A Quantitative and Qualitative Study of Food Loss in Glasshouse-Grown Tomatoes

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Abstract: Reducing food loss and waste (FLW) is one strategy to limit the environmental impact of the food supply chain. Australian data suggest that primary production accounts for 31% of national FLW, but there are no comparable data in New Zealand. This study aimed to measure food loss and explore food loss drivers for one of New Zealand’s largest tomato growers by weighing and visually assessing tomato losses at the glasshouse, packhouse and sales warehouse. Qualitative interviews were also held with the grower (n = 3), employees (n = 10), and key industry stakeholders (n = 8). Total food loss for this greenhouse tomato grower was 16.9% of marketed yield, consisting of 13.9% unharvested tomatoes, 2.8% rejected at the glasshouse and 0.3% rejected at the packhouse. The grower’s tomato loss predominantly resulted from commercial factors such as market price, competitor activity and supply and demand. Similar issues were recognized throughout the New Zealand horticulture sector. Commercial factors, in particular, are challenging to address, and collaboration throughout the supply chain will be required to help growers reduce food losses.

Keywords: food waste; horticulture; growers; glasshouse tomatoes

1. Introduction

Reducing food loss and waste (FLW) is gaining increasing attention as a viable way to limit the environmental impact of the food supply chain. By quantifying and then determining the causes for FLW throughout the food supply chain, meaningful interventions can be implemented to minimize or repurpose FLW. While there is a significant body of international research focusing on quantifying and determining the drivers for food waste at the consumer end of the supply chain, there are fewer publications with varying methodologies relating to FLW in primary production [1–3], especially relating to glasshouse-grown produce. In New Zealand, there are limited FLW data across the food supply chain and no published research focusing on food loss in the horticulture sector. New Zealand (NZ) tomatoes are predominantly grown for the local market, have a short shelf life and there is limited access to secondary markets. Furthermore, recent FLW research has suggested that high food loss levels can occur in the horticulture sector despite a well-established food supply chain with the infrastructure to manage environmental conditions that minimize food loss [4–6]. In 2018, Tomatoes NZ registered 123 members growing tomatoes with a farm gate value of over NZ$ 130 million [7], of which 94% of the tomatoes grown are for the New Zealand market [8]. The majority of New Zealand’s fresh-to-market tomatoes are grown year-round in glasshouses, a highly technology-centric food system [9].

1.1. Food Loss Data in the Tomato Industry

Reported FLW for glasshouse tomatoes internationally ranged from 2% to 6% of total production [10,11]; however, higher levels of food loss have been reported for field-grown tomatoes. A 2017 Australian study found in-field, postharvest tomato losses for two
harvest runs to be 40.3% and 55.9% of the total harvestable product [6]. Tomatoes were also found to have high levels of food loss in a 2019 report mapping Australian fruit and vegetable losses [12]. Tomato losses were reported as 27 to 36% of Australia’s annual tomato production. Similarly, in-field food loss data for tomatoes in Florida averaged 40% of the total production and losses at the packhouse averaged 39% of total production [13]. Conversely, in-field losses in California for Round and Roma tomatoes were 6.4% and 8.2% of marketed yield, respectively, with no packhouse losses provided [5].

1.2. Drivers for Food Loss in the Tomato Industry

Careful handling and management of tomatoes’ physical environment can help minimize FLW. A one-hour delay between harvesting a tomato crop and cooling will lead to a one-day loss of shelf life [14,15], while less than ideal relative humidity can lead to tomato shrinkage [14]. Tomatoes in the Australian food supply chain were cooled to below 20 °C within three hours and did not exceed the ideal temperature range until they were displayed at retail outlets, suggesting that food loss was not due to poor transport and storage practices [6]. The drivers identified were consistent with tomato food loss studies from other industrialized countries, including low market prices and failure to meet cosmetic standards [11,13,16]. Limited access to good secondary markets for underripe and green tomatoes, labor shortages and the challenges of accurately forecasting yields were also discussed as drivers for tomato loss [11].

Likewise, food loss drivers in the tomato industry corroborated with drivers identified throughout the wider horticulture sector [16–20], many of which have been outlined in a decision tree illustrating growers’ decision-making process in relation to harvesting fresh produce [19]. While having access to a ready buyer is the critical first step in the harvest decision-making process, price was cited as the most important factor when aiming to reduce food loss in the field. Food losses of perfect produce occur when the market price is too low for growers to recover the labor and processing costs of harvesting produce [5,16,18,19,21]. Growers may also be highly motivated to comply with cosmetic specifications due to associated commercial risks [4,16,19,21,22]. If non-compliant produce is packaged within a shipment and discovered when produce is being received, an entire shipment may be rejected at the retailer at the grower’s expense. To reduce the risk of rejected produce, growers cull produce that may becoming inedible by the time it reaches consumers. Alternatively, growers may cease harvesting a field completely, leaving potentially edible and marketable produce unharvested, to avoid the financial risk of investing labor, transport and potentially the disposal costs if the product is rejected.

