 b
	3 harvests per week	4.9 b	6.2 b
Mean time from harvesting to transport to the packing shed	1 h	18.7 d	19.0 d
	2 h	19.9 d	21.9 d
	3 h	22.5 cd	21.9 d
	4 h	26.8 bc	23.9 c
	5 h	29.0 bc	32.8 b
	≥6 h	32.8 b	37.2 a
Sorting undertaken prior to on-farm storage	Yes	22.2 c	26.0 c
	No	30.6 b	34.7 a
Frequency of sorting undertaken during on-farm storage/ripening	Daily	23.3 c	21.5 c
	Every second day	27.2 b	26.7 b
	Every third day	32.8 a	33.6 a
On-farm packing or storage shed design	Open shed (no side walls)	30.2 b	34.6 a
	Enclosed shed	20.8 c	22.2 c

^z Mean postharvest loss was determined by farmer recall based on 115 farmers surveyed. Means with different letters in rows (variable) and columns (location) within harvesting and postharvest practice were significantly different ($p < 0.05$) using Levene's test for equality of variances.

The longer the harvested crop was held in-field prior to being transported to the farm shed or farmhouse, the higher the postharvest loss (Table 5). There was no significant difference in the amount of postharvest loss observed in value chains that harvested and transported product between 1 and 3 h, in either Sigatoka Valley or eastern Viti Levu farms. Value chains where harvested product was held in the field for 4 h had significantly greater postharvest loss (26.8% and 23.9%) compared to chains where product was held in the field for 1 h (18.7% and 19.0%), in the Sigatoka Valley and eastern Viti Levu, respectively. Value chains where product was stored in-field for ≥6 h had 32.8% and 37.2% postharvest loss, in the Sigatoka Valley and eastern Viti Levu, respectively. Eastern Viti Leu value chains with prolonged in-field storage (≥6 h) had 37.2% loss compared to 19% loss when harvested product was transport within 1 h. Delayed in-field storage was common practice with 45% and 46% of Sigatoka Valley and eastern Viti Levu farmers storing product in-field for 5 or more hours (Figure 2D).

