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Quantifying Postharvest Loss and the Implication of Market-Based Decisions: A Case Study of Two Commercial Domestic Tomato Supply Chains in Queensland, Australia

Tara J. McKenzie *, Lila Singh-Peterson  and Steven J. R. Underhill

Faculty of Science, Health, Education and Engineering, University of the Sunshine Coast, Maroochydore, QLD 4558, Australia; lsinghpe@usc.edu.au (L.S.-P.); sunderhi@usc.edu.au (S.J.R.U.)

* Correspondence: tjm009@student.usc.edu.au; Tel.: +61-407-771-247

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Abstract: Using a multi-disciplinary approach, this study quantifies horticultural postharvest losses of two medium-sized (annual pack volume 4500 t) commercial, domestic, tomato supply chains. Quantification of loss was based on weight or volume, consistent with direct measurement methods of the *Food Loss and Waste Accounting and Reporting Standard 2016* and qualitative techniques were used to identify the drivers of the loss and contextualise the findings. Postharvest loss was found to be between 40.3% (55.34 t) and 55.9% (29.61 t) of the total harvestable product. It was determined that between 68.6% and 86.7% of undamaged, edible, harvested tomatoes were rejected as outgrades and consequently discarded due to product specifications. Between 71.2% and 84.1% of produced tomatoes were left in the field and not harvested. This study highlights significant factors contributing to high levels of food loss and waste. Edible products are being removed from the commercial food supply chain, rejected as outgrades deemed cosmetically defective due to market-based decisions. With only 44.1% and 59.7% of the harvestable crop reaching the consumers of the two supply chains, respectively, it is perhaps more appropriate to describe a food “waste” chain as opposed to a food “supply” chain.

Keywords: food security; horticulture; tomato; postharvest loss; food loss and waste; private food policy and standards; destination of loss

1. Introduction

Feeding a global population of 9.5 billion by 2050 is anticipated to become one of the greatest challenges of our time [1–3]. Rapid population growth [1,3–7], decreasing agricultural productivity [8–10], climate change [3,10,11], natural resource scarcity [3,12], and biofuel production [3,13–18] collectively undermine the current and future capacity of global food production systems. The risk of food insecurity is no longer a challenge exclusive to lesser-developed countries. In Australia, one in six Australians reported having experienced food insecurity in 2016 [10], with an estimated 2 million people having sought food relief [19,20].

While there have been considerable effort to identify strategies to enhance and diversify current food production systems [4,5,9], of equal importance is an increasing realisation of significant inefficiencies in the global food system due to food loss and waste (FLW) [6,21–25]. Global FLW has been estimated to represent 27% to 50% of total agricultural production [26–31]. Annually, there is around 4 Mt or AUD8 billion worth of FLW in Australia, 33% of which is horticultural product [19,32,33]. Due to their relative perishability, horticultural products are considered particularly vulnerable to elevated losses. Until recently, reliable and systematic estimations of global FLW have been difficult to

determine, due to an absence of a universal and consistent quantification methodology for reporting and managing food removed from the food supply chain [31,34–36]. In response, the Food Loss and Waste Protocol was established in 2013, with the first international *FLW Accounting and Reporting Standard* ratified in June 2016 during the Global Green Growth Forum (3GF) in Copenhagen.

FLW within commercial food supply chains is shaped by multifarious contributors, including various types of production system inefficiencies and consumer behaviour [21,23,24,27,28]. Of increasing concern and importance is the discourse between the food marketing and consumer purchasing behaviour that is perpetuating FLW throughout the food supply chain [3,6,22,25,31,37,38]. Supermarkets showcase only premium and unblemished product, fabricating unrealistic expectations of how fruits and vegetables should appear. Accordingly, consumers often equate food safety and freshness with elevated cosmetic standards. In combination, these factors have created intrinsically wasteful food systems [1,3,19,22,24,25,27,29,31,35,39]. Private food policy and standards aligned with marketing campaigns often reinforce high levels of FLW via cosmetic product specifications and use-by-dates, driving losses up-stream within the food supply chain [3,19,37].

In seeking to address FLW, potential remediation strategies are predominantly directed at the consumer-end of the food supply chain, in part due to difficulties in quantifying loss at the primary production stages [6]. Highlighting this fact, a newly established protocol for quantification of FLW [40] specifically quantifies postharvest losses, deliberately excluding pre-harvest losses and consumer waste. There is a premise that commercial farms, operating highly mechanised and technology-centric agricultural production systems have achieved an optimum level of FLW minimisation [31,41]. While it is intuitive to presume low levels of FLW within technology-dense horticultural supply chains, there is increasing evidence to the contrary [21,22,25,27,28,42] proposing that such production systems may in fact be more wasteful given the stringent adherence to private food policy and standards.