1.3. Aim of the Study

There are many similarities between the New Zealand horticulture sector and the horticultural sectors for other industrialized countries such as Australia, the United States of America (USA) and the United Kingdom (UK); therefore, lessons can be learnt. However, New Zealand is also an island nation in the Pacific with an extensive domestic and export horticultural industry producing over 100 types of fruit and vegetables. This study aimed to provide an understanding of food loss experienced by the wider New Zealand horticulture sector by measuring food loss for one of New Zealand’s largest glasshouse tomato growers as well as exploring the drivers for the food loss. Furthermore, by comparing the drivers for food loss experienced by the tomato grower with food loss drivers discussed by a range of key stakeholders in the broader horticulture sector, this study aimed to provide insight into food loss throughout the New Zealand horticulture sector.

2. Materials and Methods

2.1. Study Design

This was a mixed-methods study to assess food loss and waste in the agricultural produce sector in New Zealand. The study was conducted in three parts. The first part involved semi-structured interviews with key stakeholders for the New Zealand horticulture
and food waste sectors. These interviews drew attention to the potential for high levels of food loss in glasshouse-grown tomatoes. Consequently, large, loose fresh-to-market glasshouse-grown tomatoes were selected as the focus produce for this study. The second part of the study involved obtaining quantitative food loss data via an audit. A leading New Zealand tomato grower, with glasshouses throughout New Zealand, was identified and approached to participate in the study. Tomatoes are grown year-round in rockwool media in heated glasshouses, which is typical of the production methods used by most New Zealand glasshouse tomato producers, and are primarily sold as large, loose, fresh-to-market tomatoes. In this study, food loss was measured for aspects of the tomato food supply chain that were within the grower’s control, including at the glasshouse, packhouse and sales warehouse, but excluded the retail sector. For the third part of the study, semi-structured qualitative interviews were undertaken with employees of the tomato grower, who were suggested by the grower based on the employees’ involvement with food loss at various stages of the grower’s operation. Additional employees were approached on site if they were identified as having an understanding of the observed levels of food loss. The study was conducted between July 2019 and June 2020, with food loss data collected in March 2020, one week before New Zealand entered COVID-19 Alert Level 4 lockdown [23]. The study was approved by the University of Otago Ethics Committee (D19/206). For brevity, the methodology for the quantitative component (e.g., measuring food loss of tomatoes) of the study is presented next, followed by the qualitative component (e.g., semi-structured interviews).

2.2. Quantitative Food Loss Data at the Glasshouse, Packhouse and Sales Warehouse

Two heated glasshouses producing different varieties of large, loose fresh-to-market tomatoes in rockwool media at one North Island site were selected for the food loss audits. The first glasshouse (Glasshouse 1) was 19,000 m$^2$, contained 150 full rows of tomatoes, and the second glasshouse (Glasshouse 2) was 21,000 m$^2$, contained 164 full rows and 3 half rows of tomatoes. The tomato vines from both glasshouses were planted in January (New Zealand summer) and had been harvested for two weeks, or six harvest runs, prior to the audit taking place. Food loss was quantified using two different methods in this study: [1] a counting system for unharvested tomatoes in the glasshouse runs, and [2] the total weight of reject tomatoes from the harvested tomatoes at the glasshouse, packhouse and sales warehouse. Food loss results were presented as raw weight as well as a percentage of marketed yield, consistent with reporting from other primary production research [5,24].

2.3. Unharvested Tomatoes on Tomato Vines

When auditing the number of unharvested tomatoes on the tomato vines, eight rows, or 4% of the total number of rows, were selected, spread throughout each glasshouse. Rows on both sides of the glasshouse were included to allow for variations in light levels throughout the day, and all rows were a similar length (i.e., rows on the edges of the glasshouse were avoided). The number of tomatoes left unharvested on or below the harvest truss was counted immediately after a harvest, but before the vines were lowered. The total weight of unharvested tomatoes was calculated using the following equation:

\[
\text{Number of unharvested tomatoes} \times \text{Weight of reject tomatoes at glasshouse} \\
\text{Total number of reject tomatoes at glasshouse}
\]

2.4. Reject Tomatoes from the Glasshouse, Packhouse and Sales Warehouse

Harvesters are instructed to collect all reject tomatoes in bins as a standard practice. The total weight of collected reject tomatoes from each glasshouse was weighed on the grower’s floor scales (Wedderburn DIGI DI-166 weighing indicator). At the packhouse, all reject tomatoes were collected in crates at the end of the grading belt and the total weight was measured on a calibrated scale (Alpha 770, Seca, Hamburg, Germany). At the sales
warehouse, the weight of any unsold tomatoes that became food loss was obtained from the packhouse manager.

