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ORIGINAL PAPER

Horticultural postharvest loss in municipal fruit and vegetable markets in Samoa

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Abstract Reducing horticultural postharvest loss is a priority in Samoa, due to declining agricultural productivity and wider dietary-based health concerns within the human population. Efforts to remediate loss is currently impeded by little information about the current levels of horticultural loss in Samoa or the factors contributing to this loss. In this study we quantified commercial postharvest loss of 23 horticultural crops at the Fugalei central municipal market on the Island of Upolu, Samoa, using direct weighing. Mean postharvest loss was further determined in all six municipal, community and private fruit and vegetable markets on the Samoan Islands of Upolu and Savai'i using vendor and farmer-trader surveys. Postharvest horticultural loss in the Fugalei municipal market was 6.2% (determined by weight) and 13.3% (based on vendor recall). There was no significant difference between mean postharvest loss in fruits compared to vegetables. The highest level of daily postharvest loss (5% to 22%) was observed for soursop, papaya, Tahitian lime, mustard cabbage and choko. Negligible loss (<1%) was observed in limes, vi (*Spondias dulcis*), eggplant, long bean, soa'a (plantains), lemon, cherry tomato, cucumber, pumpkin and ginger. The level of postharvest loss varied across the municipal, village and road-side markets surveyed, with higher losses in non-urban markets. There was no difference in the level of postharvest loss between any of the three urban markets in the Apia region. With most horticultural production located less than 20 km from the municipal market and little evidence of in-transit damage, transport logistics were unlikely to be an important contributor to loss. We believe low or sporadic consumer purchasing behaviour resulting in protracted market storage at high tropical ambient temperatures was the central contributor to observed losses. The potential importance of low consumer purchasing activity and the proportion of commercial vendor to transient farmer-trader in each of the markets is discussed in terms of being possible contributing factors to the resulting levels of postharvest loss and market variability.

Keywords Food security · Postharvest loss · Food waste · Municipal market · Samoa · Pacific · Horticulture

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1 Introduction

Postharvest horticulture loss in less-developed transitional economies has received increasing attention in recent years from the perspective of benefits to food and nutritional security, and development of rural livelihoods (Kader 2004; Parfitt et al. 2010; Hodges et al. 2011; Kitinoja et al. 2011; Kitinoja 2013; Mohammed 2014; Affognon et al. 2015). In seeking to quantify and remediate postharvest loss, much of the current academic literature has focussed on sub-Saharan Africa and

the Asian region (Weinberger et al. 2008; Kitinoja and AlHassan 2010; Mashau et al. 2012; Oelofse and Nahman 2013; Kaminski and Christiaensen 2014). The combination of high levels of horticultural loss and social disadvantage that can translate into significant population impact, justifies such attention (Mwaniki 2006; Brown et al. 2009).

In comparison, very few studies have documented postharvest loss in the South Pacific. Pacific horticultural value chains are predominantly structured around smallholder and semi-subsistence farmers employing low-intensity production systems. Postharvest handling infrastructure is commonly inadequate, with farmers and market vendors often constrained by limited postharvest capacity and knowledge (Veit 2009; Fink et al. 2013; Underhill 2013; Underhill and Kumar 2015). It is not surprising then, that postharvest loss is considered to be too high (Cocker 2000; Veit 2009; Lazar-Baker et al. 2011). In one of the few recent studies undertaken in the South Pacific region, postharvest loss in municipal markets in Fiji was shown to be between 2.5% and 10% (Underhill and Kumar 2014). Comparatively low postharvest loss in this study was attributed to short intra-island transport distance coupled with rapid market throughput. Given no comparable studies elsewhere in the region, it is unclear whether such losses and associated contributors are atypical or representative of the wider Pacific region.

Postharvest loss is of particular importance in Pacific Polynesia Island nations such as Samoa. High rates of non-communicable diseases (NCD) that are symptomatic of transient dietary patterns away from the consumption of fresh fruit and vegetables (Seiden et al. 2012; Ichiho et al. 2013), declining smallholder participation in agriculture (Samoa Bureau of Statistics 2009), and a greater reliance on food imports (McGregor et al. 2009), have collectively focussed attention on the need to improve horticultural productivity and postharvest handling efficiency. The South Pacific region now has one of the highest rates of obesity and diabetes in the world, with NCDs accounting for more that 70% of all deaths in the region (Tuitama et al. 2014; Hawley and McGarvey 2015). In an attempt to revitalise the horticultural industry and achieve pro-health outcomes, the Samoan Government launched the *Fruit and Vegetables Development Strategy for Samoa* in 2009. Reducing postharvest loss was identified as a core priority. The lack of information as to the extent of current commercial horticultural postharvest loss in Samoa, where along the value chain the loss is occurring, and the key contributory factors to postharvest loss in Samoa have impeded efforts to improve postharvest handling systems.

In this study, we sought to quantify postharvest loss for a range of domestically grown fruit and vegetable crops at the main central municipal market in Apia, Samoa. A wider survey-based assessment of postharvest loss for all of the fruit and vegetable markets on the Islands of Upolu and Savai'i was further undertaken to assess any spatial variability and to validate postharvest loss. The potential influence of transport conditions, packaging and market storage as possible contributors to postharvest loss were also examined.

