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Quantifying postharvest losses along a commercial tomato supply chain in Fiji: A case study

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Abstract

This paper reports on a detailed case study of postharvest losses along a commercial small holder tomato supply chain in Fiji. It is the first systematic quantification of postharvest horticultural losses undertaken in Fiji. Postharvest loss was measured from harvest through to product arrival at the Suva municipal fruit and vegetable markets, with post-municipal market loss determined using simulated storage conditions. In this study, 32.9% of the harvested product was removed from the commercial supply chain due to rots (8.8%), failure to ripen (8.9%), insufficient volume fill a carton (7.8%), physical damage during transport (0.1%) and fruit being over-ripe (6.4%). Poor temperature management during on-farm product ripening and limited on-farm postharvest hygiene were key contributors to the observed loss. In trace-back studies to identify the end-use of all product removed from the commercial chain, of the 32.9% total commercial postharvest loss, 11.0% was consumed at home and/or traded within the village, 6.3% was fed to domestic livestock, and a further 14.7% ended up as on-farm waste or dumped at the municipal refuge. Based on simulated ambient storage condition, once the fruit arrived at the municipal markets, daily postharvest loss thereafter was between 8.3% and 13.4%. Overall accumulative postharvest losses based on three days post-market ambient storage was 60.8%. Postharvest ripening, storage and transport conditions along the supply chain are discussed.

Key words: Pacific, Fiji, supply chain, postharvest horticulture, food wastage, food security.

Introduction

Postharvest horticultural waste is of profound importance in Fiji. While commercial postharvest horticultural supply chains tend to be relatively short, fast and involve comparatively few intermediaries, they are far from efficient. With much of Fiji's horticultural productivity sourced from a large number of small and low-input farms, many located in regions of high transient poverty and social hardship (Narsey, 2007; 2008; Daye, 2012; Pabon *et al*., 2012), resultant postharvest losses can have tangible social and economic consequences.

Paradoxically, there have been very few previous studies undertaken in Fiji that have sought to quantify the level of postharvest product loss. Little is known regarding current levels of postharvest losses, the contributing risk factors, or the resultant food quality, nutrition and food safety implications. While recent work by Bamman (2007), Salvioni (2007), Young and Vinning (2007), Veit (2009), Martyn (2011) and Underhill (2013)have provided a much better understanding of the underlying horticultural supply chain operations in Fiji, most only provide desultory consideration of the underlying postharvest handling system.

Cocker (2000), in his synopsis of postharvest practices in the South Pacific, highlighted capricious supply-chain logistics, poor road infrastructure, with smallholder farmers often disconnected from the market in terms consumer expectations and resultant postharvest loss. Postharvest losses of around 50% have been reported across the region (Cocker, 2000; Chang *et al*., 2008; Lazar-baker *et al*., 2011). While this is consistent with other lesser-developed countries (LDC) (Hodges *et al*., 2011; Kitinoja and Alhassan, 2012; Olayerni *et al*., 2012), in the context of the South Pacific such quantification is simply the subject of informed estimates.

This paper reports on a preliminary assessment of postharvest handling practices of a commercial tomato supply chain on the main Island of Viti Levu, Fiji Islands. The purpose of the study was to quantify resultant postharvest loss along the chain, and using trace-backs studies, identify the resultant the end-uses of product removed from the commercial supply chain. As in-transit damage is often considered one of the primary causes of postharvest loss in the Pacific, we measured the physical risk factors (temperature and vibration) along the transport chain to identify postharvest handling and transport practices that might contribute to observed levels of loss.

Materials and methods

This study was based on a commercial smallholder farm located near the village of Toga (17°58' 45.73" S, 177° 35' 35.96"E) in the mid-western bank of the Sigatoka Valley, on the main Island of Viti Levu, Fiji, supplying tomato (*Solanum lycopersicum* v. Raising Sun No2) into the Suva municipal fruit and vegetable markets. The Sigatoka Valley is the main vegetable production region in Fiji, and the Suva markets, the largest fruit and vegetable municipal market. The farm-to-market supply chain was selected to ensure farm production practices, postharvest storage and handling, and mode of transport to market were typical of the majority of smallholder farmers, based on previous work by the author (Underhill, 2013).