This study sought to quantify horticultural postharvest losses associated with a highly mechanised commercial tomato enterprise with access to appropriate and effective postharvest handling equipment and infrastructure. The aim of this study was to document accumulative and overall postharvest losses, and to better understand the impacts of technology (e.g., packing shed mechanisation and grading/sorting automation), supply chain length (distance, time, and biophysical conditions), and private food policy and standards (i.e., supermarket standards and product specification) on FLW. To do so, a multi-disciplinary approach was undertaken, based on quantitative documentation of postharvest losses and handling conditions, and qualitative techniques to identify the drivers of the loss and contextualise the findings within the food supply chain.

2. Materials and Methods

2.1. Experimental Design

Two medium-sized (annual pack volume 4500 t) commercial domestic tomato supply chains, with product sourced from the same farm but with divergent market destinations and associated transport distance were assessed. Harvesting and handling practices and biophysical conditions were documented, postharvest loss along the food supply chain was quantified by weight, and interviews were conducted to evaluate how supply chain actors influenced postharvest losses in their decision-making. This study was collectively undertaken in November to December 2014. FLW calculations included postharvest and destination of loss, but did not include pre-harvest losses and consumer waste. However, an opportunistic and independent assessment of pre-harvest losses was undertaken and documented here, but losses were not included with the total postharvest loss for the supply chains assessed. Terminology used in this paper is based on the *FLW Accounting and Reporting Standard 2016*, with destination of loss referring to the end use or destination of product removed from the commercial food supply. Pre-harvest loss, such as weather or pest-related damage is about maximising potential, as opposed to addressing losses of material ready for harvest or in subsequent stages of the food supply chain [40].

2.2. Study Location and Production System

The farm selected for this study was located in Queensland's Bundaberg region, one of Australia's largest tomato production regions, with an annual farm-gate value of AUD500 million [43]. The selection of the farm was undertaken in consultation with the Bundaberg Fruit and Vegetable Growers Association to ensure production; postharvest handling and transport practices were typical for the region. The farm, located in Elliot Heads (Figure 1), was supplying tomatoes (*var. Lava*) to domestic markets in either Brisbane or Bundaberg. Product for the two trials was sourced from separate harvests in the spring/summer season of 2014. Both supply chains were based on tomatoes being trellis-grown in an open field with a rain-fed production system, and incorporated mechanized harvesting, modern and efficient packaging and grading equipment, and access to cool storage infrastructure.



Figure 1. Map of study area, Bundaberg, Queensland.

2.3. Supply Chains Assessed

The first supply chain (SC1) involved product sourced during the mid-season harvest (11–18 November) using a mechanical harvest aid, transportation to a commercial packing shed for sorting, grading, packing, and refrigerated storage, then transportation by a fully-enclosed, refrigerated semi-trailer truck to the Rocklea Wholesale Fruit and Vegetable Market, Brisbane, and further transportation by a fully-enclosed, unrefrigerated light truck to a retail outlet in Morningside, Brisbane.

The second supply chain (SC2) involved the same commercial farm and associated harvesting and pre-distribution practices, however, product was sourced from a harvest one month later (10–13 December) at the end of season and was instead transported by a small, fully-enclosed, unrefrigerated truck to a small local wholesale/retail outlet in Bundaberg.

2.4. Quantification of Loss

2.4.1. Field and Packing Shed Horticultural Postharvest Losses

Quantification of loss was based on weight or volume, consistent with direct measurement methods of the *FLW Accounting and Reporting Standard* [40]. Field losses were determined by counting the number of individual pieces of fruit of commercial maturity (one-quarter to full-colour fruit) that remained in-field immediately following a completed harvesting cycle, based on a sub-sample of 608.18 kg, within a transect of 1311.80 m². Field losses were then calculated relative to a total harvested area of 8.5 and 12.14 ha respectively for SC1 and SC2. Field loss was defined as mature fruit left on the vine or product on the ground left by the harvest aid and/or bucket pickers, or discarded from the harvest aid where preliminary discarding of product was performed. The primary destination of all field loss was via 'land application'. 'Land application' is the term used to describe the destination whereby losses are discarded through spreading, spraying, injecting, or incorporating organic material onto or below the surface of the land to enhance soil quality [40].