2 Methodology

2.1 Direct weighing of postharvest loss in Fugalei market

Postharvest loss of fruits and vegetables in the Fugalei municipal markets in Apia, Upolu Island, Samoa was determined using the direct weighing method as previously reported by Underhill and Kumar (2014, 2015). While this study preceded the release of the Food Loss and Waste (FLW) Protocol (2016), this method was also consistent with key elements of the FLW standard pertaining to the quantification of food losses. A total of 18 commercial market vendors were assessed. Sampling was undertaken in February and March 2015 to ensure the inclusion of seasonal fruit crops in the study and validated with further sampling in May 2015. Postharvest loss was defined as the percent of product removed from the municipal market component of the commercial supply chain. While on-farm harvesting loss was not directly assessed, most horticultural product in Samoa is packed in-field, with sorting and grading only occurring once the product arrives at the markets. As such, municipal market loss reported in this study also includes transport loss and potentially on-farm loss. Fruit and vegetable postharvest loss was determined by first measuring the weight (g) of all product for sale at the commencement of each trading day per vendor and per commodity type, using a 5-kg commercial-balance calibrated hourly. Plastic bins were then provided to each market vendor to retain potential postharvest loss incurred during the day due to sorting and grading of product on arrival, trimmings, and market display and storage. Prior to the commencement of each trading day, commercial loss from the previous day was segregated accordingly to crop, individually weighed, and the loss was calculated as a percent of initial consignment weight (expressed as daily postharvest loss). The risk of sampling error due to postharvest loss being otherwise disposed by the vendor, was determined in discussions with each vendor on a daily basis. Where there was any uncertainty, data were not included. Mean daily postharvest loss was calculated on the basis of the mean consignment loss per crop relative to the number of vendor trading days that the product was observed for sale. This study did not assess post-municipal market loss due to consumer waste or the destination of loss (i.e. product that was commercially harvested but not transported to the municipal market, or the end-destination for product removed from the market).

The Fugalei market was selected as the study site because it is the largest and most important municipal fruit and vegetable market in Samoa. As each vendor had up to ten types of fruits

or vegetables for sale at any given time, vendor loss was segregated per crop and mean crop-specific losses also determined. Due to low frequency trading of some crops (product being sold by a single vendor or only traded on a limited number of days) postharvest loss is only reported for the 23 most-traded commodities. In total, this study involved 41 vendors-trading days (number of vendors sampled x number of days when sampling undertaken) with a total of 3166 kg of product assessed.

2.2 Survey of vendor postharvest loss

A survey of vendor postharvest loss was conducted in all of the municipal and private fruit and vegetable markets in Samoa. A total of 58 market vendors and farmer-traders from the Fugalei municipal market (33), Taufusi private market (10), Vaitele markets (8), Afega village market (5), Saleimona road-side market (2), and the Salelologa municipal markets (8), were interviewed to determine postharvest loss per vendor, and to identify those crops with the highest perceived net loss. While this study preceded the release of the FLW Protocol (2016), the survey method used was consistent with key elements of the standard pertaining to food loss surveys. Interviews were informal and undertaken in local Gagana Samoa language, interviewer-administered, and involved vendor recall of horticultural market loss specific to their own enterprise. The Fugaeli, Taufusi, Vaitele, Afega and Saleimona markets are located on the main island of Upolu. The Salelologa municipal market is the sole fruit and vegetable market on the island of Savai'i (approximately 22 km from Upolu). The Fugaeli, Taufusi and Vaitele markets were all located within the greater Apia region and represent urban markets. Given the absence of wholesale fruit and vegetable markets in Samoa, all the markets surveyed were retail markets. The close proximity island of American Samoa was not included in this study. The 58 vendors and farmer-traders interviewed represented at least 90% of the vendors and traders present at the time of sampling. This study did not include self-service roadside stalls which are commonly observed on the island of Savai'i, or commercial retail shops that also sell fresh fruits and vegetables.

2.3 Postharvest supply chain factors

Product storage conditions at the Fugalei market were recorded using TinyTag Tansit-2 temperature loggers (Gemini Dataloggers, United Kingdom) which were placed adjacent to one of the vendor stalls for the duration of the first market sampling period (February 2015) with temperature (°C) recorded every two seconds.

The transport distance from farm to the Fugalei market was measured using Google Earth™ distance calculator. Production location for each commodity and the mode of transport (truck, bus, taxi/car) was determined in discussions with individual market vendors. Likely transport routes were identified on the basis of shortest anticipated road path, known commercial transport routes, and local bus routes. Mean transport distance was calculated to account for multiple source locations.

2.4 Data and statistical analysis

Analysis of fruit and vegetable (combined) loss on a fresh weight basis (in kg) was undertaken using one-way analysis of variance (ANOVA). Analysis of municipal market vendor survey loss was undertaken using ANOVA followed by Tukey-Kramer multiple comparison test (with consideration for uneven vendor numbers between markets). The relationship between weekly postharvest loss and the time that fruits and vegetables were stored in the municipal markets was determined using both linear and polynomial regression analysis.

3 Results

Mean daily postharvest horticultural loss at the Fugalei central municipal market was calculated as 2.3% for vegetables and 2.5% for fruits (Table 1), based on the direct weighing method. There was no significant difference between postharvest losses in fruits compared to vegetables. The amount of postharvest loss varied between crops. The higher levels of daily postharvest loss (5% to 22%) were observed for soursop, papaya, Tahitian limes, mustard cabbage, and choko. Negligible loss, at less than 1% of the daily loss, was observed in limes, vi (*Spondias dulcis*), eggplant, long bean, soa'a (plantains), lemon, cherry tomato, cucumber, pumpkin and ginger. No postharvest loss was observed in pumpkin, ginger or Samoan orange (Table 1).

