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Postharvest Losses of Pomegranate Fruit at the Packhouse and Implications for Sustainability Indicators

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Abstract: Pomegranate fruit, like other types of fresh horticultural produce, are susceptible to high incidence preharvest and postharvest losses and waste. Several studies have been done to improve the production and handling of pomegranate fruit to meet market standards, but little has been done in loss quantification, especially in the early stage of the value chain such as the packhouse. Therefore, the aim of this study was to quantify the magnitude of pomegranate fruit losses at the packhouse, identify the causes, and estimate the impacts of losses. The study was conducted on a case study packhouse in the Western Cape Province of South Africa from February to March 2020. The direct measurement method, which involved physical identification of the causes of loss on individual fruit, was used for data collection. Loss quantification involved the calculation of lost fruit proportional to the amount put in the packhouse processing line. The results showed that losses ranged between 6.74% to 7.69%, which translated to an average of 328.79 tonnes of pomegranate fruit removed during packhouse operation per production season at the investigated packhouse. This magnitude of lost fruit was equivalent to over ZAR 29.5 million (USD 1,754,984) in revenue, in addition to the opportunity costs of resources used to produce lost fruit.

Keywords: pomegranate; losses; nutrition; environmental; resources; packhouse; postharvest; impacts

1. Introduction

Pomegranate (Punica granatum L.) is an ancient fruit believed to be first cultivated around 3000 and 4000 BC, and was mentioned both in the Bible and the Quran [1]. Its origin is traced to the Middle East, in present-day Iran, and it adapts to a variety of soil conditions in the Mediterranean, subtropical, and tropical climates [2,3]. Currently, it is grown in many countries for fresh consumption and industrial uses [4,5]. As a result, more than 500 cultivars are grown globally, with some cultivars named differently in different parts of the world [2,4–6]. The awareness of its numerous uses and benefits has made it popular among other fruit [5,6]. Pomegranate can be eaten as fresh produce or juiced and stored in the appropriate temperature and relative humidity. It is sweet, sour, or acidic depending on the cultivar and rich in vitamins, minerals, and other organic compounds [4,5]. The consumption of pomegranate has been linked with a great health outcome in different studies [3,7–10]. The phenolic compounds present in pomegranate have been found to be great anti-inflammatory, anti-oxidative, and anti-carcinogenic chemical compounds, which helps to reduce tumour growth and chronic inflammation [11]. The hypoglycaemic activity of pomegranate juice has been found to prevent diabetes mellitus [12]. Pomegranate fruit consumption has been reported to reduce cardiovascular diseases [13]. Chemical compounds in pomegranate fruit are also used in the treatment of diseases such as ulcers,
acidosis, haemorrhage, aphthae, diarrhoea, dysentery, respiratory pathologies, and microbial infections [3,9]. The manufacturing industries use pomegranate aril and peel as a raw material in the production of jams, ink, dye, and oil [3].

Trends in Production and Trade of Pomegranate Fruit in South Africa and Globally

There has been a rapid increase in the production of pomegranate globally, but the trade has grown more locally in the major producing countries [14,15]. Countries such as India, China, Iran, and Turkey are the leading producers, while India and Iran are the highest exporters of the fruit [2]. However, because the fruit are often grown and picked from small farms in different locations in the major producing countries, there are no articulated data available about global production area [1,2,15]. However, global production was estimated to have increased from about 3 million tonnes in 2014 to 3.8 million tonnes in 2017 [1].

The production of pomegranate fruit in different parts of the world is primarily divided into two (Northern Hemisphere and Southern Hemisphere) due to different seasons of production in the regions [15,16]. The demand for the fruit, especially in the Northern Hemisphere, is derived in nature in the sense that it is mainly driven by industrial usage since there is no close substitute for the antioxidants found in pomegranate [15]. The supply is stratified according to the variation in the production seasons, which allows the Southern Hemisphere to fill the niche market gap in the Northern Hemisphere. The Northern Hemisphere, however, accounts for above 90% of the total production, hence, it has a higher share in the global trade [15]. According to Kahramanoglu [1], global pomegranate production area is increasing, but some of the producing countries are facing quality issues, which leads to considerable postharvest losses and waste. Europe is the biggest market for pomegranate followed by Asia and the Middle East, as almost all the producing countries share the European markets [1]. Peru and Chile are the biggest exporters of pomegranate fruit from the Southern Hemisphere with 74% and 14% respectively, while South Africa and Argentina have a combined 12% contribution to export from the region [17]. Iran, China, India, Turkey, Spain, and Israel are the highest producers in the Northern Hemisphere, but most of the production in this region is consumed locally [1,14].

The pomegranate fruit is one of the deciduous fruits grown in South Africa, occupying about 1024 hectares of land in 2019 from 771 hectares in 2011 [16]. It is mostly grown in the Western Cape, which accounts for about 81% of total production [16]. In South Africa, the majority of the production is exported, which earns export revenue for the country and income for the farmers and value chain actors. In 2019, about 76% of the total production was exported [16], and in 2018, the local market generated about ZAR 67,000 per tonne [17]. Production and export have grown from about 837,250 cartons (3.8 kg equivalent) in 2014 to 1,676,160 cartons (3.8 kg equivalent) in 2019, and are projected to increase to 2,055,271 cartons (3.8 kg equivalent) by 2024 [16]. Between 2014 and 2019, about 7,557,906 cartons (3.8 kg equivalent) were exported [16]. The major market for South African pomegranate is Europe. About 61% of the total export is in the European markets and 22% in the Middle East, with Asian and African countries importing a small amount [17]. The main competition for export market share comes from the Southern Hemisphere countries, whose pomegranate fruit is ready in the market almost in the same period as that of South Africa.

While the pomegranate industry is growing rapidly in South Africa and globally, fruit are susceptible to losses and waste (wastage) which reduce profitability due to a wide range of preharvest and postharvest factors, including pest and disease attack [18,19], bruise damage [20], moisture loss [21,22], and mechanical damage [23]. Industry estimates in South Africa also suggest that the incidence sunburn (a preharvest skin defect) alone can be high, causing grower losses that may exceed 30% of harvested fruit [24]. Despite the identified causes of wastage of the fruit in South Africa, there is a lack of quantitative and science-based data on the magnitude of losses to guide the implementation of loss reduction strategies. During typical packhouse operation, fruit are cleaned, sorted, graded, labelled,
and packed, and those that do not meet quality specifications due to the preharvest and postharvest factors outlined are considered as loss and thus discarded or sold at a nominal price for juice or animal feed. As the last point of fruit handling and quality control prior to storage, marketing, and distribution, the packhouse is a critical step in assessing the magnitude and causes of fruit postharvest loss which are critical pieces of information for informing loss reduction strategies. Discussions on the magnitude of postharvest losses and the causes are often based on estimates, without site-level measurements which are known to be difficult and costly. However, researchers globally agree on the need for more studies to directly quantify the amount of postharvest food losses and to identify the site-specific contributing factors along the value chain [25–28]. Therefore, the objective of the current research was to assess the magnitude of pomegranate fruit postharvest losses at the packhouse level based on a case study in South Africa, identify the causes, and estimate the socio-economic and environmental impacts of the losses.