Sub-samples of rejected tomatoes for each harvest run that were collected at the glasshouse and packhouse were visually assessed to identify the reasons for rejection. The total number of edible and inedible rejected tomatoes was also recorded. As unharvested tomatoes were not collected during the audit, a visual assessment was not carried out on these tomatoes.

2.5. Temperature and Relative Humidity

The environmental temperature and relative humidity for the harvested tomatoes were monitored to determine whether transport and storage conditions were contributing factors to food loss. Temperature and relative humidity from the point of harvest to the start of the grading process were measured using hygrochron temperature (DS1921G-F5#) and temperature/humidity (DS1923-F5#) data loggers or iButtons (iButtonLink Technology, Whitewater, WI, USA). Three pre-activated iButtons were attached to a different crate of harvested tomatoes at one-hour intervals throughout the harvest for each glasshouse. Temperature and relative humidity were measured as the tomato crates were transported 46 km in non-refrigerated trucks to the packhouse. The iButtons were deactivated as tomatoes were loaded onto the grading belt at the packhouse. Data from the temperature and relative humidity readings were presented as line graphs and compared against the ideal temperature (10°C and 20°C) and relative humidity (85–95% RH) ranges for tomato storage [14,25,26].

2.6. Semi-Structured Qualitative Interviews

2.6.1. Participant Selection and Recruitment

Key stakeholders in the New Zealand horticulture and food waste sectors were identified from the list of submissions made to the New Zealand Parliament Select Inquiry into food waste [27], an internet search, and snowball sampling. The key stakeholder interviews highlighted the diversity of the New Zealand horticulture sector and, during these interviews, several comments were made about the potential for food loss for glasshouse-grown tomatoes. Employees of the tomato grower to be interviewed were suggested by the grower based on the employees’ involvement with food loss at various stages of the grower’s operation. Additional employees were approached for interviews while on site if they were identified as having an understanding of the observed levels of food loss. Prior to conducting interviews, all interviewees were presented with information sheets and consent forms. Eight key stakeholders from the New Zealand food waste or horticulture sectors agreed to be interviewed. The tomato grower and six employees were recruited for interviews.

2.6.2. Interview Guide and Procedure

Interviews were either carried out face to face or using Zoom video conferencing software (Zoom Video Communications, San Jose, CA, US). Key stakeholder interviews were 45 to 60 min in duration, while all interviews with the tomato grower and employees were 15 to 20 min in duration. Interviews were audio-recorded and transcribed non-verbatim. To maintain the confidentiality of the interviewees, key stakeholder names and the organizations they worked for were removed and replaced with unique identification numbers ranging from (Int. 1) to (Int. 8). Unique identifiers were assigned to the grower and each employee interviewed ranging from (Int. A) to (Int. G).

A semi-structured interview format was selected for interviews with key stakeholders, the tomato grower and employees. This format allowed a standardized set of questions as well as a deviation in questioning to follow up on emerging points of interest [28]. The key stakeholder interview guide included 6 to 10 questions about the best ways to engage growers in the study, preferred terminology, and practical aspects of data collection. Questions were also asked to gain an understanding of key stakeholders’ observations as
to the extent of food loss in the New Zealand horticulture sector and potential contributing factors to this food loss. Six questions for the tomato grower and employees focused on how typical the observed food loss levels were, contributing factors for the tomato food loss observed during the audits at the glasshouse, packhouse and sales warehouse and how contributing factors varied throughout the growing season. While on site, reject tomatoes from other glasshouses were observed, which were also queried. The grower, packhouse manager and sales representative were asked an additional four questions to explore the impact of COVID-19 on tomato losses for the tomato grower.

2.6.3. Thematic Analysis

Key stakeholder interviews were analyzed using inductive thematic analysis, a six-phase process outlined in Braun and Clarke [29] and were collated using the qualitative analysis software program NVivo Version 12 Pro (QSR International, Melbourne, Australia). A coding structure was developed with themes emerging from the interviews related to the contributing factors for food loss in the New Zealand horticulture sector. Deductive thematic analysis, using the coding structure developed for key stakeholders, was conducted to analyze a total of 13 interviews with the tomato grower and employees.