On average, product was stored at the Fugalei municipal market for 2.89 days, with 2.64 days for vegetables and 3.13 days for fruits (Table 1). Given that there was no refrigerated storage infrastructure at the Fugalei market (or in any of the Samoan municipal or village markets), storage time in the market is indicative of the length of time taken to sell the product, or for the product to be removed from sale due to spoilage. Storage time did vary between crops. The mean storage time for soursop and vi was 5 days, whereas pak choi, cherry tomato and choko were held for 1.48, 1.50 and 1.70 days respectively (Table 1). Perishable or higher-value crops such as leafy Asian vegetables and cherry tomato tended to be stored for a shorter time. Fig. 1 shows the percentage of individual consignments subjected to prolonged market storage. On Monday, all products for sale had been in the market for 3 days, with up to 33–57% of the product for sale on successive days having been held in the markets for 4 or

Table 1 Postharvest loss, transport distance and storage time for a range of fruits and vegetables in the Fugalei municipal fruit and vegetable market, Upolu, Samoa

Commodity	Mean daily postharvest loss[a] (%)	Mean time at municipal market[b] (days)	Mean postharvest loss (%) (a*b)	Volume assessed(kg)
Soursop	21.8	5.33	100	20.88
Papaya	12.4	2.13	26.4	208.53
Tahitian lime	8.8	3.91	34.2	43.80
Pak choi	6.8	1.38	9.4	93.50
Mustard cabbage	6.1	2.25	13.6	12.37
Choko	5.1	1.70	8.7	109.71
Chinese cabbage	2.8	2.25	6.4	35.16
Head cabbage	2.5	3.5	8.9	559.25
Chili (small)[c]	2.5	4.13	10.4	5.96
Avocado	2.2	3.09	6.7	147.57
Pineapple	1.9	1.94	3.7	45.60
Banana (all types)	1.0	1.94	2.0	125.18
Lime	0.6	3.80	2.3	51.96
Vi (*Spondias dulcis*)	0.5	5.00	2.5	36.89
Eggplant	0.4	3.36	1.3	316.45
Long bean	0.3	1.29	0.4	108.40
Soa'a (Incl. Plantains)	0.3	2.86	0.7	14.52
Lemon	0.2	2.80	0.7	84.60
Cherry tomato	0.01	1.50	0.02	26.47
Cucumber	0.01	2.50	0.03	119.65
Pumpkin	0.0	2.35	0	885.31
Ginger	0.0	4.55	0	23.11
Samoan Orange (navel type)	0.0	3.3	0	82.49
All vegetables	2.3a	2.64	6.0	2272.22
All fruits	2.5a	3.13	7.7	894.33
Total	2.1	2.89	6.2	3166.54

[a] Vendor postharvest loss is the mean percent loss per crop, per vendor, per trading day, averaged across three sampling periods

[b] The number trading days across all vendors that a specific consignment was presented for sale

[c] Chili (Thai pepper or birds eye chili type) has been included due to the high number of vendors (11) selling the product

Values followed by the same letter are not significantly different at $P < 0.05$

Postharvest loss for garlic chives, melon, okra, rambutan, green mango, spring onion, passionfruit, sweet potato and snake bean was determined but not presented due to low frequency of trading (single vendor or less than 4 vendor trading days)

Table 2 A comparison of vendor postharvest loss at the Fugalei municipal fruit and vegetable market, Samoa, February verses March 2015

	Sampling period	Mean daily postharvest loss (%)
All vegetables	Feb	1.4a
All vegetables	March	2.2a
All fruits	Feb	2.6a
All fruits	March	2.2a

Values followed by the same letter are not significant different at $P < 0.05$

more days. On Friday, 12.7% of product for sale had been in the market for at least 7 days. While in the Fugalei municipal market, product was stored at 26.5 to 32°C (in February) (Fig. 2) and 24 to 27°C (during March and April – data not shown).

Given extended market storage, commercial postharvest loss is best represented when daily postharvest loss is combined with the mean number of days that product was stored in the markets. Accordingly, mean postharvest loss for vegetables was 6.0% and 7.7% for fruits, with an overall municipal market loss (for all crops) of 6.2% (Table 1). The most vulnerable crops to high levels of

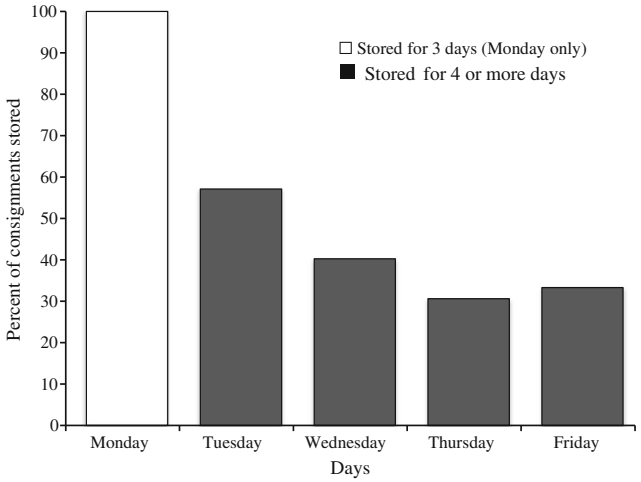

Fig. 1 Percent of individual vegetable and fruit consignments subjected to prolonged storage (3+ days) at the Fugalei central markets, Samoa. Note: On Fridays, 21.7% of the assessed consignments presented for sale in the market had been stored/held in the market for 7 days under high ambient temperature conditions

commercial postharvest loss were soursop (100%), Tahitian limes (34.2%) and papaya (26.4%). Leafy vegetables such as pak choi, Chinese cabbage, cabbage and mustard cabbage had moderate to high levels of postharvest loss (6.4% to 13.6%).

When crops were separated according to high or low postharvest-loss crops, there was a significant and high correlation between the length of market storage and the amount of postharvest loss (Fig. 3). In high loss crops, postharvest losses followed a quadratic polynomial with a dramatic increase after 3 days (Fig. 3a). In low postharvest loss crops, the overall loss was small (less than 5% loss), it progressed slowly and followed a linear relationship (Fig. 3b).