2. Materials and Methods

2.1. Study Settings

The study was conducted from February to March 2020 in the Western Cape Province (Latitude 33.2278° S, Longitude 21.8569° E) of South Africa. The province was chosen because over 80% of total production of pomegranate fruit in the country is done in the region [16] and the case study packhouse is arguably the biggest packhouse in the area. The study was conducted on the three most commercially grown pomegranate cultivars in the country, namely ‘Herskawitz’, ‘Acco’, and ‘Wonderful’. ‘Herskawitz’ has a sour taste with hard seeds, ‘Acco’ has a sweet taste with softer seeds, while ‘Wonderful’ has a vinous taste with soft seeds [29]. The study was carried out by assessing the physical quality of fruit sorted as ‘waste’ from the packhouse production line. The assessment started at about 9:00 a.m. and ended by 3:00 p.m. daily. ‘Herskawitz’, which is the early cultivar, was assessed by mid-February while ‘Acco’ was assessed by early March. ‘Wonderful’ was assessed by mid and late March. The handling and packaging practices at the packhouse were observed. The unit of measurement of lost fruit was the bin [length (1270 mm) × width (1070 mm) × height (720 mm)]. A total of 251 bins, containing 1300–1500 fruit each which were processed by the packhouse during the study period, were used to assess the magnitude of fruit losses (‘Herskawitz’ 84, ‘Acco’ 89, and ‘Wonderful’ 78) by putting fruit through the packhouse line for sorting and grading. The bins handled by the packhouse during the study period were all examined in order to provide a sufficient and representative dataset based on commercial practice. The magnitude of loss was estimated for each pomegranate cultivar based on the number of waste bins containing lost/rejected fruit. Fruit sorted into waste bins were sampled into ventilated cartons (length (35 mm) × height (25 mm) × width (22 mm)) and later examined individually to determine the causes of loss. A total of 18 bins containing lost (discarded) fruit, six bins for each cultivar, were used to determine the causes of fruit loss by examining each fruit individually. Given that the same person carried out all the individual fruit assessment to reduce human error, this was the maximum number of bins and fruit that could possibly be examined during the research period. Loss calculations included the number of bins of discarded fruit for defect reasons proportional to the number of bins put in the processing line. The assessment was made based on the external quality of fruit. Quantification was done by collecting sample fruit to identify reasons for loss (defects) and how they contribute to total fruit loss.

2.2. Method of Data Collection

The research method for this study was the sampling method, which has been identified as a practical method for conducting a study where there is a large variable of data to consider and also in conditions where data collection is constrained [30]. Because the assessment of this present study was carried out simultaneously during full packhouse commercial operations, which constrained space and time for data collection, it was necessary to use the sampling method. Researchers have used sampling methods to conduct
postharvest studies [31–33]. This present study involved the physical identification of the causes of fruit loss by examining individual fruit sorted into the waste bin at the packhouse. Qualitative data were also collected by physical observation during packhouse operation and interaction with the packhouse workers.

The economic impact of fruit losses was estimated using the supermarket retail price (ZAR 89.99/kg) in Stellenbosch, Western Cape, South Africa during the period of study. The environmental impacts were estimated using the values from previous studies reported in literature. The energy used for storage and processing activities and greenhouse gas (GHG) emission associated with fruit production were estimated using 6.1 MJ/kg and 0.48 CO₂ eq/kg, respectively [34]. The values were estimated for apples, which is a deciduous fruit like the pomegranate and which have similar packhouse processes. The water footprint was estimated with 910 m³ ton⁻¹ [35]. The nutritional impacts were calculated using values from [36] and [37]. Furthermore, cropland use was estimated by the size of the farm and the average yield produced.

2.3. Data Collection

The data collection protocol was consistent with the direct measurement method of the Food Loss and Waste Protocol (FLWP) [38]. For fruit loss data collection, a total of 251 bins (containing 1300–1500 fruit each) were put through the packhouse line and the number of waste bins (fruit loss) produced for each cultivar were recorded. Altogether, a total of over 351,400 individual fruit were assessed which comprised of 89, 84, and 78 bins of ‘Acco’, ‘Herskawitz’, and ‘Wonderful’ pomegranate, respectively. To determine the causes for the loss, fruit in 18 waste bins (6 per cultivar) were further examined. For each bin, a sample of 30 fruit was randomly selected each from the bottom, middle, and top and placed into ventilated cartons. Each fruit was visually assessed based on physical appearance (presence of rot, Alternaria disease, crack, injury, sunburn, blemish, insect damage), sorted, counted, and recorded according to each type of defect. In total, 1630 fruit (540 per cultivar) were examined to determine the quality defects causing fruit loss.

Data collection for each cultivar was done in three days, and six bins (n = 6) were assessed per cultivar (‘Acco’, ‘Hershkawitz’, and ‘Wonderful’). The waste bins were labelled and two bins were assessed per day. It is important, however, to mention that pomegranate fruit losses at the packhouse level are not necessarily cultivar dependent, rather they originate from direct (primary sources) and indirect (secondary sources) [39]. Nonetheless, it was important to categorise fruit defects by cultivar for ease of data collection and comparison with historical packhouse data.

2.4. Historical Packhouse Data

Historical data on pomegranate postharvest fruit losses collected by quality control staff at the case study packhouse for the two years where data were available (2016 and 2019) were obtained as secondary data. These data are presented and discussed in comparison with the results obtained in the present study.