3. Results and Discussion

This study provides insights into the levels of food loss experienced by fresh-to-market glasshouse-grown tomatoes as well as highlighting the causes for the levels of food loss. The results from the tomato grower and employee interviews were also compared to the results from the key stakeholder interviews in the horticulture and food waste sectors because, taken together, they provide a comprehensive overview of the drivers for food loss in the wider New Zealand horticulture sector.

3.1. Food Loss Levels for Glasshouse-Grown Tomatoes

Harvesters collected a total of 388 kg and 170 kg of reject tomatoes from the audited harvest runs for Glasshouse 1 and 2, representing 3.9% and 1.6% (average 2.7%) of the marketed yield, respectively. Despite the grower’s harvesting instructions to remove all unmarketable tomatoes from the tomato vines during a harvest run, it was calculated that after harvesting had been completed 1274 kg of tomatoes or 12.6% of the marketed yield were left unharvested on the vines in Glasshouse 1 and 1595 kg of unharvested tomatoes or 15.1% of the marketed yield for Glasshouse 2 (average 13.9%). A total of 10,110 kg and 10,608 kg of tomatoes were delivered to the packhouse from the two glasshouses being audited, respectively. Unmarketable, reject tomatoes from these deliveries weighed 21 kg and 37 kg for Glasshouse 1 and 2, respectively, representing 0.2% and 0.4% (average 0.3%) of the marketed yield. There was no food loss from the warehouse for either harvest run, with 100% of tomatoes sold. Food loss measured at each stage of the large loose tomato supply chain under the control of the grower is summarised in Table 1.

<table>
<thead>
<tr>
<th>Total Food Loss (kg)</th>
<th>Percentage of Marketed Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glasshouse 1</td>
<td>Glasshouse 2</td>
</tr>
<tr>
<td>Unharvested</td>
<td>1274</td>
</tr>
<tr>
<td>At glasshouse</td>
<td>388</td>
</tr>
<tr>
<td>At packhouse</td>
<td>21</td>
</tr>
<tr>
<td>At warehouse</td>
<td>0</td>
</tr>
<tr>
<td>Total reject tomatoes</td>
<td>1683</td>
</tr>
</tbody>
</table>

Table 1. Total food loss and percentage of marketed yield at glasshouse, packhouse and sales warehouse for the audited harvest runs.

There are limited tomato food loss data available, both nationally and internationally, to provide a comparison to the levels of food loss experienced by the glasshouse tomato.
grower in this study. Two studies cited glasshouse tomato food loss levels [10,11], while the other three studies were carried out on field-grown tomatoes [5,6,13]. In addition to the limited number of studies available, the study designs and methods used to report food loss levels differed from those used in the current study, making comparisons difficult. A 2019 study stated that food loss accounted for 2% of total production for the Norwegian and Belgian glasshouse tomato industries [10]; however, it is unclear how these food loss figures were calculated. In 2020, a total of 6% surplus and waste was reported for conventional glasshouse-grown tomatoes in the UK by a tomato grower participating in the farmer-led food loss data gathering pilot conducted by WRAP [11]. As the UK tomato grower sold truss tomatoes, the harvesting and grading processes do differ from the processes used for large, loose tomatoes. The tomatoes removed from the food supply chain at the glasshouse in this study accounted for 2.7% of the marketed yield for each of the audited harvest runs. A comparison with the results from the Norwegian, Belgium and UK tomatoes growers suggests that the New Zealand grower is experiencing levels of food loss similar to other growers in the industry. However, as the audits for the current study were completed at the beginning of the harvest season, when less food loss is anticipated by the grower, there may be an opportunity to lower the levels of food loss for the New Zealand tomato grower when compared to the total food loss levels reported for Norway and Belgium.

Nevertheless, a comparison of the food loss results from the glasshouse tomato grower with data from field-grown produce indicates that field-grown tomatoes incur higher levels of food loss. Total food loss of 16.9% market yield was reported for this New Zealand tomato grower, consisting of 13.9% unharvested tomatoes, 2.8% rejected at the glasshouse and 0.3% rejected at the packhouse. Conversely, the in-field food loss levels for Florida’s fresh-market tomato supply chain averaged 40% of the total production and packhouse estimates for food loss were reported as 39% of total production [13]. Similarly, an Australian tomato case study measuring post-harvest losses reported that 44.1% and 59.7% of the harvestable crop from the two audited harvest runs reached consumers, with the majority of the tomatoes being rejected either in the field or at the packhouse [6].