Product transport distances from farms to the Fugalei market were short, often less than 20 km (Table 3). While horticultural product is sourced from across Upolu Island, most of the horticultural production is located close to the fruit and vegetable markets. The Aleisa region, where most commercial-scale farms are located, is less than 15 km from the Fugalei municipal market. Longer transportation distances (up to 52 km) were limited to taro and taro leaf sourced from remote villages in the south-east and south-west regions of Upolu.

The most common reason for product being removed from commercial sale was due to postharvest disease or being overripe (Table 3). In leafy vegetable crops, loss was associated with daily trimming of the leaves, rather than net crop loss. A large single consignment of choko allowed for a more detailed segregation of the underlying contributors, with most loss due to on-farm damage (insect damage 65%; appearance 7%, and size/physical damage 10%) symptomatic of limited on-farm sorting and grading.

Plastic packaging was commonly used for small and high-value crops such as chili, eggplant, pak choi, cherry tomato, and for avocado and choko, which were sold by the bag (Table 3). While the use of plastic packing is likely to extend product shelf-life through a reduction in the rate of dehydration, particularly in leafy crops such as pak choi, that was not specifically assessed in this study.

To validate postharvest loss, a wider survey of vendor postharvest loss of all the commercial fruit and vegetable markets in Samoa (on Upolu and Savai'i Islands) is reported in Table 4. The Taufusi private market had significant lower levels of loss (10%) compared to the Afega village market (17%) and Salelologa market (20%). There was no significant difference in the level of postharvest loss between any of the three urban markets located in the Apia region; Taufusi (10%), Vaitele (12.6%) or the Fugalei central markets (13.25%). The Salelologa market (on Savai'i Island), the only market not located on Upolu island, had significantly higher levels of

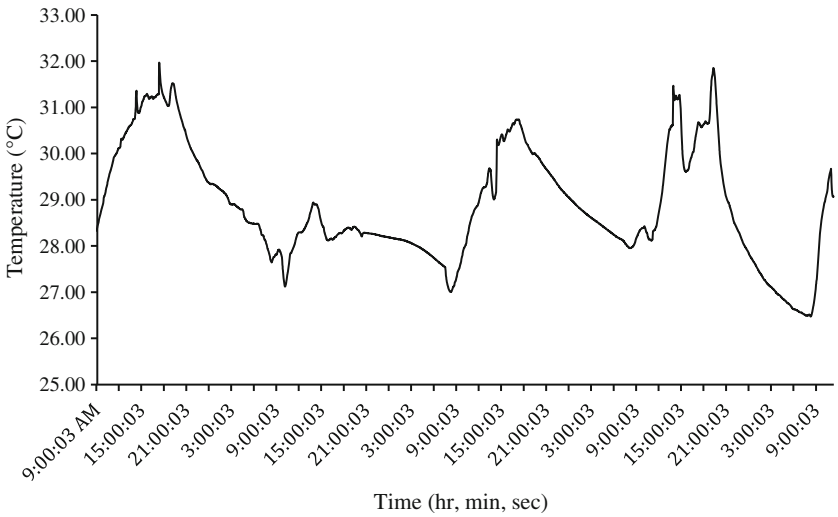

Fig. 2 Temperature at the Fugalei market, Samoa, during the primary assessment period of February 2015. Note: The temperature profile below is the ambient air temperature during the initial 4 days in February 2015 of the sampling period, and therefore indicative of day-time market storage conditions. At the cessation of the trading day vendors covered their product with heavy plastic sheets to protect against theft. This practice was not assessed and is not presented above

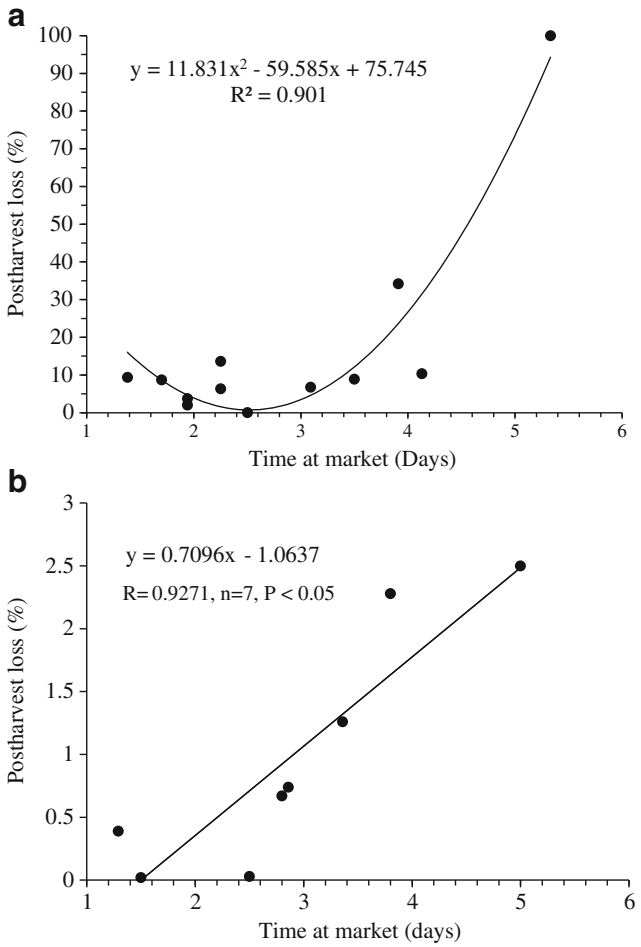

Fig. 3 Relationship between time in market and weekly postharvest loss for fruits and vegetables in Samoa (**a**) High postharvest loss crops using quadratic polynomial (**b**) Low postharvest loss crops using linear regression

postharvest loss compared to all other markets, with the exception the Afega village market.