Tomatoes were grown in an open field using a rain-fed production system in the absence of trellising. Product was sourced from a mid-season harvest (August), which represents the peak supply period for tomato in Fiji. The entire harvest (160 Kg) was used in this study. Harvesting and postharvest handling practices were observed daily and recorded.

The incidence of postharvest loss was determined by directly recording the number of fruit removed from the commercial supply chain, from the point of harvest through to the completion of retail trading at the Suva Municipal markets, proportional to the number of fruit initially harvested. Postharvest loss at the Suva municipal market was not directly measured with data obtained by interviewing the relevant wholesale traders the following day. To validate postharvest loss at the Suva market and to quantify post-market potential shelf-life, a sub-sample of 1000 fruit was obtained immediately on arrival at the market and stored for four days at ambient temperature (22-28°C consistent with market storage conditions). Tomato was assessed daily for the presence of postharvest rots and physiological breakdown. Product was deemed unsalable (*i.e.* loss) based on visual appearance (physical abrasions, puncture, size and shape), softness, or pathogenic deterioration at the Suva municipal markets. Where product was removed from the commercial supply chain, trace back studies were undertaken to identify the end-use of product (*i.e.* home use, animal feed, municipal wastage).

Temperature during on-farm storage and ripening was measured using Tiny Tag Tansit-2 temperature loggers (Gemini Data loggers, United Kingdom). Mean fruit core temperature were assessed using a EcoScan Temp 5 with thermistor probe (Eutech Netherlands) based on continuous sub-sampling of the same 20 fruit. Road transport conditions from the farm to the Suva municipal market were assessed by recording the temperature and the incidence and intensity of vibration every two sec using a Tiny Tag Tansit-2 temperature logger and a Tiny Tag TGG-0650 vibration (0-50mm/s) logger. Temperature and vibration loggers were located in the centre of the cartons during transport and in the case of temperature loggers, centrally within the fruit load during on-farm ripening. Truck speed and route were concurrently recorded every two seconds using a Super Trackstick® Telespial Systems Inc California with global position system (GIS) referencing uploaded onto Google Earth™. All loggers and global positioning equipment were time synchronized to allow a spatial and temporal cross-referencing of truck speed, temperature and vibration data.

Results

Commercial postharvest handling of tomatoes resulted in significant wastage. In the present case study, between the point of harvest and arrival at the municipal markets, 32.9% of the harvested crop was removed from the commercial supply chain (Table 1). Most of this loss occurred on-farm, with 25.5% of the harvested crop not entering the commercial-supply chain (Table 1). Postharvest loss was primarily due to postharvest pathogens, and based on visual diagnosis appeared to be caused by one or more of the following diseases: yeast rot (*Geotrichum candidum*), anthracnose (*Colletotrichum coccodes*) and penicillium rot (*Penicillium spp.*) (E. Lazar–Baker, 2013 pers. comm).

During on-farm ripening, mean tomato core temperatures of 28.4 °C were recorded in the product placed in partial shade, and 39.1°C in product left in the full sun. Fruit were often covered with a thick plastic sheet during ripening, presumably in an attempt to speed up the ripening process, with temperatures under the plastic sheeting reached 63 °C (Fig. 1). As most farmers don't use postharvest fungicides, fruit deteriorated rapidly. Fruit sorting and removal of rotten fruit was only undertaken during final packing into plastic crates, 24 h prior to transport to the municipal markets. After five days from harvesting the woven mats on which the fruit were ripened were saturated with decaying fruit residue. Fruit were not washed prior to packing. It could be observed that the spatial distribution of rotten fruit within the

Table 1. The percentage of total harvested crop removed from the commercial supply chain and its associated end-use. Additional postharvest losses associated with municipal market storage based on simulated ambient storage

Postharvest descriptor	Crop wastage (%)	End use
On farm (after harvest)		
Postharvest pathogens (rots)	8.8	On-farm refuge
Failed to ripen (at time of packing)	8.9	Multiple use[b]
Not commercially traded[a]	7.8	Home/community use
Unaccounted	0.9	
Transport to market		
Physical damage (abrasion or punctures)	0.1	Municipal refuge
Municipal markets		
Over-ripe[d]	6.4[e](7.2)[f]	Municipal refuge[c]
Total amount of product not commercially traded	32.9	
Simulated storage (postharvest losses each day)		
After 1 day Postharvest pathogens	8.3	
After 2 days Postharvest pathogens	6.2	
After 3 days Postharvest pathogens	13.4	
Anticipated total commercial postharvest wastage harvest after 3 days post market (inclusive of on-farm to market wastage)	60.8	