2.5. Statistical Analysis

Microsoft Excel 2013 (Microsoft Corporation) was used to collate the data collected. In order to find the trend of variation between cultivars and fruit defects and to consider their correlation, data were investigated according to principal component analysis (PCA) using XLSTAT software Version 2012.4.01 (Addinsoft, Paris). The mean value ± standard error of fruit defects was also presented and where there was a statistical significance difference (p < 0.05), analysis of variance (ANOVA) was performed using Statistica Version 13.5.0 to evaluate the differences between cultivars and fruit defects. Significant differences between means were separated using Duncan’s multiple range test.
3. Results

3.1. Magnitude of Fruit Losses and Waste

The magnitude of pomegranate fruit losses at the packhouse was measured by the proportion of bins of discarded fruit to the number of bins initially put in the fruit processing line. Loss quantification involved a total of 251 bins of fruit put into the processing line from the three cultivars studied, of which 18 bins were discarded for failing to meet the minimum market required standard. The total lost fruit among the three cultivars ranged from 6.74 to 7.69% (Table 1). ‘Acco’ produced the least lost fruit as 89 fruit bins put in the processing line produced 6 bins of discarded fruit, while 84 fruit bins of ‘Hershkawitz’ produced 6 bins of discarded fruit. Lastly, ‘Wonderful’ produced the highest amount of lost fruit as 78 bins of fruit put in the processing line produced 6 bins of discarded fruit.

Table 1. Amount and percentages of each pomegranate cultivar fruit lost (discarded) based on the amount of fruit put through the packhouse line.

| Pomegranate Cultivar  | Fruit Put through the Processing Line (Bins) | Discarded Fruit (Bins) | Loss (%) |
|-----------------------|---------------------------------------------|------------------------|---------|
| ‘Acco’                | 89.00                                       | 6.00                   | 6.74    |
| ‘Hershkawitz’         | 84.00                                       | 6.00                   | 7.14    |
| ‘Wonderful’           | 78.00                                       | 6.00                   | 7.69    |
| Total                 | 251.00                                      | 18.00                  | 21.5    |
| Mean                  | 83.60                                       | 6.00                   | 7.16    |

Estimates of pomegranate fruit losses at the packhouse level in South Africa have been reported in recent years by the Pomegranate Association of South Africa (POMASA). In 2017, POMASA reported 11% loss in ‘Wonderful’, 13% loss in ‘Hershkawitz’, and 11% loss in ‘Acco’ [40]. In 2018, a 7% loss of ‘Wonderful’ was reported, an 8% loss in ‘Hershkawitz’, and a 9% loss in ‘Acco’ [18]. Additionally, in 2019, 9% of ‘Wonderful’ was reported as a loss, 25% loss in ‘Hershkawitz’, and 13% loss in ‘Acco’ [16]. Pomegranate fruit loss estimation at the packhouse is measured throughout the production season with fruit from multiple farmers with different preharvest and postharvest practices, which could affect the quality of fruit delivered to the packhouse and, hence, the amount of loss recorded. These factors account for the higher incidence of postharvest losses at the packhouse based on reported historical industry-wide data compared with the site-specific results obtained in the current study through a case study.

Bond [41] reported a 20% loss in carrots at the packinghouse level in Norway. The estimation was done using secondary data from experts in the carrot industry and surveys with semi-structured interviews with managers of packhouses. The study revealed that mechanical damage (harvesting technique at the farm) is a major source of loss at the packhouse since the superficial injuries during harvest open wounds for decay and disease infestation. A postharvest loss assessment of avocado, banana, guava, mango, papaya, and tomato was carried out among fruit growers and traders in north-western Ethiopia by Bantayehu et al. [42]. The results show that 18–28% of losses occurred during harvesting, storage, and transportation, while 18–25% of losses were reported at transportation and marketing levels. The major causes of loss are superficial injury, bruising, sunburn, handling technique, and physiological disorders, which are similar to the causes of pomegranate fruit loss in this present study. Semi-structured questionnaires and interviews were used for data collection in the study. Furthermore, a study in Nepal reported 35% loss in carrots [43]. Farmgate loss was estimated at 10%, 2% at a collection point, 5% at the wholesale market, and 18% at the retail level, and crack and splits were identified as the major cause of carrot loss [43]. Irrespective of the magnitude of loss reported in the studies, losses due to environmental stress and mechanical damage have remained dominant among the causes of fruit loss, which are similar to the results of this present study.
3.2. Causes of Packhouse Pomegranate Fruit Losses

The causes of packhouse pomegranate fruit losses were assessed based on the quality issues of why fruit were removed from the packhouse processing line as waste. These quality issues have contributory factors, and some are direct (primary source) while some are indirect (secondary source) [39]. The main indirect (secondary) cause of packhouse pomegranate fruit loss is the high market standard. South Africa exports about 76% of the total pomegranate production [16] and 61% of the total export goes to the European markets [17]. The trend of pomegranate marketing in Europe shows that South Africa faces strong competition with other countries of the Southern Hemisphere for the market share [1,16]. This competition is believed to have raised the market standard, which means that only premium quality fruit are processed for export at the packhouse. The implication of this is that pomegranate fruit are sorted again at the packhouse to ensure that only the best quality fruit are packed for sale. The ‘good fruit’ that are deemed not to meet the premium quality required in the export market are processed for sale. The effect of this is that more fruit are lost or sold at a cheap price for juicing and other purposes. Additionally, handling at the packhouse is another source of loss categorised as a direct (primary) source of loss. Losses due to handling manifested mainly as fruit bruises and superficial injuries. However, the two major reasons for physical loss as identified in this study were sunburn and injury. Other reasons are *Alternaria*, bruises, cracks, being oversized, insect damage, rot, decay, blemishes, and malformation.

3.2.1. Environmental Stress (Sunburn, Cracks, and Splits)

Sunburn

In the three cultivars assessed, sunburn was recorded as the highest cause of loss. Losses due to sunburn at the packhouse originated from the farm where pomegranate fruit were exposed to direct sunlight, which causes discolouration of the rind of the affected fruit, hence downgrading the fruit quality [44]. This shows the effect of high temperature on the quality of pomegranate fruit. After sorting for premium quality fruit at the packhouse, sunburn accounted for 28.70% and 29.8% of the discarded fruit in ‘Acco’ and ‘Hershkawitz’, respectively (Table 2). The highest fruit loss incidence was in ‘Wonderful’, where it contributed to 34.81% of losses. Sunburn showed a positive relationship with oversized fruit in the correlation analysis result (Table 3). This relationship is the only positive relationship result in the analysis, which indicates that more oversized fruit with sunburn were deemed fit for export at the farm level but could not meet the minimum market standard according to the evaluation of the packhouse. The market standard in Europe and the Middle East does not allow fruit with noticeable sunburn, which means that such fruit are sold at a low price locally, mainly for juicing.