Comparing the two assessment methods, vendor perception of postharvest loss at the Fugalei market was slightly higher (13.3%) (Table 4) than loss determined by direct weighing (6.2%) (Table 1). Across all markets, vendors consistently identified banana, papaya and avocado as the most likely crops to incur high levels of postharvest loss. While this was consistent with high levels of postharvest loss quantified in papaya (26.4%), we found relatively low levels of postharvest loss in banana (2.0%), and moderate loss in avocado (6.7%).

The proportion of commercial market vendors to farmer-traders in each market is presented in Table 4. On Upolu Island, markets that were dominated by farmer-traders, such as the Afega village and Saleimona roadside markets, tended to have higher levels of postharvest loss. This was not the case for the Salelologa market (on Savai'i Island), which had both high postharvest loss and high commercial vendor representation.

4 Discussion

Postharvest horticultural loss in the Fugalei central municipal market in Samoa was 6.2%. While there was no significant difference in mean daily postharvest loss between fruit and vegetable crops, more perishable soft-skinned fruits such as soursop and papaya, and leafy and western vegetables were the most likely to incur elevated levels of postharvest loss (Tables 1 and 2). High-value crops such as ginger, early-season citrus, and cherry tomato, tended to have lower-levels of postharvest loss. Surprisingly, banana and pineapples, two crops commonly associated with high levels of postharvest loss (Murthy et al. 2007; Babalola et al. 2009), incurred comparatively little loss.

While poor agronomic and postharvest handling practices obviously play a role in shaping resultant market loss in Samoa, we believe that much of the overall level of postharvest loss observed in the market, as well as crop-specific differential postharvest loss, was due to prolonged storage in municipal markets. Municipal market storage conditions involved product being loosely displayed on benches, covered with thick plastic sheeting overnight to protect against theft, with excess product often held in large sacks in the full sun. Intuitively, given that such handling practices also included the product held for up to 7 days under high tropical ambient storage temperatures of up to 32°C, it is logical to assume elevated levels of postharvest losses. When crops were segregated according to high or low postharvest loss, we found a significant and high correlation between the mean observed postharvest loss in the market and the length of time that the product was held in the market. In crops with low levels of postharvest loss this relationship was linear, with the level of postharvest losses increasing daily. In crops associated with high levels of postharvest losses, these losses occurred rapidly, increasing after 3 days of storage.

Interestingly, based on observations during the market loss assessments, there was very little evidence of anticipated vendor practices to reduce postharvest losses, such as price discounting or processing, or in-market consumption. Such practices tended to be limited to a small cohort of the more professional market vendors in the Taufusi and Fugalei markets, or by vendors selling commodities such as cabbage that required progressive leaf trimming. Instead, vendors tended to seek to minimize loss by limiting the volume of product sold, only selling highly perishable crops (such as watercress and rambutan) on high-volume through-put days such as Saturdays, or not selling the more perishable crops. This latter point possibly explains the notable disparity between high postharvest loss in soursop based on direct weighing (Table 1), whereas when surveyed very few vendors indicated a concern with this crop in terms of associated losses (Table 4).

Table 3 Transport distance, storage time and packaging type for a range of fruit and vegetable crops at the Fugalei municipal market, Samoa

Commodity	Mean transport distance[1] (km)	Packing options used	Reason for postharvest loss
Soursop	15.37	Nil	Disease (rots), over-ripe
Papaya	15.57	Nil	Over-ripe, rots
Tahitian lime	28.33	LDBP bags	Rots, over-ripe (yellow)
Pak choi		LDBP open sleeve; nil*	Trimming
Mustard cabbage		Nil	Trimmings, insect damage
Choko[2]	25.15	Nil*; LDBP bags	Disease (18%), appearance (7%), size/ physical damage (10%), insect (65%)
Chinese cabbage	11.54	Nil	Trimmings (wilting leaves)
Cabbage	17.42	Nil	Trimmings (wilting leaves)
Chili	19.11	LDBP bags*; nil	Disease (rots)
Avocado	14.47	LDBP bags*; nil	Over-ripe, disease (rots)
Pineapple	13.06	Nil	Disease (rots), over-ripe
Banana	15.79	Nil	Over-ripe, disease (rots)
Lime	14.95	LDBP	Disease (rots), over-ripe
Vi	14.83	Nil	Field damage
Eggplant	16.43	LDBP bags*; nil	Disease (rots)
Soa'a	4.53	Nil	Over-ripe, disease (rots)
Lemon	15.80	Nil*; LDBP bags	Disease (rots), over-ripe
Long bean	16.31	Nil* LDBP bags	Desiccated
Cucumber	28.33	Nil; LDBP Bags*	Over-ripe
Cherry tomato	16.98	LDBP bags	–
Pumpkin	12.86	Nil	–
Ginger	22.14	Nil	–
Taro	34.21	Nil	–
Taro leaf	52.23	Nil	–

LDBP (low density biodegradable plastic) bags. Only biodegradable plastic bags can be used in commercial retail in Samoa

*Indicates most common packing used. (−) Indicated nil postharvest low or limited sample volume

[1] Mean transport distance is the distance from farm to the Fugalei markets, accounting for multiple source locations and number of consignments

[2] There was a large single consignment loss (33.4 kg) allowing for a more detailed assessment of the underlying contributors of postharvest loss

The importance of market storage on postharvest loss is further highlighted in a recent and comparative study of losses in the Fiji central municipal market (Underhill and Kumar 2014). On the basis of mean daily postharvest loss per crop, there is little difference in the level of loss between horticultural crops in the Fugalei municipal market to that of the Fiji central municipal market (Underhill and Kumar 2014). What is notably divergent is the period of time in which the crops are held in the market prior to sale. In the central municipal market in Fiji, produce tends to be sold within 1 to 2 days (Underhill and Kumar 2014), which is in direct contrast to the prolonged length of storage at the Fugalei market in Samoa. When market storage is taken into consideration, resultant postharvest loss in the Fugalei market is more than double that seen in the Fiji municipal market.