During the harvest of SC1, a sub-sample of 100 fruits was taken to determine the mean weight of a single tomato at the field and packing shed stages of the supply chain. During the harvest of SC2, three random sub-samples of discarded field and shed product were utilised to determine the causal factors of out-grading. Product that left the supply chain was deemed unsaleable based on product specification (i.e., physical blemishes/abrasions, size and shape), colour and maturity, or physical damage (punctures or pathogenic deterioration).

Postharvest loss in the on-farm packaging shed was calculated based on the volume of product removed during sorting and grading, proportional to total volume of product initially arriving at the shed. Packing shed volumes were based on a count of harvest bins with a mean net weight of 330 kg, entering and leaving the packing shed during a complete harvesting cycle. Saleable product was packaged in 10-kg cardboard cartons, and pre-cooled prior to transportation to market within 24 h. The destinations of packing shed losses were partially quantified; they were used for 'land application' and 'animal feed'. 'Animal feed' refers to destination of loss by diverting material from the food supply chain (directly or after processing) to animals [40]. Truck transport for the discarded product was empty at the commencement and cessation of the sampling period. To further validate loss at this stage, packing shed losses were recorded for a further two days consecutive to the SC2 trial period using the same method.

As SC2 represented a late seasonal harvest and was immediately followed by an abrupt cessation of seasonal harvesting due to depreciation of the market, we were also able to determine pre-harvest loss and destination of loss, independent of the SC1 and SC2 postharvest loss trials. Pre-harvest loss included unharvested product from the commercial harvesting cycle, being mature residual product remaining in-field on or off the vine, at the cessation of the commercial harvesting season. On completion of seasonal harvesting a field of 3.64 ha was defoliated in preparation for the next seasons planting. An assessment of pre-harvest loss was undertaken to determine percentage loss relative to the volume of the entire seasonal harvest for the field. Twenty-six trellises were randomly selected within the field of 8400 trellises. The number of individual fruits remaining on each vine was counted and recorded for each trellis and later extrapolated across the field's entire seasonal harvest based on carton volume leaving the farm.

2.4.2. Wholesale and Retail Horticultural Postharvest Losses

Wholesale and retail losses were determined by individually counting the number of unsaleable fruit based on a sub-sample of 3 × 10.80-kg cartons at the wholesale stage, and a subsequent 1 × 10.80-kg carton at the retail stage. Wholesale losses of the sub-sample were determined on point of arrival at market. Retail losses of the sub-sample were determined at the end of the retail period, when the last of the sub-samples was sold to consumers. For SC1, this was done using simulated conditions following a period of refrigerated storage with the retailer. The sub-sample was collected from the retailer to be

held under ambient conditions for 24 h simulating the display period prior to consumer purchase in the retail store. For SC2, the wholesale and retail enterprises were combined, located within the same outlet. Wholesale losses were determined as in SC1. Retail losses were determined by the retailer using a logbook to document daily losses, consistent with the *FLW Accounting and Reporting Standard 2016* [40].

2.5. Bio-Physical Postharvest Conditions

Temperature management along the supply chain was assessed to determine whether storage conditions were a potential contributor to observed postharvest losses. Postharvest storage conditions were assessed based on continuous sub-sampling of mean fruit core temperature from point-of-harvest to retail point-of-sale using an EcoScan Temp 5 with thermistor probe (Eutech Netherlands). In SC2, the storage and transport temperature was also continuously recorded every 2 min using a Tiny Tag Tansit-2 temperature logger (Gemini Data loggers, West Sussex, UK). Temperature loggers were located centrally within the product load during harvest, storage and transport.

Truck routes were concurrently recorded every 2 s, using a Super Trackstick® (Telespial Systems Inc., Burbank, CA, USA) with global positioning system (GPS) referencing uploaded onto Google Earth™. All loggers and GPS devices were time-synchronised to allow spatial and temporal cross-referencing of truck speed and product temperature.

2.6. Informal and Semi-Structured Interviews

Nineteen informal interviews (Table 1) along both supply chains were undertaken to understand the decision-making of supply chain actors and how these factors influenced postharvest losses. Interviews were conducted on-farm concurrent to the quantitative assessment, as farm workers went about their daily duties, with each interview lasting up to 20 min. Following the supply chain assessments, five semi-structured interviews (Table 2) with key supply chain actors and industry specialists were undertaken to reflect on findings and investigate the drivers and impacts of FLW, specifically drawing on the role of technology, supply chain length, and private food policy and standards. With participant consent, all interviews were audio-recorded and transcribed verbatim. Standard thematic analysis techniques were used, supported by NVivo qualitative data analysis Software (QSR International Pty Ltd., version 11.4.0). All subjects gave their informed consent for inclusion prior to participation in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of the University of the Sunshine Coast (HREC S/14/691).

