Understanding Postharvest Losses of Pomegranate Fruit in South Africa: Magnitude, Causes and Impacts

by

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Declaration

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Abstract

Fruit and vegetables losses contribute to a substantial amount of food losses, and this has remained a significant problem in the food system despite the technological innovations to prolong shelf life. The high water content (often >80%) and succulent nature of most fruit and vegetables make them susceptible to insect damage, bruises, superficial injuries, rots and spoilage.

Pomegranate fruit is one of the commercially grown fruit in South Africa and is highly susceptible to losses due to environmental factors (such as sunburn, crack and splits) and mechanical damage in the form of superficial injuries and bruises. Despite the rapid growth of the pomegranate industry in South Africa, there is lack of data on the magnitude and impacts of postharvest fruit losses and waste along the value chain, and this inhibits management decision on the application of appropriate control measures to specific loss hotspots. Therefore, this research aims to determine the extent of postharvest losses and waste of pomegranate fruit in South Africa and to assess the economic, natural resource and environmental impacts.

The study followed a mixed method using qualitative and quantitative data. Numerical data on fruit losses were collected by sorting and counting the discarded fruit to quantify the magnitude and identify the causes of loss at the farm and packhouse, respectively. Qualitative data such as method of fruit handling during harvesting and packhouse processes were collected by close inspection and physical examination of individual fruit. The results showed that about 15.3 to 20.1% of the harvested pomegranate fruit were lost at the farm and 6.74 to 7.69% at the packhouse in South Africa annually. Defects due to environmental factors including sunburn, crack and splits accounted for 43.93% of all on-farm losses and 49.44% of total packhouse fruit losses, while mechanical damage accounted for 17.99% and 37.84% of the on-farm and packhouse losses, respectively. The losses represent revenue loss of about R826,472,659.50 ($50,219,211.90) annually and contribute to wastage of natural resources and negative environmental impacts such as greenhouse gas (GHG) emissions. Therefore, strategies to reduce postharvest losses of pomegranate fruit should include target preharvest environmental control (such as temperature and sunlight) and orchard management (such as irrigation, crop load, pest and diseases) factors, and improvement of harvesting and handling.

Opsomming

Vrugte en groente dra tot aansienlike hoeveelhede voedselverliese by en, ten spyte van die tegnologiese innovasies om raklewe te verleng, bly dit ’n wesenlike probleem in die voedselstelsel. Die hoë waterinhoud (dikwels > 80 %) en sukkulente aard van die meeste vrugte en groente maak hulle vatbaar vir insekskade, knesing, oppervlakkige beserings, verroting en bederf.

Granaatvrugte is een van die vrugte wat kommersieel in Suid-Afrika gegroei word en is hoogs vatbaar tot verliese as gevolg van omgewingsfaktore (soos sonbrand, krake en splete) en meganiese skade in die vorm van oppervlakkige beserings en knesing. Ondanks die vinnige groei van die granaatbedryf in Suid-Afrika is daar ’n gebrek aan data oor die omvang en impak van die na-oesvrugte se verliese en afval in die waardeketting, en dit belemmer bestuursbesluite oor die toepassing van gepaste beheermaatreëls op spesifieke verlies-brandpunte. Hierdie navorsing beoog dus om die omvang van na-oes verliese en afval van granaatvrugte in Suid-Afrika te bepaal, en die ekonomiese, hulpbron- en omgewingsimpakte te evalueer.

Die studie het ’n gemengde metode gevolg deur kwalitatiewe en kwantitatiewe data te gebruik. Numeriese data oor vrugteverliese is ingewin deur dit te sorteer en te tel om die omvang te kwantifiseer, en die oorsake van verlies by onderskeidelik die plaas en pakhuis te identifiseer. Kwalitatiewe data is ingewin deur die oes- en pakhuisprosesse noukeurig waar te neem, en die afsonderlike vrugte fisies te ondersoek. Die resultate het getoon dat daar jaarliks in Suid-Afrika ongeveer 15,3 tot 20,1 % van die geoesde granaatvrugte op die plaas verlore geraak het en 6,74 tot 7,69 % by die pakhuis. Omgewingsfaktore insluitend sonbrand, krake en splete was vir 43,93 % van alle verliese op die plaas verantwoordelik en vir 49,44 % van die totale verlies van pakhuisvrugte, terwyl meganiese skade onderskeidelik vir 17,99 % en 37,84 % van die plaas- en pakhuisverliese verantwoordelik was. Die verliese verteenwoordig jaarliks ’n inkomsteverlies van ongeveer R826,472,659.50 ($ 50,219,211,90) en dra by tot die vermorsing van natuurlike hulpbronne en negatiewe omgewingsimpakte soos die vrystelling van kweekhuisgasse. Strategieë om na-oes verliese van granaatvrugte te verminder, moet dus die die beheer van omgewingsfaktore voor die oes (soos temperatuur en sonlig) teiken, boordbestuur (soos besproeiing, gewaslading, peste en siektes), en verbetering van die oesproses en vrughantering.

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Table of Contents

List of Figures

List of Tables

List of Acronyms and Abbreviations

EPA	United States Environmental Protection Agency
GDP	Gross Domestic Product
GHG	Greenhouse Gas
FAO	Food and Agricultural Organization of the United Nations
FLAW	Food Losses and Waste
POMASA	Pomegranate Producers Association of South Africa
SDGs	Sustainable Development Goals
UK	United Kingdom
UN	United Nations
UNEP	United Nations Environmental Programme
US	United States of America
WHO	World Health Organisation
WRAP	The Waste and Resource Action Programme

Definition of Terms

The definition of terms and concepts pertaining to food vary and have different connotations in socio-cultural belief, religious faith, and geographical locations. So, it is important to define some key terms and phrases used in this study to eliminate ambiguity. The understanding of losses and waste with regards to food is subjective; therefore, different studies adopt definitions that are relevant to the context of their study. For this present study, the following definitions have been adopted.

Food

If an item is regarded as 'food' by any society, it will be regarded as 'food' in this study.

Fruit

Fruit in this study will include all 'fruit' edible by humans irrespective of the biological process of production.

Damage

'Damage' will be regarded as any deterioration, which reduces the commercial value of fruit and leads to eventual removal from the value chain.

Food value chain

Food value chain refers to the people, organisations, and all the systems and activities that are involved in getting food materials from the producer to the final consumer.

Food loss

Food loss refers to downgraded food due to defect and mostly sold at a lower price. Part of the food in this category can still be consumed or used for industrial purposes.

Food waste

Food waste refers to food produced for consumption but ends up discarded and not used. Food in this category usually end up in landfill.

Fruit loss

Fruit loss in this study refers to fruit removed from the value chain due to physical damage and sold at a lower price for fresh consumption, juicing, and other industrial uses.

Fruit waste

Fruit waste refers to fruit removed from the value chain as a result of deterioration and discarded. Food in this category is composted or disposed outrightly.

Wastage

Wastage in this study refers to losses and waste. It therefore means food removed from the value chain for either physical or partial loss leading to downgrading. It also entails food removed from the value chain due to total loss leading to disposal as waste.

Postharvest

'Postharvest' refers to the period when the food material is separated from the growth medium, including all the activities along the value chain, to the final consumer.

Chapter 1 - General introduction

1.1 Background

1.1.1 Food losses and waste

According to the United Nations Food and Agriculture Organization (FAO, 2011), a third of the food produced in the world – approximately 1.3 billion tonnes, which equates $750 million is lost or wasted, with fruit and vegetables accounting for over 45%. This amount of food loss and waste (FLAW) reduces the quantity of food available for consumption and increases thefood production cost since a large part of what is produced is not consumed (Galford, Peñaa, Sullivan, Nash, Gurwick et al., 2020). This also represents a huge loss of natural resources such as land and water used for food production and postharvest handling, which are already depleted (Beretta, Stoessel, Baier & Hellweg, 2013). For example, water used to produce and handle lost and wasted food account for 24% of global freshwater use while the total cropland area used to produce wasted food is estimated at 23% (Kummu, De Moel, Porkka, Siebert, Varis et al., 2012). In South Africa, food waste accounts for a significant amount of total food produced. On average, 9-10 million tons of food are wasted annually, which accounts for about 31% of annual food production (Oelofse & Nahman, 2013). Also, a study in South Africa revealed that about 12-46% of cabbage is lost annually with an economic loss estimated at over $1 million (Munhuweyi, Opara & Sigge, 2016). Furthermore, the dumping of lost and wasted food contributes to environmental pollution and degradation, which negatively impacts health and the planet (Nahman, De Lange, Oelofse & Godfrey, 2012).

The incidence of food losses and waste sabotages efforts to achieve Agenda 3 of Sustainable Development Goal 12, which targets to halve food waste and reduce losses along the value chain by 2030, including postharvest (UN, 2015). In addition, the planetary boundaries are negatively impacted since agricultural activities are the leading human activities causing trespass to the planetary boundaries (Campbell, Beare, Bennett, Hall-Spencer, Ingram et al., 2017).

The problem of FLAW is multifaceted as it contributes to food and nutritional insecurity challenges (Opara, 2013; Opara, 2010; FAO, 2010; Opara, 2006) and greenhouse gas emission (Blakeney, 2019; Munhuweyi et al., 2016; Gustavsson, Cederberg, Sonesson, Van Otterdijk & Meybeck, 2011; Bakas, 2010). FLAW is a major contributor to landfill waste, particularly in urban areas (Oelofse & Nahman, 2013). Postharvest wastage is more severe in developing countries, where the urban population is projected to grow exponentially during the next 30 years (Gardas, Raut, & Narkhede, 2018; Swilling & Annecke, 2012; UN, 2011). It is expected that the problem of food waste in these countries will also increase. Therefore, to achieve the Sustainable Development Goal 12(Agenda 3), reducing food losses and waste along the food value chain will be key (Beretta et al., 2013).

1.1.2 Nutritional value of fruit with an emphasis on the pomegranate fruit

Food provides important nutrients necessary for life and the promotion of good health and prevention of diseases (Liu, 2003). Foods in the form of fruit and vegetables are nutritious with many health benefits for the human body. Over the years, researchers have found important and complimentary relationships between the increase in fruit and vegetable consumption and decrease in diseases and ill health such as hypertension, pulmonary disease, stroke, and cancer (Kerch, 2015; Li, Li, Zhang, Xu, Chen et al., 2014; Opara & Al-Ani, 2010; Liu, 2003; Van Duyn & Pivonka, 2000). According to Van Duyn and Pivonka (2000), increased fruit consumption should be encouraged as a protective measure to reduce disease risk and increase healthy eating. This is because, preventive measures are cheaper, better, and more effective than treatment of diseases (Liu, 2003).

Pomegranate (*Punica granatum* L.) is among the family of fruit called *Punicaceae* with high nutritional value (Fawole & Opara, 2013). The fruit is indigenous to India, Iran, China, and Afghanistan (Ismail, Sestili & Akhtar, 2012). Due to the health-promoting benefits and numerous uses of pomegranate fruit, different cultivars are grown commercially in different parts of the world (Fawole & Opara, 2013; Fawole, Opara & Theron, 2012; Holland, Hatib & Bar-Ya'akov, 2009; Al-Yahyai, Al-Said & Opara, 2009; Al-Said, Opara & Al-Yahyai, 2009). Pomegranate is a horticultural crop that adapts easily to saline and poor soils in arid, semi-arid and Mediterranean climates (Al-Maiman & Ahmad, 2002; Melgarejo, Salazar & Artes, 2000). However, proper irrigation is required for optimum fruit production. Many processing industries currently use pomegranate fruit (both the edible and inedible parts) for several production purposes. For example, different fruit parts are used in the production of juice, seed oil, wine, and jellies (Holland et al., 2009). Due to its high content of antioxidant compound including phenolics, pomegranate fruit is highly utilised in the pharmacological, beverage and medicinal industries (Fischer, Carle & Kammerer, 2011).

The nutritional value and health benefits attributed to the consumption of pomegranate fruit cannot be overemphasised. The aril, which is the edible part of the fruit, contains nutrients such as polyphenols, organic acids, sugars, vitamins, and mineral elements (Fawole & Opara, 2013; Al-Maiman & Ahmad, 2002). Pomegranate fruit can be eaten as fresh produce or processed into food flavour, jams, jellies and preserved with appropriate temperature (Melgarejo et al., 2000). Pomegranate fruit is referred to as the "healing food" and was used in ancient traditional medicine to get rid of parasitic worms (Viuda-Martos, Fernández-López & Pérez-Álvarez, 2010). It is also used to treat illnesses such as ulcers, acidosis, haemorrhage, aphthae, diarrhoea, dysentery, respiratory pathologies, and microbial infections (Viuda-Martos et al., 2010). As a result of the numerous health-promoting benefits of the fruit, there is a rapid global awareness and increase in demand of the fruit (POMASA, 2019; Arendse, Fawole, Magwaza & Opara, 2016; Arendse, Fawole & Opara, 2014; Viuda-Martos et al., 2010; Opara, Al-Ani & Al-Shuaibi, 2009).

1.1.3 Status of pomegranate production and export in South Africa

The production of pomegranate in South Africa started in the early 2000s with imported plants from India, Israel, and the United States of America (Venter, Lennox & Meitz-Hopkins, 2017). Over the years, the production area has increased to 1024ha (POMASA, 2019). The three major pomegranate cultivars grown in the country are Wonderful, Acco and Herskawitz (Figure 1). The production occurs mostly in the Western Cape Province, which accounts for about 81% of total production, with a small amount grown in other provinces (Figure 2).

A. ‘Wonderful’ B. ‘Acco’ C. ‘Herskawitz

Figure 1.1: Main pomegranate fruit cultivars commercially grown in South Africa. Adapted from Ampem (2017).

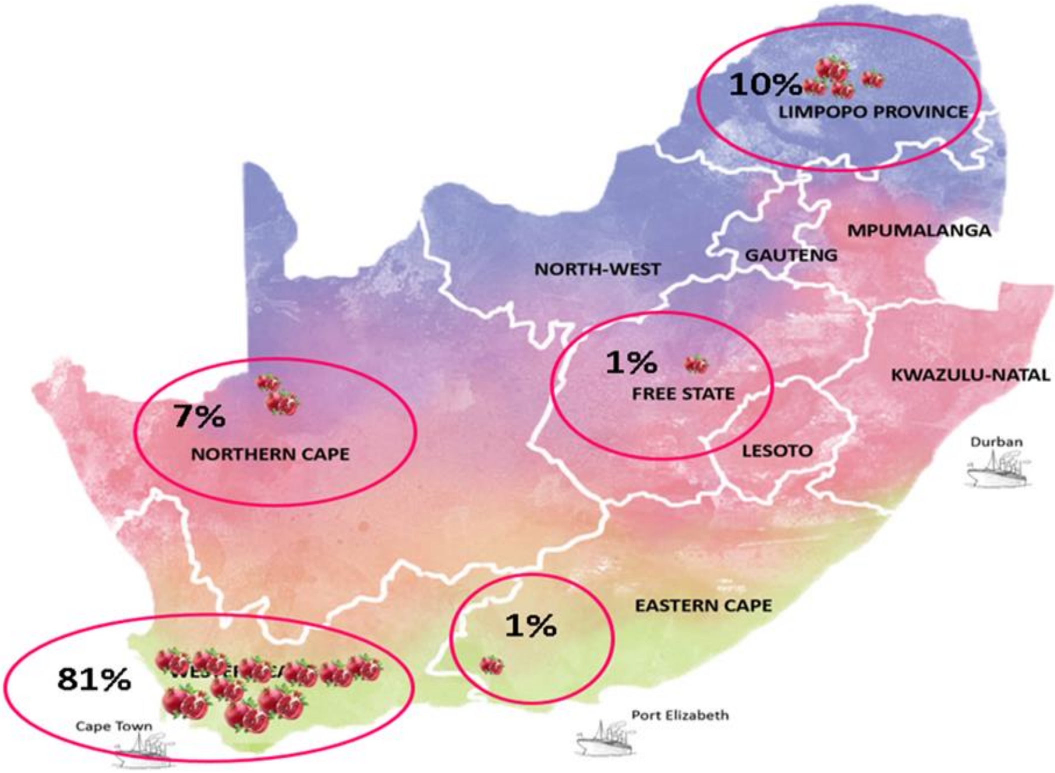

Figure 1.2: Pomegranate production regions in South Africa**.** Adapted from POMASA (2019).

The Western Cape is a region that experiences water shortages and this impacts the sustainability of commercial production of pomegranate in the country. During the past decade, the production of pomegranates has increased rapidly in South Africa (Table 1.1) and has become an important source of livelihood and income for farmers. South Africa is an important pomegranate producer in the Southern Hemisphere. In 2019, South Africa exported about

1,676,160 cartons of 3.8 kg equivalent (Table 1.1), with competition from Peru, Chile and Argentina (Table 1.2). Like other fruit types, the major causes of revenue loss are the high incidence of defects, including mechanical damage and spoilage of pomegranate fruit, which contribute to losses at harvest and during postharvest handling (Aulakh & Regmi, 2013; Matare, 2012).

Table 1.1: Volume of pomegranate production in South Africa (POMASA, 2019)

Year	**Planted area (ha)**	**Total export (3.8 kg eqv. Cartons)**
2011	771	-
2012	792	483,609
2013	849	595,474
2014	750	837,250
2015	862	1,097,900
2016	828	1,337,998
2017	832	1,440,777
2018	937	1,167,821
2019	1024	1,676,160

Table 1.2: Increase in pomegranate fruit export in the Southern Hemisphere countries (POMASA, 2019; POMASA, 2018).

Year	South Africa (tonnes)	Argentina (tonnes)	Chile (tonnes)	Peru (tonnes)
2012	1838	182	5918	5024
2013	2263	434	4644	5861
2014	3182	449	5614	9948
2015	4172	475	5410	15,989
2016	5084	962	6671	18,205
2017	5475	1775	5716	28,779
2018	4438	910	5866	31,860
2019	6369	973	-	-

Fruit are highly susceptible to damage and spoilage after harvest, and these are major contributors to the high incidence of postharvest food losses. In South Africa, it has been estimated that fruit and vegetables account for about 44% of total food losses and waste, and this commonly occurs early in the food value chain (Von Bormann, 2019). Poor preharvest conditions, harvest management and postharvest handling affect fruit quality (Opara, 2007). In addition, poor preharvest and postharvest management practices contribute to the fruit being susceptible to a wide range of defects and diseases such as bruising, weight loss, decay, and rot (Opara, Atukuri & Fawole, 2015).

In summary, FLAW is a major problem at both global, regional and national levels, including South Africa. Fruit and vegetables are the most highly susceptible and account for about 45% of total food losses and waste (Von Bormann, 2019; FAO, 2011). The FLAW problem is complex and multi-faceted depending on the type of food product and value chain, among other factors. Therefore, to reduce the problem and the negative socio-economic and environmental impacts, it is important to carry out research at the local levels on specific value chains so that the extent of the problem can be quantified, causes identified and appropriate, cost-effective control measure proposed.

1.2 Problem statement

Literature revealed that globally, food insecurity is partly caused by food losses and waste, which impacts society negatively through the pollution to the environment and depletion of natural resources (Campbell et al., 2017). FLAW also impose revenue loss on farmers and the various actors in the food value chain (Munhuweyi et al., 2016), and reduces availability of food (Galford et al., 2020; FAO, 2011; Opara, 2010).

The commercial production and marketing of pomegranate in South Africa is growing rapidly, and there is a lack of data on the magnitude and impacts of pomegranate postharvest losses and waste along the value chain which will assist in the application of appropriate control measures. Postharvest loss and waste incidence vary remarkedly across value chains, production and handling systems, type of produce, season, hence, control measures must be tailored to specific value chains based on evidence from scientific research. In this research project, Blydeverwacht Farm and Sonlia Packhouse in the Western Cape – the major producers and postharvest handlers of pomegranate in South Africa, will be used as case studies to quantify the magnitude of postharvest losses and waste of pomegranate fruit. The study will also identify the causes of pomegranate fruit losses and waste and estimate the economic and environmental impacts of pomegranate wastage.

1.3 Objectives of the study

This research study aims to determine the extent of postharvest losses and waste of pomegranate fruit in South Africa and to assess the economic and environmental impacts. The specific objectives are to:

i. Quantify the magnitude of postharvest losses and waste of pomegranate fruit at Blydeverwacht Farm and Sonlia Packhouse, respectively;
ii. Identify the causes of loss and waste of pomegranate fruit; and
iii. Estimate the economic and environmental impacts of fruit losses and waste.