| Table 2. Percentage fruit loss of three pomegranate cultivars due to different defects at packhouse. |
|------------------|------------------|------------------|------------------|
| **Fruit Defect** | ‘Acco’ (Loss %) | ‘Hershkawitz’ (Loss %) | ‘Wonderful’ (Loss %) |
| Alternaria       | 4.30             | 3.10             | 2.96             |
| Bruise           | 13.33            | 12.80            | 10.94            |
| Injury           | 23.33            | 23.70            | 19.07            |
| Sunburn          | 28.70            | 29.80            | 34.81            |
| Crack            | 18.70            | 18.34            | 17.96            |
| Insect damage    | 3.90             | 2.20             | 2.77             |
| Crown rot        | 2.22             | 2.96             | 1.67             |
| Decay            | 2.22             | 1.90             | 2.22             |
| Blemish          | 3.30             | 3.30             | 3.70             |
| Misshapen        | 0.00             | 1.90             | 1.66             |
| Oversized        | 0.00             | 0.00             | 2.24             |
Table 3. Pearson correlation coefficient matrix between defects on three pomegranate cultivars (‘Acco’, ‘Hershkawitz’, and ‘Wonderful’).

| Defects          | Alternaria | Oversized | Bruise | Injury | Sunburn | Crack | Insect Damage | Crown Rot | Decay | Blemish | Misshapen |
|------------------|------------|-----------|--------|--------|---------|-------|---------------|-----------|-------|---------|-----------|
| Alternaria       | 1          |          |        |        |         |       |               |           |       |         |           |
| Oversized        | −0.267     | 1         |        |        |         |       |               |           |       |         |           |
| Injury           | 0.157      | −0.356    | −0.170 | 1      |         |       |               |           |       |         |           |
| Sunburn          | −0.020     | 0.376     | −0.179 | −0.267 | 1       |       |               |           |       |         |           |
| Crack            | −0.246     | −0.112    | −0.230 | −0.184 | −0.402  | 1     |               |           |       |         |           |
| Insect damage    | 0.116      | −0.133    | −0.157 | −0.219 | −0.208  | 0.157 |               |           |       |         |           |
| Crown rot        | 0.067      | −0.218    | −0.093 | 0.042  | −0.181  | −0.063 |               | 0.003     |       |         |           |
| Decay            | −0.088     | 0.108     | −0.209 | 0.041  | −0.208  | 0.076 |               | 0.055     | −0.011|         | 1         |
| Blemish          | −0.362     | 0.131     | −0.100 | −0.112 | −0.094  | 0.096 | −0.124        | −0.160    | −0.008| 1       |           |
| Misshapen        | −0.088     | 0.201     | −0.007 | −0.327 | −0.007  | 0.126 | −0.257        | −0.130    | 0.002 | 0.011   | 1         |

Values in bold are significant at $p < 0.05$.

Temperatures exceeding 35 °C and low relative humidity at the farm level contribute to a higher incidence of sunburn [45] and because ‘Wonderful’ pomegranate produces bigger fruit with a larger surface area and is a late cultivar in South Africa, this results in fruit hanging on the tree much longer before harvest. With most of the fruit exposed to direct sunlight outside the tree canopy, the incidence of sunburn is exacerbated. This combination of factors makes ‘Wonderful’ pomegranate fruit more susceptible to sunburn than ‘Acco’ and ‘Hershkawitz’.

Cracks and Splits

The results show that the amount of fruit affected by cracks and splits in the three cultivars studied are similar as they ranked third in the causes of loss in the cultivars. The highest incidence was in ‘Acco’, where they accounted for 18.70% of losses (Table 2). For ‘Hershkawitz’, cracks and splits contributed to 18.34%, while in ‘Wonderful’, they accounted for 17.96% of losses. Cracks and splits had a negative relationship with sunburn according to the correlation analysis result (Table 3). This shows the impact of fruit sorting at the farm level; otherwise, it is reasonable to believe that higher sunburn would result in more cracks and splits due to the hardening of fruit rinds due to direct sunlight, which aids cracking when the moisture content fluctuates. Like sunburn, pomegranate cracks and splits as observed at the packhouse mostly originated from the farm and were a result of environmental stress, specifically soil moisture imbalances [46,47] as pomegranate fruit are highly sensitive to variation in the soil moisture content [48]. Therefore, fruit with cracks and splits at the packhouse are due to either oversight by the farm fruit sorters or the assumption that the fruit could meet the minimum market standard.

Cracks and splits create an open wound that enhances moisture loss and disease infestation, which lowers the quality of the affected fruit [49]. Fruit discarded from the packhouse due to cracks and splits were sold locally for industrial use.

3.2.2. Mechanical and Physical Damage (Superficial Injuries, Bruise Damage, and Blemishes)

Superficial Injuries

Superficial injuries were the second highest cause of pomegranate fruit loss at the packhouse after sunburn. Injuries constituted 23.33% of the total loss in ‘Acco’ (Table 2). For ‘Hershkawitz’, injury contributed 23.70% of the loss, which is the highest incidence of injury recorded among the three studied cultivars. ‘Wonderful’ recorded the least amount of injury with 19.07% of losses in the cultivar. Superficial injuries showed a negative relationship with oversized fruit in the correlation matrix (Table 3). This indicates that a higher incidence of injury was due to handling and not fruit sizes. Some of the superficial injuries observed were cases of opening fruit with a suspicion of internal disease by packhouse fruit sorters with false results. Furthermore, losses due to injuries originating from preharvest and handling technique at the farm level were observed. Injuries in this category were deemed
insignificant at the farm level, but the affected fruit failed to meet market standards by the packhouse. Pomegranate fruit were only stored for a few days (when necessary) at the packhouse before they were processed; therefore, chilling injuries were not observed.

**Bruise Damage**

The results show that bruise damage is the fourth cause of loss in the three pomegranate cultivars assessed. ‘Acco’ recorded the highest incidence of bruise damage, which accounted for 13.33% of losses in the cultivar (Table 2). Bruise damage contributed to 12.80% of the losses recorded for ‘Hershkawitz’ and 10.94% of the losses in ‘Wonderful’. Bruise damage showed no significant relationship with any other defect in the correlation analysis result (Table 3), which suggests that bruise damage at the packhouse is solely a function of mechanical damage during transportation and handling at the packhouse.

Like an injury, a bruise is caused by mechanical damage as a result of impact during harvesting, transportation, and handling [50]. Most of the bruises observed were believed to occur during transportation to the packhouse and packhouse handling. Many farm roads are rough, thereby causing vibration and compression of the fruit during transportation, which results in bruising damage [50,51]. Moreover, vibration and impact occur during fruit unloading at the packhouse and conveyance to the processing line. These assumptions were made because the affected areas of the fruit were already brownish in colour and soft, illustrating that the bruising was not an immediate occurrence. However, there were cases where the affected fruit were discarded during packaging with no visible discolouration of the rind but with softness in the affected parts. Bruised fruit do not meet either the export or the local market standards, and therefore, are sold at a low price for industrial use.