[a]Product not commercially traded as quantity too small to fill the standard 25-kg crate
[b]Multiple use = 64% fed to chickens and 35% home and/or local community use
[c]Municipal refuge also incorporates wastage subsequently used for commercial animal feed (pigs)
[d]The term "overripe" was used by the trader and is anticipated to reflect postharvest disease
[e] Municipal market wastage based on interviewing the vendor
[f]This value represents wastage following 24 h simulated municipal market storage (validation of vendor estimation)

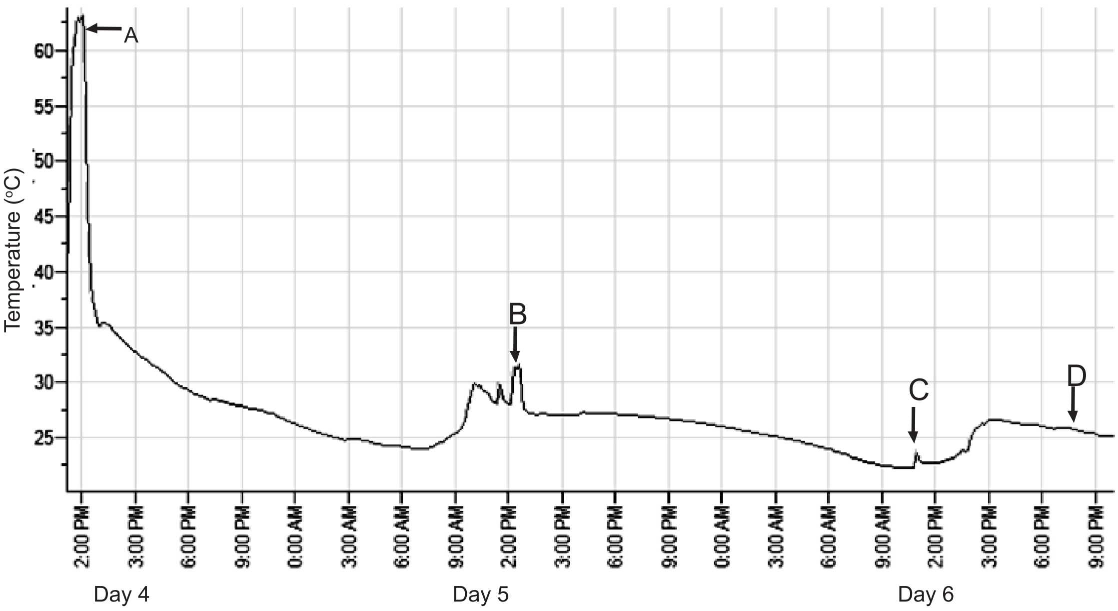

Fig. 1. Storage temperature along the supply chain, based on air temperature within the centre of the consignment (A) during on-farm ripening (fruit being ripened under plastic sheeting in partial sun) (B) fruit sorted and placed in plastic crates (C) consignment departs farm (D) consignment arrives at the Suva market.

consignment and the prevalence of initial visual symptoms at the fruit-to-fruit contact points were consistent with extensive cross-contamination. Collectively, 8.8% of the harvested crop was not packed due to pathogen spoilage (Table 1).

A further 8.9% of on-farm postharvest wastage was incurred through product failing to ripen prior to packing, with partially ripen or unripe tomatoes not commercially traded (Table 1). At completion of product sorting and packing there was insufficient remaining fruit to completely fill the 25-kg plastic crates used to transport product to market. This fruit was traded within the community and incorporated in home use (Table 2), representing an additional 7.8% of the crop being removed from the commercial supply chain (Table 1).

The commercial transport chain between farm and the central Suva market was 136.1km, taking 8 h 15 min and inclusive of 15 stops (Fig. 2, Table 3). Considering the road conditions between the farm and the Suva market, especially the initial section through the middle Sigatoka Valley, there was an expectation of considerable in-transit postharvest damage. However, evidence of physical damage to the product (*i.e.*) immediately following arrival at the market was negligible (Table 1). Moreover, post-market simulated storage also failed to detect any evidence of bruising or impact damage.