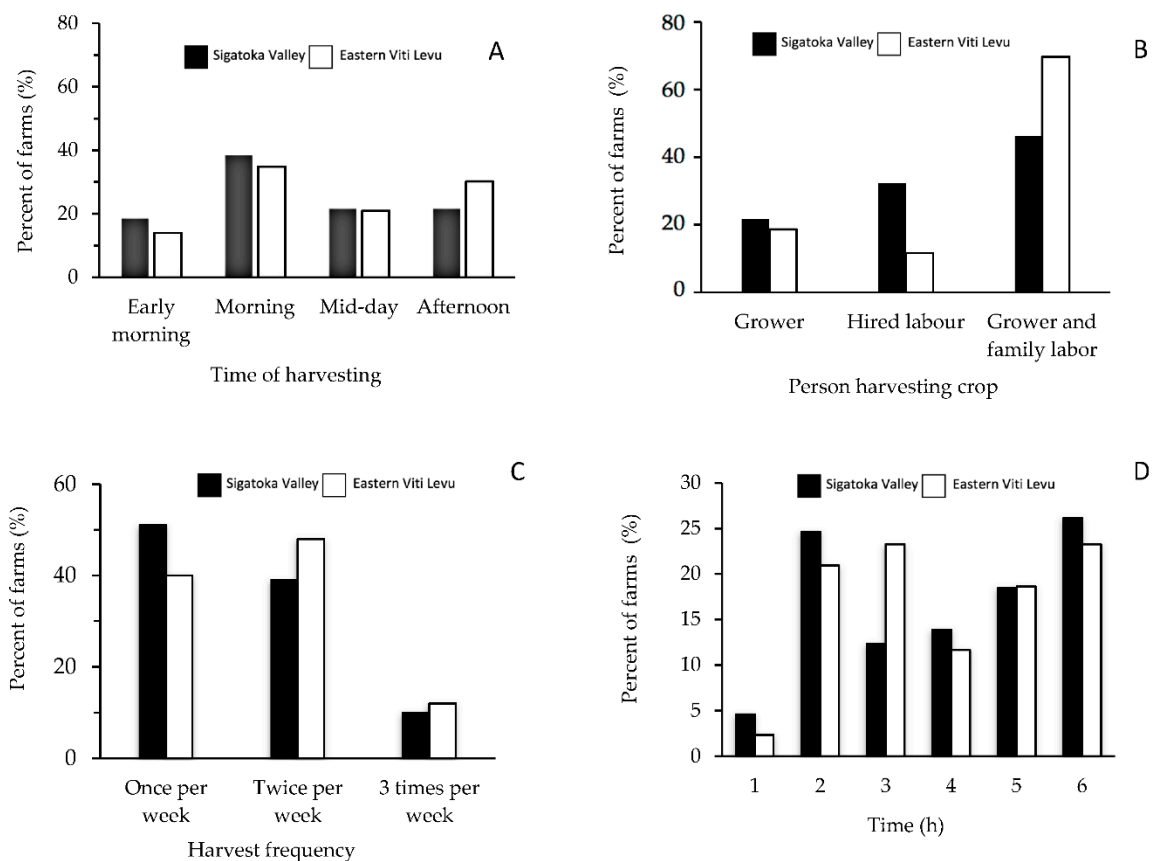


Figure 2. The percentage of Fijian tomato farmers (value chains) in the Sigatoka Valley and Eastern Viti Levu, according to specific harvesting practices used. (A) Time of day that the crop was harvested. (B) The person who undertook the harvesting of the crop. (C) The frequency the crop was harvested per week. (D) The time between when the product (tomato) was harvested and when it arrived at the on-farm packing site (i.e., the delay in transporting the product from field to the farm packing shed or similar on-farm infrastructure to be ripened).

Once product was transported to the farm shed or farmhouse, most value chains (Sigatoka Valley and eastern Viti Levu) undertook some form of pre-storage sorting to remove damaged or poor-quality product (Figure 3A). Value chains that sorted product prior to storage and on-farm ripening had 22% to 26% loss, whereas those chains that did not have significantly higher loss (30.6% to 34.7%, in Sigatoka Valley and eastern Viti Levu, respectively) (Table 5). Most Sigatoka Valley farms (50%) further sorted every 2 days during storage, whereas eastern Viti Levu farms tended to sort every three days (44%) (Figure 3B). Value chains that sorted product more frequently had significantly less overall postharvest loss (Table 5). Sigatoka Valley farms that sorted daily had 23.3% loss, compared to those that sort every three days which had 32.8% loss. A similar trend was observed in eastern Viti Levu farms, with value chains undertaking daily sorting during on-farm storage having 21.5% loss compared to 33.6% loss when sorted every three days (Table 5). Observations during on farm storage and ripening of tomato in the Sigatoka Valley, noted extensive postharvest rots possibly due to poor temperature management. More frequent sorting possibly lessened loss due to avoiding fruit-to-fruit pathogenic cross-contamination.

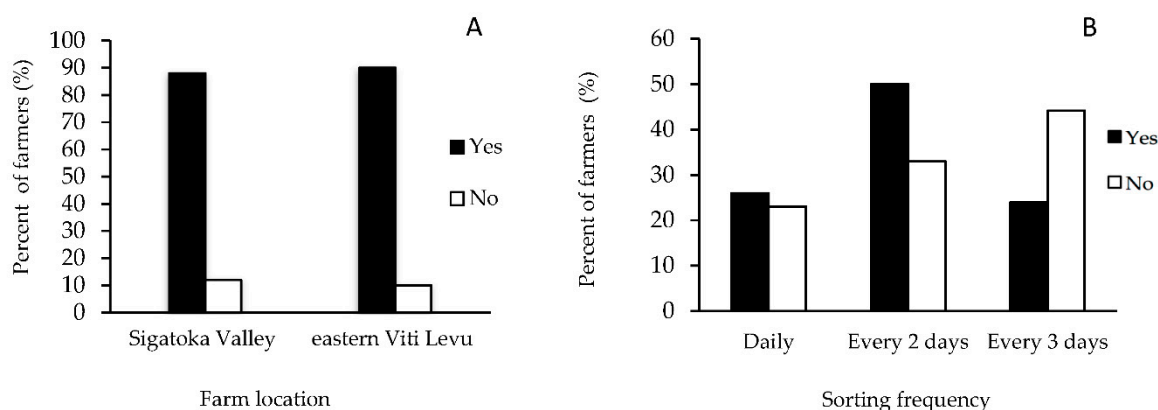


Figure 3. The percentage of Fijian tomato farmers (value chains) in the Sigatoka Valley and Eastern Viti Levu, that employed specific on-farm sorting and grading practice. (A) Farmers that sorted (i.e., removed poor quality or damage product) before on-farm ripening/storage versus farmers that did not pre-sort prior to ripening/storage. (B) The frequency of stored product sorting during the on-farm ripening period.

The type and nature of farm infrastructure used to store tomato during ripening, sorting and packing had a significant effect on postharvest loss. Value chains that used open-sheds (no side walls) had 30.2% to 34.6% loss compared to those chains that used closed and protected sheds, 20.8% to 22.2% loss, in Sigatoka Valley and eastern Viti Levu, respectively (Table 5).