Field-grown tomatoes are more susceptible to variable weather conditions that impair the quality of the tomatoes [16], whereas growers of glasshouse tomatoes have better control of the growing environment [30]. Furthermore, the tomato grower for the current study explained that they wanted to valorize as much produce as possible to recover the high production costs associated with establishing and maintaining the glasshouse tomato vines. Recently published literature has reported that high levels of food loss may occur in primary production for countries with highly industrialized food supply chains [6,24,31]. However, food loss results from the tomato grower in the current study suggest that this observation may not apply to glasshouse-grown produce. An over-representation of food loss studies focusing on field-grown produce and a notable lack of data relating to glasshouse-grown produce may overestimate the reported food loss levels for the horticulture sector. Having an accurate estimation of the levels of food loss at each stage of the food supply chain ensures that FLW reduction efforts are focused on actions that will have the greatest overall impact and provide more useful data for measuring the impact of FLW reduction initiatives. Therefore, further data collection for this aspect of the horticulture sector is required.

3.2. Physical Evidence of the Drivers of Food Loss for Glasshouse-Grown Tomatoes

Understanding the contributing factors for food loss is helpful information for growers seeking to reduce their levels of food loss or valorize reject produce. A visual assessment of reject tomatoes may highlight production, harvesting and grading practices that impact food loss levels, while knowledge of the total volume of edible food loss informs the grower about the potential produce available for valorization.

Sub-samples of rejected tomatoes at Glasshouses 1 and 2 (n = 460 and n = 247) were visually assessed as to why they had been removed from the supply chain. At the packhouse, all rejected tomatoes from both glasshouses (n = 220 and n = 257) were assessed to determine the main reasons for rejection. Overall, 50% of the reject tomatoes at the glasshouse,
and 22% of the reject tomatoes at the packhouse, were rejected due to non-compliance with contract specifications relating to color, size, and shape. Tomatoes were also rejected for operational reasons such as harvest cuts and tears or being classified as “floor fruit,” which occurs when harvesters and vine maintenance workers unintentionally knock produce to the floor as they work amongst the tomato vines. A summary of the total number of tomatoes recorded for each contributing factor identified at the glasshouse and packhouse, as well as a percentage breakdown, is presented in Table 2.

Table 2. Breakdown of the reasons tomatoes became food loss at the glasshouse and packhouse for the audited harvest runs.

<table>
<thead>
<tr>
<th>Reasons for food loss</th>
<th>At Glasshouse</th>
<th></th>
<th>At Packhouse</th>
<th></th>
<th>Average for Both Harvest Runs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Glasshouse 1</td>
<td>Glasshouse 2</td>
<td>Glasshouse 1</td>
<td>Glasshouse 2</td>
<td>Glasshouse 1</td>
</tr>
<tr>
<td>Total Reject Tomatoes</td>
<td>79</td>
<td>17</td>
<td>114</td>
<td>46</td>
<td>101</td>
</tr>
<tr>
<td>Inedible</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blossom End Rot</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>Cuts &amp; Harvest Tears</td>
<td>9</td>
<td>2</td>
<td>25</td>
<td>10</td>
<td>71</td>
</tr>
<tr>
<td>Floor Fruit</td>
<td>62</td>
<td>13</td>
<td>74</td>
<td>30</td>
<td>0</td>
</tr>
<tr>
<td>Squashed/Split</td>
<td>8</td>
<td>2</td>
<td>5</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Machine Damage</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>Pest Damage</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>11</td>
</tr>
<tr>
<td>Total</td>
<td>79</td>
<td>17</td>
<td>114</td>
<td>46</td>
<td>101</td>
</tr>
<tr>
<td>String Marks &amp; Blemishes</td>
<td>51</td>
<td>11</td>
<td>38</td>
<td>15</td>
<td>34</td>
</tr>
<tr>
<td>Too Small</td>
<td>1</td>
<td>0</td>
<td>4</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Too Soft/Too Red</td>
<td>305</td>
<td>66</td>
<td>60</td>
<td>24</td>
<td>65</td>
</tr>
<tr>
<td>Edible</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>King Tomatoes</td>
<td>10</td>
<td>2</td>
<td>17</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Discolouration</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Shrinkage</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Compression Marks</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>381</td>
<td>82</td>
<td>133</td>
<td>54</td>
<td>119</td>
</tr>
</tbody>
</table>