Assessment of road condition, based on vibration and truck speed, highlighted a series of segments of the transport chain where the consignment was subject to high intensity and high frequency vibrations events (Table 3). GIS-synchronized data loggers, enables individual vibration events to be spatially mapped along the transport route. The initial 5.1 km journey between the farm and Quanasau, incurred a large number of medium intensity vibration events; however, most vibration loading was recorded in the 6.3km segment between Nawalcoba and the Vulo Road works (Sigatoka Valley Road). Much of the recorded vibration events were associated with small sections of road that had been damaged by previous flooding, and high-use road junctions or where the road was currently undergoing repairs (Fig. 3). As expected there was a notable reduction in vibration events where the road was sealed, or where the dirt road had recently been graded.

Table 2. End-point use of tomatoes removed from the commercial supply chain

End use of non-commercially traded product	Crop wastage (%)[a]
Home use and intra-community traded	11.0
Feed to domestic livestock (pigs and chickens)	6.34
On-farm and municipal refuge (non-composted)	14.69
Product end use not identified	0.9
Total product removed from the chain	32.93

[a]Values expressed as a percentage of total crop harvested

On arrival at the Suva market, fruit were held on the truck overnight and off-loaded the following morning. Fruit were then sorted by the market trader, held at ambient conditions throughout (22-28 °C) and all sold within 36 h of arriving at the markets. At point of first commercial trading a further 6.4% of the product was rejected by the market vendor due to being “over-ripened” (Table 1). Market vendor wastage was not directly measured, but was based on information provided by the market vendor. Simulated market storage for 24 h (Table 1) resulted in comparable levels of postharvest losses (7.2%), all of which was due to postharvest disease.

Postharvest storage and transport temperatures were assessed throughout (Fig. 1). While the supply chain had no capacity to incorporate any form of pre-cooling or cold chain management, poor on-farm postharvest practices elevated postharvest temperature risk. Postharvest ripening practices, where fruit were left in the full sun or partial shade or under heavy plastic sheets, resulted in fruit being unnecessarily exposed to high temperatures (Fig.1). When combined with poor on-farm hygiene, poor temperature management during ripening is thought to be the underlying cause of much of the observed postharvest wastage. In comparison, the temperature within the crates during transport to the municipal market did not exceed 26 °C. Strategies to reduce and manage field heat were absent throughout the supply chain. For example, the partially loaded truck (*i.e.* tomatoes were loaded first) was left in the sun for around 6 h as other crops were harvested and loaded.

As postharvest supply chains in Fiji are often disrupted due to unreliable transport or road closures, it is important to determine the postharvest shelf-life resilience of the product. Simulated storage of the tomatoes at ambient temperatures for a further one, two, and three days after fruit were sold at the market, resulted in a daily postharvest loss of 8.2, 6.2 and 13.4%, respectively (Table 1). When combined with pre-market wastage, an additional three days of post-market-storage would have led to 60.8% of the harvested product being removed from the commercial supply chain.

There is evidence of significant volume of rejected product being re-used within the local community or as animal feed. Based on trace-backs studies of the 32.9% of harvested product that was removed from the commercial supply chain, 11.0% was re-incorporated in home use and intra-community trade, 6.3% was fed to domestic livestock, and a further 14.7% ended up in non-recycled on-farm or municipal refuge (absolute wastage) (Table 2). The 6.3% domestic livestock use can be further disaggregated, with 5.7% used on-farm for chicken feed and 0.64% sourced from the Suva municipal market by local pig farmers. All of the rejected rotten (mature-ripe) tomatoes ended up as general refuge with no intent for compost or subsequent livestock use. Conversely, of the product that failed to ripen, 64% was used on-farm as animal feed (chicken) and 35% was used for home or community use. The present study was unable to account for 0.9% of the end-point use of the commercial wastage.