On-farm storage was undertaken to pre-ripen the product before transport to the market. Fijian tomato farmers commonly harvest tomato hard-green to reduce the perceived risk of in-field damage due to pests and disease, with market vendors also selectively purchasing pre-ripened fruit due to limited in-market storage capacity. On-farm storage time is, therefore, highly dependent on the ripening practice, market demand and access to transport. In most of the value chains, product was stored on-farm for 7 days (46% of Sigatoka Valley and 28% of eastern Viti Levu farms) (Figure 4).

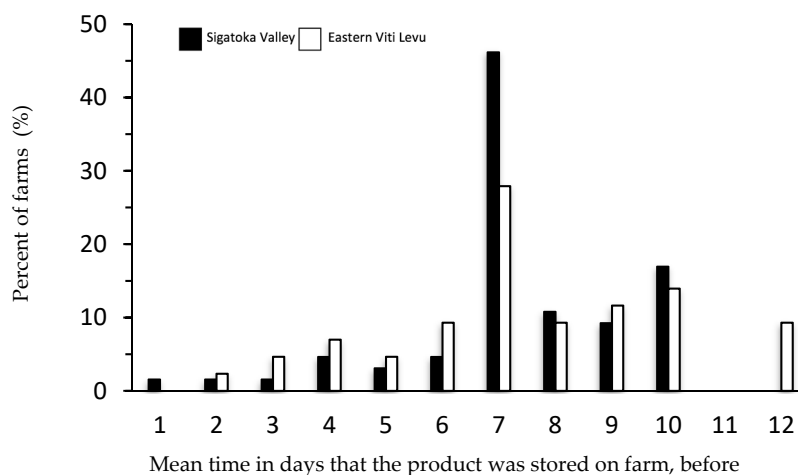


Figure 4. Number of days that product was held on-farm to ripen prior to transport to market, for smallholder tomato farmers in the Sigatoka Valley and Eastern Viti Levu, Fiji.

4. Discussion

On-farm postharvest loss for Fijian smallholder farmer tomato value chains was between 26.1% to 27.6%. This finding is consistent with quantification of postharvest loss in Fijian tomato chains by the direct determination method [5]. This would imply that Fijian smallholder farmers are aware of the extent of their postharvest loss but possibly not the specific determinants, or they lack the physical capacity or economic incentives to remediate against loss. Recent work to quantify smallholder farmer

tomato value chain loss in Sub-Saharan Africa [7,27–29], would suggest this amount of loss was comparatively high, especially given that the current study only included on the farm-component of the value chain, with further loss likely following transport and in-market storage. One notable difference between Fijian tomato value chains and those reported from Sub-Saharan Africa was that the Fijian smallholder tomato chains were almost exclusively oriented towards supplying fresh-product, with little evidence of commercial-scale processing or value-adding [7,19,29]. Limited local processing options effectively negates the capacity of Fijian tomato farmers to redirect second-grade product or surplus supply volumes, elevating the potential risk of postharvest loss.

There were notable differences in the socio-demographics and on-farm practices between and within the Sigatoka Valley and eastern Viti Levu value chains. Smallholder tomato farmers from the eastern Viti Levu region tended to be older, were a more male-dominated cohort, had a smaller household size, had less farming experience, were less likely to use hired labour, and more likely to be reliant on crown land compared to tomato farmers in the Sigatoka Valley. Uncertainties experienced by both Sigatoka Valley and eastern Viti Levu farmers in securing land access possibly impeded their capacity or willingness to investment in infrastructure to improve on-farm storage or handling. While farms in Sigatoka and the eastern Viti Levu were of a similar size (1.8 to 2.1 ha), the average area under tomato production was less in eastern Viti Levu (0.4 ha) compared to (0.8 ha) in the Sigatoka Valley. This may partially explain the greater reliance on hired labour in the Sigatoka Valley farms and the prevalence of slightly more frequent harvesting by eastern Viti Levu farmers. In spite of these differences, mean postharvest loss for Sigatoka Valley versus eastern Viti Levu tomato value chains were relatively similar, but with a slightly higher loss in eastern Viti Levu.