Table 1. Informal interviews—list of supply chain actors interviewed.

Reference	Interview Location	Number of Interviewees
Labour contractor	Field	1
Fruit picker	Field	1
Field supervisors	Field	3
Fruit sorters	Packing shed	4
Fruit packer	Packing shed	1
Growers	Office shed	2
Packing shed supervisor	Packing shed	1
Farm forklift and truck operator	Packing shed	1
Ex-wholesale agent	Packing shed dispatch	1
Wholesale agent	Brisbane Market	1
Retailers	Brisbane Market and Retail Outlet	2
Retail manager	Bundaberg Wholesale Outlet	1
Total		19

Table 2. Semi-structured interviews—list of industry specialists interviewed.

Reference	Industry Experience (year)	Location/Duration
Extension officer 1	35	Telephone, 34 min
Extension officer 2	30	Telephone, 47 min
Grower 1	42	In person, 24 min
Grower 2	40	In person, 19 min
Academic, emeritus professor of rural sociology	40	Telephone, 1 h 11 min

No statistical analysis was undertaken in this case study as data was based on overall actual loss at each point along the chain, rather than replicated mean sub-sampling. This approach is consistent with recent FLW studies [44–46] and reflects an emphasis on comparative loss along the chain rather than specific loss.

3. Results

3.1. Quantification and Destination of Horticultural Postharvest Loss

3.1.1. Quantification of Loss

Supply chain one involved a total 137.41 t of harvestable product. Between the point-of-harvest and the retail point-of-sale, 55.34 t or 40.3% of harvestable product was removed from the commercial supply chain (Table 3). A total of 28.7% (39.4 t) of harvestable product was discarded in-field. Packing shed losses were 10.8% (10.56 t), based on the total volume of product entering the shed of 98.01 t (Table 3). Following grading, sorting and packing, a consignment of 4128 cartons was transported 392 km from the farm to the Rocklea Market, Brisbane. On arrival at the market, 7 h 20 min after leaving the farm, the consignment was moved into refrigerated storage, with no observed postharvest losses on arrival (Table 3). At 28 h, product was moved to the market floor where it was held at an ambient temperature for 3 h before being transported to the Morningside retail outlet, 14.2 km from the Rocklea Market. At 5 days of retail storage and display, 5.4% (5.38 t) of the product was deemed unsaleable by the retailer, with 100% of the loss going to landfill (Table 4).

Supply chain two involved a total 52.96 t of harvestable product. Between the point-of-production and the retail point-of-sale, 29.61 t or 55.9% of harvestable product was removed from the commercial supply chain (Table 3). A total of 47% (24.9 t) of harvestable product was discarded in-field. Packing shed losses were 14.1% (3.96 t), based on the total volume of product entering the shed of 28.05 t (Table 3). When averaged with two consecutive days', mean packing shed losses were 14.6%, based on the total volume of product entering the shed. A consignment of 300 cartons was transported 19.1 km from farm to a local wholesale/retail market in Bundaberg. On arrival at the market, 1.5 h after leaving the farm, the consignment was moved into refrigerated storage, with no observed postharvest losses on arrival (Table 3). At 17 h product was moved to a refrigerated display where it remained until it was sold, 12 h later. At 2.5 days of retail storage and display, the retailer deemed 2.4% (0.74 t) of the product unsaleable, with 100% of the loss going to landfill (Table 4).

Despite a lower total at-harvest yield, SC2 had proportionally higher postharvest losses in the field and packing shed when compared to SC1 (Table 3). The reason for this variability is thought to be due to differences in out-grading. Supply chain two did not include a third-grade product and harvesting cycles were more frequent, every one to two days, with less fruit on the vine. Supply chain one involved picking and packing all sizes and colours, with less frequent harvesting cycles, every third day, with more fruit on the vine. Differences in transport distance between SC1 (392 km) and SC2 (19 km) had no tangible impact, with no determined wholesale loss in either chain.

Table 3. Percent of actual and cumulative losses by location within the supply chain where postharvest loss was determined, and calculation of the percentage of harvested product made available to the consumer.