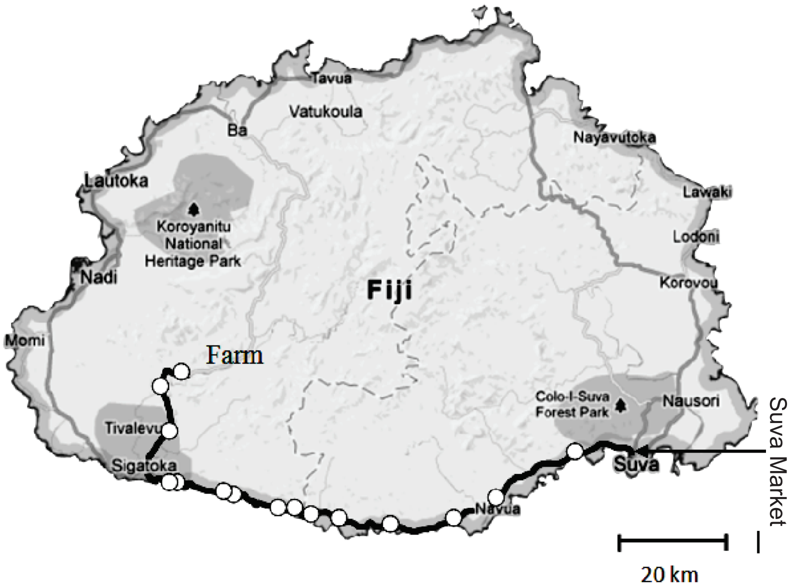

Fig. 2. The island Viti Levu, Fiji, showing the commercial supply chain from the farm in the mid-western bank of the Sigatoka Valley to the Suva municipal fruit and vegetable markets. All in-transit stops >1 min (O) are shown. (Map source: GoogleMap™ with Super Trackstick® Telespial Systems GIS data overlays.)

Discussion

While observed rates of tomato postharvest loss are concerning, they are not unexpected and in fact highly consistent with recently reported analogous vegetable supply chain studies in other LDC (Maheshwar and Chanakwa, 2006; Weinberger *et al*., 2008; Buntong *et al*., 2013). In Fiji, and elsewhere across the Pacific, a significant portion of this wastage is thought to be end up as domestic livestock feed. Based on trace-back studies undertaken, livestock (primarily chickens and pigs) re-use was comparatively small, with most of the product that was removed from the commercial supply chain ending up as on-farm or municipal refuge or incorporated in intra-community home consumption. When we account for alternative re-use of the product, 14.7% of the harvested crop can be considered postharvest loss. It is important to highlight that the portion of absolute wastage to domestic livestock end-use will vary between crop types and time of year. For example, cabbage wastage is preferentially sourced from the Suva market refuge bins by local pig farmers, whereas over the summer months when general vegetable supply is limited, sourcing from Suva market tends to be absent or highly sporadic. The present study did not seek to quantify post-retail wastage or further segregate product end-use associated with intra-community trading.

Poor road infrastructure, product handling and consignment loading have been shown to be major contributors to postharvest loss in other LDC's (Tomlins *et al*., 2000, 2002; Sahay and Mohan, 2003; Aba *et al*., 2012). While we found negligible in-transit physical damage to the product in this case study, this does not imply that existing road infrastructure is not an issue in Fiji, nor that postharvest quality is not adversely influenced by in-transit conditions. A significant number of high intensity vibration events were recorded along the transport chain, most of which were restricted to relatively small portion of the western bank Sigatoka Valley road. Road infrastructure in Fiji is comparatively poor with more than half of Fiji's 3, 440km road network unsealed

Table 3. Postharvest logistics between the farm and central municipal fruit and vegetable markets in Suva, indicating road conditions, truck speed, and the number and intensity of vibration events

Sections of the transport	Road type	Distance (km)	Average speed (km/h)	Total number of vibration events (>20mms/km)	Number of high intensity vibration events (>40mms/km)
Farm (Toga) to Quanasau Ck	Unsealed[a]	5.13	21.28	12.09	0.78
Quanasau creek to Nawalcoba	Sealed	0.95	24.13	1.05	0.00
Nawalcoba to lower Bilalevu	Unsealed[a]	2.74	26.75	18.25	2.55
Lower Bilalevu to Vulo	Unsealed	2.58	23.37	19.38	2.33
Vulo road works (VRW)	Unsealed[b]	1.01	31.18	14.85	3.96
VRW to Nacocolevu	Unsealed[b]	5.47	30.76	10.42	0.73
Nacocolevu to Sigatoka town	Unsealed[c]	3.45	27.60	3.77	0.00
Sigatoka to Vatukarasa	Sealed[d]	11.28	32.09	1.15	0.00
Vatukarasa to Tagaqo	Sealed[d]	5.71	35.89	2.80	0.00
Tagaqo to Komare	Sealed[d]	12.04	34.43	1.33	0.00
Komare to Naboutini	Sealed[d]	5.97	25.59	2.68	0.34
Naboutini to Suva	Sealed	79.80	32.60	0.02	0.00
Totals		136.13			