**Blemish**

Blemish is one of the least frequent causes of loss in the three pomegranate cultivars studied. For ‘Acco’, it ranked seventh out of eight in the causes of loss and accounted for 3.30% of losses. It ranked fifth in ‘Hershkawitz’ and contributed to 3.30% of fruit loss. The highest occurrence of blemish was recorded in ‘Wonderful’ with 3.70% of losses. The presence of fruit with blemish at the packhouse is usually the result of oversight from the on-farm fruit sorters as they are unlikely to be caused by packhouse handling operations. Blemish is mostly a result of mechanical damage during and after pruning before pomegranate fruit are picked. Again, sharp tree branches scratch fruit when thrown against them by the wind, leaving blemish marks on the affected fruit. Blemish is a strong factor in determining pomegranate fruit quality both for export and local market because external attractiveness of pomegranate fruit depends strongly on a blemish-free appearance [52].

**3.2.3. Biological Damage (Insect Damage)**

**Insect Damage**

The results show that insect damage contribution to pomegranate fruit losses at the packhouse was low. The highest incidence of insect damage was in ‘Acco’, where it ranked sixth in the causes of loss and accounted for 3.90% of losses (Table 2). The lowest incidence was in ‘Hershkawitz’ with 2.20% of losses and ranked eighth in the causes of loss. For ‘Wonderful’, it accounted for 2.77% of losses. Insect damage had no significant relationship with other defects assessed in the correlation analysis (Table 3). This indicates that insect damage in this present study occurred independently of other defects and that it was not as a result of packhouse operation. It could also mean that a significant amount of fruit damaged by insects were discarded at the farm level.

Insect damages downgrade the quality of pomegranate fruit since a small portion of the fruit is consumed, which results in a partial loss of the affected fruit and in making them not meet market standard. The affected fruit were discarded from the processing line and sold at a low price since part of the fruit could still be used for other purposes such as the manufacturing of dye and animal feed.
3.2.4. Microbial and Pathological Spoilage (Decay and Rots, *Alternaria*, Crown Rot)

**Decay and Rots**

Decay and rots are one of the least frequent causes of pomegranate fruit loss among the three cultivars assessed at the packhouse. For ‘Acco’, it accounted for 2.22% of losses (Table 2). They contributed to 1.90% of losses in ‘Hershkawitz’ and 2.22% in ‘Wonderful’. Decay and rot had no significant relationship with other defects in the correlation analysis (Table 3). This indicates that decay at the packhouse, in this present study, was not a result of packhouse operation (handling). Therefore, the decayed fruit were because of a sorting oversight at the farm level. Decay and rot are a result of microbial pathogens that break down the rind of the affected fruit, which results in partial or total decay and rot [20]. Decayed fruit do not meet market standard and are often buried or composted.

**Alternaria**

*Alternaria* disease varied among the three studied cultivars at the packhouse. However, its contribution to total fruit loss was low. The highest incidence of *Alternaria* was in ‘Acco’, where it contributed to 4.30% of losses (Table 2). For ‘Hershkawitz’, *Alternaria* accounted for 3.10% of loss and ranked sixth in the causes of loss in the cultivar, and contributed 2.96% of loss in ‘Wonderful’. *Alternaria* disease occurs at the farm and fruit discarded at the packhouse due to the disease were due to a sorting oversight at the farm because often, it is difficult to determine infected fruit physically.

*Alternaria* is a pomegranate fruit disease caused by the *Alternaria alternata* pathogen. The disease causes fruit to decay partially or totally from the inside. In contrast, the rind of the affected fruit appears healthy [19]. The affected fruit are light in weight, which makes them float during chlorine baths at the packhouse processing line. *Alternaria*-affected pomegranate fruit are intensely reddish in colour compared to an *Alternaria*-free fruit. These fruits are often buried or composted.

**Crown Rot**

Crown rot accounted for a low amount of pomegranate fruit loss at the packhouse. It contributed to 2.22% of losses in ‘Acco’ (Table 2). The highest occurrence of crown rot was in ‘Hershkawitz’, where it accounted for 2.96% of loss and ranked seventh in the causes of loss for the cultivar. For ‘Wonderful’, it ranked tenth in the causes of loss and accounted for 1.67% of losses. Crown rot showed no significant relationship with other defects in the correlation analysis (Table 3), which suggests that it occurred for reasons outside of the packhouse. Like *Alternaria*, crown rot is a farm disease and did not originate at the packhouse, rather, it was found due to a sorting oversight at the farm.

Crown rot is caused by *Coniella granati*, a fungi pathogen [19], which mostly affects pomegranate fruit on the farm. The rind of the affected fruit shows the presence of pycnidia with rotten crown [19]. Fruit affected by crown rot were discarded for not meeting the market standard, and as such, were sold at a cheap price for industrial products such as ink and dye.

3.2.5. Irregular Fruit Size and Shape (Oversized and Misshapen)

**Oversized**

Oversized fruit were only observed among the ‘Wonderful’ cultivar and in a very small quantity. Therefore, oversized fruit contributed little to overall pomegranate fruit loss in the cultivar. Oversized fruit accounted for 2.24% of loss (Table 2). The oversized fruit were not able to fit comfortably into the 3.8 kg equivalent carton used for pomegranate fruit packaging, and therefore, were sorted to be sold and used for other purposes such as juicing.

**Misshapen**

Pomegranate fruit discarded for being misshapen were very few and contributed least to the causes of loss. Such fruit were found only in ‘Hershkawitz’ and ‘Wonderful’.
For ‘Hershkawitz’, it contributed to 1.90% of loss, and in ‘Wonderful’, 1.66% (Table 2). The misshapen fruit were good fruit with irregular shapes, hence, they did not appear appealing for the shelves but could be used for producing juice, jam, and dye.