The primary reason tomatoes were removed from the supply chain for Glasshouse 1 was cosmetic, with 66% of the fruit being too small to meet quality standards. Other reasons included floor fruit, which occurs when harvesters and vine maintenance workers unintentionally hit produce during vine maintenance, (13%), and string marks and blemishes (11%). Reject tomatoes from Glasshouse 2 were predominantly removed due to being floor fruit (30%), being too small (24%) and string marks and blemishes (15%). The average weight of edible tomatoes across both glasshouses was 190 kg, representing 1.32% of marketed yield. The main reasons tomatoes were removed from the supply chain at the packhouse for Glasshouse 1 were cuts and harvest tears (32%), being too small (30%), and string marks and blemishes (15%). Of the tomatoes removed from this harvest run, 54% were edible. Tomatoes were removed from the supply chain at the packhouse for Glasshouse 2 predominantly due to blossom end rot (41%), cuts and harvest tears (28%), or string marks and blemishes (12%). Only 21% of reject tomatoes were edible. The average edible food loss collected at the packhouse for the audited harvest runs accounted for 11 kg or 0.04% of the marketed yield. Similar reasons for rejection were noted by in-field tomato growers in Australia and Florida with in-field and packhouse tomato food losses typically being due to irregular shape or size (too small or too big), being too ripe or damaged [6,13].

The environmental temperature and relative humidity for the harvested tomatoes were monitored from 17 to 24 h. It took between 2 h 40 min and 5 h 40 min for the temperature of the tomatoes to drop consistently below 20 °C. Tomatoes from Glasshouse 1 were held at the ideal relative humidity on four individual occasions ranging in duration from 10 to 40 min and tomatoes from Glasshouse 2 were held at the ideal relative humidity range for 5.5 h consecutively. Despite the time it took for the temperature of tomatoes to drop below 20 °C and the less than ideal relative humidity, over-ripeness and shrinkage were not identified as reasons for rejection at the packhouse. Therefore, less than ideal temperatures
and relative humidity were not identified as contributing factors for food loss at this stage of the supply chain.

3.3. Contributing Factors of Food Loss from Interviews

Interviews with key stakeholders highlighted three broad themes in relation to the drivers for food loss in the horticulture sector: environmental drivers, operational drivers and commercial drivers. Each of these drivers was further subdivided to highlight sub-themes presented during the interviews. A breakdown of the themes, sub-themes and their definitions are outlined in Table 3. A deductive approach was used to analyze the grower and employee interviews based on the emerging themes presented from the key stakeholder interviews. Extracts from the grower and employee interviews linked directly to all sub-themes identified in key stakeholder interviews, other than planned overproduction to meet contract specifications and, at the time the interviews were held, issues with the availability of labor. One notable difference was that the grower and employees discussed the interrelationship between seasonal, environmental drivers and market conditions, whereas key stakeholders were more likely to discuss environmental or operational drivers independently of commercial drivers.

Table 3. A breakdown of the themes, sub-themes from key stakeholder interviews.

<table>
<thead>
<tr>
<th>Themes</th>
<th>Sub-Themes</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental Drivers</td>
<td>Weather &amp; Seasons</td>
<td>Weather and seasonal events that result in food loss.</td>
</tr>
<tr>
<td></td>
<td>Pests, Mold and Rot</td>
<td>Pests, mold or rot that results in food loss.</td>
</tr>
<tr>
<td></td>
<td>Harvesting and Plant Maintenance</td>
<td>Harvesting and plant maintenance processes such as hand-harvesting versus machine harvesting produce that lead to food loss.</td>
</tr>
<tr>
<td>Operational Drivers</td>
<td>Packing, Storage &amp; Logistics</td>
<td>The packaging, storage and transportation of produce that results in food loss.</td>
</tr>
<tr>
<td></td>
<td>Over-production</td>
<td>The production of produce in quantities that are in excess of those contracted by buyers.</td>
</tr>
<tr>
<td></td>
<td>Labor</td>
<td>The availability and skill levels of staff to harvest, sort and pack produce.</td>
</tr>
<tr>
<td>Commercial Drivers</td>
<td>Market Price</td>
<td>The price for a product set by the market.</td>
</tr>
<tr>
<td></td>
<td>Supply &amp; Demand</td>
<td>The supply and demand into the market for a particular fruit or vegetable as a driver for food loss.</td>
</tr>
<tr>
<td></td>
<td>Competitor Activity</td>
<td>The business activity of any person or entity which offers a similar product or service.</td>
</tr>
<tr>
<td></td>
<td>Minimizing costs &amp; cost recovery</td>
<td>Choosing not to carry out a process to minimize costs that may not be recovered or selling produce at a lower than ideal price to help recover some of the production costs for a fruit or vegetable.</td>
</tr>
<tr>
<td></td>
<td>Access to Secondary Markets</td>
<td>The availability of buyers or markets for a lower grade or excess produce such as food processors or community F&amp;V markets.</td>
</tr>
<tr>
<td></td>
<td>Quality Standards &amp; Contract Specifications</td>
<td>The quality standards set by the grower to establish or maintain their brand integrity or a buyer’s quality expectations, outlined in a contract or when checking the delivery of produce.</td>
</tr>
<tr>
<td></td>
<td>Does not make economic sense</td>
<td>The cost and/or effect required to get product to market is too great to justify doing it.</td>
</tr>
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Environmental drivers such as pests, mold and rot, as well as seasonality, the associated light levels and weather events, were discussed in both key stakeholder and grower
interviews, but there was little evidence suggesting that environmental drivers contributed to the observed levels of food loss in the current study. The grower reported that pests, mold and rot became more of an issue at later stages of the harvest season; therefore, the results from this study do not accurately reflect the impact of these drivers throughout the harvest season “[P]est damage, that comes at the end of the crop” (Int. B).