1.4 Rationale for the Study

Pomegranate fruit production and marketing is an emerging sector in the South African horticultural industry. The fruit is highly susceptible to physical defects, rapid weight loss and spoilage, which contribute to the incidence of losses and waste. Current industry estimates suggest that losses and waste up to 6-9% of total fruit production can occur at the packhouse level in one season (POMASA, 2019; POMASA, 2018). The lack of science-based data on the magnitude of pomegranate fruit losses and causes along the value chain is a major limiting factor in efforts to control and reduce the problem.

Therefore, this study seeks to provide data on the magnitude and sources of pomegranate fruit losses at the farm and packhouse levels in South Africa. In addition, the study also quantifies the economic and environmental impact of the losses and waste of pomegranate. This information will provide the baseline data for the development and implementation of cost-effective solutions for loss and waste reduction strategies.

1.5 Scope of the study

This study aims to quantify the magnitude of postharvest wastage in the South African pomegranate industry and to identify the hotspot along the value chain. The study was conducted in Wellington, Western Cape Province, which accounts for about 81% of total pomegranate fruit production in South Africa (POMASA, 2019). Only one orchard (Blydeverwacht Farm) and a packhouse (Sonlia Packhouse) were selected as case studies as these are the largest in the region and indeed South Africa. Although the study is on postharvest losses and waste, it was necessary to be aware of the harvesting process on the farm. This information helped to demonstrate the influences of harvesting methods on fruit quality that may lead to postharvest wastage later along the value chain. Based on the magnitude of fruit losses and waste, the study also estimated the economic and environmental impacts of pomegranate losses and waste in South Africa.

1.6 Research methodology and design

The study followed a mixed mode methodology to collect quantitative and qualitative data (Bryman, Bell, Hirschsohn, Dos Santos, Du Toit et al., 2014; Creswell & Poth, 2016). Specifically, the convergent parallel mixed method was applied, which merges the collected quantitative and qualitative data to enable a comprehensive data analysis (Creswell & Poth, 2016). In this mixed-method model, qualitative and quantitative data are simultaneously collected, and the information is combined while interpreting the results. Numerical data were collected by sorting and counting of the discarded fruit to quantify the magnitude and the causes of loss and waste. Qualitative data collected included close observation of the harvesting and packhouse processes and physical examination of individual fruit . The environmental impacts of pomegranate fruit losses and waste were estimated based on literature evidence on the amount of inputs required to produce pomegranate fruit and the environmental impacts associated with fruit production and handling. Lastly, the economic impact was estimated based on pomegranate fruit retail price in Stellenbosch, Western Cape, South Africa.

The comparative design approach was adopted for this research, which consists of using identical methods or cases in conducting a study (Bryman et al., 2014). The comparative design sees value in comparison. This implies that research problems are understood better when examined using two or more cases. This design approach supports the convergent parallel mixed method (Creswell & Poth, 2016) as adopted for the methodology of this study. To apply this approach in this study, data collected from Blydeverwacht Farm and Sonlia Packhouse were compared to understand the amount of fruit losses and waste better at different hot spots along the pomegranate value chain in South Africa. The research strategy followed to complete this study is summarised in Figure 1.3, while Figure 1.4 outlines the contents of the thesis.

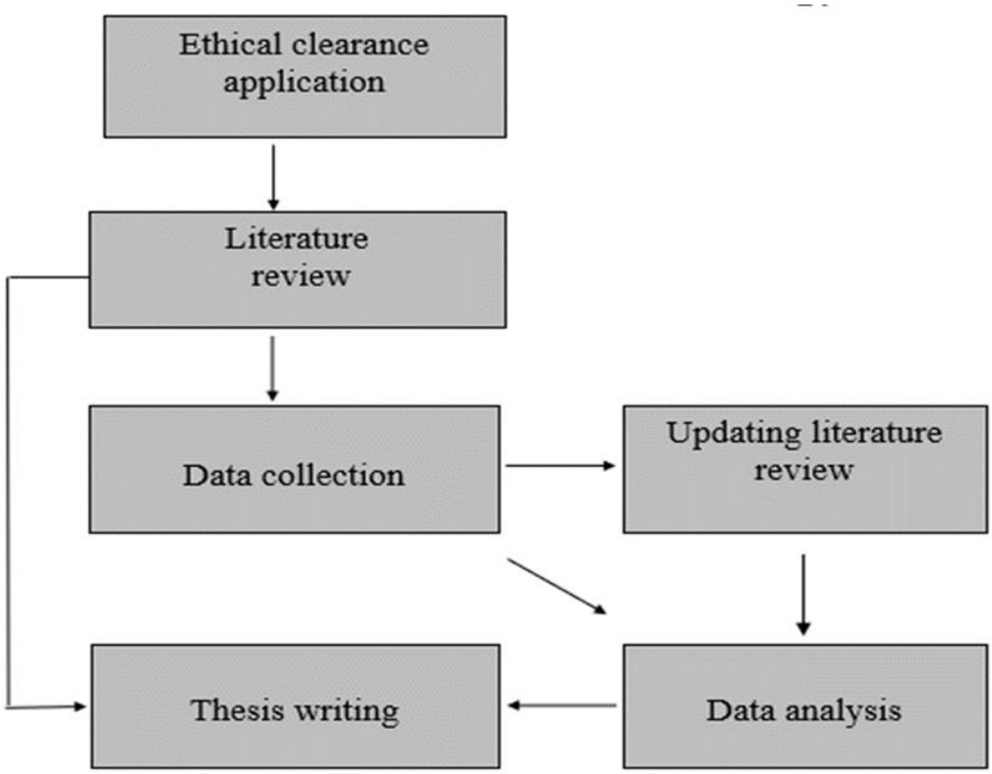

Figure 1.3: Research strategy for the study.

1.7 Chapter Outline

Below is the outline of this thesis and the content of each chapter.

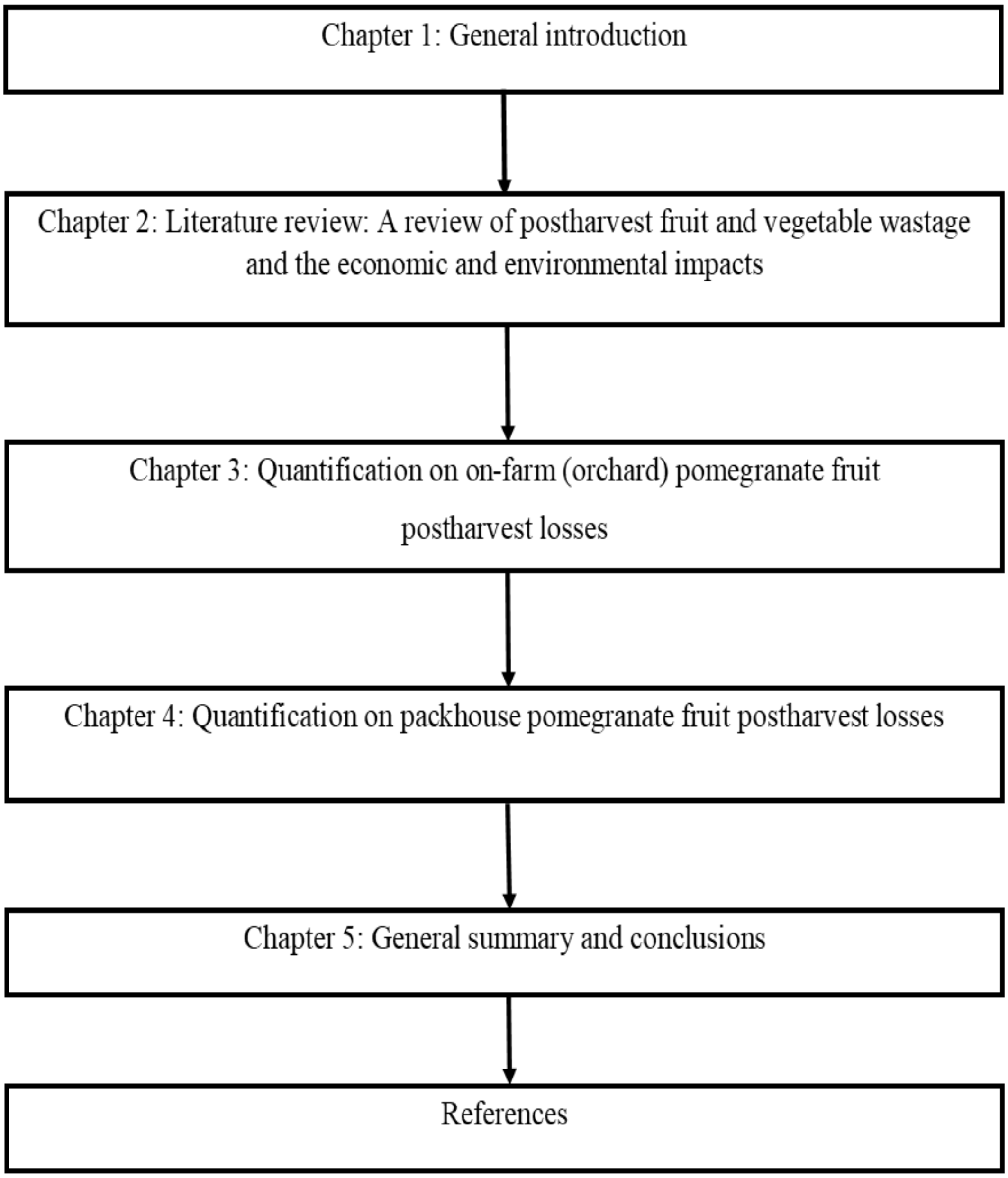

Figure 1.4: Outline of thesis

Chapter 2 - A review of postharvest fruit and vegetable wastage and the economic and environmental impacts

2.1 Introduction

Food security has been a topical issue among researchers and experts in the food system with a recent focus on nutritional security, owing to the FAO 1996 definition of food security, which gave cognisance to nutritional security and food preference. Nutrient rich diets contain a healthy, high quality range of food commodities in appropriate proportion. According to the WHO (2016), about 2 billion people do not have sufficient intake of micronutrients. This could present a serious concern with the projection of over 9 billion people to live in the world during the next 30 years (UN, 2011).

Fruit and vegetables contain essential micro and macronutrients that are necessary for a healthy life. Fruit and vegetables contribute enormously to good health and wellbeing, and there has been a strong correlation between fruit and vegetable consumption and good health outcome (Keatinge, Yang, Hughes, Easdown & Holmer, 2011). Fruit and vegetables contain essential nutrients that are necessary for adequate nutrition and wellbeing such as vitamins, amino acids, minerals, calories and fibre (Keatinge, Waliyar, Jamnadas, Moustafa, Andrade et al., 2010). A strong correlation was found for fruit and vegetable consumption with cardiovascular disease protection, reduced risk of pancrease diseases, low risk of depression, cancer and stroke protection (Angelino, Godos, Ghelfi, Tieri, Titta, Lafranconi et al., 2019). Also, there is evidence of fruit and vegetable consumption in improving mental and cognitive health in older adults (Gehlich, Beller, Lange-Asschenfeldt, Köcher, Meinke et al., 2019; Ocean, Howley & Ensor, 2019). Consumption of fruit and vegetables have been linked to slowing ageing process (Ocean et al., 2019). These benefits are as a result of essential nutritional contents such as phytochemicals and antioxidants (Opara & Al-Ani, 2010), including phenolic compounds and bioactive compounds that exhibits anti-inflammatory and antitumoral properties (Viuda-Martos, Fernández-López & Pérez-Álvarez, 2010).

Historically, insufficient availability of fruit and vegetables have persisted due to postharvest wastage despite the health benefits (Mason-D'Croz, Bogard, Sulser, Cenacchi, Dunston et al., 2019). This presents a serious food and nutritional security challenge. Globally, fruit and vegetables wastage is as high as 37-55% (Gustavsson et al., 2011) and account for about $750 billion (FAO, 2013). The incidence of fruit and vegetables postharvest wastage in South Africa is estimated at 4.2 million tonnes, accounting for 47% of the total food losses and waste in the country (Oelofse & Nahman, 2013). This high level of losses constitutes severe negative impacts on the environment, and economic losses to farmers and the actors along the value chain.

The global production and trade of fruit and vegetables makes significant economic contribution to to the gross domestic product (GDP) many countries. For example, in 2013, vegetables contributed about $25.25 billion and $6.25 billion to the national revenue of China and India, respectively (Produce Marketing Association, 2016). Fruit production in China amounted to 260 million tonnes in 2014, and the total export accounted for 4.1% of global fruit export (Produce Marketing Association, 2016). India produced a combined 179 million tonnes of fruit and vegetable in 2011, accounting for 21.2 % of total global fruit and vegetable production (Mahajan, 2020). The annual value of fruit and vegetable production globally is estimated at $1 trillion (Schreinemachers, Simmons & Wopereis, 2018). In South Africa, fruit alone contributed an estimated revenue of about $1.8 billion in 2015, with deciduous fruit contributing $835 million, citrus contributing $834 million and other selected subtropical fruit contributing $205 million (Louw, 2016). The fruit industry in the country helps to curtail the rising rate of unemployment by employing people who work in the farms and along the value chain. The deciduous fruit sector employs an estimated 75,657 permanent staff, and the citrus fruit sector about 95,690, while some subtropical selected fruit employs about 24,375 persons (Louw, 2016). Louw (2016) indicated that these estimates are only for in-farm employment. The job opportunities created down the value chain were not included as the system at the value chain is more complicated with multiple activities and complexities at a different level that makes it difficult for a comprehensive estimate.

Reducing postharvest wastage of fruit and vegetables has been argued by recent studies as the most sustainable means to mitigate food and nutritional insecurity, and improve the local economy especially in the developing countries (Ellis, Kwofie & Ngadi, 2020; Nshizirungu & Kitinoja, 2019; Louw, 2016). Postharvest wastage in developing countries due to inefficiency at production and handling stages can be as high as 40-50% (Nshizirungu & Kitinoja, 2019). Hence, assessing the amount of postharvest wastage and identifying the hotspot for losses and waste is as important as food production itself. This is because it does not make economic sense only to increase production to solve food and nutritional security problem if a third of what is produced goes to waste. Therefore, there is consensus among researchers, development practitioners and policy experts that reducing postharvest waste should be one of the strategies to increase food and nutrition security amid the increasing world population (Opara, 2010). This review aims to discuss the causes and impacts of fruit and vegetables wastage in relation to economic loss, unsustainable use of resources and nutritional security. Many studies have been done on postharvest wastage of fruit and vegetables in different countries and regions. However, these studies focused on quantitative loss, environmental impacts and reduction strategies with little or no attention to nutritional loss due to postharvest wastage. For example, Porat, Lichter, Terry, Harker and Buzby (2018), assessed the magnitude and causes of fruit and vegetable losses during retail and consumption and the emerging technologies and strategies to prevent wastage at retail and home. Kasso and Bekele (2016) assessed the factors causing quality deteriorating and postharvest wastage of horticultural crops in Dire Dawa region of Ethiopia. McKenzie, Singh-Peterson and Underhill (2017) quantified postharvest wastage of tomato using weight and volume in two commercial, domestic supply chains in Queensland, Australia. The drivers and factors contributing to postharvest losses were qualitatively identified and analysed. Underhill, Joshua and Zhou (2019) assessed postharvest losses of horticultural produce in roadside markets and municipal markets in Guadalcanal, Solomon Islands using short semi-structured interviews. The factor contributing to postharvest losses were also discussed. Kitinoja, Tokala and Brondy (2018), did a comprehensive review of 268 postharvest losses and waste studies, including assessment methodologies. The study discovered that out of the 268 postharvest wastage studies reviewed, interviews and questionnaires were the most used to measure quantitative losses, and direct measurement was the least used method. The review also revealed that most of the postharvest wastage studies provided data on quantitative losses, while few studies included information on qualitative and economic loss measurements. Only 5 out of the 268 studies provided information on nutritional losses as an impact of postharvest wastage. Kummu, De Moel, Porkka, Siebert, Varis et al. (2012) estimated postharvest losses and the impacts on natural resources and other production inputs at the global food supply chain level. There is a gap in the literature on information about nutritional losses due to postharvest wastage of fruit and vegetables. Therefore, this review would provide information on postharvest wastage of essential nutrients that could benefit people by improving health and wellbeing.

To conduct this study, a search was conducted on databases to make sure that the study does not replicate previous research. Searches on Google Scholar and Scopus were done to obtain articles in academic journals, and no evidence of duplicate result was seen. Special attention was given to articles to ensure that most of are obtained from peer review and reputable journals. The search was done using the following keywords and phrases; "food losses", "food waste", "food losses and food waste", "fruit losses", vegetable losses", "fruit and vegetable losses", "quantifying fruit losses and waste", "postharvest losses", "postharvest waste", "understanding fruit losses and waste", and "environmental impacts of food losses and waste". The results of the review were summarised under the following sub-topics: (a) an overview of postharvest wastage in the global fruit and vegetable industry; (b) types of postharvest wastage of fruit and vegetable; (c) causes of postharvest wastage of fruit and vegetables; and finally (d) an overview of the impacts of postharvest wastage of fruit and vegetables.

2.2 Postharvest wastage in the global fruit and vegetable industry – an overview

Postharvest wastage in the value chain can be reasonably large in the fruit and vegetable industry. About 45% of the total food losses globally are fruit and vegetables (FAO, 2011), of which an estimated 50% occur at production, handling and storage, and 46% occur during processing, distribution and final consumption. Postharvest wastage of fruit and vegetables is a challenge both in developed and developing countries (Musasa, Mvumi, Manditsera, Chinhanga, Musiyandaka et al., 2013). In the developed countries, fruit and vegetables waste occurs mainly at the retail and consumer levels (Porat et al., 2018). In contrast, in developing countries, losses and waste occur mostly at production and processing (Porat et al., 2018; Kasso & Bekele, 2016). Louw (2016) reported that an estimated 32% of the total production is lost in the fruit and vegetable industry in the developing countries. Despite the high amount of fruit and vegetable lost annually (Table 2.1), only less than 5% of research funding is allocated for postharvest research globally (Louw, 2016). This makes it challenging to invest in postharvest research and innovation needed to cost-effectively reduce the losses and waste. For example, in South Africa, handling, storage, processing, and packaging is still ranked the highest in the contributors of waste in the food value chain (Oelofse & Nahman, 2013). However, there has been an improvement in postharvest packaging, shelf life, transportation, storage, and disease and pest control before access to the market (Louw, 2016).

The magnitude of fruit and vegetables postharvest wastage varies significantly among types of fruit and vegetables, production area and seasons. The estimation of fruit and vegetable wastage became popular in the 1960s and 1970s (Ceponis & Butterfield, 1973). One of the early estimations was done by the US Department of Agriculture, Consumer and Marketing Services (C&MS, 1970), which revealed that in 1969, the value of fresh fruit and vegetables at wholesale wasted in New York alone was $450 million and which was projected to reach $750 million in retail value. In the UK, an estimated 3 million tonnes of fruit and vegetables are wasted annually (WRAP, 2009). However, there has been a reduction recently to 1.6 million tonnes amounting to over $4.8 billion (WRAP, 2019), as a result of the vigorous effort by government and food businesses to reduce food waste. These wastes are due to grading, customer behaviour and inconsistencies in the value chain. However, it was noted that losses due to natural causes such as environmental conditions could not totally be controlled (WRAP, 2011).

The seminal report from the United States National Academy of Sciences (NAS) about half a century ago on postharvest food losses in developing countries concluded that the magnitude of fruit and vegetables wastage in the developing countries ranges between 21 – 50% (NAS, 1978). While the FAO (2011) estimates for fruit and vegetables in the developing countries was 37 – 55%. Recent studies have estimated postharvest wastage of fruit and vegetables in the developing countries as high as 60% (Yahia, 2019; Yahia, Fonseca & Kitinoja, 2019). The reasons for this include inadequate skilled personnel, inadequate cold storage and transport facilities, and the generally poor state of postharvest technology (Porat et al., 2018; Hodges et al., 2011). On the other hand, higher loss of fresh produce (including fruit and vegetables) from retail to consumption was reported in the developed countries (Yahia, 2019; FAO, 2011), which can be attributed to high market grade and preference, as well as economic prosperity (WRAP, 2019). Hence, people tend to buy more than they can consume. This defeats the argument of increasing production to feed the anticipated increase in world population in the future. Table 2.1 presents the postharvest wastage magnitude of some fruit and vegetables in some developing countries.