3.3. Comparative Analysis of Pomegranate Fruit Based on Defects

Fruit were discarded from the processing line for not meeting market standard due to bruising and injury (during handling), and other defects such as sunburn and microbial and pathological diseases that originated from the farm. Although packhouse defects are not considered cultivar-dependent, this study evaluated the relationship between pomegranate fruit defects and the cultivars using principal component analysis (PCA). The result was observed in biplot axes, which shows a relationship by the clustering of active variables (defects), in the red colour, around active observations (cultivars), in the blue colour (Figure 1). The result revealed that oversized and misshapen fruit were most common amongst the ‘Wonderful’, as evidenced by their clustering around ‘Wonderful’. At the same time, insect damage and Alternaria were predominant in ‘Acco’. Decay and crown rot were primarily associated with ‘Herskawitz’. Bruise and injury, which are mainly due to fruit handling, were observed to affect the three cultivars relatively equally. Environmental stress factors (sunburn and cracks) were also found to affect the three cultivars in a similar proportion. A dendrogram cluster analysis was done to evaluate whether different packhouse management practices would be advisable for the handling of each cultivar (Figure 2). The result suggests that implementing different packhouse management practices is not necessary for each cultivar as the three cultivars clustered around each other in cluster 2 and 3, which supports the fact that packhouse fruit loss is not cultivar dependent, rather due to postharvest handling practices and preharvest factors which caused some of the defects ab initio. Cluster 1 consists only of ‘Wonderful’, and this could be attributed to misshapen and oversized fruit, which were majorly associated with the cultivar.

Figure 1. Observation chart showing fruit defects according to cultivars.
The analysis of variance (ANOVA) was performed to evaluate differences in how the defects affect cultivars, as presented in Table 4. The effects of defects on ‘Acco’ and ‘Hershkawitz’ were similar but different in ‘Wonderful’ except for sunburn and superficial injury. The defects originated from sources such as environmental stress, mechanical and physical damage, biological damage, microbial and pathological spoilage, and lastly, irregular fruit size and shape (Table 4). The results show that environmental stress was the major cause of pomegranate fruit losses at the packhouse. However, it is important to note that the environmental factors originated from the farms and the affected fruit were discarded at the packhouse as they did not meet the required market standard. Environmental stress accounted for the highest incidence of loss, with 49.44% of the total losses. Mechanical and physical damage also caused significant loss of fruit, accounting for 37.84% of total fruit losses. The biological damage factor was only insect damage, which contributed 2.96% of losses while irregular fruit size and shape contributed least to losses with 1.92% and were mostly in ‘Wonderful’. Lastly, microbial and pathological spoilage accounted for 7.84% of total losses.
### Table 4. Comparison between cultivars and fruit defects contributing to postharvest loss in the case study packhouse.

| Defects                        | Cultivar                  | Acco (Mean) | Acco (Total) | Hershkawitz (Mean) | Hershkawitz (Total) | Wonderful (Mean) | Wonderful (Total) | Total | Loss (%) |
|-------------------------------|---------------------------|-------------|--------------|--------------------|--------------------|-------------------|-------------------|-------|---------|
| **Biological**                |                           |             |              |                    |                    |                   |                   |       |         |
| Insect damage (mean)          | Hershkawitz               | 3.50 ± 0.72 | 21           | 2.00 ± 0.68        | 12                 | 2.50 ± 0.43       | 15                |       | 2.96    |
| Total                         | Hershkawitz               | 21          | 21           | 12                 | 15                 | 48                | 2.96              |       |         |
| Irregular fruit size and shape| Misshapen                 | 0.00 ± 0.00 | 0            | 1.67 ± 0.42        | 10                 | 1.50 ± 0.43       | 9                 |       | 1.92    |
| Oversized                     |                           | 0.00 ± 0.00 | 0            | 0.00 ± 0.00        | 0                  | 2.00 ± 0.63       | 12                |       |         |
| Total                         |                           | 0           | 10           | 10                 | 21                 | 31                | 1.92              |       |         |
| **Mechanical damage**         | Bruise damage             | 12.00 ± 1.61| 72           | 11.50 ± 0.43       | 69                 | 9.83 ± 1.08       | 59                |       | 3.74    |
| Superficial injuries          |                           | 21.00 ± 0.73| 126          | 21.33 ± 0.80       | 128                | 17.17 ± 0.54      | 103               |       |         |
| Blemish                       |                           | 3.00 ± 0.52 | 18           | 3.00 ± 0.37        | 18                 | 3.33 ± 0.42       | 20                |       | 3.74    |
| Total                         |                           | 216         | 215          | 182                | 613                | 601               | 37.84             |       |         |
| **Environmental stress**      | Sunburn                   | 25.83 ± 0.87| 155          | 26.83 ± 1.47       | 161                | 31.33 ± 0.61      | 188               |       |         |
| Cracks and splits             |                           | 16.83 ± 1.08| 101          | 16.50 ± 1.28       | 99                 | 16.17 ± 1.14      | 97                |       |         |
| Total                         |                           | 256         | 260          | 285                | 801                | 49.44             |                   |       |         |
| **Microbial and pathological**| Alternaria                | 3.83 ± 0.83 | 23           | 2.83 ± 0.70        | 17                 | 2.67 ± 0.33       | 16                |       |         |
| Crown rot                     |                           | 2.00 ± 0.26 | 12           | 2.67 ± 0.61        | 16                 | 1.50 ± 0.50       | 9                 |       |         |
| Decay and rots                |                           | 2.00 ± 0.37 | 12           | 1.67 ± 0.21        | 10                 | 2.00 ± 0.63       | 12                |       |         |
| Total                         |                           | 47          | 43           | 37                 | 127                | 7.84              |                   |       |         |

* Mean values in the same row followed by different letters (a–f) indicate significant differences ($p < 0.05$).

4. Discussion

4.1. Historical Packhouse Data on Pomegranate Fruit Losses at Case Study Packhouse in Wellington, Western Cape, South Africa

Historical fruit loss data for 2016 and 2019 at the case study packhouse were analysed in comparison with the results of this present study and presented in Figure 3. The result suggests that marketing standard is a major source of fruit loss at the packhouse. This means that some fruit deemed suitable for marketing (export and local) at the farm level do not meet the packhouse marketing standard as a result of defects originating from the farm. This is evident in the contribution of sunburn and cracks to fruit losses as compared to bruise and injury, which are believed to be because of transportation and handling at the packhouse level. Furthermore, blemish, which also originates from the farm, was found to account for a significant amount of fruit loss at the packhouse according to both the packhouse historical data and the result obtained from the present study.
During the production of pomegranate fruit, greenhouse gases (GHGs) are emitted into the atmosphere. Based on the findings of this study, the pomegranate losses at the packhouse level were estimated to emit about 157,819 CO$_2$ eq. To sink this amount of CO$_2$ eq would require planting about 4 million trees at 0.039 metric ton CO$_2$ per tree planted [54]. Furthermore, an estimated 2,005,619 MJ of energy and 299,198.9 m$^3$ of water were wasted in production. This amount of wasted water could meet the daily water requirement of up to 109,896 persons in a year at 0.05 m$^3$ utilised per person per day [55]. Again, the production of the lost fruit could take up to 8.54 ha of land, that could have otherwise been used to provide public utilities such as a shopping complex.