Location of Loss (Postharvest Stage)	Supply Chain One (SC1)			Supply Chain Two (SC2)		
	Actual Loss ^a (%)	Loss as a % of Potential Harvest ^b	Loss as a % of Overall Loss ^c	Actual Loss ^a (%)	Loss as a % of Potential Harvest ^b	Loss as a % of Overall Loss ^c
Field	28.7	28.7	71.2	47.0	47.0	84.1
Packing shed	10.8	7.7	19.1	14.1	7.5	13.4
Wholesale	0	0	0	0	0	0
Retail	5.4	3.9	9.7	2.4	1.4	2.52
Total		40.3	100		55.9	100
Percentage available for consumption		59.7			44.1	

^a Percent actual loss is the amount of loss specific to a defined point along the supply chain. ^b Percent accumulative loss is the actual loss at each point along the supply chain relative to the total potential harvest (i.e., to include point-of-harvest field loss). ^c Percent loss at each point along the supply chain relative to overall loss.

Table 4. Destination of loss.

Destination of Loss	Supply Chain One (SC1) Percentage Loss	Supply Chain Two (SC2) Percentage Loss
Not harvested ^a	71.2	84.1
Land application ^b	17.2	12.0
Landfill ^c	9.7	2.5
Animal feed ^d	1.9	1.3

^a Product (tomato) not harvested and left in the field or tilled back into the soil; ^b Product that was used as organic material on or below the surface of the land to enhance soil quality; ^c Product removed from the farm to an area of land or an excavated site specifically designed and built to receive wastes; ^d Diverting material from the food supply chain (directly or after processing) to animals.

3.1.2. Destination of Losses

In SC1, of the total loss, 71.2% (39.4 t) of harvestable product was left in the field and not harvested, 17.2% (9.5 t) was disposed of via land application, 9.7% (5.39 t) became landfill, and 1.9% (1.05 t) was used as animal feed on an adjacent property (Table 4). For SC2, 84.1% (24.9 t) of harvestable product was left in the field, 12% (3.56 t) was disposed of via land application, 2.5% (0.75 t) became landfill, and 1.3% (0.4 t) was used as animal feed (Table 4). Based on the cumulative destination of loss for SC1 and SC2, the volume of product available for consumption was 59.7% and 44.1% respectively (Table 3).

3.2. Drivers of Loss

3.2.1. Biophysical Conditions

During harvest in SC1, internal fruit core temperature did not exceed 28.4 °C (Figure 2). Following packaging, the fruit was cooled to 13.2 °C prior to transport. Transport temperature was from 10.2 °C to 12 °C. When moved to the market floor, core temperature increased, peaking at 18 °C. Product was then stored by the retailer between 13.8 °C and 17 °C. Once moved from refrigerated storage to display, the core temperature slowly increased to a peak of 25 °C. While there was minor difference in terms of specific temperature, the overall temperature storage conditions recorded in SC2 were consistent with those of SC1.

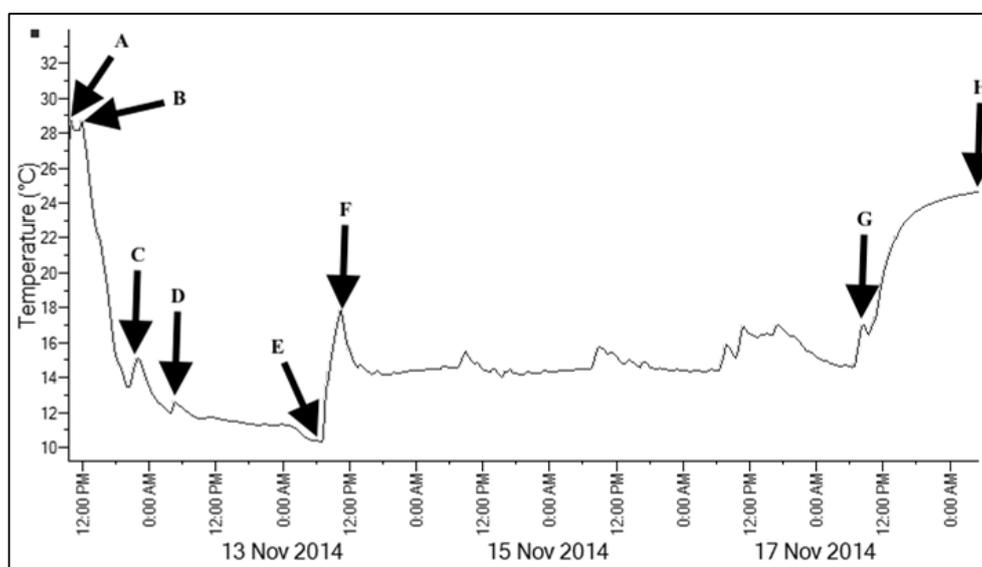


Figure 2. SC1 internal fruit core temperature of sub-sample from point-of-harvest to retail point-of-sale. (A) Product harvested; (B) Product packed into carton, moved to on-farm cold room; (C) Consignment collected by transport company from farm; (D) Truck arrives at Rocklea Market, Brisbane; (E) Consignment moved from wholesale cold room to market floor; (F) Consignment collected by retailer, transported to retail outlet, stored in cold room; (G) Moved to ambient display (H) Sold, probe removed.