Table 2.1: Estimated postharvest wastage of fruit and vegetables in some developing countries.

Country	**Commodity**	**Wastage %**	**Hotspot**	**Reference**
Ethiopia	Tomato Mango Coffee	45.32 43.53 15.75	Harvesting & marketing	Kasso & Bekele, 2016
Oman	Fresh produce	3 – 19	Supermarket	Opara, 2003
Fiji	Fruit and vegetables	0.07 – 2.44 4.07 – 10	Municipal markets	Underhill & Kumar, 2014
Fiji	Tomato	32.9	Supply chain	Underhill & Kumar, 2015
Zimbabwe	Orange	40	Villages	Musasa et al. 2013
South Africa	Fruit	50	Fruit market	Mashau, Moyane & Jideani, 2012
Solomon Island	Fruit and vegetable	7.9 – 9.5 2.6 –7	Municipal & roadside markets	Underhill. Joshua & Zhou, 2019
South Africa	Cabbage	12 – 46	Retail to consumer	Munhuweyi et al. 2016

The challenge of postharvest wastage of fruit and vegetables in Sub-Saharan Africa is complex as there is variation in magnitude at different stages of occurrence (Table 2.2). Fruit and vegetable in Sub-Saharan Africa have the highest percentage of loss compared to other crops totalling a staggering 51% of total production (Table 2.2). The losses occur more during processing and distribution, which is mainly due to mechanical damage such as bruises and excessive trimming (Hussein, Fawole & Opara, 2019a; Opara & Fadiji, 2018; Fadiji, Coetzee, Chen, Chukwu & Opara, 2016).

Table 2.2: Food wastage by type of crop in Sub-Saharan Africa (FAO, 2011).

Location	Fruits and vegetables (%)	Roots and tubers (%)	Oilseeds and pulses (%)	Cereals and grains (%)
Production	10.00	14.00	12.00	6.00
Handling and storage	8.00	15.00	7.00	8.00
Processing	20.00	11.00	6.00	3.00
Distribution	10.00	3.00	2.00	2.00
Consumption	3.00	1.00	1.00	1.00
Total	51.00	44.00	28.00	20.00

2.3 Types of postharvest wastage of fruit and vegetables

Reasons for postharvest fruit and vegetables loss vary according to the activities that occur at each stage of the food value chain. Therefore, the type of loss is determined by the causative factors and the type of defect on the fruit and vegetables. There are two main types of postharvest fruit and vegetables losses common in the mainstream literature, namely, quantitative losses and qualitative loss. Each of these types of losses occurs along the food value chain (Gardas et al., 2018; Aulakh & Regmi, 2013).

2.3.1 Quantitative loss

Quantitative fruit and vegetables loss refers to the loss in weight and volume, which are usually measured through scientific investigation (Munhuweyi et al., 2016; Batu, 2004). This is measured by weighing the fruit and vegetables along the value chain and comparing it with the original weight at the point of departure (farm or packhouse) (Matare, 2012). However, a quantitative loss can also manifest through changes in physical appearance such as shrivel (shrinking) (Fawole & Opara, 2013a) and through water loss, which affects pomegranate and other fruit and vegetables (Lufu, Ambaw & Opara, 2020). The reduction in weight is caused by factors like change in temperature and relative humidity which leads to loss in moisture content and change in chemical composition (Lufu et al., 2020). Since the appearance of the fruit and vegetables is affected, the commodity becomes less appealing for consumption which downgrades the commercial (Aulakh & Regmi, 2013). There is also variation in quantitative loss, which includes partial and total loss (Prusky, 2011). Partial loss is described as loss due to respiration and the peeling off some of the edible parts of fruit and vegetables due to damage or spoilage, leaving a portion good for consumption. A situation where the whole fruit and vegetables are unfit for consumption or industrial use and discarded is described as a total loss. The consideration of weight loss as a factor to determine quantitative food loss is argued to be unsatisfactory in some postharvest situations (Aulakh & Regmi, 2013) such as drying, which is a required postharvest process to preserve quality and safety of grain and cereal foods as well as dried fruit and vegetable products. Under this consideration, such weight loss cannot be categorised as loss.

2.3.2 Qualitative loss

Qualitative fruit and vegetables loss occur because of unwanted factors that affect the perception of the food and its market value, such as change in texture, taste, and colour (Buzby & Hyman, 2012). Qualitative loss can occur due to several factors ranging from the incident of pest and rodents to poor handling system, contamination by pesticides and insect damage (Aulakh & Regmi, 2013). Fruit and vegetable losses due to qualitative loss are mainly based on grading and market criteria to meet the local and international marketing requirements and standards (Kader, 1983). This means that the fruit and vegetables are sorted according to how appealing they look to the customers and the final consumers. This type of grading is made to have an acceptable minimum required standard of quality which helps to determine the market value of fruit and vegetables since they are susceptible to loss due to moisture content (Munhuweyi et al., 2016).

Both quantitative and qualitative losses are subject to customer and final consumer appeal, which are determined by the type of market, the minimum acceptable standard and culture. Revenue is lost when these losses occur along the value chain, and this affects the local economy and the market price. However, higher postharvest losses may create scarcity which causes an unexpected price increase (Sudheer & Indira, 2007), but this does not guarantee an increase in revenue as the spike in price affects the affordability of the commodity. To reduce losses and waste, it is important to analyse the factors causing losses and waste of fruit and vegetables at each phase of the value chain, to improve their quality and shelf life (dos Santos, Cardoso, Borges, e Almeida, Andrade et al., 2020).

2.4 Causes of postharvest loss of fruit and vegetable

Fruit and vegetables are susceptible to postharvest spoilage; therefore, they have very short shelf-live and amount up to 37-55% of the food that is wasted globally (Gustavsson et al., 2011). This accounts for about 40% of financial losses to farmers, distributors, retailers, and various actors in the food value chain (Gardas et al., 2018; Porat et al., 2018). Factors contributing to postharvest losses mostly originate from practices along the food value chain such as handling, processing, production practices, transportation facilities and infrastructures, and general production practices (Aulakh & Regmi, 2013). Also, losses occur because of pests and diseases, which are spread by pathogens (Yahaya & Mardiyya, 2019). Price stability in the marketing system is also a contributing factor (Macheka, Spelt, Bakker, van der Vorst & Luning, 2018). Environmental conditions such as relative humidity and temperature, especially during storage contribute to causing fruit and vegetables to be susceptible to microbial and pathological attacks (Yahaya & Mardiyya, 2019). Yahaya and Mardiyya (2019) also suggested that among all the causes of postharvest losses, pathological and mechanical damage are the most severe causes of loss of fruit and vegetables. These factors that cause postharvest wastage are categorised into two main types namely, primary causes and secondary causes (Table 2.3), with a distinction made according to how and when the wastage occurs (FAO, 1989).

Table 2.3: Classification of causes of postharvest fruit and vegetable wastage **(**Hussein, Fawole & Opara, 2019a; Opara & Pathare, 2014; Atanda, Pessu, Agoda, Isong, & Ikotun, 2011**).**

Primary Causes	**Secondary Causes**
Mechanical damage	Inadequate equipment and tools
Physiological damage	Poor facility and machinery maintenance
Pathological deterioration	Poor production and management practices
Environmental and physical condition	Inadequate transportation facilities
Microbiological damage	Inadequate storage facilities
Biological damage	Poor packaging
Chemical and biochemical damage	Lack of technological skills
	Legislation, quality standard, and marketing system

2.4.1 Primary causes of fruit and vegetable losses

The primary causes of postharvest wastage of fruit and vegetables are mainly due to technical factors and are direct in the way they affect fruit and vegetables. They are majorly as a result of microbial, physiological, mechanical, and environmental factors (Atanda et al., 2011). These factors are complementary in the way they affect fruit and vegetables as damage caused by microbial factors are usually as a result of previous mechanical or physical damage, which reduces the fruit or vegetable's defence mechanism by creating injury, thereby making it susceptible to bacteria and fungi attacks (Munhuweyi, 2012). Following is the description of the primary causes of fruit and vegetables postharvest wastage.

Mechanical damage

Mechanical damage occurs along the value chain and has become a major factor that reduces the market value and quality of fruit and vegetables (Opara & Pathare, 2014). Mostly, mechanical damage occurs in three different ways, which are compression, vibration, and impact during harvesting and postharvest handling (Hussein, Fawole & Opara, 2019b). Damage may also occur because of thrust and pressure during packaging and transportation (Yahaya & Mardiyya, 2019). Mechanical damage is mainly due to machinery and operational processes and is visible in the form of bruises, injuries and excessive trimming of fruit and vegetables causing loss (Hussein et al., 2019a; Opara & Pathare, 2014; Atanda et al., 2011; Opara, 2003).

Sometimes, the impact of mechanical damage is not visible as the damage to fruit and vegetables is internal by way of ruptured cells and tissues, which make the fruit and vegetables prone to faster deterioration during senescence (when chemical reactions are weak, which result to aging and death of tissues) (Yahaya & Mardiyya, 2019). Mechanical damage also occurs during processing of the fruit and vegetables. Processing operations cause damages such as abrasion and excessive polishing (Yahaya & Mardiyya, 2019; Bourne, 1977). During packaging, defective seals and storage units also cause mechanical damage. Mechanical damages cause injuries which result in loss of moisture and an increase in respiratory activities leading to qualitative loss.

Physiological damage

Physiological damage is as a result of prolonged storage leading to ageing. It is evident in senescence in fruit and vegetables, and other natural reactions caused by respiration and transpiration (Lufu, Ambaw & Opara, 2019). Respiration and transpiration cause significant weight loss as heat is also generated during this process (Atanda et al., 2011). Changes because of this natural process result in terminating dormancy, causing fruit and vegetable to sprout and increases susceptibility to pathogens infection. This leads to qualitative loss, making fruit and vegetables lose appeal to customers (Buzby & Hyman, 2012).

Pathological deterioration

Pathological deterioration is caused by microorganisms like bacteria and fungi (Salunkhe & Desai, 1984). Fruit and vegetables are high in moisture content and are succulent, making them susceptible to microbial attack and damage. The rate of pathological deterioration is dependent on many environmental factors such as the velocity of the air, relative humidity, and atmospheric composition (Mukama, Ambaw & Opara, 2020). If the environmental factors are favourable to the pathogens, they thrive and cause damage to fruit and vegetables.

Environmental and physical condition

Environmental and physical conditions play an important role in the quality of fruit and vegetables along the value chain. Such conditions are temperature, relative humidity, the composition, and proportion of gases in atmospheric controlled storage (Mukama et al., 2020; Nshizirungu & Kitinoja, 2019; Yahaya & Mardiyya, 2019). While insufficient or improper atmosphere affects the shelf life of fruit and vegetables (Miguel, Fontes, Antunes, Neves & Martins, 2004), high temperature and relative humidity encourage the growth of microorganisms that cause damage to fruit and vegetables (Yahaya & Mardiyya, 2019). Also, high temperature increases the rate of respiration of fruit and vegetables, causing a breakdown of internal tissues resulting in the qualitative loss (Lufu et al., 2019). Therefore, optimum temperature and relative humidity are required for the storage of fruit and vegetables according to their biochemical and biological composition.

According to Yahaya and Mardiyya (2019), the role of relative humidity is as important as that of temperature. This is because, during storage, the effect of temperature and relative humidity is similar on fruit and vegetables (Yahaya & Mardiyya, 2019). Therefore, air distribution in a storage unit is required; this operation allows heat transfer from fruit and vegetables to cold air which reduces their temperature and physiological response (Opara & Fadiji, 2018). Air movement in storage units directly affects temperature and relative humidity, and such could make fruit and vegetables more susceptible to diseases and decay if air movement is inadequate. This is because fruit and vegetables have different temperature and relative humidity requirements for cold storage along the value chain. Although many deciduous fruits have similar temperature and relative humidity requirement for cold storage (Table 2.4), it is important to note that some of the environmental requirements for storage and quality maintenance can vary according to the type of cultivar and growing location. In this case, in order to minimize qualitative loss, adequate storage condition is required according to the specific fruit and vegetable cultivar. Excessive heat supply, and inappropriate composition of atmospheric gases in storage and inappropriate cold storage temperature and relative humidity all contribute to postharvest wastage. These environmental factors cause fruit and vegetables tissue damage, which manifest in the form of change in texture, taste and colour. Therefore, it affects the perception of the fruit and vegetables and its market value (Buzby & Hyman, 2012).

Table 2.4: Recommended storage temperature and relative humidity for selected deciduous fruit (DAFF, 2017).

Fruit name	**Storage temperature (°C)**	**Relative humidity (%)**	**Storage period (weeks)**
Pomegranate	5-7	90-95	-
Plum	varies	95	2-4
Apple	0.5	95	16-32
Peach	0.5	95	-
Grape	0.5	95	6-8
Nectarine	0.5	95	-
Pear	0.5	95	10-40
Apricots	0.5	95	4

Microbiological damage

The succulent nature of fruit and vegetables makes them susceptible to microbial attack. Microorganisms like microbes, bacteria and fungi damage fruit and cause losses (Nshizirungu & Kitinoja, 2019; Atanda et al., 2011). Microbes eat small portions of fruit and vegetables, which usually damage the fruit and vegetables, thereby making it unacceptable to the market and sometimes unfit for consumption due to defects. Microbial infection happens rapidly and causes an extensive breakdown of fruit and vegetables and sometimes affect the entire fruit and vegetables batches leading to total loss (Yahaya & Mardiyya, 2019). The source of microbial infection is mostly from the farm. Also, fruit and vegetables contact with infected equipment, unclean water used for washing and untidy storage environment leads to microbiological infestation (Atanda et al., 2011).

According to Yahaya and Mardiyya (2019), the common fungi causing rot in fruit and vegetables are *phomopsis*, *penicillium*, *botrytis*, and *fusarium*. Bacteria are *pseudomonas*, *ervinia* and other microbes. Substances that are toxic like carcinogen and patulin, which are mycotoxins produced by mould and fungi are harmful, thereby causing affected fruit and vegetables to be unfit for consumption and therefore lost (Atanda et al., 2011).

Biological damage

Biological damage occurs by the consumption of fruit and vegetables by rodents, insects, birds and even large animals (Atanda et al., 2011). This causes partial or total loss of the fruit and vegetables (Prusky, 2011). Atanda et al. (2011) asserted that in some cases, fruit and vegetables contamination by the feather of birds, hair of furry animals and animal excreta are to the extent that the fruit and vegetables are unfit for consumption resulting to a total loss. Biological damage on fruit and vegetables can also occur through webbing and deposit of substances that release unpleasant smell by animals, hence affect the quality of fruit and vegetables (Atanda et al., 2011).

Chemical / Biochemical damage

The chemical makeup of some stored fruit and vegetables naturally reacts to cause discolouration, loss of texture and flavour, and even loss of nutritional content (Nshizirungu & Kitinoja, 2019; Atanda et al., 2011). An example of such reaction is the Maillard reaction which causes discolouration, especially in dried fruit (Atanda et al., 2011). In the process of handling, there could be an incident of contamination of fruit and vegetables with toxic substances such as chemicals or pesticides that makes the fruit and vegetables unfit for consumption thereby resulting to qualitative loss (Aulakh & Regmi, 2013). Also, biochemical enzyme related reactions occur in stored fruit and vegetables, causing them to soften with undesirable taste (Nshizirungu & Kitinoja, 2019; Atanda et al., 2011).

There are cases where losses occur due to more than just one of the primary causes. In this case, the primary causative factor may work at the same time or one after the other (Bourne, 1977). For example, there could be insect attack and the growth of mould simultaneously, and on the other hand, the growth of mould first, before enzyme or biochemical reaction causing discolouration and soft texture.

2.4.2 Secondary causes of fruit and vegetable losses

Secondary causes of loss are described by Kader (1983) as socio-economic factors that lead to conditions that enable primary causes of loss to occur. These factors are indirect and are described by the way they affect postharvest wastage (Hodges et al., 2011). They are mostly as a result of unavailability, poor or inadequate postharvest facilities that ensure that the quality of fruit and vegetables are maintained along the value chain (Atanda et al., 2011; Hodges et al., 2011).

Inadequate or unavailability of the necessary facilities and equipment and poor maintenance of infrastructure results in huge loss of fruit and vegetables along the value chain (Kasso & Bekele, 2016; Cardoen, Joshi, Diels, Sarma & Pant, 2015; Murthy, Gajanana, Sudha & Dakshinamoorthy, 2009). Also, the lack of enhanced production and management practices contribute to postharvest losses, especially in developing countries (Porat et al., 2018; Hodges et al., 2011). This is evident in the FAO (2011) study, which was carried out at local and international levels, and postharvest wastage compared in the developed and developing countries. For example, poor transportation network, inadequate storage facilities, inadequate packaging, lack of processing facilities are among the major causes of postharvest wastage in Ethiopia (Kasso & Bekele, 2016). A similar situation was observed in the value chain of selected fruit and vegetables in India, where fruit and vegetable losses amount to $34 billion annually (Cardoen et al., 2015; Murthy et al., 2009).

Most times, fruit and vegetable handlers (in harvesting, packing, packaging, and transportation) have inadequate knowledge of how to maintain fruit and vegetable quality along the value chain in the developing countries, due to limited training and low skill. Lack of technological skills required at each stage of the value chain to maintain the quality of fruit and vegetables can be a huge source of postharvest wastage. This is because fruit and vegetables are susceptible to spoilage due to their high moisture content and succulent nature. Kader (1983) asserted that in the developing countries, cold chain transportation is not available in some transportation modes or is inadequate, where available, thereby making their demand more than the supply. This leads to delay between harvesting and preservation by cooling, which causes qualitative loss such as a change in texture, taste, and colour (Buzby & Hyman, 2012). Additionally, poor maintenance of packhouses, inadequate packing space, late repairs on facilities, and other poor management decisions affect the quality of fruit and vegetables.

Legislation and marketing system could also be an indirect source of postharvest wastage. Laws, grading, and standards about consumption are contributing factors in determining the quantity of food consumed in a community and what is wasted (Atanda et al., 2011; FAO, 1989). Also, the extent of government influence and control in the marketing system, especially on pricing and the middlemen along the value chain, contribute to losses (Kasso & Bekele, 2016; Murthy et al., 2009). This is because multiple middlemen would mean a longer time for the fruit and vegetables to get to the retail stores and the final consumer. Because fruit and vegetables are perishable commodities, longer time along the value chain makes them susceptible to quality loss. Irrespective of the causes, postharvest wastage of fruit and vegetables have a detrimental impact on the farmer and value chain actors as well as the natural environment and ultimately human health.

2.5 Impacts of postharvest wastage of fruit and vegetables – an overview

Transitioning to a more sustainable future has at its core, the transformation of the food system to minimizing food wastage and ensuring food and nutrition security (Atanda et al., 2011). If the goals of research organisations, policymakers, and various actors in the food industry are to be met in terms of a sustainable food system (with minimal impact on the environment, economy and society), conditions that encourage postharvest wastage must be reduced. According to FAO (2011), over 45% of the total food lost annually are fruit and vegetables. This comes with huge impacts on the farmers and the food system actors along the value chain. For example, the total loss of pomegranate fruit at the packhouse level in South Africa in 2016 and 2019 were estimated at 13% and 6% respectively (POMASA, 2019; POMASA, 2016). This may sound acceptable, but it was without the record of the losses and waste at the farm level. The amount of fruit losses at the farm level could spike the figures and reveal the actual percentage of loss of pomegranate fruit in 2016 and 2019. Postharvest wastage impact is enormous in terms of economic loss, negative impact on the environment (GHG emission, freshwater use and cropland use), and negative impact on food security in terms of nutritional loss.

2.5.1 Economic impact

The economic impact of postharvest wastage is mostly in terms of financial loss that farmers and food actors along the value chain incur as a result of loss and waste. Postharvest losses also impact the consumers directly as much as it impacts the farmers (Gustavsson et al., 2011; Murthy et al., 2009). For example, a food-insecure household would have an improved livelihood if they cut down on the amount of food they waste, as this simply means that more money would be spared to purchase other household items other than food. For farmers, the losses will result in a direct loss of production inputs in monetary terms. The cost of global food waste was about $750 billion with vegetables accounting for 23% of total cost and fruit 19% (FAO, 2013). This is due to the high susceptibility of fruit and vegetables to postharvest wastage, especially in developing countries.