4.2. Economic, Environmental, and Resource Impacts

The impacts of pomegranate fruit loss estimated in this study are based on the magnitude of incidence of pomegranate fruit loss at the case study packhouse in Wellington, Western Cape Province and retail price in South Africa. This is to reveal the potential production inputs and resources that are wasted in producing the pomegranate fruit that are lost. For example, the energy used for the production of wasted food could be used for another productive purpose such as cold storage to preserve food. Typically, the amount of packhouse fruit loss at the national and global level might be different depending on a range of factors including production practices, postharvest handling, and the market standard at the importing markets. The estimations are particularly important to raise awareness on the importance of reducing fruit losses at the packhouse level given several sustainability challenges that the world is facing, which require prudent use of resources today to create a future with sufficient material and natural resources [53].

The retail price of pomegranate fruit at the supermarket means that ZAR 88.99 (USD 5.26) is lost per 1 kg of lost pomegranate fruit in South Africa. Based on the average annual loss of 7.16% at the case study packhouse (Table 5), which translates to 328.79 tonnes, the monetary loss of the total annual production was estimated at ZAR 29.5 million (USD 1,754,984). During the production of pomegranate fruit, greenhouse gases (GHGs) are emitted into the atmosphere. Based on the findings of this study, the pomegranate losses at the packhouse level were estimated to emit about 157,819 CO$_2$ eq. To sink this amount of CO$_2$ eq would require planting about 4 million trees at 0.039 metric ton CO$_2$ per tree planted [54]. Furthermore, an estimated 2,005,619 MJ of energy and 299,198.9 m$^3$ of water were wasted in production. This amount of wasted water could meet the daily water requirement of up to 109,896 persons in a year at 0.05 m$^3$ utilised per person per day [55]. Again, the production of the lost fruit could take up to 8.54 ha of land, that could have otherwise been used to provide public utilities such as a shopping complex.
Table 5. Summary of the magnitude of pomegranate fruit losses and impacts at the packhouse, South Africa, and global levels.

| Factors                           | Case Study Packhouse | South Africa | Global          |
|-----------------------------------|----------------------|--------------|-----------------|
| Production volume (tonnes) *      | 4592.00              | 32,572.11    | 3139 × 10³      |
| Average loss (%)                  | 7.16                 | 7.16         | 7.16            |
| Retail price (ZAR/kg) a           | 89.99                | 89.99        | 89.99           |
| **Estimated physical and economic losses** |                     |              |                 |
| Physical loss (tonnes)            | 328.79               | 2,332.16     | 224,792.50      |
| Monetary loss (ZAR)               | 29 × 10⁶             | 209 × 10⁶    | 20,229 × 10⁶    |
| **Environmental impacts**         |                      |              |                 |
| Estimated GHG emission (CO₂ eq) b | 157 × 10³            | 1 × 10⁶      | 107 × 10⁶       |
| Estimated energy used (MJ) c      | 2 × 10⁶              | 14 × 10⁶     | 1371 × 10⁶      |
| **Resource impact**               |                      |              |                 |
| Water footprint (m³) d            | 299 × 10³            | 2122 × 10³   | 204,561 × 10³   |
| Equivalent land used to produce lost fruit (ha) | 8.54                 | 60.58        | 5838.77         |

* Production statistics is estimated from Sonlia packhouse [56]. a Supermarket retail price in Stellenbosch, Western Cape, South Africa. b,c Impacts per unit fruit produced estimated from [34]. d Impact per unit fruit produced estimated from [35].

The economic and environmental impacts of pomegranate fruit losses at packhouse were also estimated at the national (South Africa) level. Losses at the national level were estimated at 2332.16 tonnes (Table 5), which translates to an estimated ZAR 209.87 million (USD 12.64 million) annual revenue loss. Losses at the national level were found to emit about 1.11 million CO₂ eq. To sink this amount of CO₂ eq would require planting at least 28 million trees at 0.039 metric ton CO₂ per tree planted [54]. Furthermore, about 14.22 million MJ of energy and 2.12 million m³ of water were wasted to grow the lost fruit. The wasted water could meet the daily water requirement of about 116,289 people for a year at 0.05 m³ consumed per person per day [55]. Lastly, the land used to produce the lost fruit was estimated at 60.58 ha of land.

Furthermore, the economic and environmental impacts of pomegranate fruit losses were estimated at the global level using the incidence of losses and retail price in South Africa. This assumes a 7.16% loss of total fruit conveyed to the packhouse for processing globally, which was estimated at 224,792 tonnes (Table 5) and a retail price of ZAR 88.99/kg (USD 5.26/kg). The revenue loss due to the lost fruit was estimated at ZAR 20.22 billion (USD 1.2 billion). Based on the estimation, about 107.90 million CO₂ eq were emitted annually due to losses of pomegranate fruit. To sink this amount of CO₂ eq would require planting at least 2.7 billion trees at 0.039 metric ton CO₂ per tree planted [54]. Additionally, about 1.37 billion MJ of energy and 204.56 million m³ of freshwater were wasted. The wasted water could meet the daily water requirement of about 11.2 million people for a year at 0.05 m³ utilised per person per day [55]. Lastly, about 5838.77 ha of land was used to produce the lost fruit. Postharvest losses of pomegranate fruit mean a significant loss of revenue and resources that could have otherwise been put to beneficial use.