3.2.2. Market Price

In SC2, 390.76 t of residual product was not harvested due an abrupt end to the season. These losses represent 94% of the entire season's harvest volume for the field. Grower 1, grower 2 and extension officer 2 identified the wholesale market price as a key driver of this loss. A grower is unable to recover operational costs of harvest when the farm-gate value of a carton (10.80 kg) falls below AUD7.50–8.00—a dollar value equal to the operational cost to harvest, pack and transport product to market. At this point, the farmer suffers production losses of AUD7.50 per carton based on combined production and operation costs of AUD15–15.50 per carton (Table 5). Grower 1 commented that *“The supply [was] far superior to . . . demand. We're getting towards the end of the line with our crop, so our quality is going to start dropping back. It's still quite good . . . in the box, but [we've] got to work harder at it. If [we] haven't got the right sizes [that is, product specified for orders] to get the better return, because the market is low, [we're] going to lose a lot of money so therefore [we] have to make the decision whether to cut [our] losses or continue.”*

Table 5. Actual, calculated full day's postharvest losses (kg) and estimated economic loss and potential market value along the supply chain.

Location of Loss (Postharvest Stage)	Supply Chain One (SC1)			Supply Chain Two (SC2)		
	Actual Loss ^a (kg)	Calculated Loss of Entire Harvest (kg)	Financial LOSS ^b (AUD)	Actual Loss ^a (kg)	Calculated Loss of Entire Harvest (kg)	Financial Loss ^b (AUD)
Field	608.2	39,400	\$29,550 (\$39,400) ^c	269.1	24,906	\$1880 (\$24,906)
Packing shed	10,560	10,560	\$7920.00 (\$10,560)	3960	3960	\$2970.00 (\$3960)
Wholesale	0	0	\$0.00 (\$0)	0	0	\$0.00 (\$0)
Retail	0.6	5381	\$4035.92 (\$5381)	0.3	747	\$560.43 (\$747)
Total		55,341	\$41,506 (\$55,341)		29,613	\$22,210 (\$29,613)

^a Actual loss is the amount of the loss sampled specific to a specific point along the supply chain. ^b Estimated production cost based on \$7.50 per 10 kg carton (i.e., immediate loss to grower). Values are shown in AUD.

^c Estimated farm-gate value based on \$10 per 10 kg carton.

3.2.3. Product Specification

The standards by which product is removed from the supply chain was variable and market dependent. It was determined that between 68.6% and 86.7% of undamaged, edible field and shed products were rejected as outgrades, and consequently discarded due to product specifications (Table 6). Interviews with supply chain actors involved in harvesting (Table 1), revealed that on any day specific instructions from field supervisors were critical in determining harvestable product. Field Supervisor 1 commented *“The size we pick depends on the days' price . . . if the price is a little bit high, the market wants the small tomatoes as well. Otherwise, if the price is low, . . . we do not pick the small stuff.”* Interviews with sorters (Table 1) affirmed that high field and packing shed losses were mostly due to cosmetic appearance, with edible product being discarded. A sorter commented *“Sometimes [they're] too small . . . , too big . . . , too odd shaped—plus the markings [so we throw them out]”*. When there is an over-supply of volume, secondary lines are out-graded due to buyers tightening the specification in favour of premium product. However, standards are not only a reflection of supply and demand, but also a reduced market share, with increased competition from newer varieties coming onto the market, placing upward pressure on standards. Grower 1 explained *“it has changed dramatically in the last 10 or 15 years but particularly in the last 4 years. our market share has diminished a lot...when I first started, there was only round [tomatoes], there was nothing else. there wasn't even romas . . . [now] 42 years later . . . a decent retail shop . . . could have 15 lines of tomatoes. A housewife . . . might pick a few gourmets, a couple of romas, a few cherries, and couple of teardrop, maybe a truss, whatever suits.”* due to a reduced market share and in the absence of new market opportunities, it is likely that levels of postharvest losses at the primary production stage will increase in subsequent years. Private supermarket policy and standards were mentioned by most supply chain actors and industry specialists as a driver of postharvest losses via stringent specifications and the ability to reject product, by the pallet, based on a single blemish. The practice of supermarkets over-ordering and then having a pick of premium product was highlighted by

extension officer 1 “they pick and choose and they control the market”. Another example of an asymmetric supermarket practice likely to elevate postharvest loss is the re-negotiation on price due to subjective quality standards. Extension officer 1 revealed that “... you’ll lock in a price ... two weeks ahead, which is what you have to do ... and if there is a change in market, you can bet your bottom dollar that [your product is] going to be rejected [in part or full] ... because [the supermarkets] will go and buy if off the [market] floor at a cheaper price.”