A study in three different counties in Kenya revealed that on average, the economic loss due to postharvest wastage of African nightshade plant amounted to over $2.7 million (Gogo, Opiyo, Ulrichs & Huyskens-Keil, 2017). At the macro level in India, which is the second fruit and vegetables producing country in the world, annual fruit and vegetable wastage was estimated at $1.8 billion, which was based on 30% loss (Murthy et al., 2009). On average, in South Africa, about 21,950 tonnes of cabbage valued at $973,147 is lost at the retail level annually (Munhuweyi et al., 2016). The losses represent a loss of production input and investments at all levels and impact on food security in these countries. The amount of postharvest wastage impacts the price of food available in the market, thereby causing food insecurity. This is because market prices impact access to food as poor households do not have the purchasing power to get sufficient and nutritional food (Papargyropoulou, Lozano, Steinberger, Wright & bin Ujang, 2014). Another form of economic cost of postharvest wastage, is that the resources used to produce wasted food would have otherwise, been used for other activities such as providing ecosystem services. For example, land used to produce wasted foods could be used for recreational parks to generate revenue.

In economic terms, reducing postharvest wastage could be a way of lowering food prices, thereby making it possible for the poor and food insecure to be able to afford healthy food that meets their nutritional requirements. Also, the reduction in postharvest wastage results in saving cost, which is not only linked to reduced food prices in the market but also the cost of waste disposal (EPA, 2012). The cost of waste disposal by the government is reduced with minimised postharvest wastage, which makes more fund available for developmental projects in other sectors of the economy. According to UNEP (2011), minimizing postharvest wastage saves the cost of production and helps agricultural businesses identify new business areas to boost employment and competitiveness in the larger economy. Again, economic investments made to reduce postharvest losses and waste are less expensive for farmers and agricultural businesses than increasing production (which seem conventional) to affect food security (Gogo et al., 2017).

2.5.2 Environmental impact

Literature suggests that studies have been conducted to quantify the environmental impacts of food losses and waste (Kashyap & Agarwal, 2020; Bais-Moleman, Schulp & Verburg, 2019; Heard, Bandekar, Vassar & Miller, 2019; Goossens, Berrens, Custers, Van Hemelryck, Kellens et al., 2019; Kummu, De Moel, Porkka, Siebert, Varis et al., 2012). These studies focused on how postharvest wastage results in unsustainable use of natural resources. The environmental impact of postharvest wastage is of serious concern because as the world population grows, the demand for food increases with resultant postharvest wastage. Also, the increase in demand for food further put pressure on the environment for agricultural food production. This usually leads to unsustainable use of resources, which are currently depleting and increasing the risk of climate change that is currently a global issue (Willersinn, Möbius, Mouron, Lansche & Mack, 2017; Munhuweyi et al., 2016; Beretta et al., 2013; Ridoutt, Juliano, Sanguansri & Sellahewa, 2010).

The environmental impacts of postharvest wastage can be assessed by five different factors: greenhouse gas emission (GHG), freshwater use, cropland use, biodiversity disruption and the landfill (FAO, 2013). Resources such as freshwater used for irrigation, cropland, energy, fertilizer, and other agricultural inputs are limited in nature and as such, require sustainable utilization in food production and consumption.

Greenhouse gas (GHG) emission

GHG is made up of methane, nitrous oxide, and carbon dioxide. According to Robertson, Paul and Harwood (2000), the radiative force of the atmosphere of the Earth is increasing due to the increase in the emission of the GHG. Due to mechanisation in farming and processing of agricultural produce, agriculture is known to be a significant contributor to GHG. The GHG attributed to agriculture is estimated at 22% of GHG emission (FAO, 2013). Food waste has a significant contribution to agricultural-related GHG emission. The FAO has reported that food waste would be third if put into the country ranking of GHG emitters with only China and the US coming first and second, respectively (FAO, 2013). This amount of GHG from food waste is more than that of Turkey, South Africa, Spain, and Ukraine put together according to FAO estimation. This means that food losses and waste is a huge contributor to global warming and climate change. Postharvest wastage of fruit and vegetables is significant in terms of their impact to climate change, because of the amount of waste they generate due to their moisture content and susceptibility to waste (Beretta, Stucki & Hellweg, 2017). The GHG emission attributed to fruit and vegetables is linked to their harvesting, processing, storage, transportation and ultimately waste disposal in landfills. Fruit and vegetables contribute a combined 27% of carbon footprint (Table 2.5) as compared to other food commodities.

Table 2.5: Comparing commodity contribution to food wastage and carbon footprint (FAO, 2013).

Food commodity	**Wastage (%)**	**Carbon footprint (%)**
Cereals	25.00	34.00
Starchy roots	18.00	5.00
Oil crops and pulses	3.00	2.00
Fruit	16.00	6.00
Meat	4.00	21.00
Fish and sea food	2.00	4.00
Milk and egg	7.00	7.00
Vegetables	24.00	21.00

Agricultural GHG emissions are also directly generated by the addition of fertilizer to the soil and the application of pesticides (Beretta et al., 2017). This is because fertilizers and pesticides contain chemical compounds that diffuse into the atmosphere and contribute to global warming. In the developed countries where fruit and vegetable farming are extensively mechanised, the onsite (farm) GHG emission is more because of farming activities that involve the use of various machines and the application of fertilizers. However, agricultural GHG emission is relatively low in countries where fruit and vegetable farming are not mechanised or where the country depend on importation for most of its fruit and vegetable supply. For example, in the UK, the agricultural sector is considered a low GHG emitter because energy use for agricultural purposes in relation to fruit and vegetable production is relatively low (Garnett, 2006). This is because most fruit and vegetables are imported as opposed to Spain and the US that grow most of their fruit and vegetables (Garnett, 2006). Germany has a heavily mechanised agricultural and food production system and produces 2.7 tonnes of GHG emission per cap/year (Eberle & Fels, 2016). In Australia, 79% of agricultural GHG emission is from primary production (farm level) (Reutter et al., 2017). In Sweden, the emission attributable to food waste is estimated at 25% of the food consumed (Reutter et al., 2017). Following this analogy, if a third of the food produced is wasted (according to the FAO estimates), the environmental impact of food waste could be higher than estimated in the studies. This is because the embedded GHG already emitted along the value chain before the food gets to the final consumption phase were not accounted for in the studies.

The impact of GHG emission on the Earth's atmosphere directly triggers climate change, which is an environmental problem affecting the whole world but especially the developing countries. The effect of climate change was described as "a unique and involuntary exposure to many societies, and therefore represents possibly the largest health inequity of our time" (Patz, Gibbs, Foley, Rogers & Smith, 2007:397). This is because the effects of climate change are most felt in the poor societies, who have contributed less to it and are already experiencing many health challenges associated with the rise in temperature (Patz et al., 2007). Climate change has also caused severe natural disasters such as flooding, wildfire, and pollution (Anbumozhi, 2020). Majority of these devastating effects of GHG emission can be mitigated by reducing postharvest wastage of food.

Biodiversity loss

There have been estimations of how much additional food production that is required to meet the global food need in the future. However, one of the pitfalls of this idea is the further degradation of biodiversity and loss of natural habitat of animals. Loss of natural habitats result in the depletion of microorganism and higher animals and consequently lead to their extinction. Commercial agriculture involves the use of chemical fertilizers and heavy mechanisation, which causes soil nutrient imbalances and disrupts soil formation, respectively (Blakeney, 2019; Cardoen et al., 2015). The nutrient elements in chemical fertilizers such as urea leach to contaminate underground water bodies and are harmful to several microorganisms (Cardoen et al., 2015). In India, for example, the loss of nitrogen from fertilizers is up to 60 – 80% (Cardoen et al., 2015), this comes with huge consequences on the natural environment.

Furthermore, the production of fruit and vegetables use the most amount of pesticides (Zhang, Jiang & Ou, 2011). For example, in the US, 80% of fruit and vegetables are produced using fungicides (Zhang et al., 2011). This high use of pesticides has huge devastating effects on humans and biodiversity (Pimentel & Burgess, 2014). Pesticides and their residue find their way to rivers, the atmosphere and in the soil, which results to the gathering of harmful substances that are harmful to biodiversity and human health (Rani, Saghir, Usman, Ch & Ali, 2020). According to a survey in the Chinese fruit and vegetable markets, 41 out of 81 samples of vegetables showed the presence of pesticide residue (Zhang et al., 2011). Cabbage and leek showed residues more than 60% and 80% respectively of the Chinese minimum acceptable standard (Zhang et al., 2011). Richter (2002), reports that globally, about 26 million people suffer from pesticide poisonings resulting in an estimated 220,000 deaths in a year. This means that the combined number of microorganisms and animals affected by using chemical fertilizers and pesticides for fruit and vegetables production would be higher. Therefore, postharvest losses of fruit and vegetables also mean losses of biodiversity and huge threat to human life.

Landfill challenges

Landfill waste disposal has a serious environmental impact of postharvest wastage. It poses a serious challenge both in the developed and developing countries as wasted food usually end up in landfills (Blakeney, 2019). The disposed food waste decomposes to produce noxious gases, which contributes to global warming (Nahman et al., 2012). Postharvest wastage does not only contribute to GHG emission from the energy used during production, distribution, and storage but also, produce methane, which is known to trap heat 21 times more than carbon dioxide (Adhikari, Barrington & Martinez, 2006). In the US, for example, about 25% of methane emissions are from landfill where municipal waste is disposed, and only about 3% of the waste along the value chain is converted to compost (Gunders & Bloom, 2017). The landfill is a significant contributor of methane in the US and in other developed countries (Blakeney, 2019). In the UK, it is reported that if food waste were removed from all landfills, the GHG emission mitigation would be equal to removing one-fifth of cars in the country from the roads (Gunders & Bloom, 2017).

Furthermore, carbon dioxide and litter are produced from landfill and pollute the surrounding environment with an offensive odour that has a significant negative impact on human health (Nahman et al., 2012). Leachate is another problem associated with landfill as the liquid produced by the breakdown of food waste permeates into the soil to pollute the groundwater and soil (Blakeney, 2019; Nahman et al., 2012; Osei, Osae, Fianko, Adomako, Laar et al., 2011). So, reducing postharvest wastage means reducing the area of land used as landfill and mitigate its environmental consequences in terms of GHG emission, environmental pollution, and leachate.

2.5.3 Natural resources

Freshwater use

Water is one of the essential commodities upon which plants and animals depend for life. According to the Summary Report of the FAO on the footprint and impact of food wastage on natural resources in 2013, water resources accounting is either by withdrawal or consumption.

Water withdrawal was described as the withdrawal of water from either surface or groundwater sources while water consumption entails the water used by plants by transpiration, consumed by animals or consumed in another form (FAO, 2013). Agricultural water use is consumptive in nature and accounts for about 92% of the total water footprint of humans (Hoekstra & Mekonnen, 2012). There have been suggestions that global water demand would be about 6,900 billion m^3/year by 2030 (Blakeney, 2019). Table 2.6 presents the global freshwater use by region and indicate that the freshwater loss per capita/year due to lost and wasted food is high in the developed countries. This could be attributed to the high food wastage at retail and consumption level in these countries (Yahia, 2019).

Table 2.6: Total global freshwater use per region (Kummu et al., 2012).

Region	**Total freshwater use (m^3/cap/year)**	**Used for lost and wasted food (m^3/cap/year)**
Sub-Saharan Africa	52.00	12.00 (22%)
Europe	59.00	18.00 (31%)
Industrialised Asia	74.00	19.00 (25%)
Latin America	65.00	22.00 (34%)
North Africa & West-Central Asia	258.00	86.00 (33%)
North America & Oceania	120.00	42.00 (35%)
South & Southeast Asia	161.00	30.00 (18%)
Global	111.00	27.00 (24%)

Hoekstra and Mekonnen (2012) suggest that majority of the water usage in agriculture is at the production level. Estimates suggest that the total freshwater used to produce food crops that are lost and wasted along the value chain is about 24% (27m^3/cap/year) (Kummu et al., 2012). In the UK, avoidable food waste amount to about 6% of water footprint per person (Blakeney, 2019). Water use in Germany seem even more as 14m^3 of freshwater is used for agricultural production purposes per person and water used for food production amounts to one-third of the household's water use (Eberle & Fels, 2016).

To differentiate the process of freshwater use in fruit and vegetable production, Ridoutt et al. (2010) classified freshwater use into two – orchard operations and postharvest operations. Freshwater use in orchard pomegranate production operations, for instance, is intensive with irrigation accounting for about 23% of the capital cost of production (POMASA, 2019). This is important to note because, in South Africa, pomegranate is mainly grown in the Western Cape Province, which has a history of water scarcity. Water scarcity and agricultural water usage have remained a major challenge in many regions of the world (Wada, Van Beek & Bierkens, 2011). The study by Ridoutt et al. (2010) on the water footprint of fresh mangoes grown in Australia reported that from production to consumption, an annual average of 26.7 Gl (gigalitres) of rainfall water and 16.6 Gl of irrigation water are wasted. In general, water associated with food waste in Australia is estimated at 8980 Gl, which accounts for 9.1% of the total water use in the country (Reutter, Lant, Reynolds & Lane, 2017). In another study, Liu, Lundqvist, Weinberg and Gustafsson (2013), reported that the water footprint of China associated with fruit and vegetables is estimated at 14% of the total water footprint. In the US, it was estimated that about 34% (1237 kcal/cap/day) of food was lost in 2015, with 90km^3/y (cubic kilometres/year) of water footprint attributable to this loss (Mekonnen & Fulton, 2018). At the retail level, fruit and vegetables accounted for 18% of the water footprint of the lost food (Mekonnen & Fulton, 2018).

From the FAO estimation (Table 2.7), fruit and vegetables account for a combined 26% of the irrigation water footprint of food losses and waste (FAO, 2013). Irrigated agriculture poses serious environmental challenges such as waterlogging causing soil degradation, salinization, and groundwater depletion (Aldaya, Allan & Hoekstra, 2010). Therefore, postharvest wastage of fruit and vegetables does not only represent an unnecessary waste of freshwater that could have been used for other purposes but also, cause degradation to the natural environment.

Table 2.7: Comparing commodity contribution to food wastage and irrigation water footprint (FAO, 2013).

Food commodity	**Wastage (%)**	**Irrigation water footprint (%)**
Cereals	26.00	52.00
Starchy roots	19.00	2.00
Oil crops and pulses	4.00	6.00
Fruit	16.00	18.00
Meat	5.00	8.00
Milk and egg	8.00	8.00
Vegetables	25.00	8.00

Cropland use

Land is a natural resource which is scarce in supply in the sense that humans cannot create more of it. Land for crop cultivation occupies an estimated 1.53 billion hectares of the total Earth landmass (Foley, Ramankutty, Brauman, Cassidy & Gerber et al., 2011). The cultivation of crops comes with severe consequences and impacts on biodiversity, animal habitats, soil condition, and carbon sequestration. These impact on the natural environment disrupt the enjoyment of ecosystem services that comes from the natural environment. Furthermore, the use of fertilizers for crop production also depletes resources like phosphorous (Dawson & Hilton, 2011). Also, there are problems of GHG associated with food losses and waste (Garnett & Wilkes, 2014). Challenges associated with cropland usage due to postharvest wastage can be huge in some countries. For example, in the US, up to 40% of the food produced goes to waste (Gunders & Bloom, 2017).

Table 2.8 shows that the total global cropland area used for lost and wasted food along the value chain account for 23%, which translates to 198 Mha/yr (Kummu et al., 2012). This amount of land used for farming wasted food could be used to plant trees and build parks for the enjoyment of ecosystem services. This is particularly important given that a significant part of the Amazon forest in Brazil, which is referred to as the Earth’s lungs got burnt in 2019.

Table 2.8: Total global cropland use per region (Kummu et al., 2012).

Region	Total cropland use (m^2/cap/year)	Used for lost and wasted food (m^2/cap/year)
Sub-Saharan Africa	1950.00	431.00 (22%)
Europe	1282.00	334.00 (26%)
Industrialised Asia	948.00	232.00 (25%)
Latin America	1475.00	361.00 (24%)
North Africa & West-Central Asia	1473.00	407.00 (28%)
North America & Oceania	1611.00	498.00 (31%)
South & Southeast Asia	1298.00	237.00 (18%)
Global	1334.00	305.00 (23%)

2.5.4. Food and nutrition security

The health status of a community is determined by the lifestyle choices and nutritional security of its people (Paul & Shaha, 2004). Whether a community is food secure or not is a function of what people consume and the impact on their health. Until 1996, food security was defined as "access by all people to enough food to live a healthy and productive life" (Pinstrup-Anderson, 2009:1). The World Food Summit of the FAO in 1996, modified this definition to incorporate nutritional security and preferences. The FAO definition states that food security is achieved when "all people, at all times, have physical, and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO, 1996). The definition has gained more attention owing to the numerous health-related and pharmaceutical benefit discoveries about fruit and vegetables. Fruit and vegetables are an important part of human dietary need as they contain essential vitamins that help to maintain nutritional security (Liu, 2003). Also, fruit and vegetables add colour and flavour to foods and serve as a source of dietary fibre, minerals, and energy (Kader & Barrett, 1996).

However, despite all the benefits derived from fruit and vegetable consumption, fruit and vegetables are still the most wasted food commodities globally (FAO, 2013). Efforts to advance food security and feed the world's teeming population is undermined by postharvest wastage of fruit and vegetables. This is because food security does not only entail the availability of food but also the availability of the right nutritional content (FAO, 1996). This support the argument of Pinstrup-Andersen (2009) that having enough calorie in a diet does not mean that the diet is healthy and nutritional.

What nutrients are contained in lost and wasted fruit and vegetables?

Fruit and vegetables contain essential minerals that helps to maintain a healthy life. Minerals are referred to as inorganic substances that are required by an organism in small quantity for the maintenance of important processes that are essential for life (Paul & Shaha, 2004). Examples of macro and micro minerals are calcium, iron, potassium, zinc, magnesium, sodium, phosphorous and copper, while vitamins include ascorbic acid, riboflavin, and thiamine (Table 2.9). Also, dietary fibres, phenolic compounds, organic acids and sugar derivatives are richly available in fruit and vegetables (Sagar, Pareek, Sharma, Yahia & Lobo, 2018). Table 2.9 and Table 2.10 present some nutrients, vitamin and mineral content of selected fruit and vegetables.

Table 2.9: Selected nutrient and vitamin contents of some fruit and vegetables (Paul & Shaha, 2004)

Fruit	**Fibre ($g100^{-1}g$)**	**Carbohydrate ($g100^{-1}g$)**	**Thiamine ($mg100^{-1}g$)**	**Ascorbic acid ($mg100^{-1}g$)**
Pomegranate	0.50	9.90	0.06	15.00
Tomato	5.00	14.90	0.10	30.00
Orange	0.30	6.00	0.12	62.00
Pineapple	8.60	23.50	0.20	35.00
Lemon	1.60	10.80	0.02	37.00
Blackberry	0.60	16.00	0.12	30.00
Plum	-	8.90	0.04	10.00
Litchi	0.50	18.90	0.14	39.00

Deficiency in essential calorie, vitamins and micro and macro minerals elements fosters the development of diseases and may result in overall decline in physical health and the ability of the body to protect itself against diseases (WHO-FAO, 2005). For example, according to Bender (2003), 10 mg intake of vitamin C is required per day to prevent deficiency and 20 mg required to heal wounds. Fruit such as citrus and berries contain more than 20 mg of vitamin C in less than 100 g tissue (Matare, 2012). Also, the consumption of fruit and vegetables ensures the intake of vital nutrients such as antioxidant vitamins, polyphenols, and other nutrients, which are essential in lowering the risk and development of chronic diseases (Kerch, 2015). The phytochemicals in fruit and vegetables help to prevent oxidative stress, thereby, preventing diseases like cancer, diabetes and cardiovascular diseases (Li, Li, Zhang, Xu, Chen et al., 2014; Opara & Al-Ani, 2010). This makes fruit and vegetables important in solving the global micronutrient deficiency crisis. Consumption of fruit and vegetables serve as the most sustainable sources of micronutrients in foods.