4.3. Nutritional Impacts

The loss of pomegranate fruit contributes to food and nutritional insecurity in South Africa due to a huge loss of essential nutrients in the lost pomegranate fruit. Some of the nutrients lost due to postharvest losses at the case study packhouse in Wellington, Western Cape Province of South Africa during the 2020 season are presented in Table 6. The nutritional impacts of fruit and vegetable cannot be over-emphasised, especially given the effect of the COVID-19 pandemic on the livelihood of individuals and their ability to afford healthy and nutritious food. Based on the annual loss of pomegranate fruit during operations at the case study packhouse, the lost content of sodium, fibre, carbohydrate, iron, and ascorbic acid in fruit were estimated to meet the daily recommended nutrition intake of 1, 7, 25, 5, and 66 people, respectively.
Table 6. Selected nutritional impacts of pomegranate fruit losses at the case study packhouse, Wellington, in the Western Cape Province of South Africa.

| Nutrition factor | Case Study Packhouse | National (South Africa) | Global |
|------------------|----------------------|-------------------------|--------|
|                  | Amount lost (mg/100 g) | Nutritional loss (per capita/day) | Amount lost (mg/100 g) | Nutritional loss (per capita/day) | Amount lost (mg/100 g) | Nutritional loss (per capita/day) |
| Fibre            | 164.39               | 7.00                    | 1166.08 | 47.00                  | 112 × 10^3               | 4496.00                |
| Carbohydrate     | 3255.02 **           | 25.00                   | 23,088.38 | 71.00                  | 314 × 10^4               | 6842.00                |
| Protein          | 460.30 **            | 10.00                   | 3265.02 ** | 71.00                  | 314 × 10^4               | 6842.00                |
| Iron             | 98.64                | 5.00                    | 699.65  | 39.00                  | 67 × 10^3                | 3747.00                |
| Ascorbic acid    | 4931.85              | 66.00                   | 34,982.40 | 3747.00                | 3747.00                  | 3747.00                |
| Calcium          | 9863.70              | 13.00                   | 27,985.92 | 6744.00                | 6744.00                  | 6744.00                |
| Magnesium        | 3945.48              | 13.00                   | 27,985.92 | 6744.00                | 6744.00                  | 6744.00                |
| Sodium           | 1315.16              | 1.00                    | 9328.64  | 8702.00                | 8702.00                  | 8702.00                |
| Potassium        | 56,223.09            | 12.00                   | 398,799.40 | 8179.00                | 8179.00                  | 8179.00                |

* Amount lost is based on [32]. ** Nutritional loss is based on [31]. *** Amount lost is estimated in g/100 g.

The nutritional impacts of pomegranate fruit losses were also estimated at the national (South Africa) level using the incidence of losses at the case study packhouse, in the Western Cape Province of South Africa (Table 6). Based on the annual losses of pomegranate fruit at the packhouse level, the estimate at the national level suggests that the lost content of sodium, fibre, calcium, magnesium, and ascorbic acid in fruit could meet the daily recommended intake of 5, 47, 70, 90, and 466 people, respectively.

The estimation of postharvest nutritional losses of pomegranate fruit at the global level showed a huge loss of essential nutrients that could benefit people in a period where micro and macronutrient deficiency affects not less than a third of the world population and negatively impacts the quality of life [57]. Based on the annual incidence of losses in South Africa, the selected nutrient loss globally due to pomegranate losses at the packhouse was estimated (Table 6). The lost content of sodium, fibre, protein, potassium and ascorbic acid in fruit could meet the daily recommended nutrition intake of 450, 4496, 6842, 8179 and 44,959 people respectively. The findings revealed that postharvest losses of pomegranate fruit at the packhouse level also contribute to global food and nutrition insecurity.

4.4. Possible Solutions to Overcome and Limit Fruit Loss at the Packhouse

This study identified quality issues that lead to the downgrading of a significant proportion of the fruit processed at the packhouse. The quality issues are categorised into indirect (secondary) and direct (primary) causes of loss [39]. Indirect sources of loss are mainly due to high market quality standard at the importing markets. At the case study packhouse, pomegranate fruit that did not meet market quality standard were majorly due to the loss of aesthetic and physical appeal because of defects and damages leading to downgrading. Fruit losses due to high market quality standards could be classified as unavoidable loss [58]. This is because market quality standards are determined by market specifications on produce quality attributes and economic factors that are beyond the control of the packhouse operation. Under this situation, the application of the best available postharvest technologies at the packhouse cannot prevent such losses due to products that fall short of market standards.

Fruit losses due to direct (primary) causes at the case study packhouse include losses due to postharvest handling of fruit during transportation from storage to the processing line, sorting and grading; these are manifested as superficial injuries, cuts, and bruises [50]. Since poor postharvest handling practices are a major cause of fruit loss, possible solutions to reduce loss must be practical and technologically driven [59,60]. Fruit quality improvement can be achieved by local investment in technological innovations through research to improve knowledge in life cycle assessment, processing, and handling of pomegranate fruit at the packhouse [59,61,62]. The conventional manual sorting technique used at the packhouse is subjective and often leads to damaging wholesome fruit because fruit sorters most times are unable to make distinction between internally damaged fruit and a good fruit. Hence, possible technological improvements in the packhouse line such as non-destructive sorting techniques using remote sensing along the processing line would...
limit basic sorting errors leading to cutting fruit open to ascertain the presence of internal diseases. In addition to technological innovation, the reduction of fruit loss will require the continuous training of packhouse staff on fruit handling, especially the fruit sorters and forklift drivers. This is important because reckless transportation from temporal cold storage to the packhouse processing line causes bruises, which lead to fruit loss. This could be limited by educating forklift drivers about the impact of vibration and compression on pomegranate fruit.

5. Conclusions

This study found that pomegranate fruit loss at the case study packhouse in Wellington, Western Cape Province of South Africa ranged between 6.74 to 7.69%. This translates to 328.79 tonnes of pomegranate fruit removed from the packhouse processing line per production season. This amount of fruit is removed from the value chain for not meeting the minimum market standard and are sold at a low price for juicing and as raw material for dye and ink production. The major direct cause of pomegranate fruit loss at the packhouse, as identified in this study is handling (bruise and injuries). Environmental stress (sunburn and cracks) and microbial and pathological diseases were also contributors to loss. It is interesting to note that the result of the causes of loss in this study is similar to the historical packhouse report as analysed.

The result of the magnitude of losses shows that the incidence of loss was lowest in ‘Acco’ with 6.74% of losses. The amount of loss in ‘Herskawitz’ and ‘Wonderful’ were similar with 7.14% and 7.69%, respectively. Market standard (especially the export market) is greatly influential on the amount of losses recorded at the packhouse. This is because most of the produce are exported to Europe and the Middle East, where only premium quality fruit are accepted. This means that fruit deemed marketable at the farm level may be discarded at the packhouse resulting in loss.

Packhouse fruit losses have a huge economic, environmental, resource, and nutritional impacts as exemplified in this study. The economic impact reflects the loss of revenue by farmers and other actors along the value chain. Environmental and resource impacts are evident in the unsustainable use of resources to produce lost and wasted fruit, and the nutritional impact results in food insecurity due to the wasted nutrients that would have otherwise benefitted people. Considering the various impacts of postharvest losses at the packhouse level, postharvest losses and waste reduction is a sustainable means of ensuring food and nutritional security. Furthermore, reducing postharvest losses and waste would help mitigate the effects of global warming and increase revenue for the food value chain actors.

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