[a]dirt road in poor condition
[b]dirt road undergoing extensive road works
[c]dirt road that has been graded
[d]sealed bitumen road with a large number of speed bumps associated with adjacent community settlements

(Agrawala *et al*., 2003). The major horticultural transport-routes down the east and west banks of the Sigatoka Valley are under constant repair and often inaccessible in poor weather.

The apparent absence of physical in-transit damage observed in this study is attributed to load configuration, the use of plastic crates and relatively short transport distances. The importance of load configuration and stack height in terms of resultant fruit damage has been well documented in the literature (Shahbazi *et al*., 2010). In Fiji, trucks commonly transport multiple crops sourced from several farms. Tomatoes are placed at the front of the consignment where vibration and impact loading is known to be less severe (Shahbazi *et al*., 2010), with product such as cabbage and eggplant placed at the rear. In practice such load configurations simply reflect the fact that more bulky product tended to be packed in-field and therefore loaded last, rather than any purposeful placement of the product to reduce damage.

The potential benefit associated with smooth plastic field crates to transport the fruit, coupled with a comparatively short transport route, is consistent with findings in other LDC tomato supply chains (Aba *et al*., 2012; Bishop and Ramma, 2012; Buntong *et al*., 2013). The use of plastic crates to transport horticultural produce is not common in Fiji due to their relative expense and often restricted to those chains where there is a strong underlying farmer-to-market trader relationship. In the chain studied they actually represented a low-cost alternative for the farmer negating the need to purchase additional packing. The farmers' direct participation in the transport chain thereby assuring plastic carton return and re-use being critical. Where farmers in Fiji take a less active role in the supply chain, through direct on-farm trading or the use of trader-intermediaries, alternative packaging such as small wooden boxes, plastic sacks or thin carbon cartons are far more prevalent. Such packaging options are known to be more prone to in-transit movement or in the case of cardboard cartons highly susceptible to collapse.

The current commercial practice in Fiji of transporting pre-ripened tomatoes needs to be considered also. While previous studies on tomatoes have demonstrated underlying sensitivity to vibration and impact stress loading (Assi and Ahrens, 1992; Lee *et al*., 2007; Shahbazi *et al*., 2010; Mutari and Rees, 2011), the stage of fruit ripeness can influence the degree of resultant damage (Olorunda and Tung, 1985; Sargent *et al*., 1992). Mature hard-green tomatoes tend to be less sensitive to vibration stress than breaker-stage tomatoes (Sargent *et al*., 1992), however, with further ripening a reverse effect has been reported (Lee *et al*., 2007). Lee *et al*. (2007) attributed this partial tolerance in more advanced ripening stages to reduced postharvest fruit turgidity, with Olorunda and Tung (1985) also highlighted the additional benefit of low-level in-transit compression. Under elevated or prolonged mechanic stress loading associated with simulated or protracted LDC tomato supply chains (Olorunda and Tung, 1985; Aba *et al*., 2012), there is no evidence that pre-ripened fruit has any benefit in terms of resultant in-transit mechanism damage; in fact the evidence is more to the contrary. However, in the context of the very short intra-island transport chains seen in Fiji (*i.e.*<130 km), the possibility of on-farm ripening having some contributory benefit in terms low in-transit damage cannot be excluded.

Table 4. A preliminary assessment of potential *E. coli* risk on bulk tomato samples commercially sourced from the Suva municipal markets

Level of *E. coli* detected (MPN/100g)	Percent of tomato samples[b]
0-30[a]	53
30-50	20
50-100	13
100-300	13

[a]Levels considered equivalent to a nil result.
[b]n=3, data sets are too small to statistically analyse, but are included to highlight the need for further work.