Table 2.10: Selected mineral content of some fruit and vegetables (Paul & Shaha, 2004)

Fruit	**Calcium ($mg100^{-1}g$)**	**Magnesium ($mg100^{-1}g$)**	**Sodium ($mg100^{-1}g$)**	**Phosphorus ($mg100^{-1}g$)**	**Potassium ($mg100^{-1}g$)**
Pomegranate	30.00	12.00	4.00	30.00	171.00
Tomato	27.00	17.00	5.50	28.00	275.00
Orange	25.50	16.20	28.00	24.20	99.40
Pineapple	15.00	42.00	2.90	20.90	228.00
Lemon	70.00	12.00	1.50	10.00	148.00
Blackberry	21.50	49.80	3.50	18.50	130.00
Plum	20.00	9.80	4.10	20.00	12900
Litchi	9.80	22.50	0.80	17.20	89.90

Postharvest nutritional loss is mostly related to factors such as temperature, light, moisture, oxygen, and duration of exposure to heat (Matare, 2012). The loss of nutrients, especially vitamins C, through postharvest wastage of fruit and vegetables reduces health benefits obtained from the consumption of fruit and vegetables. This is because vitamin C, which is the most important vitamin in the human diet, is mainly supplied by fruit and vegetables (Lee &

Kader, 2000). Therefore, according to Opara and Al-Ani (2010), inadequate intake of fruit and vegetables contribute to micronutrient deficiencies that have devastating effects such as a weakened immune system and even birth defects. Postharvest wastage of fruit and vegetables means loss of nutrients that could have been consumed to ensure food security and maintain healthy life. So, reducing postharvest wastage of fruit and vegetables means having more micronutrients available to ensure food and nutritional security.

Impact on nutrition security

The impact of postharvest losses on food and nutritional security cannot be overemphasised. A report by the US Department of Agriculture's Economic Research Service estimates that about 141 trillion calories/year, which amounts to 1,249 calories/capita/day, in the food value chain in 2010 was wasted (Buzby, Farah-Wells & Hyman, 2014). In 2012, the amount of wasted food at the retail and consumer levels in the US contained 1216.5 calories/capita/day (Table 2.11). Given that the daily calorie intake for a healthy living is 2000cal/capita/day for adult women, these amounts of calorie wasted per year could meet the daily requirement of not less than 1.3 million women in a year. Regrettably, fruit and vegetables consist of 19% of the contributing food commodities (Buzby et al., 2014). Also, Gunders and Bloom (2017) reported that reducing food wastage by only 15% would save enough food requirement for over 25 million people in the US every year given that one in every six American does not have an adequate food supply. Additionally, Kummu et al. (2012) found that about 614 kcal/cap/day, which accounts for about a quarter of the produced food supply is lost along the value chain. Table 2.11 demonstrates the magnitude of nutrient loss in food commodities in the US in 2012 at retail and consumer levels only.

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Table 2.11: The magnitude of nutrient loss in wasted food at the retail and consumer levels in the US in 2012 compared to the daily nutritional requirement for adult women (Spiker et. al., 2017).

Nutrition	Recommended daily intake (adult women)	Nutrient loss (daily/capita)	Equivalent number of recommended intakes (millions of adults/capita/day)
Energy (kcal)	2000.00	1216.50	190.90
Dietary fibre (g)	25.00	5.90	73.60
Magnesium (mg)	310.00	85.00	86.00
Vitamin C (mg)	75.00	35.40	148.00
Calcium (mg)	1000.00	286.10	89.80
Potassium (mg)	4700.00	880.20	58.80
Vitamin E (mg)	15.00	3.60	75.90
Iron (mg)	18.00	5.30	92.60
Vitamin A (mcg)	700.00	308.30	138.30
Vitamin D (mcg)	15.00	1.70	36.60

In Africa, where poor households in remote villages depend on agriculture for survival (Opara, 2010), nutritional insecurity deepens due to higher postharvest loss of fresh fruit and vegetables (Kitinoja & Kader, 2015). For example, it has been estimated that the magnitude of nutritional loss in the common beans value chain in the district of Luwingu, Northern Province of Zambia, is enough to meet the recommended daily allowance for 49 people (Ellis, Kwofie & Ngadi, 2020). Matare (2012) and Munhuweyi (2012) discussed the proximate composition of some fruit and vegetables, and the magnitude of postharvest wastage of the commodities at the national level in South Africa in 2011. The studies reported the nutritional loss of fruit per 100 g loss (Table 2.12). Matare (2012) reported the annual wastage of peach, pear and tangelo at the retail level to an estimated 7,240 tonnes, 418 tonnes and 1,000 tonnes, respectively. Carrot, cabbage and tomato annual wastage during the same period were estimated at 15,250 tonnes, 24,470 tonnes, and 15,250 tonnes, respectively (Munhuweyi, 2012). The nutritional loss from the wasted fruit and vegetables could meet the daily nutritional requirement of at least 25,000 people per capita/year in South Africa.

Table 2.12: Nutrient loss per 100g in lost fruit and vegetables at the retail level in South Africa in 2011 (Matare, 2012; Munhuweyi, 2012).

Commodity	**Protein (g)**	**Crude fat (g)**	**Dietary fibre (g)**	**Carbohydrate (g)**	**Energy (kJ)**	**Annual Wastage (tonnes)**
Peach	2.50	0.05	1.13	10.95	202.33	7240.00
Pear	2.45	0.05	0.95	9.82	111.67	418.00
Tangelo	3.21	0.07	2.43	23.83	-	1000.00
Carrot	1.11 – 1.20	-	2.04 – 2.3	22.12 – 36.05	18.96 – 30.56	15250.00
Cabbage	1.06 – 1.20	0.03	-	4.39 – 5.32	92.18 – 110.38	24470.00
Tomato	0.78 – 0.80	0.01 – 0.02	0.96 – 1.13	3.43 –3.77	71.18 – 73.77	15250.00
Total						**63628.00**

Reducing postharvest wastage means reducing the waste of energy used for production and transportation of fruit and vegetables, and consequently reduced pollution because of transportation. Postharvest wastage represents a significant loss of production output and loss on investment, loss of scarce resources, nutritional loss, lost labour, and all farm inputs. This means a gross financial loss to farmers when equated in monetary terms and perpetuates poverty and micronutrition deficiency, especially in the developing countries. Therefore, reducing postharvest wastage calls for sustainable handling, distribution, and utilization of food supplies to enhance food and nutritional security (Opara, 2010). To emphasise the role of the value chain to reduce postharvest losses and enhance the availability of perishable foods such as fruit and vegetables, Adam and Gollin (2015) suggested that sophisticated and highly streamlined processing and real-time value chain to link farmers and consumers is necessary.

Impact on food availability

There is a persistent concern about satisfying the demand for food currently, and this could be worse if the world attains the over 9 billion population estimated to live in the world by 2050 (Swilling & Annecke, 2012; UN, 2011). There has been a suggestion about increasing food production by 70% to alleviate food insecurity and to feed the world teeming population (FAO, 2009). Nevertheless, more food is currently produced to feed the world, yet 925 million people are food insecure (FAO, 2010). This flaws the suggestion of increased food production because it does not make sense to produce more food when postharvest wastage persists. Therefore, conscious efforts should be made to improve technology and innovation, and skills at food production and distribution levels especially in the developing countries where facilities to maintain the quality of food along the value chain are inadequate (Atanda et al., 2011; Hodges et al., 2011). Also, behavioural changes towards food are necessary in the developed countries, where food wastage is high at the retail and consumptions levels (FAO, 2011; Kadar, 2005).

The nutritional content and overall quality of food, especially fruit and vegetables are retained when adequate and proper storage and handling system is in place along the value chain, given their susceptibility to spoilage due to high moisture content (Kader, 1983; Munhuweyi et al., 2016). But in the developing countries where value chain facilities are inadequate, postharvest losses persist, deepening the problem of fruit and vegetable availability for consumption. It is estimated that losses and waste amount up to 31% of total fruit and vegetable production in the developing countries (Oelofse & Nahman, 2013), thereby, contributing to food insecurity by reducing fruit and vegetable availability.

Furthermore, increase in population in the developing countries also means an increase in urbanisation (Swilling & Annecke, 2012), which means that more people are moving away from the areas of primary production of fruit and vegetables leading to longer time along the value chain before the fruit and vegetables reach the final consumer. This reduces the availability of the commodities because the more time it takes for the fruit and vegetables to reach the consumer, the more they are susceptible to postharvest loss (Kader, 1983). At the same time, the need to meet the demand of the rising population in the urban areas continues to increase. Postharvest wastage occasioned by physical, biological, and environmental factors impact on the nutritional value of fruit and vegetables. Literature suggest that postharvest losses in storage are more with higher temperature and prolonged storage period. For example, the management of temperature and storage condition of citrus fruit impact the retention of vitamin C in such fruit (Lee & Kader, 2000). Also, leafy vegetables tend to lose nutrients in conditions that favour loss of moisture content (Lee & Kader, 2000; Kerch, 2015).

2.6 Conclusion

Postharvest wastage of fruit and vegetables is a global challenge and must be mitigated if food and nutritional security of over 9 billion people to live in the world by 2050 will be met. Literature reveals that postharvest wastage occurs both in the developed and developing countries; however, the difference is that wastage occurs more during production and along the value chain in the developing countries and at retail and consumption in the developed countries. This is understood to be because of the poor and inadequate postharvest storage and handling facilities in the developing countries and consumer behaviour in the developed countries. Therefore, the nutritional impacts of postharvest wastage in the developed and developing countries are similar as demonstrated by the amount of food and nutrition loss in the US and UK as compared to countries like Zambia and Ethiopia.

The major inconsistency in literature is the definition of 'food losses' and 'food waste'. Some authors defined them according to food value chain stage, while others defined them according to what happened to the food material. But all agreed that despite where and how losses occur, they impact farmers, food value chain actors and affect the environment negatively. The types and causes of fruit and vegetable postharvest wastage are similar in literature. Quantitative losses are mostly internal and evident in weight loss and other internal damages, while qualitative losses are mostly physical losses that affect the appearance and perception of the food leading to downgrading. Postharvest wastage due to mechanical, environmental (especially in storage) and handling damage are more profound in how they affect the quality of fruit and vegetables along the value chain.

The impacts of postharvest wastage reflect on economic loss, environmental degradation and food and nutritional insecurity. These impacts of postharvest wastage manifest in unsustainable utilisation of natural resources, which results in loss of resources that could have been put to other beneficial use. The continuous unsustainable use of energy, water, cropland and other production inputs as occasioned by postharvest wastage of food means that it makes no sense to increased food production if postharvest wastage is not reduced. Also, nutritional insecurity and micronutrient deficiency could be mitigated by reducing postharvest wastage and increasing postharvest technology and innovation, especially in the developing countries.

Chapter 3 - Quantification of on-farm (orchard) pomegranate fruit postharvest losses

3.1 Introduction

3.1.1 Socio-economic importance and nutritional value of fruit and vegetables

The importance of consuming fruit and vegetables as part of the human daily diet has been stressed by the World Health Organization (WHO, 2003). WHO's recommendation is to consume at least 400g/capita/day of fruit and vegetables to provide adequate and essential nutrients to the human body (WHO, 2003). Consumption of fruit and vegetables is known to provide multiple nutrients compared to biofortified foods and supplements (Keatinge, Waliyar, Jamnadas, Moustafa, Andrade et al., 2010). The importance of fruit and vegetable consumption is numerous and are evident in their ability to reduce susceptibility to diseases such as cancer, cardiovascular diseases, high blood pressure, diabetes, and other chronic diseases (Paul & Shaha, 2004). These diseases contribute to the high rate of mortality, especially in the developing countries and impose a huge cost to the health care system in these countries (Keatinge, Yang, Hughes, Easdown & Holmer, 2011). Also, the prevalence of diseases due to malnutrition directly impacts on attaining some of the SDGs (Keatinge et al., 2011). Hence, reducing postharvest wastage of fruit and vegetables could be one of the ways of reaching many of the SDGs such as Goal 2 (Zero Hunger), Goal 3 (Good Health and Well-being), Goal 12 (Responsible Consumption and Production), and Goal 13 (Climate Action).

Malnutrition is a major health related problem facing the world, among other challenges. Malnutrition related problems such as micronutrient deficiency, undernutrition and excessive consumption of fat and foods high in carbohydrate affect not less than a third of the world population and impact negatively on the quality of life (Keatinge et al., 2010). For healthy living, a balanced diet is necessary and can be achieved by the consumption of an appropriate amount of nutrients such as vitamins, amino acids, minerals, calories and fibre (Keatinge et al., 2010; Paul & Shaha, 2004). Fruit and vegetables contain these nutrients that are necessary for healthy living in diverse quantities (Sagar et al., 2018; Keatinge et al., 2011).

3.1.2 Postharvest losses and waste of fruit and vegetables – an overview

Fruit and vegetables are prone to a high incidence of postharvest losses and waste, largely in part due their high moisture content (often exceeding 80%), high respiration rate and susceptibility to handling damage. The high incidence of fruit and vegetable postharvest losses has remained a major challenge to food and nutritional security (Opara, 2006, 2010). Global estimates on the amount of postharvest losses of fruit and vegetables range from 37 to 55% (Gustavsson et al., 2011), and this is the highest among all food commodities, with an estimated economic loss of $750 billion per annum (FAO, 2013). In South Africa, fruit and vegetable losses are estimated at 4.2 million tonnes, accounting for 47% of the total food losses and waste in the country (Oelofse & Nahman, 2013). High level of postharvest losses, especially in the developing countries, have prompted consensus among food system experts that reducing postharvest wastage is one of the strategies to increase food and nutrition security amid the increasing world population (Opara, 2010).

3.1.3 Status of pomegranate fruit production and losses in South Africa

During the past decade, there has been a marked increase in the total area of land used for the cultivation of the various cultivars of pomegranate fruit in South Africa. This is evidenced by the significant increase from below 800 ha in 2011 to about 1024 ha in 2019 (POMASA, 2019). The total export has also increased rapidly. In 2019, about 76% of the total production was exported (POMASA, 2019). This resulted to an increase from 483,609 cartons (3.8 kg equivalent) in 2012 to 1,676,160 cartons (3.8 kg equivalent) in 2019 and projected to increase to 2,055,271 cartons (3.8 kg equivalent) by 2024 (POMASA, 2019). Increased production and export has established South Africa as an important producer in the Southern hemisphere, which enables it to fill the niche market gap in the Northern hemisphere due to different seasons of production in the two regions (POMASA, 2019; Rymon, 2011).

Production and consumption of pomegranate have grown globally, with more than 500 different cultivars grown in different parts of the world (Kahramanoglu & Usanmaz, 2016). Global production was estimated to have increased from about 3 million tonnes in 2014 to 3.8 million tonnes in 2017 (Kahramanoglu, 2019). Despite the increase in production and technological innovations in packaging and postharvest handling (Mukama, Ambaw & Opara, 2020; Hussein, Fawole & Opara, 2019; Arendse, Fawole, Magwaza, Nieuwoudt & Opara, 2018; Belay, Caleb & Opara, 2017; Fawole & Opara, 2013), the incidence of postharvest losses and waste persist (Kahramanoglu, 2019; POMASA, 2019). This is because pomegranate fruit is highly susceptible to losses and waste due to several preharvest and postharvest factors such as diseases attack (Munhuweyi, Lennox, Meitz-Hopkins, Caleb & Opara, 2016), bruise damage (Hussein et al., 2019), high rates of transpiration and respiration of fruit resulting to weight loss and quality loss during storage (Lufu, Ambaw & Opara, 2019 and 2020; Fawole & Opara, 2013).

In South Africa, the incidence of pomegranate fruit losses and waste in the industry are historically measured only at the packhouse level, and this presents a problem in proffering solution to be tailored to the farm level. Losses and waste have been reported with variation in the three most grown cultivars in the country from 2016 to 2019 (Table 3.1). 'Hershkawitz' accounted for the highest incidence of postharvest losses and waste with a mean value of 15%, followed by 'Acco' with a mean value of 8.8% and lastly 'Wonderful' with a mean value of 7% (Table 3.1).

Table 3.1 Pomegranate fruit losses and waste (%) of three major cultivars in South Africa at the packhouse level (2016 to 2019).

Year	Wonderful	Hershkawitz	Acco	Reference*
2016	1.0	14.0	2.0	POMASA, 2016
2017	11.0	13.0	11.0	POMASA, 2017
201	7.0	8.0	9.0	POMASA, 2018
2019	9.0	25.0	13.0	POMASA, 2019
Mean	7.0	15.0	8.8	

*Pomegranate Producers Association of South Africa.

While there is a growing body of scientific knowledge on improved techniques and procedures for the production and handling of quality pomegranate fruit to meet market demand, little is known about the magnitude of losses and waste which occurs at the orchard and post farmgate. This information is needed to guide the development and application of an evidence-based scientific solution to reduce fruit wastage in specific loss hotspots. Therefore, this study aimed to quantify the magnitude, identify causes and estimate the environmental impacts of pomegranate losses at the farm in South Africa.

Generally, only a few studies on on-farm quantification of food losses and waste have been done (Baker, Gray, Harwood, Osland & Tooley, 2019; Moller, Hansen., Svanes, Hartikainen, Silvennoinen et al., 2014). This means that on-farm losses and waste measurement is not often done or have not been recorded (Moller et al., 2014). The lack of quantitative data at farm level may be as a result of the cost and time, given that direct on-site measurements are usually expensive and time consuming (Moller et al., 2014; Lipinski, Hanson, Lomax, Kitinoja, Waite et al., 2013). Other factors are lack of cooperation from farmers, production variability and concerns about food safety, which limit access to farms (Baker et al., 2019).

3.2 Study location

The study was carried out at Blydeverwacht farm, Wellington, in the Western Cape Province of South Africa. Wellington is the second highest pomegranate production area in the country, accounting for 14% of the total cultivated area (POMASA, 2019). Blydeverwacht farm started commercial growing of pomegranate fruit in 2008 and since then have become one of the biggest pomegranates growing farms in Wellington. Production reaches an average of 80 bins of fruit per day in peak fruit season. The total production area is 17.6 ha with about 1000 trees per hectare, producing the major pomegranate cultivars (Wonderful, Acco and Herskovitz) grown in South Africa. In one fruit season, the trees are harvested about 2-3 times using different ring sizes until they are completely stripped. The farm has its tractors and other equipment used by permanent staff for fruit production. The produce is mainly for export, although fruit that does not meet the export minimum standard are sold locally.

3.3 Research methodology

3.3.1 Research design

The study was done by assessing fruit bins harvested on the farm each day. The assessment started at about 8:00 am and ended by 4:00 pm daily. The study was carried out in February and March. ‘Herskawitz’, which is the early cultivar was assessed by mid-February while “Acco” was assessed by late February and early March, while ‘Wonderful’, the late cultivar was assessed by late March before the Covid-19 pandemic national lockdown in South Africa. Harvesting and handling practices at the farm were observed. The unit of measurement used is the fruit bin with the following dimension: length = 125 m x height = 61 m x width = 109 m. A total of 18 bins for all the three cultivars were studied, six bins for each cultivar. Loss calculations included fruit discarded in the ‘waste bin’ for defect reasons but did not include fruit left in the field, which are insignificant in number. The assessment was made based on the external quality of fruit, that is, presence of defects. Quantification was done by sorting and counting of fruit to identify reasons for the loss and how they contribute to total fruit loss.

3.3.2 Research method

Researchers have used different approaches to conduct postharvest wastage studies, which include sampling (Dome & Prusty, 2017; Opara & Al-Ani, 2010), surveys (Kumar & Underhill, 2019; Dome & Prusty, 2017; Musasa, Mvumi, Manditsera, Chinhanga, Musiyandaka et al., 2013; Opara, 2003), and estimates (FAO, 2011). Because this present study involved the physical identification of the causes of fruit losses on individual fruit, sorting and counting was the preferred method for data collection. Also, qualitative data such as observing the method of harvesting and handling was collected by physical observation during harvesting and discussion with permanent farm workers.