Operational drivers were only occasionally discussed by key stakeholders, the grower and employees and did not account for large quantities of the reject tomatoes collected at the glasshouse or packhouse. Examples of operational drivers included “floor fruit” and the limited storage capacity to hold excess produce to meet food processor requirements for the quantity or quality of tomatoes.

“The processor, when we talked to the processor he said he could only take 4 tons a week. So the strip pick, you can’t hold that much fruit, 100 tons, because we don’t have enough space here. So, you only have a small window. So if you keep that fruit here for a week, you can give him 4 ton and what he needs either a whole color or dead green. So if we give that to him in one week it will be orangey. But he doesn’t need orange, he needs full color. So then you have to keep it for nearly a month or so. At least two or three weeks, to get it full color. And then he will only take 4 ton at a time” . (Int. C)

The exception for operational drivers observed during the audit process was the high percentage of unharvested tomatoes. In the two weeks prior to the food loss audit taking place, harvesting time targets had been introduced which may have resulted in increased levels of unharvested tomatoes to meet these new requirements. This suggests that incidental episodes of food loss may occur as a result of operational changes and that it would be advantageous for growers to monitor systems more broadly so that adjustments can be made as issues arise. Given the timing of this study, a follow-up audit was unable to be conducted to reassess these observations.

Commercial drivers were the issues most commonly discussed when interviewing key stakeholders, the grower and employees, specifically market price, competitor activity and supply and demand. Of course, these factors are interrelated with supply being influenced by competitor activity, which impacts market price. As one participant from the horticulture sector mentioned, “[T]he trickiest thing if you think about growing in New Zealand for the New Zealand market is that the New Zealand market is the New Zealand market. So, if we plant a variety and our competitors plant the same variety then suddenly, we have a whole lot of mandarins coming on, then we have too many mandarins and then it floods it. People will only buy so many mandarins”. (Int. 3).

Comparisons between the contributing factors for food loss discussed in grower and employee interviews for this study and those presented in international literature suggested that, despite differences in the growing environment between glasshouse- and field-grown crops, many of the underlying factors are the same. Results from this study reinforce the findings from a previous study when they interviewed growers about their decision-making process when harvesting field-grown crops [19]. Glasshouse-grown tomatoes need to be harvested regularly to ensure the longer-term maintenance of the vines; nevertheless, having a ready buyer and a market price that covers operating costs were still key determinants of food loss levels. This factor was highlighted in an adventitious discussion about a food loss event relating to 32 tons of “strip pick” tomatoes that were going to be dumped as the grower was struggling to find a buyer. It was explained that “there was one processor . . . where the cost to train [tomatoes] from here to there, the return they are giving us is 50 cents but it is costing us 80 cents to ship [it] there” (Int. C). To minimize further losses associated with the harvest, the grower had to “dump” the tomatoes.

The agreement between the contributing factors discussed by the grower, employees and key stakeholders suggests that commercial factors are predominantly influencing food loss levels across the New Zealand horticulture sector. Working independently, growers may have limited ability to influence these drivers. Therefore, a collaborative...
approach is required that engages actors throughout the New Zealand food supply chain, politicians, food technologists and research teams. Similar recommendations were made in recent publications [11,17,32–35], with examples including supply chain communication to minimize overproduction by growers and signal limited supply or cosmetic impairment to consumers, government policy that directs food loss disposal up the food waste hierarchy and infrastructure to shorten supply chains, improve access to secondary markets and support the valorization of reject produce.