Table 6. Identified reasons for product being removed from the commercial supply chain, expressed as a percent of total losses in the field or in the packing shed.

Postharvest Descriptor	Loss (%)
During harvesting ^a	
Undamaged, edible product	86.7
Field blemish	60.2
Size	8.9
Irregular shape	17.7
Damaged product	11.5
Physically damaged	0.9
Insect damage	0.9
Overripe	5.3
Diseased	4.4
Other	1.8
Harvesting error ^c	1.8
Packing shed ^b	
Undamaged, edible product	68.6
Field blemish	37.3
Size	16.7
Irregular shape	14.7
Damaged product	30.4
Physically damaged	3.9
Overripe	11.8
Diseased	14.7
Other	1.0
Harvesting error	1.0

^a Includes losses collected off the ground, walking behind harvest aid during harvest, and losses thrown away by sorters on harvest aid in field. Sample number (harvesting) = 113. ^b Collected off waste conveyer from the first sorting point in packing shed. Sample number (packaging shed) = 102 ^c Mistakenly harvested, likely due to being knocked from bush during harvest.

Discussion with industry specialists (Table 2) focused on the wider consumer purchasing and behaviour elements that underpin private food standards. Extension officer 1 stated that “perfect fruit [was] the crux of the whole matter”, commenting that “as an agricultural society we have not done enough work in educating the consumer” about produce, particularly produce appearance and the purpose of used-by-dates. In support of this view, extension officer 2 likened the supermarket standards to expecting produce to “conform like a packet of Arnott’s biscuits!”. The academic summarised that “Supermarkets have gained a lot of power, and with that power they are imposing their own rules and standards,” they “demand from their wholesalers and primary suppliers exactly [what they] want.” He continues, “this is

important because [supermarkets] have been imposing more stringent standards and . . . the growers . . . have got to abide by very, very, particular standards." He finishes stating that "the rigid regime . . . probably does lead to food waste in the field."

3.2.4. Technology and Supply Chain Length

Counterintuitively, extension officer 2 and the ex-wholesale agent both viewed technology as a driver of postharvest loss, specifically packing shed mechanisation. Technologies such as laser colour graders have enabled growers to consistently produce uniform product that conforms with stringent specifications escalating volumes of out-graded product. While transport distance was not considered a contributor to postharvest loss, behavioural practices of supply chain actors were, with retailer 1 commenting, "You could have two people in the chain, and if one of them doesn't care about how he handles the fruit, you're going to have [postharvest loss]".

4. Discussion

Postharvest loss in the two commercial tomato supply chains assessed in this case study was between 40.3% (55.34 t) and 55.9% (29.61 t). The highest incidence of postharvest loss occurred at the harvesting and grading stages of the supply chains, including field and packing shed losses, accounting for between 90.3% and 97.5% of overall losses. The lowest incidence of postharvest loss occurred after the farm-gate, accounting for between 2.5% and 9.7% of overall losses. Retail losses were 2.4% and 5.4%, with the highest incidence in SC1, which was the longer (by distance and time) of the two supply chains. Destination of loss was predominantly to land application, due to the high incidence of point-of-harvest field loss. It is difficult to contextualise these findings due to few comparable horticultural FLW studies of technology-dense supply chains, with no previous FLW assessment of tomato supply chains in developed countries identified in the literature. In an older study Parfitt et al. [31] reported postharvest losses in tomatoes of 18% to 43% in Egypt. Underhill and Kumar [45], in an assessment of smallholder farmer tomato supply chains in Fiji, found destination losses of 60.8%, whereas a Cambodian study found losses between 22.5% and 23% in a comparative study between traditional and modern supply chains [47]. None of these studies assessed in-field point-of-harvest losses, so it is difficult to draw a meaningful conclusion as to relative postharvest losses observed in the two supply chains. Given the importance of global tomato production [48], the apparent dearth of previous FLW tomato studies, especially pertaining to developed countries, is interesting. In comparison to global FLW loss, where it is widely accepted that one-third of total agricultural production is lost or wasted along current food supply chains [27], the level of FLW within the two Bundaberg tomato chains appears to be comparatively high.