Postharvest handling practices adopted by smallholder farmers had a significant effect on postharvest loss within the value chain. Those value chains associated with farms that only harvested once a week, or in the early morning or mid-day onwards, stored harvest product in field for more than three hours, did not sort or grade prior to on-farm ripening, or used packing sheds that had relatively open designs consistently had significantly higher levels of postharvest loss. These findings are consistent with postharvest studies of smallholder tomato farmer practice elsewhere [7]. Interestingly, value chains that used hired labour to harvest the crop had higher levels of postharvest loss. While this may reflect potential differences in the level of care and attention taken during harvesting, it might also reflect differences in the volume of crop harvested. Intuitively, value chains based on farmer-only harvesting are likely to be associated with smaller crop volumes, which may be more easily harvested and transported, whereas larger crop volumes with more complex harvesting issues are more likely to necessitate additional labor inputs. During field visitations it was observed that the majority of hired-pickers used by Fijian tomato value chains were females. A recent comparative gender-based study of smallholder tomato farmers in Nigeria indicated a significant correlation between female participation in harvesting and elevated postharvest loss [27]. While this study attributed this finding to female farmers taking longer to harvest the crop, the proposed relationship between harvesting time and elevated loss was not explained. The potential for possible gender-based factors within the value chain were not explored in this study, but might be an interesting area of future study especially in the context of behavioral drivers underpinning postharvest handling decision making and practice.

The determinants of postharvest loss identified in this study were consistent with smallholder farmer or small-scale value chain studies elsewhere [7,11,27,30–32]. While there is no doubt the introduction of locally-appropriate postharvest handling infrastructure and equipment would reduce postharvest loss, such interventions can be economically impractical for many Fijian smallholder farmers. Lower-cost interventions, such as the possible introduction of chemical-based strategies aimed at reducing the incidence of postharvest diseases, would be beneficial [5], but need to be considered in the context of wider concerns of excessive agricultural chemical usage in Fiji [33] and smallholder farmer safety [34]. In seeking to improve tomato chain practice in Zimbabwe, Macheke et al. [7] segregated postharvest loss determinations into several categories: context characteristics (i.e., production system and postharvest infrastructure), quality control activities (i.e., postharvest handling practices) and

logistic control activity (i.e., the volume of supply), and proposed that remediation of low-intensity small-holder farmer chains should first focus on quality and logistical control interventions that are low or nil cost, and independent of the need for postharvest chemical treatments. With most Fijian tomato value chains demonstrating poor postharvest temperature management, improving on-farm postharvest temperature practices should be a priority. Interventions based on avoiding excessive field heat due to prolonged in-field storage after harvest [35], combined with harvesting in the morning, would be likely to reduce on-farm tomato postharvest loss in Fiji significantly. However, a limited awareness of good postharvest temperature management amongst Fijian farmers is also likely to impede practice change. For example, some smallholder farmers stored tomato in the full sun as a strategy to shorten the on-farm ripening time (i.e., especially in the early season when prices are atypically high). Moreover, potentially poor information channels between municipal market vendors and smallholder farmers may also result in farmers being unaware of the down-stream consequences of poor on-farm postharvest temperature management.

While evidence of best practices clearly exists in some Fijian tomato value chains, most chains employed comparatively poor quality-control activities. The reasons for this disparity, especially when many of the identified quality control strategies were likely to involve low or nil costs, are unclear. For example, why is it that 22% of Viti Levu value chains decided or were able to limit in-field product storage to 2 h with 21% resultant loss, whereas 23% of farmers in the same location stored product in the field for ≥ 6 h resulting in 37% loss? It is possible that given the comparatively small individual farm area under tomato production, farms were likely producing a range of crops creating conflicting agronomic or postharvest value-chain constraints. Similarly, potential disincentives within the value chain associated with farmers progressively disengaging from the industry due to age-based demographics, limited or insecure land access, difficulties in accessing farm labor, and poor or variable market price, might have created a situation whereby informed decision-making necessitated poor postharvest practices or impeded postharvest handling remediation. Disaggregating the drivers of poor postharvest handling practice remains a key challenge to developing effective smallholder postharvest handling remediation in the South Pacific. Effective postharvest remediation strategies need to be based on a clear understanding of which practices are based on informed commercial decision making (and, therefore, necessitate wider market reform to resolve), or reflect an absence of appropriate infrastructure, labour resources or transport logistics, or are simply due to a limited awareness of the potential adverse down-stream impacts.

While this current study highlighted the likely impact of on-farm postharvest handling practices on tomato value chain loss, and in doing so improves our understanding of the importance of possible on-farm contributors, what remains unclear are the underlying drivers associated with current postharvest handling behaviour and decision-making that shaped these quality and logistic control activities.

5. Conclusions

Farmers were aware of the extent of their postharvest product loss on-farm, but possibly unclear of the specific contributing factors and/or lacked the physical capacity or economic incentives to remediate against this loss. When value chains were segregated according to specific postharvest handling practices, the contributors to postharvest loss were often behavioral or decision-based. In seeking to remediate postharvest loss within Fijian tomato value chains, a better appreciation of the drivers underpinning current postharvest handling decision making and attitudes of smallholder Fijian farmers is now required.

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