It is difficult to draw meaningful comparisons from studies in other lesser-developed transient countries located outside of the South Pacific region, given significant differences in supply chain logistics and market dynamics. While elevated loss at the wholesale/retail market end of the value chain, and adverse impact associated with prolonged market storage have been well documented elsewhere (Idah et al. 2007; Berinyuy and Fontem 2011; Msogoya and Kimaro 2011), specific levels of crop loss are highly variable (Prabakar et al. 2005 and Msogoya and Kimaro 2011).

Protracted municipal market storage is often symptomatic of supply exceeding demand. In the Pacific, this is normally associated with short-term and high volume supply of seasonal crops, and as such is transient and crop-specific in nature. This did not appear to be the case in Fugalei market during the three sampling periods. Most market vendors only had very

Table 4 Postharvest loss in all of the fruit and vegetable markets on the Islands of Upolu and Savai'i, Samoa, based on a survey of vendor recall

Fruit and vegetable market[1]	Postharvest loss (%)	High postharvest loss crops	Type of trader in each market	
			Vendors[4]%	Farmer traders[5]%
Taufusi private market	10 a	Banana, papaya, avocado	100	0
Vaitele municipal market	12.6 ab	Papaya, banana, soursop	11	89
Fugalei municipal market[2]	13.3 abc	Banana, papaya, breadfruit	74	26
Afega village market	17.0 bcd	Banana, avocado, pineapple	0	100
Saleimona roadside market[3]	17.5	Banana	0	100
Salelologa municipal market	20.0 df	Banana, papaya, tomato	100	0
All markets	12.5		42	58

Total of 67 vendor and famer-traders across all assessed markets

[1] Mean values followed by different letters are significantly different at $P < 0.05$

[2] Fugalei municipal market is the main fruit and vegetable market for Samoa

[3] Not included in statistical analysis as this roadside market only had two traders

[4] Vendors are individuals that maintain an ongoing and consistent commercial market presence (commercial market vendors)

[5] Farmer traders are individuals who intermittently sell product at the market and are primarily associated with farm production

small quantities of product for sale, coupled with low overall vendor occupancy at the markets (around 50% of the available vendor stalls at the Fugalei markets were not used). Observations during numerous subsequent visits to the market noted limited consumer presence and purchasing, especially during the early part of the week. This would imply that prolonged market storage might be more a result of consistent and low intensity of consumer demand, rather than short-term elevated product supply. The disconnect between supply and demand in the Fugalei market, leading to high levels of postharvest loss in some crops, may be due to limited consumer purchasing of fruits and vegetables, reflecting wider NCD-food dietary trends in Samoa based on elevated consumption rates of highly processed and energy-dense imported food products.

Transport logistics are not considered to have a major effect on overall postharvest loss in the Fugalei municipal market. Much of the horticultural production on the island of Upolu is grown within 15 km of the market, and even accounting for remote horticultural production centres, transport logistics were rarely more than 50 km. Supporting this view is the apparent lack of physical injuries to the produce, often symptomatic of in-transit damage, observed during postharvest loss assessments. Contrary to horticultural postharvest supply chains in the Fiji Islands (Underhill 2013), Papua New Guinea (Chang and Spriggs 2007), or Southeast Asia (Weinberger et al. 2008), Samoan fruit and vegetable supply chains commonly involve product transported in small quantities on comparatively well-maintained sealed roads, with consignment-overloading rarely observed (Underhill 2017). However, we cannot totally exclude transport as a possible contributor simply on the basis of short transport distance. Traditional root crops such as taro were commonly sourced from the more remote villages where there was limited access to commercial transport, necessitating a greater reliance on local commuter buses. This often had the flow-on effect of farmers needing to harvest the previous day and then store product over-night on-farm or on the roadside awaiting bus transport the following morning. While transport distance might be relatively short, future work is required to examine the possible importance of the mode of transport, particularly in the more perishable crops and more remote production source locations.

The importance of product packaging on the level of observed postharvest loss observed in the Fugalei market is unclear. Compared to other Pacific horticultural markets, there was a greater tendency to use plastic bags and packaging in Samoan horticultural markets. While the postharvest benefits of plastic packaging have been well reported (Barmore 1987), given prolonged and high ambient storage temperatures and negligible postharvest disease control, such benefits might be quickly negated through possible elevated incidence of diseases. During the postharvest loss assessment there was no consistent evidence of reduced losses associated with the use of plastic packaging. The use of plastic bags by vendors appeared to be more for bulk-packaging rather than any purposeful effort to remediate against postharvest loss. As product is sold by volume and number, and not by weight in Samoan markets, there was also no indirect economic benefit associate with plastic packaging.

In this study we also sought to determine vendor perceptions of postharvest loss in the Fugalei central market as well as all of the other fruit and vegetable markets (municipal, village and road side markets) on the main island of Upolu and the adjacent island of Savai'i. The perceived level of postharvest loss based in the Fugalei municipal market was higher (13.3%) than when losses were measured through direct weighing (6.3%). The reason for this disparity is unclear, and may simply reflect that vendors believe the postharvest losses are worse than they actually are, or that vendor perception of loss is inclusive of additional economic considerations such as possible price discounting, re-sorting and grading, and/or disposal costs. As the vendor survey included both commercial vendors and transient farmer-traders, whereas direct weighing determination was limited to commercial market vendors who regularly participated in the market, there is also the possibility of differential loss among vendor cohorts. This would imply slightly higher postharvest losses incurred by farmer-traders compared to the more professional commercial market vendors. This is consistent with the observation that the markets dominated by farmer traders had higher levels of postharvest loss, at least on the main Island of Upolu (Table 4). While this was not the case in Savai'i, the Salelologa municipal market on Savai'i was atypical in that commercial vendors primarily sold general household products, with fresh fruit and vegetables as minor-traded items. The fact that vendors identified breadfruit as a crop vulnerable to high postharvest loss is also important (Table 4). In the quantification (by weight) of actual postharvest losses, none of the commercial vendors sold breadfruit. This observation not only supports the view that sampling method is likely to account for differences in postharvest loss between the two assessment methods, but also raises the issue of some disparity as to the type of crops being sold by commercial vendors verses farmer-traders.