The data collection protocol is consistent with the Food Loss and Waste Protocol (FLWP) (Hanson, Lipinski, Robertson, Dias, Gavilan, et al., 2016). On-farm loss assessment involved direct measurement by monitoring tractors carrying bins of harvested fruit along the farm rows and to the farm shed, where the 'waste bins' were sorted and the individual piece of fruit counted in portions according to the defects observed on the fruit (McKenzie, Singh-Peterson & Underhill, 2017; Hanson et al., 2016).

The economic impact of pomegranate losses and waste was estimated using the supermarket retail price (R89.99/kg) in Stellenbosch, Western Cape, South Africa. The environmental impacts were estimated using the values from previous studies. The energy used and GHG emission values were estimated using 6.1 MJ/kg and 0.48 CO_2eq/kg, respectively (González et al., 2011). The water footprint was calculated with 910 m^3 ton^{-1} (Mekonnen & Hoekstra, 2011). The nutritional impact was calculated using values from Spiker et al. (2017) and Paul and Shaha (2004). Lastly, cropland use was estimated by the size of the farm and the average yield produced.

The magnitude of fruit losses and waste for 'Acco'and 'Hershkawitz' was similar, given that for every 5 bins of 'good fruit', 1 bin of 'waste fruit' was produced. For 'Wonderful', it was observed that for every 4 bins of 'good fruit', 1 bin of 'waste fruit' was produced. The following formulas were used to calculate the percentage of the 'waste fruit':

$$Waste\ fruit = sum\ of\ the\ fruit\ in\ the\ waste\ bin\ per\ tractor \qquad 1$$

$$\% \ of \ waste \ fruit \ per \ tractor = \frac{waste \ fruit}{Total \ expected \ fruit \ per \ tractor} X \ 100 \qquad 2$$

$$where: expected \ number \ of \ fruit \ in \ a \ bin = 1400 \ to \ 1500 \qquad 3$$

$$Average \ number \ of \ fruit \ in \ a \ bin = \frac{(1400 + 1500)}{2} = 1450 \qquad 4$$

$$Total \ expected \ fruit \ per \ tractor = 1450 \ X \ 6 = 8700 \qquad 5$$

3.3.3 Data collection

Data collection involved monitoring bins of fruit conveyed by tractors, in order to record the number of bins of lost fruit per trip. For each cultivar, six tractors each conveying six fruit bins were monitored during harvesting as they move along the farm rows until the bins were full and unloaded at the farm shed, where sorting, counting and recording was done. Fruit were assessed by physical inspection and categorised by the following factors: *Alternaria*, oversize (good fruit that were believed to be too big to fit into the 3.8kg equivalent carton used for pomegranate fruit packaging), bruise, sunburn, crack, insect damage, crown rot, decay, blemishes, and undersize/misshapen.

Data collection for each cultivar was done in three days, and 6 bins (n = 6) were assessed per cultivar (Acco, Hershkawitz and Wonderful). Bins 1 and 2 were assessed on day one of assessment, bins 3 and 4 assessed on day two, and bins 5 and 6 assessed on day three. The tractors conveying the fruit bins were also marked, and 6 tractors (n = 6) for each cultivar was used. The fruit were harvested with rings of size 85, 80, 75 and 70 to ensure that the right sizes of fruit were harvested on each day, except for Wonderful, where the trees were completely stripped at once.

3.3.4 Data analysis

Statistical analysis

Microsoft Excel 2013 was used to collate the data recorded on the farm. Mean value ± standard error of fruit defects were presented. Analysis of Variance (ANOVA) was performed using Statistica Version 13.5.0 to evaluate differences between cultivars and fruit defects. Where there was statistical significance difference (p<0.05). Significant differences between means were separated using Duncan's multiple range test (Fawole & Opara, 2013a). 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, France).

3.4 Results and discussion

During field work to collect primary postharvest fruit loss data, it was noted that farm workers referred to fruit loss as 'waste fruit', both in verbal terminology and when referring to historical fruit wastage data record. To ensure global consistency in reporting wastage, data collected and analysed in this study are referred to as 'fruit loss'.

3.4.1 Causes of on-farm pomegranate fruit losses

The causes of pomegranate fruit losses and waste were classified based on the reasons why fruit were sorted from the supply chain. Such reasons include quality issues caused by environmental factors, mechanical damage and pests and diseases (Baker et al., 2019). The two major reasons for the physical loss in pomegranate fruit, as identified in this study are environmental factors such as sunburn and crack (Figure 3.1). Other reasons for loss include crown rot, *Alternaria*, insect damage, blemishes, decay, injury, undersize and misshapen, oversize, and bruise. To establish the relationship between pomegranate fruit defects and how they affect each other, Pearson correlation analysis was used to investigate the interrelationship.

Environmental stress

i Sunburn

Sunburn recorded the highest reason for fruit loss in the three pomegranate cultivars assessed. For 'Acco', it accounted for 24.04% of losses and 21.25% of losses in 'Hershkawitz'. It was highest in 'Wonderful' with 28.80% of losses (Table 3.2). Sunburn showed a very strong positive correlation with oversize fruit (Table 3.3), which were mostly observed in 'Wonderful'. Usually, 'Wonderful' produces big size fruit with a larger surface area that are often exposed to direct sunlight outside the tree canopy. Additionally, 'Wonderful' is a late cultivar, and that means that it is exposed to the sun for a more extended period than 'Acco' and 'Hershkawitz'.

Sunburn is as a result of the sun rays hitting the fruit directly, thereby causing discolouration of the fruit rind. The discolouration of the affected fruit reduces the fruit appeal, causing qualitative loss (Aulakh & Regmi, 2013; Weerakkody, Jobling, Infante & Rogers, 2010). Yazici and Kaynak (2006) established that sunburn occurs when the fruit surface temperature reaches 35±1°C. Hence, high temperature mostly exceeding 35°C as experienced in the Western Cape last summer could be a factor for the high incidence of sunburn. Also, low relative humidity and high air temperature have been identified as contributing to sunburn (Yazici & Kaynak, 2006).

Table 3.2: On-farm percentage loss of pomegranate fruit due to defects.

		Cultivar	
Defects	**Acco (%)**	**Hershkawitz (%)**	**Wonderful (%)**
Alternaria	6.84	4.33	2.58
Bruise	9.43	9.07	5.43
Injury	11.79	13.50	5.06
Sunburn	24.04	21.25	28.80
Crack	18.54	19.53	19.43
Insect damage	6.76	3.61	1.43
Cron rot	6.92	11.70	1.38
Decay	4.09	5.74	1.18
Blemish	5.70	5.53	5.69
Misshapen	5.89	5.74	25.35
Oversize	0.00	0.00	3.67

Table 3.3: Pearson correlation coefficient matrix between defects in 'Acco', 'Hershkawitz' and 'Wonderful'

Defects	Alternaria	Bruise	Injury	Sunburn	Crack	Insect damage	Crown rot	Decay	Blemish	Misshapen	Oversize
Alternaria	**1**										
Bruise	**0.774**	**1**									
Injury	**0.605**	**0.886**	**1**								
Sunburn	-0.456	**-0.760**	**-0.904**	**1**							
Crack	**-0.510**	**-0.553**	**-0.546**	0.453	**1**						
Insect damage	**0.943**	**0.806**	**0.657**	-0.440	**-0.641**	**1**					
Crown rot	0.397	**0.734**	**0.903**	**-0.968**	**-0.478**	0.409	**1**				
Decay	**0.488**	**0.769**	**0.873**	**-0.953**	**-0.543**	**0.471**	**0.957**	**1**			
Blemish	-0.147	-0.287	-0.263	0.261	-0.064	-0.011	-0.231	-0.207	**1**		
Misshapen	**-0.729**	**-0.913**	**-0.947**	**0.889**	**0.588**	**-0.758**	**-0.888**	**-0.899**	0.138	**1**	
Oversize	**-0.761**	**-0.907**	**-0.909**	**0.889**	**0.556**	**-0.748**	**-0.869**	**-0.907**	0.190	**0.978**	**1**

Values in bold are significant at $p<0.05$

ii Cracks and splits

The results also show that crack and splits are major sources of pomegranate fruit loss. They were the second highest cause of loss in ‘Acco’ and ‘Hershkawitz’, and the third cause of loss in ‘Wonderful’. In ‘Hershkawitz’ and ‘Acoo’, they accounted for 19.53% and 18.54% of losses respectively (Table 3.2). For ‘Wonderful’, 19.43% of loss is attributed to crack and splits. Although crack and splits in pomegranate is mostly attributed to soil moisture content (Galindo, Rodríguez, Collado-González, Cruz, Torrecillas, et al., 2014; Abd El-Rhman, 2010; Ahmed, 2009), the correlation matrix show that crack and split have a very significant positive relationship with oversize fruit (Table 3.3), which were observed in ‘Wonderful’. This is because oversize fruit loose moisture as they are mostly exposed to the sun and the loss of moisture content stretches the rind of the pomegranate fruit and cause them to crack.

Different cultivars respond differently to cracking due to their morphological make-up (Ahmed, 2009; Hepaksoy, Aksoy, Can & Ui, 2000). Hence, irrigation and soil moisture monitoring are essential in pomegranate farming (Galindo et al., 2014). Also, the positioning and pruning of pomegranate trees should not expose pomegranate fruit to direct sunlight in order to reduce sunburn, crack and splits. Furthermore, application of borax at the beginning of fruit set, and irrigation at an appropriate interval according to the cultivar need has shown to reduce fruit cracking and improve fruit yield (Ahmed, 2009).

Mechanical and physical damage

i Superficial injuries

The result revealed that superficial injuries contributed to fruit loss in the farm in varying magnitude in the three cultivars studied. The highest incidence of superficial injuries was in ‘Hershkawitz’, with 13.50% (Table 3.2). Nevertheless, it only ranked third in the total causes of loss for ‘Hershkawitz’. In ‘Acco’, it accounted for 11.79% of losses and ranked third in the causes of loss. Superficial injuries contributed to 5.06% of losses and ranked six in the causes of loss for ‘Wonderful’. Also, superficial injuries show a very strong positive correlation with decay and crown rot (Table 3.3). This could be attributed to the fact that superficial injuries to fruit manifested in the form of scratches and cuts of varying shapes, sizes and depth on the rind of the fruit (Martinez-Romero, Serrano, Carbonell, Castillo, Riquelme et al., 2004). Hence, creates wounds that allow decay and crown rot pathogens to get into the fruit and cause a defect.

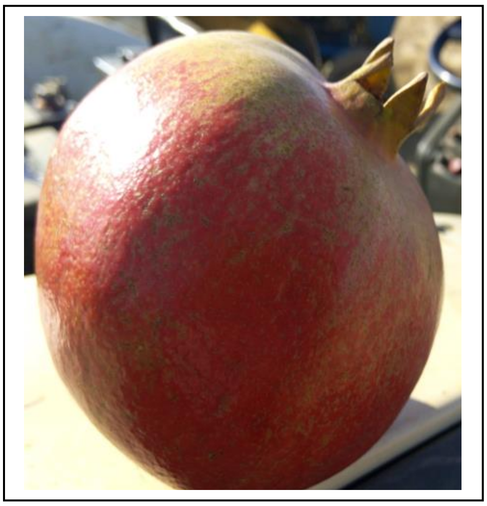
The incidence of injury was because of preharvest practices such as pruning, which was done a few days before the fruit were harvested. Also, poor harvesting technique such as injuring the fruit during picking and handling accounted for a considerable amount of injury to fruit. Pomegranate is susceptible to injury due to its high moisture content and succulent nature of its rind.

The result shows that there was a significant reduction in cut injuries as the fruit pickers harvested more fruit and became aware of the impact of the harvesting technique and handling on the fruit, that is, superficial injuries in ‘Hershkawitz’>’Acco’>’Wonderful’. This followed the sequence of fruit picking at the farm and agrees with the fact that injury is a function of fruit harvesting technique and handling, leading to mechanical damage (Hussein et al., 2019).

Defects	Photographs	Description
Crown rot		Fruit show rotten crown with cream-colour or dark brown to black rind with the presence of pycnidia (Munhuweyi et al., 2016; Thomidis, 2015).
Alternaria		The fruit shows an intense reddish colour on the rind and light weight, while the arils are totally or partially decayed (Munhuweyi et al., 2016; Kahramanoglu, Usanmaz & Nizam, 2014).
Crack		Crack fruit shows split rind exposing the arils and internal tissue of the fruit. The split on the fruit were mostly dry.

Decay		Decayed fruit were characterised by dark brown or black soft rind with the presence of the causative pathogens in form of white-milky patches and spots (mould) (Munhuweyi et al., 2016; Labuda, Hudec, Piecková, Mezey, Bohovič et al., 2004).

Figure 3.1: Photographs of representatives of the defects used to categorise fruit into losses.

Defects	Photographs	Description
Oversize		Oversize fruit are good fruit that were believed to be too big not to fit into the 3.8kg equivalent carton used for pomegranate fruit packaging. They mostly weighed above 300g.

Blemish		A blemish on fruit was evident by the presence of superficial scalds, scratches, patches and spots of different sizes and shapes on the rind of the fruit, making the fruit unappealing and downgraded.
Insect damage		Insect damage on the affected fruit were in the form of wounds and holes bored on the rind of the fruit by suckling and piercing pests such as Cocktail ant, Common earwig and False codling moth (Wohlfarter, Giliomee & Venter, 2010).

Sunburn		Pomegranate fruit sunburn was evident by the hardened rind and discolouration (dark spots) of the affected fruit (Melgarejo, Martınez, Hernández, Martınez-Font, Barrows et al., 2004). Some of the affected fruit showed slight lateral crack.

Figure 3.1: Photographs of representatives of the defects used to categorise fruit into losses (contd)

Defects	Photographs	Description
Bruise damage		Bruise damage manifested in the form of discolouration and softness of the affected area on the fruit rind (Hussein et al., 2019), as a result of damaged internal tissue of the fruit without superficial injury on the rind (Hussein, Fawole & Opara, 2017).

Undersize		The undersize fruit were mostly immature fruit that are slightly greenish in colour and small in size. They were discarded for not meeting the minimum market standard.
Misshapen		Misshapen fruit were fruit with irregular shapes and were mostly found among the undersize and immature fruit.
Superficial injury		Fruit in this category had the presence of cuts of varying shapes, sizes and depth, which were visible and easily detectable on the rind of the fruit (Martinez-Romero, Serrano, Carbonell, Castillo, Riquelme et al., 2004).

Figure 3.1: Photographs of representatives of the defects used to categorise fruit into losses (contd)

ii Bruise damage

Bruise in 'Acco' accounted for 9.43% (Table 3.2) of losses and ranked fourth in the causes of loss for the cultivar. In 'Hershkawitz', bruising accounted for 9.07% of losses and ranked fifth in loss cases. For 'Wonderful', the result showed that 5.43% of the losses is attributed to bruise and it also ranked fifth in the causes of loss for the cultivar. The correlation matrix shows that bruise has a very significant positive relationship between decay and insect damage (Table 3.3). This means that bruised fruit are prone to insects' attack because bruising makes the affected spot on the fruit rind soft and susceptible to insect attack. Also, bruise discoloured the affected spot on the fruit as the fruit's inner tissue is damaged. The damaged tissue deteriorates due to the action of hydrolytic enzymes such as cellulases (Martinez-Romero et al., 2004) and causes the fruit to decay. This result in a quality loss as it makes the affected area vulnerable to both microbial and insect attack (Yahaya & Mardiyya, 2019).

Mechanical damage is a major cause of bruising, just like an injury. Bruise damage is caused by compression, vibration, and impact during harvesting and handling (Hussein, Fawole & Opara, 2019; Martinez-Romero et al., 2004). In this present study, bruises were observed to be caused by contact between fruit when the fruit are put into the harvesting buckets, and contact with the fruit bin as the tractor convey the bins along the farm rows with consequent vibration, pressure and thrust on the fruit. Bruise downgrades the quality of pomegranate fruit by damaging the internal tissue of the fruit without physical injury on the rind but manifests in discolouration of the affected area (Hussein et al., 2019).

Hussein et al., (2019) found that pomegranate fruit susceptibility to bruising is in the order of 'Wonderful'> 'Hershkawitz' >'Acco'. However, the variation observed in the outcome of this present study could be attributed to the size of the fruit harvested. 'Wonderful' trees, unlike 'Acco' and 'Hershkawitz', were stripped completely at once giving rise to a high number of undersize fruit, which are not weighty enough to exert high impact energy to cause a bruise.

iii Blemishes

The amount of fruit loss due to blemishes are similar in the three cultivars studied. For 'Acco', it constituted 5.70% of fruit losses, 5.53% in 'Hershkawitz'and 5.69% in 'Wonderful'. The ranking of blemishes in the causes of loss is nineth, seventh, and fourth in 'Acco', 'Hershkawitz' and 'Wonderful' respectively. Although it ranked fourth in the causes of loss in 'Wonderful', the result shows that its contribution to loss is low compared to sunburn and crack. Blemish had a strong negative correlation to other loss defects studied, which explained that it occurs independently of other defects in the three cultivars.

Blemishes are as a result of many factors such as mechanical damage during pruning of trees. Also, pomegranate fruit are thrown against branches and each other in windy weather condition as experienced in the Western Cape, causing the affected fruit to scratch and develop blemishes on the rind. Additionally, preharvest practices, like the application of pesticides and sunscreen, often react to leave patches and spots that result to blemish on the affected fruit.

Biological damage

i Insect damage

Insect damage contributed to 6.76% of losses in 'Acco' ranking seventh in the causes of loss in the cultivar. For 'Hershkawitz', it accounted for 3.61% of losses ranking nineth in the causes of loss (Table 3.2). Lastly, 1.43% of losses in Wonderful was due to insect damage and also ranked ninth in the causes of loss for the cultivar. Insect damage has a very strong positive correlation with bruise and also a strong positive correlation with superficial injuries (Table 3.3), which means that insect damage was high where fruit are susceptible to bruise and superficial injuries. This agrees with the fact that 'Acco', which accounted for the highest incidence of insect damage is also ranked first in bruise damage and second in injury because its rind is softer than 'Hershkawitz' and 'Wonderful', making it more susceptible to insect attack, bruise and injury.

Furthermore, the varying magnitude of damage by insects in the three studied cultivars could also be attributed to the taste of the cultivars as some insects are known to attack sweet cultivars more than the sour ones. 'Acco' is the sweetest of the three cultivars studied, so it is reasonable for it to account for the highest incidence of insect damage because of its taste. Also, preharvest practices such as the application of pesticides could be another factor to determine the extent of insect attack but was not considered significant in this study, because it is assumed that the farming practices is the same since the study was conducted in one farm.

Insects consume a small portion of fruit, which causes partial loss of fruit in most cases (Prusky, 2011). As a result, the fruit loses its appeal and fail to meet the market standard. Although this present study did not identify the particular types of insects that caused damage to pomegranate fruit, various insects such as Pugnacious ant (*Anoplolepis custodiens*), Mediterranean fruit fly (*Ceratitis capitate*), Soft brown scale (*Coccus hesperidum*), Cocktail ant *(Crematogaster* *peringueyi*), Common earwig (*Forficula senegalensis*), Kromnek thrips (*Frankliniella schultzei*), False codling moth (*Thaumatotibia leucotreta*) among others have been identified as the major causes of insect damage to pomegranate fruit in South Africa (Wohlfarter, Giliomee & Venter, 2010).

Microbial and pathological spoilage

i Decay and rots

Decay and rots are one of the lowest causes of pomegranate fruit losses and waste among the three cultivars studied. In 'Acco', it contributed to 4.09% of loss (Table 3.2) and is the least source of fruit loss in the cultivar. Although decay and rots ranked sixth in the causes of loss in 'Hershkawitz', it was the highest in the three cultivars studied. It caused 5.74% of the losses in 'Hershkawitz'. Like in 'Acco', decay and rots were the least cause of loss in 'Wonderful', with 1.18%. The correlation matrix result revealed that decay and rots have a significant positive relationship with bruise and injury (Table 3.3). This entails that pomegranate fruit are more susceptible to decay and rots when bruised or injured. This is because decay and rot causative pathogens mostly infect fruit through superficial wounds on the rind of the fruit. This reason also applies to the positive relationship between decay and crown rot, which were mostly observed in 'Hershkawitz'.

Decay in pomegranate fruit is caused by a number of microbial pathogens such as Aspergillus fruit rot (*Aspergillus niger*), Grey mould rot (*Botrytis cinereal)*, Blue/Green mould (*Penicillium implicatum*) among others (Munhuweyi et al., 2016). These pathogens breakdown the rind of the fruit and ultimately result in decay.