The finding that loss was concentrated at the primary production end of the chain is consistent with a study [27] of FLW in North America and Oceania, where 26% of FLW was attributed to the primary production level and 12% to the distribution and retail stages [27]. However, the present results are inconsistent with Lipinski et al. [24] who reported 24% of total production was lost at the point of production, and another 24% during transport and storage, and Griffin et al. [42] who found losses of 20% at primary production, 1% during processing and 19% during distribution. An American report described losses of 15% to 35% at the production stage and 27% at the retail level [30]. While much of the current literature advocates equal losses between the retail and primary production ends of the supply chain, the omission or limited inclusion of point-of-harvest loss would appear to have resulted in proportionally higher losses elsewhere along the chain. Results in this study were consistent with the consensus that horticultural commodities experience comparatively higher FLW than most other commodities, with FLW at around 50% of total production [28,36,39,49]. Postharvest losses in our study exceeded findings of a synthesis report [49] indicating horticultural postharvest losses in a developed country between 2% and 23% at the production end, dependent on horticultural commodity. However, our study was more consistent with an Iranian study [50] finding postharvest losses in strawberries of 35% to 40% and a study from the United Kingdom [39] stating that characteristic

losses for fresh vegetables could be as high as 50% in the primary production stages of a fresh food supply chain.

Few studies of FLW have sought to quantify and segregate destination of losses [28,29,39,42]. Noting the exclusion of in-field point-of-harvest losses in quantifying FLW in those studies, it is not surprising that landfill, rather than land application, is the predominant destination of loss.

High levels of FLW are immanent to horticultural production systems of developed countries, driven by fierce competition and financial incentives that have crafted the current 'business model' that favours wasteful practices [2,28,35,39]. Edible products are being removed from the commercial food supply chain as outgrades deemed cosmetically defective [31]. Private standards, prescribing 'perfect' product ensure high levels of FLW, inducing consumer intolerance of 'substandard' product and impacting purchasing behaviour [3,22,28,37]. Extension officer 2 broached the subject of consumer demand and the implications of those at the primary production level. Among consumers in developed countries, there was limited understanding around the implications and prevention of waste, [3,6,22,25,31,37,38] perpetuated by supermarkets who showcase only premium, unblemished product fabricating unrealistic expectations of how fruit and vegetables should appear.

The quantification of FLW in the context of high-technology production systems in developed countries has received relatively little attention. The premise that developed countries operate highly efficient agricultural systems optimising FLW minimisation [31,41], may in part explain this situation. Central to this view is a pre-occupation with consumer waste [6] in affluent populations as the largest and most visible portion of FLW [31,35] and that, given the inherent difficulty in changing human behaviour [24], no significant or further FLW reductions can be achieved [51]. In this study, to the contrary, the highest postharvest losses occurred at the primary production end of the chain. Discussions with industry experts revealed the potential role of technology, particularly packing shed mechanisation, in driving high levels of FLW due to uniformity of product in the sorting and grading processes. Contributing factors of FLW observed in the two tomato chains in the study were not due to poor postharvest or storage practices, or transport distance, but rather a series of commercial decisions. The most apparent driver was the cost-benefit of harvesting, based on market price, supply volume, and perceptions of retailer and consumer purchasing behaviour, which effectively made high levels of loss an economically acceptable outcome. The supply chain actors were both aware of the extent of loss and had strong and consistent views as to these key contributors. With only 44.1% and 59.7% of harvestable crop reaching the consumers of the two supply chains assessed, perhaps there should be discussion of a food "waste" chain as opposed to a food "supply" chain.

5. Conclusions

This study sought to quantify postharvest losses associated with a highly-mechanised enterprise to determine drivers of FLW independent of postharvest handling practices. The storage conditions observed for the packaged and ripening fruit along both chains were unlikely to have had any adverse effect on product shelf life or have been a contributor to postharvest loss [52,53]. In the context of the supply chains assessed, this study has demonstrated that postharvest loss is due to the deliberate and informed actions of supply chain actors, dictated predominantly by private food standards and market value rather than a lack of access to appropriate postharvest handling infrastructure. Stringent product specifications enforced via private food standards due to the combination of asymmetric supermarket business practices and consumer purchasing behaviour are considered by the supply chain actors to be the fundamental cause of high FLW. Given the notable lack of research on food loss and waste in developed countries, the results of this paper necessitate a greater research effort, particularly at the production end of the food supply chain.

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