Postharvest loss in the other fruit and vegetable markets in Samoa was between 10% and 17.5% (Upolu island) and 20% on the Island of Savai'i. On Upolu, all the markets were located either in Apia (the Taufusi market is only 240 m away from the Fugalei market) or in close proximity to the key production centres. With markets in close proximity to each other and short farm-to-market transport distance, differences in market loss are unlikely to be due to geographic propinquity. On the island of Savai'i, there was a limited supply of fresh fruits and vegetables, with product either imported or sourced from Savai'i with limited evidence of inter-island supply chains observed at the time of sampling.

While not quantified, there was a notable observational difference in the level of consumer activity between the markets, with the private Taufusi market considerably busier than all of the other markets assessed. This is interesting given the Taufusi market had significantly lower postharvest losses compared to the Afega village, the Saleimona road-side markets, and the Salelologa market. This is consistent with the view that lower consumer demand may be contributing to extended market storage, and higher resultant postharvest loss. Further work is needed to examine and verify the possible importance of consumer purchasing behaviour as a possible contributor to postharvest loss in fruit and vegetable markets in Samoa.

5 Conclusions

Mean postharvest loss in the main Fugalei municipal fruit and vegetable market in Samoa was considered to be comparatively high relative to similar municipal markets in Fiji. While poor agronomic and postharvest handling practices no doubt influence such levels of postharvest horticultural loss, we believe extended market storage involving high tropical ambient temperatures was of critical importance. There was some evidence that prolonged market storage may be due to low consumer demand, but more work is required to validate this conclusion. Given differences in the level of postharvest loss between the various fruit and vegetable markets in Samoa, further work is also needed to explore the potential influence of vendor practice, market design, market location and operations.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

Affognon, H., Mutungi, C., Sanginga, P., & Borgemeister, C. (2015). Unpacking postharvest losses in sub-Saharan Africa: a meta-analysis. *World Development, 66*, 49–68.

Babalola, D. A., Megbope, T. A., & Agbola, P. O. (2009). Post harvest losses in pineapple production: case study of Ado-odo Otta local government area of Ogun State. *Bowen Journal of Agriculture, 5*(1), 55–62.

Barmore, C. R. (1987). Packing technology for fresh and minimally processed fruits and vegetables. *Journal of Food Quality, 10*(3), 207–217.

Berinyuy, J. E., & Fontem, D. A. (2011). Evaluating post harvest opportunities and constraints to utilization and marketing of African leafy vegetables in Cameroon. *African Journal of Food, Agriculture, Nutrition and Development, 11*(2), 4647–4664.

Brown, M. E., Hintermann, B., & Higgins, N. (2009). Markets, climate change, and food security in West Africa. *Environmental Science and Technology, 43*(21), 8016–8020.

Chang, H. S., & Spriggs, J. (2007). *Sweet potato marketing in PNG highlands* (pp. 1–20). Working paper series in agricultural and resource economics, University of New England, Australia. https://www.researchgate.net/profile/Christie_Chang/publication/228967415_Sweet_Potato_Marketing_in_PNG_Highlands/links/00b7d53150104ad297000000.pdf. Accessed 11 May 2017.

Cocker, E. (2000). Postharvest handling status and problems of the Pacific Island countries. In G.I, Johnson., L. Van To., N. Duy Duc., and M.C. Webb, (Eds.): Quality assurance in agricultural produce. pp. 57–59, ACIAR Proceedings 100, Canberra, Australia.

Fink, A., Neave, S., Hickes, A., Wang, J. F., & Nand, N. (2013). Vegetable production, postharvest handling and marketing in Fiji. AVRDC-World Vegetable Center, Research in Action No 7. pp. 43.

Food Loss and Waste Protocol (2016). Food loss and waste accounting and reporting standard. http://www.wri.org/sites/default/files/FLW_Standard_final_2016.pdf. Accessed 8 May 2017.

Hawley, N. L., & McGarvey, S. T. (2015). Obesity and diabetes in Pacific Islanders: The current burden and the need for urgent action. *Current Diabetes Reports, 15*(5), 1–10.

Hodges, R. J., Buzby, J. C., & Bennett, B. (2011). Postharvest losses and waste in developed and less developed countries: opportunities to improve resource use. *The Journal of Agricultural Science, 149*(1), 37–45.

Ichiho, H. M., Roby, F. T., Ponausuia, E. S., & Aitaoto, N. (2013). An assessment of non-communicable diseases, diabetes, and related risk factors in the territory of American Samoa: A systems perspective. *Hawaii Journal of Medicine and Public Health, 72*(5), 10–18.

Idah, P. A., Ajisegiri, E. S. A., & Yisa, M. G. (2007). Fruits and vegetables handling and transportation in Nigeria. *Australian Journal of Technology, 10*(3), 176–183.

Kader, A. A. (2004). Increasing food availability by reducing postharvest losses of fresh produce. *V International Postharvest Symposium, 682*, 2169–2176.

Kaminski, J., & Christiaensen, L. (2014). Post-harvest loss in sub-Saharan Africa - what do farmers say? *Global Food Security, 3*(3), 149–158.