The result revealed that 'Acco' and 'Hershkawitz' had more decayed fruit while 'Wonderful' had a significantly low decay. Apart from the susceptibility of 'Acco' and 'Hershkawitz' to decay and rots due to bruise and injury, selective cultivar breeding by decay causative pathogens could be another reason for the vulnerability of the cultivars to decay and rot. This assumption is made because there has been a lack of studies to assess the susceptibility of the different pomegranate cultivars to diseases (Munhuweyi et al., 2016).

ii *Alternaria*

The total contribution of *Alternaria* to fruit loss in the three cultivars studied, as shown in the results is low. Its highest occurrence was in Acco with 6.84% of loss (Table 3.2). In 'Hershkawitz', it accounted for 4.33% of the loss. For 'Wonderful', *Alternaria* accounted for

2.58% of loss ranking eighth in the total causes of fruit loss in the cultivar. *Alternaria* has a strong relationship with decay according to the correlation analysis (Table 3.3). In fact, *Alternaria* is a form of decay with a causative pathogen that does not necessarily need bruise or injury to occur. "Heart rot" disease, also known as *Alternaria*, is caused by the pathogen *Al. alternata*. The disease mostly attacks the inner parts of the fruit, causing it to either completely or partially decay, while the rind of the fruit looks healthy. The affected fruit shows an intense reddish colour on the rind and is light in weight compared to the healthy fruit (Munhuweyi et al., 2016).

Although *Alternaria* infection was generally low among the cultivars, the result revealed that 'Wonderful' and 'Hershkawitz' had less fruit affected, while 'Acco' had more. This could be attributed to disease pathogen breeding for the cultivar. It could also be as a result of the morphological development (during flowering) since that is when the disease infection mostly occurs (Michailides, Morgan, Quist & Reyes, 2008).

iii Crown rot

The contribution of crown rot to the total fruit loss is relatively low. The highest occurrence was in 'Hershkawtz' with 11.7% of loss and fourth in the cultivar reasons for losses ranking (Table 3.2). For 'Acco', it accounted for 6.92% of losses and is fifth in the ranking of causes of loss. Lastly, in 'Wonderful', crown rot contributed 1.38% of losses and is only higher in occurrence than decay among the other causes of loss in the cultivar. It was interesting to notice that the negative relationship between crown rot and sunburn was the highest of all the negative correlations. This suggests that crown rot causative pathogens may not thrive in high temperature that results in sunburn. The pathogen responsible for crown rot is *Coniella granati*. The affected fruit shows rotten crown with cream-colour in some cases. The rind of the affected fruit also shows the presence of pycnidia (Munhuweyi et al., 2016).

'Hershkawitz' showed the highest incidence of Crown rot, which could be attributed to the tree morphology, since the leaves harbour moisture as they are not spread out like in 'Acco' and 'Wonderful'. *Coniella granati* thrives between the temperature range of 25 to 30°C (Munhuweyi et al., 2016). Hence, the leaves of 'Hershkawitz' provide a breeding spot enhancing the growth of the fungi.

Irregular fruit size and shape

i Oversize

Oversize fruit were noticed only in 'Wonderful', which naturally produces bigger fruit sizes with larger surface area more than 'Acco' and 'Hershkawitz'. Some of the fruit are big enough not to fit into the 3.8kg equivalent carton used for fruit packaging. Such fruit contributed to only 3.67% of the losses in 'Wonderful' (Table 3.2). The fruit were removed from the value chain because of their size and could be used for other purposes. Oversize fruit has a strong positive correlation relationship with sunburn and a strong correlation with crack (Table 3.2). This agrees with the fact that big fruit with larger surface area are mostly exposed to direct sunlight outside the tree canopy, which result to sunburn. Additionally, fruit with larger surface area like 'Wonderful' are most susceptible to crack due to internal moisture content regulation by the tree and fruit.

ii Undersize and misshapen

The result of the study shows that undersize and misshapen fruit accounted for a similar amount of loss in 'Acco' and 'Hershkawitz' with 5.89% and 5.74% respectively (Table 3.2). Undersize and misshapen fruit together contributed to 25.35% of loss in 'Wonderful'. It is important, however, to note that the major contributor to this is undersize fruit. Undersize and mishappen fruit accounted for the second highest cause of losses in 'Wonderful' after sunburn. It was found that many of the fruit were small and irregular in shape, making them unappealing and not meeting marketing standards. Undersize and misshapen fruit have a very strong negative relationship with bruise, injury and decay in the correlation result, suggesting that fruit are only vulnerable to defects such as bruise, injury and decay when they are fully mature and increase in size.

'Wonderful' had the highest number of small fruit because the trees were strip-harvested at once. Harvesting of 'Wonderful' fruit coincided with the national lockdown in South Africa in response to the Covid-19 pandemic. Therefore, the farmer decided to strip the 'Wonderful' trees in one harvest, which resulted in harvesting undersize fruit, and hence causing huge losses. It should be noted that for optimum fruit quality, trees are usually harvest at least three times during the harvest period (early, mid and late). For 'Acco' and 'Hershkawitz' cultivars, fruit were harvested with the aid of harvesting rings to ensure that only fruit of particular size were harvested at each harvesting time.

Comparative analysis of pomegranate fruit cultivars based on defects

To compare the relationship between pomegranate fruit defects and the cultivars, the defects were subjected to principal component analysis (PCA) and the result observed in a biplot axes. The relationships between the fruit defects and the cultivars manifested by the short distances and clustering of defects around cultivars (Figure 3.2). The active and observation variables show that 'Hershkawitz' is more susceptible to injury, crown rot and decay than 'Acco' and 'Wonderful' while 'Acco' is more vulnerable to insect damage, Alternaria and bruise. The result revealed that 'Wonderful' was susceptible to defects originating from environmental stress than 'Acco' and 'Hershkawitz'. To make this clearer for farm management practices, a dendrogram cluster analysis was used to separate pomegranate cultivars (Figure 3.3). The two main clusters were differentiated based on their susceptibility to defects. Cluster 1 consisted of 'Wonderful' while 'Hershkawitz' and 'Acco' are in cluster 2. The analysis means that the same loss reduction strategies could be used by the farmer to reduce pomegranate fruit losses for 'Herskawitz' and 'Acco' while 'Wonderful' would require a different loss reduction approach.

Pomegranate fruit defects in the three cultivars studied varied significantly, as shown by their mean and standard error (Table 3.4). The defects originated from different sources such as mechanical, environmental, biological, among others. The result shows that environmental factors are the major causes of pomegranate fruit losses at the farm level in this present study. Environmental factors accounted for the highest incidence of loss with 43.93%, followed by losses due to mechanical damage, with 17.99%. Losses due to physiological and microbial and pathological factors are close in range and accounted for 13.76% and 14.75% respectively. The biological factor considered is insect damage, which contributed to 3.92% of the total loss. Lastly, physical loss due to blemishes contributed to 5.65% of losses.

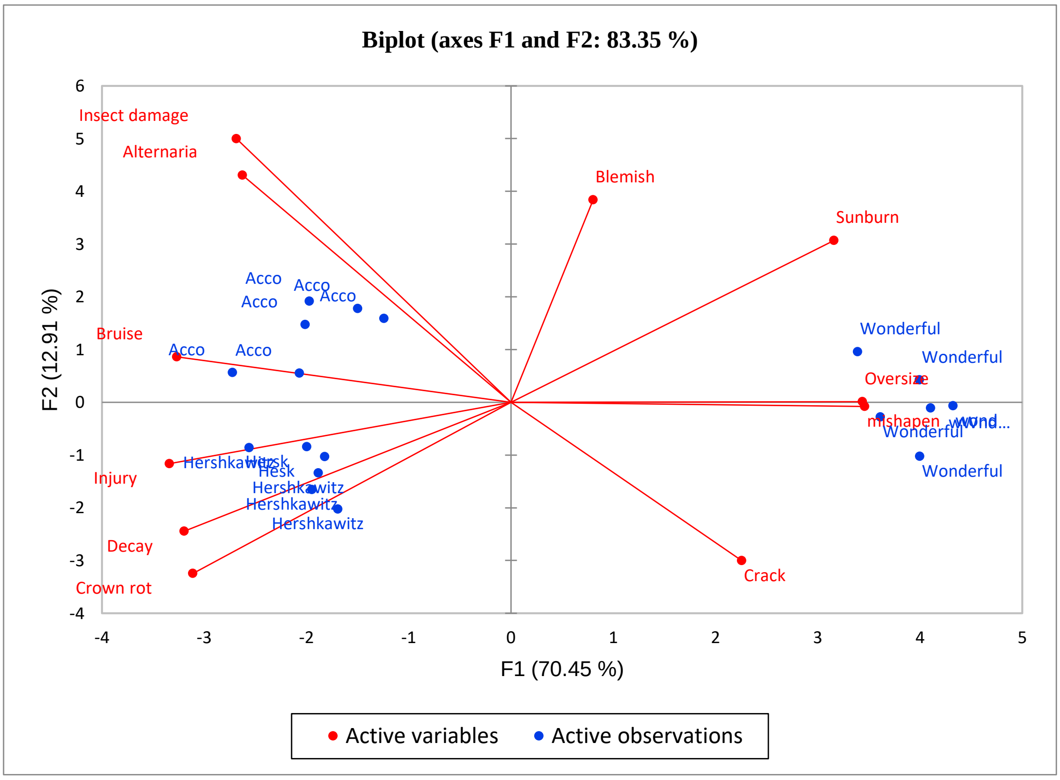


Figure 3.2: Observation chart showing pomegranate fruit defects and the susceptible cultivar.

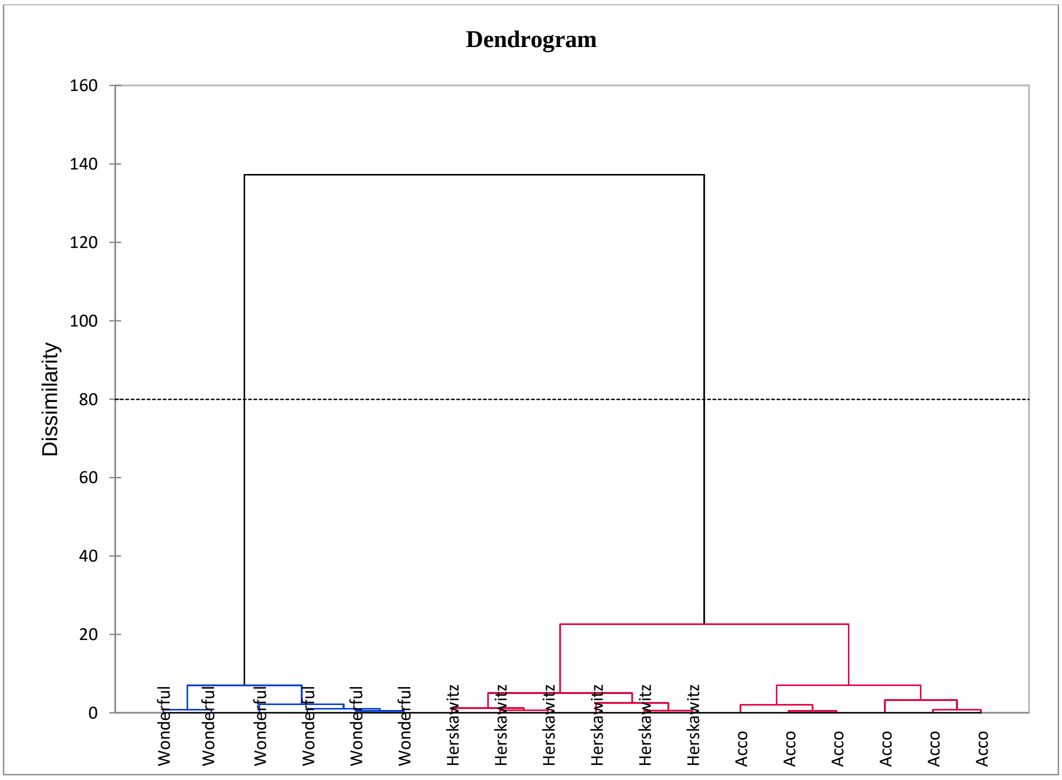


Figure 3.3: Dendrogram of clusters analysis of three pomegranate cultivars studied based on defects

Table 3.4: Comparison of the origin of on-farm fruit loss at Blydeverwacht farm, Wellington, in the Western Cape Province of South Africa.

	Cultivar							
Defects	**Acco (Mean)**	**Acco (total)**	**Hershkawitz (mean)**	**Hershkawitz (total)**	**Wonderful (mean)**	**Wonderful (total)**	**Total**	**Loss (%)**
Biological								
Insect damage (mean)	95.17 ± 3.86[c]	571	49.17 ± 4.02[a]	295	20.67 ± 2.76[b]	124		
Total		571		295		124	990	3.92
Irregular fruit size & shape								
Undersize/ malformation	83.00 ± 3.32[b]	498	78.17 ± 5.44[b]	469	366.00 ± 6.23[a]	2196		
Oversize	0.00 ± 0.00	0	0.00 ± 0.00	0	52.50 ± 3.15[a]	315		
Total		498		469		2511	3478	13.76
Mechanical damage								
Bruise damage	132.83 ± 5.46[a]	797	123.50 ± 3.25[a]	741	78.50 ± 3.39[b]	471		
Superficial injuries	166.00 ± 10.13[a]	996	183.83 ± 5.06[a]	1103	73.17 ± 6.12[b]	439		
Total		1793		1844		910	4547	17.99
Environmental stress								
Sunburn	338.33 ± 8.94[a]	2030	289.33 ± 5.38[b]	1736	415.83 ± 3.48[c]	2495		
Crack and splits	261.00 ± 4.23[b]	1566	266.00 ± 4.20[ab]	1596	280.17 ± 5.57[a]	1681		
Total		3596		3332		4176	11104	43.93
Microbial and pathological								
Alternaria	96.33 ± 2.26[c]	578	59.00 ± 3.28[a]	354	37.33 ± 2.79[b]	224		
Crown rot	97.50 ± 5.86[a]	585	159.33 ±3.44[c]	956	20.00 ± 2.07[b]	120		
Decay and rots	56.67 ± 2.93[a]	340	78.17 ± 3.22[c]	469	17.17 ± 2.57[b]	103		
Total		1503		1779		447	3729	14.75
Physical								
Blemish	80.33 ± 5.59[a]	482	75.33 ± 4.78[a]	452	82.17 ± 4.48[a]	493		
Total		482		452		493	1427	5.65

Mean values in the same row followed by different letters (a, b, ab and c) indicate significant differences ($P < 0.05$).

3.4.2 Magnitude of fruit losses and waste

Loss quantification involved a total of 96 bins of harvested fruit from 3 cultivars, of which 18 bins were sorted out as 'waste' and removed from the value chain. The total discarded (lost) fruit ranged from 15.3 to 20.1% among the three cultivars studied (Table 3.5). 'Acco' and 'Hershkawitz' showed a close range in the quantity of fruit discarded. About 15.8 to 16.5% of the harvested 'Acco' fruit were discarded, and 15.3 to 16.2% of 'Hershkawitz' was discarded. The similarity could be attributed to the fact that both cultivars were harvested in due time and with the harvesting rings to ensure that the right sizes of fruit were harvested.

'Wonderful' cultivar showed a difference from 'Acco' and 'Hershkawitz' in the range of the quantity of fruit discarded. The discarded fruit ranges from 19.7 to 20.1% (Table 3.5). 'Wonderful' is a late cultivar with big fruit of larger surface area and as a result, become more susceptible to damage due to environmental factors such as high temperature in the summer that causes sunburn. Although 'Wonderful' was harvested in due time, it was harvested without the harvesting rings. The trees were stripped at once, including the undersize and mishapen fruit. This is because the farmer anticipated the national lockdown due to Covid-19 pandemic that was implemented by the South African government by late March 2020. The decision to strip the trees at once was economical and morphological as well. According to the farmer, it was better to harvest as much fruit as possible and send to the packhouse for processing since the conditions of the anticipated national lockdown were unknown at the time. Again, the farmer cited that for morphological reasons, it was better to strip the trees instead of leaving the fruit to rot and decay on the trees. This is in order to avoid unnecessary stress on the trees and potential pest and disease attack due to rotten and decayed fruit hanging on them.

Table 3.5: Magnitude of the discarded fruit in the three cultivars.

Cultivar	**Number of good fruit**	**Number of discarded fruit**	**Discarded fruit (%)**
	min - max	**min - max**	**min - max**
Acco	7274 - 7330	1370 - 1432	15.8- 16.5
Hershkawitz	7296 - 7373	1327 - 1404	15.3 – 16.2
Wonderful	5793 - 5825	1425 - 1457	19.7 – 20.1

Many studies have been conducted to estimate the postharvest losses of many fruits, but there is a lack of information about pomegranate losses and waste, especially at the farm (orchard) level. The total pomegranate fruit loss in this study ranges from 15.3 to 20.1%. Sudharshan, Anand and Sudulaimuttu (2013) reported a 6% loss of pomegranate fruit at farm level in Bangalore and 8% in Mangalore both in India. The report of lower losses could be attributed to pre-harvest activities and environmental factors. Also, the method of data collection used in the study is the structured interview to get estimates from farmers. However, Baker et al. (2019) suggest that farmer estimates may be inconsistent with actual losses and waste at the farm, citing difficulty with farmers estimating their losses and waste.

Jadhav et al. (2020) reported that the magnitude of of banana postharvest losses was 6.81% at farm level in the Jalgaon area in Maharashtra, India. The multi-stage stratified random sampling approach was used for the estimation and the study revealed that the causes of loss were similar to this present study as factors such as mechanical damage and poor handling method contributed to significant losses. Springael et al. (2018) reported a postharvest loss of 10 to 25% during transportation of apples in Belgium. The quantification was done by vibration measurement experiment. The study established vibration (mechanical damage) as a major source of loss, causing bruises and punctures on the apples that later led to fungi disease infection through the broken tissues. The effect of bruise on banana and apple is the same on pomegranate due to its high moisture content. These studies showed a similarity to this present study in the causes of fruit loss. The variation in the magnitude of loss could be attributed to the data collection method and physiological attributes of the fruit.

However, the authors consented that postharvest wastage means loss of revenue and unsustainable use of various production inputs and natural resources, which are scarce in supply. Also, there is a huge implication of postharvest losses on food and nutritional security, because essential nutrients which could benefit humans are lost, when not less than a third of the world population suffer from malnutrition (Keatinge et al., 2010).

3.4.3 Economic, environmental and resource impacts

The estimates presented in this study are based on the magnitude of incidence of loss at Blydeverwacht farm, Wellington, Western Cape Province, South Africa and retail price in South Africa. This is in order to show the potential value of production inputs and natural resources that are wasted to produce the lost pomegranate fruit. For example, the wasted freshwater for production could have been used for domestic consumption since the Western

Cape, which produces about 81% of the total pomegranate production in South Africa (POMASA, 2019) often experience water scarcity.

The price of pomegranate fruit at the supermarkets means that R88.99 ($5.26) is lost per 1 kg of the lost pomegranate fruit. Based on the annual average loss of 17.38% (Table 3.6) at the farm, which amounted to 117.76 tonnes, the monetary loss of the total annual production was estimated at R10.5 million ($618,715.34). During the production of pomegranate fruit, GHGs are emitted into the atmosphere. Based on the findings of this study, the pomegranate losses at the farm level were estimated to emit about 56,524.80 CO_2 eq (Table 3.6). To sink this amount of CO_2 eq, it would require planting at least 1.4 million trees at 0.039 metric ton CO_2 per tree planted (U.S. DOE, 1998). Also, about 718,336.00 MJ of energy and 107,161.60 m^3 of freshwater were wasted (Table 3.6). The wasted freshwater could meet the daily water requirement of about 5,871 people for a year at 0.05 m^3 consumed per person per day (Gleick & Iwra, 1996). Lastly, about 3 ha of land was used to produce the lost fruit. The land could have been used for other productive activities such as parks for relaxation and enjoyment of ecosystem services.

Table 3.6: Economic, environmental and resource impacts of pomegranate fruit losses at farm level at Blydeverwacht farm, Wellington, Western Cape Province, South Africa.