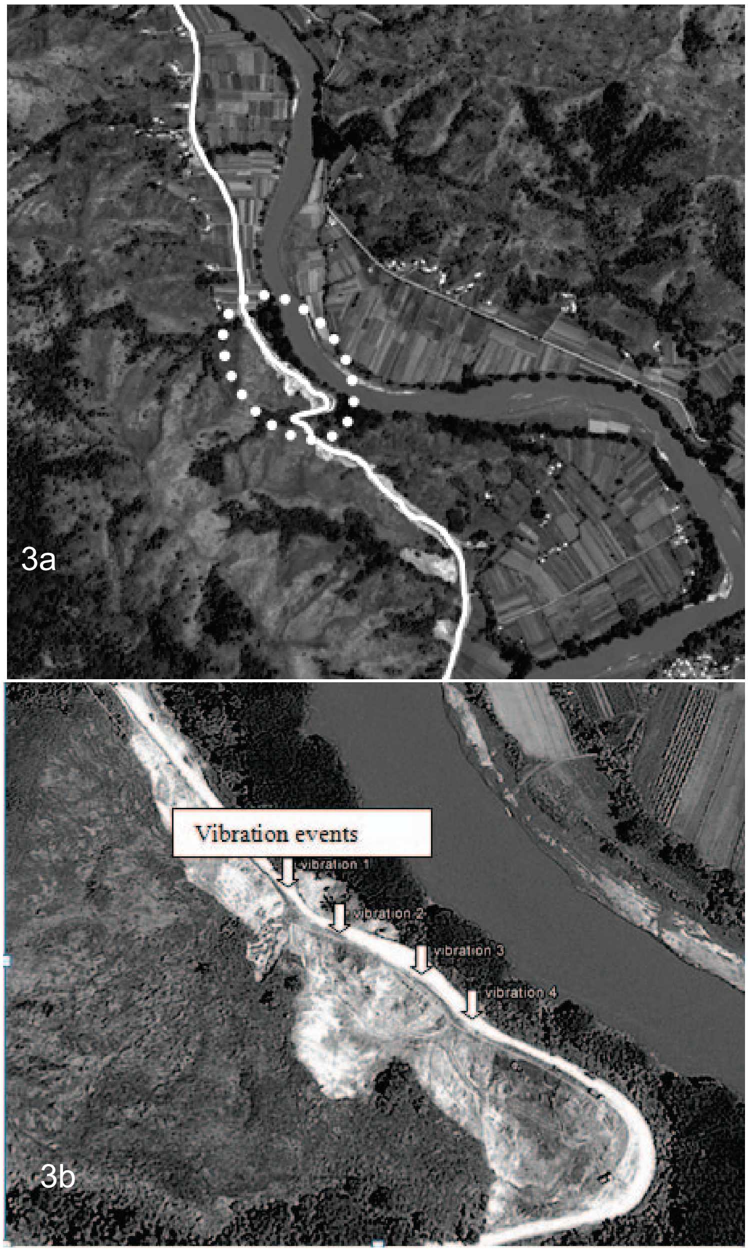

Fig. 3a. Aerial image of the truck transport route taken down the Sigotoka valley road highlighting the Vulo road works (VRW) where the largest number of high intensity vibration events was recorded (see Table 3).

Fig. 3b. Illustrates a magnified view of the VRW, with arrows indicated the specific location of each vibration event >40mm/s.

(Map source: Google Earth™ with Super Trackstick® Telespial Systems GIS and vibration event data overlays).

In seeking to remediate postharvest wastage in LDC horticultural supply chains there is often a tendency to simple focus on addressing poor postharvest handling practice. Equally important is the need to gain an appreciation of why such practices exist in the first place and their associated drivers and resistors. Inadvertent beneficiary behaviour by supply chain participants as well as product characteristics that influence underlying postharvest robustness, while far more difficult to identify need to be considered. Understanding the inter-relationship between pre-existing postharvest handling practices and the structural and operational functionality of the supply chain is therefore critical if effective and sustainable interventions are to be developed and adopted. Postharvest LDC horticultural chains are by definition inherently impeded in their capacity to absorb risk (Angelucci and Conforti, 2010), being economically fragile in nature and often operating in the context of high social disadvantage. It is important to ensure potential interventional strategies to improve LDC horticultural supply chains which are not only highly compatible with the existing chain dynamic but also highly targeted and tailored.

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