Kitinoja, L. (2013). Innovative small-scale postharvest technologies for reducing losses in horticultural crops. *Ethiopian Journal of Applied Sciences and Technology, 1*(1), 9–15.

Kitinoja, L., & AlHassan, H. Y. (2010). Identification of appropriate postharvest technologies for small-scale horticultural farmers and marketers in Sub-Saharan Africa and South Asia-Part 1. Postharvest losses and quality assessments. XXVIII International Horticultural Congress on Science and Horticulture for People, 93, pp. 31–40.

Kitinoja, L., Saran, S., Roy, S. K., & Kader, A. A. (2011). Postharvest technology for developing countries: challenges and opportunities in research, outreach and advocacy. *Journal of the Science of Food and Agriculture, 91*(4), 597–603.

Lazar-Baker, E. E., Crampton, K. A., Kenny, B., Finau, K. A., Gangai, S., & Ramita, I. (2011). Postharvest disease management of horticultural produce in the Pacific Island Countries: a brief overview. *Stewart Postharvest Review, 79*(2), 1–9.

Mashau, M. E., Moyane, J. N., & Jideani, I. A. (2012). Assessment of postharvest losses of fruits at Tshakhuma fruit market in Limpopo province, South Africa. *African Journal of Agricultural Research, 7*(29), 4145–4150.

McGregor, A., Bourke, R. M., Manley, M., Tubuna, S., & Deo, R. (2009). Pacific island food security: situation, challenges and opportunities. *Pacific Economic Bulletin, 24*(2), 24–42.

Mohammed, M. (2014). Analysis of the post-harvest knowledge system in Trinidad and Tobago: case study of pumpkin. Technical Centre for Agricultural and Rural Cooperation ACP-EU report. http://knowledge.cta.int/Dossiers/S-T-Issues/Reducing-Postharvest-Losses-A-Challenge-for-the-Scientific-Community/Feature-articles/Analysis-of-the-post-harvest-knowledge-system-in-Trinidad-and-Tobago-case-study-of-pumpkin Retrieved 26 Feb 2016.

Msogoya, J. T., & Kimaro, S. E. (2011). Assessment and management of post-harvest losses of fresh mango under small-scale business in Morogoro, Tanzania. *Journal of Animal and Plant Sciences, 11*(1), 1358–1363.

Murthy, D. S., Gajanana, T. M., Sudha, M., & Dakshinamoorthy, V. (2007). Marketing losses and their impact on marketing margins: A case study of banana in Karnataka. *Agricultural Economics Research Review, 20*(1), 47–60.

Mwaniki, A. (2006). Achieving food security in Africa: Challenges and issues. UN Office of the Special Advisor on Africa (OSAA). http://www.un.org/africa/osaa/reports/Achieving% 20Food% 20Security% 20in% 20Africa-Challenges% 20and% 20Issues.Pdf Retrieved 29 Feb 2016.

Oelofse, S. H., & Nahman, A. (2013). Estimating the magnitude of food waste generated in South Africa. *Waste Management and Research, 31*(1), 80–86.

Parfitt, J., Barthel, M., & Macnaughton, S. (2010). Food waste within food supply chains: quantification and potential for change to 2050. *Philosophical Transactions of the Royal Society, B: Biological Sciences, 365*(1554), 3065–3081.

Prabakar, K., Raguchander, T., Parthiban, V. K., Muthulakshmi, P., & Prakasam, V. (2005). Post harvest fungal spoilage in mango at different levels marketing. *The Madras Agricultural Journal, 92*(1–3), 42–48.

Samoa Bureau of Statistics (2009). Agricultural census analytical report. http://www.fao.org/fileadmin/templates/ess/ess_test_folder/World_Census_Agriculture/Country_info_2010/Reports/Reports_4/WSM_ENG_REPa_2009.pdf Retrieved 28th Jan 2016.

Seiden, A., Hawley, N. L., Schulz, D., Raifman, S., & McGarvey, S. T. (2012). Long-term trends in food availability, food prices, and obesity in Samoa. *American Journal of Human Biology, 24*(3), 286–295.

Tuitama, L. T., Young-soo, S., Clark, H., Tukuitonga, C., & Beaglehole, R. (2014). Acting on the Pacific crisis in non-communicable diseases. *The Lancet, 384*(9957), 1823–1824.

Underhill, S. J. R. (2013). Improving the effectiveness of smallholder farm postharvest practices in Fiji. *Acta Horticulturae, 1011*, 41–48.

Underhill, S.J.R. (2017). A practical guide to better postharvest handling for Samoan smallholder farmers. University of the Sunshine Coast, Qld., Australia. pp 76. http://research.usc.edu.au/vital/access/manager/Repository/usc:22202 Retrieved 11 May 2017.

Underhill, S. J. R., & Kumar, S. (2014). Quantifying horticulture postharvest wastage in three municipal fruit and vegetable markets in Fiji. *International Journal of Postharvest Technology and Innovation, 4*(2–4), 251–261.

Underhill, S. J. R., & Kumar, S. (2015). Quantifying postharvest losses along a commercial tomato supply chain in Fiji. *Journal of Applied Horticulture, 17*(3), 199–204.

Veit, R. (2009). Assessing the viability of collection centres for fruit and vegetables in Fiji: a value chain approach. FAO All ACP Agricultural Commodities Program. Series Paper No. 7, www.fao.org/fileadmin/.../FAO_AAACP_Paper_Series_No_7_1_.pdf Retrieved on 25 Feb 2016.

Weinberger, K., Genova Ii, C., & Acedo, A. (2008). Quantifying postharvest loss in vegetables along the supply chain in Vietnam, Cambodia and Laos. *International Journal of Postharvest Technology and Innovation, 1*(3), 288–297.

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