In particular, growers cautioned that efforts to reduce on-farm food losses needed to be economically viable to be successful [34]. Growers are generally open to the concept of donating produce to food rescue organizations but are reluctant to incur additional harvesting expenses, time commitments or liabilities with inexperienced harvesting teams entering their farms [34,36]. While some growers have focused on improving agricultural practices and technology to decrease on-farm food losses [33,37], others preferred efforts to focus on the creation of secondary markets and expand the food processing sector’s ability to create products from imperfect produce [34,38]. The new food trend of “upcycling” food may provide growers and food processors an opportunity to innovate with surplus or unmarketable produce. Consumer response to the upcycled food trend has been positive, with 53% of Italian millennials willing to buy upcycled food items, and 69% believe that the addition of upcycled ingredients has positive environmental benefits [39]. Notably, tomatoes have been recognized as a low-cost source of antioxidants such as carotenoids, which can be added to functional foods [40–42].

3.4. The Impact of COVID-19 Level 4 Lockdown and the Contributing Factors Identified

Given the timing for this food loss study, the closure of the majority of sales channels available to glasshouse-grown tomatoes due to the COVID-19 Alert Level 4 lockdown in New Zealand had a significant impact on food loss levels. Discussions with the grower about their experiences over this time also provided further examples of the commercial drivers contributing to food loss. With the closure of the hospitality sector, growers’ markets, and small fruit and vegetable stores, there was an excess supply of fresh tomatoes and a limited number of potential buyers. Furthermore, there was a decrease in demand for fresh tomatoes from supermarket customers, with demand shifting to lower-priced produce with a longer shelf life, such as potatoes, carrots and onions. The grower did endeavor to donate excess produce to local food rescue organizations during the lockdown period. Unfortunately, the quantities donated were limited by the food rescue organizations’ operational ability to transport, store and process the volume of tomatoes available during the lockdown. As the grower explained, the truck for one food charity “could only fit two to three pallets at a time, which was, unfortunate” (Int. A). The inability of food rescue organizations to receive larger volumes of produce has been recognized and addressed with the establishment of the New Zealand Food Network in 2021 [43]. While the COVID-19 lockdown was an unprecedented situation driving food loss for growers, it did put the spotlight on some of the everyday barriers encountered by growers endeavoring to reduce food loss. In doing so, positive changes have since been made to help address some of these issues, such as the creation of channels through which growers can donate produce [44] and changes to the operating capacity for food rescue organizations [43].

3.5. Strengths and Limitations

This research adds to the limited body of food loss data for large, loose glasshouse tomatoes. A key strength of this study is the inclusion of both quantitative and qualitative methodologies. The food loss audit has generated detailed data on the physical attributes of tomatoes that led to food loss. Interviews with the tomato grower and employees, as well as key stakeholders in the New Zealand horticulture and food waste sectors, have helped gather useful information about why produce is removed from the food supply chain. Collectively, this information helps highlight the potential to prevent or valorize food
loss and when it might be viable to move produce up the food waste hierarchy. Another strength of the study is the use of iButtons to collect temperature and humidity data.

This study also has limitations. Food loss data were obtained from two glasshouses, on one occasion only, and therefore do not indicate food loss throughout a growing season or across the glasshouse tomato industry. Food loss levels are reported to increase as the glasshouse tomato vines near the end of the harvesting season. As the food loss audit for this research was conducted at the beginning of the harvest season, the results presented in this research may be underestimated. Further research with a larger number of glasshouse tomato growers, throughout a growing season, would generate more accurate food loss data needed to support innovation to redirect or repurpose large loose tomatoes removed from the food supply chain.

4. Conclusions

This study suggests that there are low levels of food loss in the fresh-to-market glasshouse tomato supply chain, especially when compared to field-grown produce. The growing conditions of the glasshouse can be better controlled to reduce the impact of environmental and operational drivers leading to food loss. Furthermore, the significant financial investment establishing and maintaining the tomato vines throughout the harvest season motivates the grower to valorize as much produce as possible. Commercial drivers were identified as the most significant contributing factors for food loss in the glasshouse tomato supply chain and for the wider New Zealand horticulture sector. Collaboration across the food supply chain and support from other agencies will be required to help growers utilize or valorize unmarketable produce and to dispose of food loss in environmentally sustainable ways.

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