Production statistics* and impacts	**Cultivar**			
	Acco	**Hershkawitz**	**Wonderful**	**Total of three cultivars**
Production area (ha)	13.00	2.30	2.30	17.60
Production volume (tonnes)	500.50	83.30	85.75	677.60
Average loss (%)	16.50	15.75	19.90	17.38
Retail price (R/kg)[a]	89.99	89.99	89.99	89.99
Estimated physical and economic losses				
Physical loss (tonnes)	82.58	13.11	17.06	117.76
Monetary loss ($ZAR \times 10^6$)	7.40	1.10	1.50	10.50
Environmental impacts				
Estimated GHG emission (CO_2 *eq* $\times 10^3$)[b]	39.60	6.30	8.10	56.50
Estimated energy used ($MJ \times 10^3$)[c]	503.70	80.00	104.10	718.00
Resource impact				
Water footprint ($m^3 \times 10^3$)[d]	75.50	11.90	15.50	107.10
Equivalent land used to produce lost fruit (ha)	2.10	0.34	0.45	3.00

*Production statistics is based on POMASA (2019).

[a] Supermarket retail price in Stellenbosch, Western Cape, South Africa.

[b,c] Impacts per unit fruit produced estimated from González et al. (2011).

[d] Impact per unit fruit produced estimated from Mekonnen & Hoekstra (2011).

The economic and environmental impacts of pomegranate fruit losses was also estimated at the national (South Africa) retail level. Losses at the national level was estimated at 6,851.89 tonnes (Table 3.7). The monetary loss of the total annual production was estimated at R616.60 million ($36.60 million). Losses at the national level were found to emit about 3.2 million CO_2 eq (Table 3.7). To sink this amount of CO_2 eq, it would require planting at least 82 million trees at 0.039 metric ton CO_2 per tree planted (U.S. DOE, 1998). Additionally, about 41.79 million MJ of energy and 6.23 million m^3 of freshwater were wasted (Table 3.7). The wasted freshwater could meet the daily water requirement of about 341,369 people for a year at 0.05 m^3 consumed per person per day (Gleick & Iwra, 1996). Lastly, about 177.97 ha of land was used to produce the lost fruit. The land could have been used for infrastructural development, such as building public libraries.

Table 3.7: Economic, environmental and resource impacts of pomegranate fruit losses at the farm level in South Africa.

Production statistics[*] and impacts	Cultivar			Total of three cultivars	Total of all cultivars
	Acco	**Hershkovitz**	**Wonderful**		
Production area (ha)	102.40	133.10	716.80	952.30	1024.00
Production volume (tonnes)	3942.40	5124.40	27556.00	36,622.80	39424.00
Average loss (%)	16.50	15.75	19.90	17.38	17.38
Retail price (R/kg)[a]	89.99	89.99	89.99	89.99	89.99
Estimated physical and economic losses					
Physical loss (tonnes)	650.50	807.10	5483.60	6,365.04	6,851.89
Monetary loss ($ZAR \times 10^6$)	58.50	72.60	487.90	572.70	616.60
Environmental impacts					
Estimated GHG emission (CO_2 *eq* $\times 10^3$)[b]	312.20	387.40	2,632.00	3,055.00	3,288.00
Estimated energy used ($MJ \times 10^6$)[c]	3.90	4.90	33.40	38.80	41.79
Resource impact					
Water footprint ($m^3 \times 10^3$)[d]	591.00	734.00	4,990.00	5,792.10	6,235.20
Equivalent land used to produce lost fruit (ha)	16.80	20.90	142.40	165.32	177.97

[*]Production statistics is based on POMASA (2019).

[a] Supermarket retail price in Stellenbosch, Western Cape, South Africa.

[b,c] Impacts per unit fruit produced estimated from González et al. (2011).

[d] Impact per unit fruit produced estimated from Mekonnen & Hoekstra (2011).

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 17.38% loss of total production globally, which was estimated at 660,440 tonnes (Table 3.8) and retail price of R88.99/kg ($5.26/kg). The monetary loss of the total annual production was estimated at R59.43 billion ($3.4 billion). Based on the estimation, about 317 million CO_2 eq (Table 3.8) were emitted annually due to losses of pomegranate fruit. To sink this amount of CO_2 eq, it would require planting at least 8.1 billion trees at 0.039 metric ton CO_2 per tree planted (U.S. DOE, 1998). Furthermore, about 4.02 billion MJ of energy and 601 million m^3 of freshwater were wasted (Table 3.8). The wasted freshwater could meet the daily water requirement of about 32.9 million people for a year at 0.05 m^3 consumed per person per day (Gleick & Iwra, 1996). Lastly, about 17,174.02 ha of land was used to produce the lost fruit. The research findings showed that postharvest losses of pomegranate fruit do not only cause loss of revenue through lost income but also causes environmental stress and unsustainable utilisation of natural resources and the emission of GHG, which drives global warming.

Table 3.8: Estimated economic, environmental and resource impacts of pomegranate fruit losses at a global level based on the incidence of losses and retail price in South Africa.

Factor	**Statistics and impacts**
Production volume (tonnes × 10^6)[*]	3.80
Total area (ha)	98,701.29
Average loss (%)	17.38
Retail price (R/kg)[a]	89.99
Estimated physical and economic losses	
Physical loss (tonnes)	660,440.00
Monetary loss (ZAR×10^9)	59.43
Environmental impacts	
Estimated GHG emission (CO_2 eq × 10^6)[b]	317.01
Estimated energy used (MJ × 10^9)[c]	4.02
Resource impact	
Water footprint (m^3 × 10^6)[d]	601.00
Equivalent land used to produce lost fruit (ha)	17,174.02

[*]Kahramanoglu (2019).

[a] Supermarket retail price in Stellenbosch, Western Cape, South Africa.

[b,c] Impacts per unit fruit produced estimated from González et al. (2011).

[d] Impact per unit fruit produced estimated from Mekonnen & Hoekstra (2011).

3.4.4 Nutritional impacts

The loss of pomegranate represents a huge loss of nutrients owing to its numerous nutritional benefits. Table 3.9 presents some of the nutrients that are lost due to postharvest losses at Blydeverwacht farm, Wellington, in the Western Cape Province of South Africa. This is coming in a period where the Covid-19 pandemic has drastically impacted the source of livelihood of many in the country and indirectly, their ability to afford healthy and nutritious food. Based on the annual loss of pomegranate fruit at the farm, the amount of fruit lost could meet the daily recommended nutrition intake of 1-24 people in varying proportion according to the various nutrients.

Table 3.9: Selected nutritional impacts of pomegranate fruit losses at Blydeverwacht farm, Wellington, in the Western Cape Province of South Africa

Nutrition factor	**Content (mg100^{-1}g)[*]**	**Amount lost (mg100^{-1}g)**	**Daily recommended intake (mg)[**]**	**Nutritional loss (per capita/day)**
Fibre	0.50[##]	58.88[##]	25.00[##]	2.00
Carbohydrate	9.90[##]	1165.82[##]	130.00[##]	9.00
Protein	1.40[##]	164.86[##]	46.00[##]	4.00
Iron	0.30	35.32	18.00	2.00
Ascorbic acid	15.00	1766.40	75.00	24.00
Calcium	30.00	3532.80	1,000.00	4.00
Magnesium	12.00	1413.12	310.00	5.00
Sodium	4.00	471.04	<2000.00[a]	1.00
Potassium	171.00	20136.96	4,700.00	4.00

[*] Paul & Shaha (2004).

[**] Spiker et al. (2017).

[a] WHO (2012). Guideline: Sodium intake for adults and children. Geneva. (online). Available: https://www.who.int/nutrition/publications/guidelines/sodium_intake_printversion.pdf (23 August 2020).

[##] Pomegranate fruit content and the amount lost are estimated in g100^{-1}g while the daily recommended intake is in gram.

The nutritional impacts of pomegranate fruit losses were also estimated at the national (South Africa) level (Table 3.10) using incidence of losses at Blydeverwacht farm, in the Western Cape Province of South Africa. Based on the annual losses of pomegranate fruit at the farm level, the amount of fruit lost could meet the daily recommended intake of 14-1370 people in the country for selected nutrients (Table 3.10).

Table 3.10: Selected nutritional impacts of pomegranate fruit losses at farm level in South Africa.

Nutrition factor	**Content ($mg100^{-1}g$)***	**Amount lost ($mg100^{-1}g$)**	**Daily recommended intake (mg)****	**Nutritional loss (per capita/day)**
Fibre	0.50##	3425.94##	25.00##	137.00
Carbohydrate	9.90##	67833.71##	130.00##	522.00
Protein	1.40##	9592.64##	46.00##	209.00
Iron	0.30	2055.56	18.00	114.00
Ascorbic acid	15.00	102778.35	75.00	1370.00
Calcium	30.00	205556.70	1,000.00	206.00
Magnesium	12.00	82222.68	310.00	265.00
Sodium	4.00	27407.56	<2000.00[a]	14.00
Potassium	171.00	1171673.19	4,700.00	249.00

*Paul & Shaha (2004).

** Spiker et al. (2017).

[a] WHO (2012). Guideline: Sodium intake for adults and children. Geneva. (online). Available: https://www.who.int/nutrition/publications/guidelines/sodium_intake_printversion.pdf (23 August 2020).

Pomegranate fruit content and the amount lost are estimated in $g100^{-1}g$ while the daily recommended intake is in gram.

The estimation of postharvest nutritional losses of pomegranate fruit at the global level showed a huge loss of vital nutrients that could benefit people in a period where micro and macronutrient deficiency affects not less than a third of the world population and impact negatively on the quality of life (Keating et al., 2010). Based on the annual incidence of losses in South Africa, the selected nutrient loss globally due to pomegranate losses was estimated (Table 3.11). The amount of fruit lost could meet the daily recommended nutrition intake of 1,322-132,240 people (Table 3.11) in varying proportion according to the various nutrients. The research findings showed that postharvest losses of pomegranate fruit contribute to global food and nutritional insecurity.

Table 3.11: Selected nutritional impacts of pomegranate fruit losses at the global level based on the incidence of losses in South Africa.

Nutrition factor	**Content ($mg100^{-1}g$)***	**Amount lost ($mg100^{-1}g$)**	**Daily recommended intake (mg)****	**Nutritional loss (per capita/day)**
Fibre	0.50##	330 x 10^3##	25.00##	13224.00
Carbohydrate	9.90##	654 x 10^4##	130.00##	50353.00
Protein	1.40##	925 x 10^3##	46.00##	20123.00
Iron	0.30	198 x 10^3	18.00	11020.00
Ascorbic acid	15.00	991 x 10^4	75.00	132240.00
Calcium	30.00	198 x 10^5	1,000.00	19836.00
Magnesium	12.00	793 x 10^4	310.00	25595.00
Sodium	4.00	264 x 10^4	<2000.00[a]	1322.00
Potassium	171.00	113 x 10^6	4,700.00	24056.00

* Paul & Shaha (2004).

** Spiker et. al. (2017).

[a] WHO (2012). Guideline: Sodium intake for adults and children. Geneva. (online). Available: https://www.who.int/nutrition/publications/guidelines/sodium_intake_printversion.pdf (23 August, 2020).

Pomegranate fruit content and amount lost are estimated in $g100^{-1}g$ while daily recommended intake is in gram.

3.5 Conclusion

This study revealed that pomegranate fruit loss ranged between 15.3 to 20.1% at Blydeverwacht farm, Wellington, in the Western Cape Province of South Africa. This amounted to an average of 117.76 tonnes of pomegranate fruit harvested per harvest season in the case study farm. This amount of fruit is removed from the value chain and dumped or sold mainly at a low value for juicing and other purposes. The main causes of on-farm fruit loss are environmental factors. In the three pomegranate cultivars studied, sunburn and crack were identified as the leading cause of fruit loss, accounting for about 43.9 % of all on-farm losses. Also, mechanical damage, including bruising and injury and microbial factors (causing decay and spoilage) contributed to significant fruit loss. However, huge losses of ‘Wonderful’ pomegranate fruit up to 19.7 to 20.1 % were recorded due to the anticipated national lockdown due to Covid-19 pandemic, which forced the farmer to strip the ‘Wonderful’ trees at ones. It was interesting to discover the impact of Covid-19 pandemic on fruit loss as such natural disaster are usually not included as causes of fruit losses and waste.

The magnitude of on-farm fruit loss of ‘Acco’ is 15.8 to 16.5%, 15.3 to 16.2% for ‘Hershkawitz’ and 19.7 to 20.1% for ‘Wonderful’. The causes of loss in each cultivar indicated that ‘Acco’ has the highest incidence of fruit loss due to insect damage, bruise and spoilage causing pathogen (Alternaria). The highest incidence of injury, crown rot, and decay occurred in ‘Hershkawitz’ while losses due to malformation and undersize, over-size, sunburn, crack, and blemishes was highest in Wonderful. Irrespective of cultivar, these causes of fruit loss are a function of their physiological attributes, level of resistance to adverse environmental factors and lastly, the impact of a natural disaster such as Covid-19 pandemic, which occasioned the hasty harvest of pomegranate fruit as seen in the case of ‘Wonderful’ cultivar.

The losses have a significant economic impact on the farmer and the various actors along the value chain due to huge revenue loss. The estimated economic loss at Blydeverwacht farm, Wellington, in the Western Cape Province of South Africa is R10.5 million ($618,715.34). At national (South Africa) and global levels, economic loss was estimated at R616.60 million ($36.60 million) and R59.43 billion ($3.4 billion) respectively. The environmental impact of pomegranate loss reflects the GHG emission and the energy wasted to produce lost pomegranate fruit. The estimated GHG emission is 56,524.80 CO_2 eq at farm level. At national and global levels, GHG emission was estimated at 3.2 million CO_2 eq and 317 million CO_2 eq respectively. Energy wasted to produce lost fruit at farm level was estimated at 718,336.00 MJ. At the national and global levels, energy wasted was estimated at 41.79 million MJ and 4.02 billion MJ respectively. Resource impact entails the freshwater and land wasted to produce lost pomegranate fruit, which would have otherwise been put to other beneficial use. The freshwater wasted at the farm level was estimated at 107,161.60 m^3. At the national and global levels, freshwater use was estimated at 6.23 million m^3 and 601 million m^3 respectively. Land is an important resource, and significant portion of it was wasted to produce the lost pomegranate fruit. At the farm level, an average of 3 ha of land was wasted. Based on the estimates, about 177.97 ha and 17,174.02 ha were wasted at the national and global levels respectively.

Additionally, a significant amount of nutrition was lost due to pomegranate fruit losses. The nutrition lost at the farm is enough to meet the daily recommended nutritional intake of 1-24 people in varying proportion according to the various nutrients. The nutrient lost at the national and global levels is enough to meet the daily recommended nutritional intake of 1,322-132,240 people and 1,322-132,240 people, respectively. Considering the various impacts of postharvest losses at farm, national and global levels, there is no doubt that reducing postharvest losses is a sustainable way to mitigate global warming and enhance food and nutrition security, as well as increase revenue for food system actors.

Strategies to control and reduce pomegranate fruit losses and waste at the farm level should be tailored to environmental factors (sunburn and cracking) and mechanical damage (bruising and other defects) since they account for the highest sources of fruit losses and waste. This will ensure improved revenue to farmers, sustainable use of natural resources, reduction of the environmental impacts of fruit production, and more availability of quality fruit which contributed to improving nutritional security for healthy life and wellbeing.

Chapter 4 - Quantification of postharvest losses of pomegranate fruit at packhouse level

4.1 Introduction

4.1.1 Nutritional benefits of pomegranate fruit

Pomegranate (*Punica granatum* L.) is an ancient fruit believed to be first cultivated around 3,000 and 4,000 BC and was mentioned in the Bible and the Quran (Kahramanoglu, 2019). 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 climate (Kahramanoglu & Usanmaz, 2016; Middha, Usha & Pande, 2013). There are more than 500 cultivars grown globally, with some cultivars named differently in different parts of the world (Kahramanoglu & Usanmaz, 2016; Pareek, Valero & Serrano, 2015). The awareness of its numerous uses and benefits has made it popular among other fruit (Fawole & Opara, 2013; Al-Said, Opara & Al-Yahyai, 2009). 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 vitamin, minerals and other organic compounds (Pareek et al., 2015; Fawole & Opara, 2013). The consumption of pomegranate has been linked with a great health outcome in different studies (de Oliveira, Arruda, da Silva Lima, Casarotti & Morzelle, 2020; Middha et al., 2013; Faria & Calhau, 2011; Viuda-Martos, Fernández-López & Pérez-Álvarez, 2010; Heber, Schulman & Seeram, 2006). The phenolic compounds present in pomegranate are found to be a great anti-inflammatory, anti-oxidative and anti-carcinogenic chemical compound, which reduces tumour growth and chronic inflammation (Kang, Shin, Lee & Lee, 2011). The hypoglycaemic activity of the pomegranate juice has been found to prevent diabetes mellitus (Katz, Newman & Lansky, 2007). Pomegranate fruit consumption has been reported to reduce cardiovascular diseases (Wang, Zhang, Hou, Liu, Wang et al., 2020). 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 (Middha et al., 2013; Viuda-Martos et al., 2010). The manufacturing industries use pomegranate aril and peel as a raw material in the production of jams, ink, dye and oil (Middha et al., 2013).

4.1.2 Production and trade of pomegranate fruit in South Africa and globally

There is a rapid increase in production of pomegranate globally, but the trade has grown more locally in the major producing countries (Isik-Ozguven, Gultekin, Gozlekci, Yilmaz, Yilmaz et al., 2015; Rymon, 2011). Pomegranate fruit is grown in many countries, while India, China, Iran and Turkey are the leading growers, India and Iran are the highest exporters of the fruit (Kahramanoglu & Usanmaz, 2016). Due to its health-related benefits and industrial use, it is in high demand globally. As a result, different cultivars are grown in different parts of the world (Arendse, Fawole, Magwaza & Opara, 2016; Fawole & Opara, 2013; Al-Said, Opara & Al-Yahyai, 2009). But because the fruit are often grown and picked from small farms in different locations in the major producing countries, there is no articulated data available about global production area (Kahramanoglu, 2019; Kahramanoglu & Usanmaz, 2016; Rymon, 2011). However, global production was estimated to have increased from about 3 million tonnes in 2014 to 3.8 million tonnes in 2017 (Kahramanoglu, 2019).

Pomegranate fruit production in different parts of the world is majorly divided into two (Northern hemisphere and Southern hemisphere) due to different seasons of production in the regions (POMASA, 2019; Rymon, 2011). 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 (Rymon, 2011). 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. However, the Northern hemisphere accounts for above 90% of the total production, hence, having a higher share in the global trade (Rymon, 2011). According to Kahramanoglu (2019), the pomegranate production area is increasing, but some of the producing countries are facing quality issues. Europe is the biggest market for pomegranate followed by Asia and the Middle East as almost all the producing countries share the European markets (Kahramanoglu, 2019). 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% contrition to export in the region (POMASA, 2018). Iran, China, India, Turkey, Spain and Israel are the highest producers in the Northern hemisphere, but most of the production in this region are consumed locally (Kahramanoglu, 2019; Isik-Ozguven et al., 2015).

The pomegranate fruit is one of the deciduous fruit grown in South Africa occupying about 1,024 hectares of land in 2019 from 771 hectares in 2011 (POMASA, 2019). It is mostly grown in the Western Cape, which accounts for about 81% of total production (POMASA, 2019). In South Africa, the majority of the production is exported, which earns export revenue to the country and income to the farmers and value chain actors. In 2019, about 76% of the total production was exported (POMASA, 2019), and in 2018, the local market generated about R67, 000 per tonne (POMASA, 2018). Production and export have grown from about 837,250 cartons (3.8kg equivalent) in 2014 to 1,676,160 cartons (3.8 kg equivalent) in 2019 and projected to increase to 2,055,271 cartons (3.8 kg equivalent) by 2024 (POMASA, 2019). Between 2014 and 2019, about 7,557,906 cartons (3.8kg equivalent) has been exported (POMASA, 2019). 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 Asia and African countries importing a small amount (POMASA, 2018). The main competition for export market share comes from the Southern hemisphere countries, which their pomegranate fruit is ready in the market almost the same period as that of South Africa.

Pomegranates are susceptible to wastage due to pest and disease attack (Venter, Lennox & Meitz-Hopkins, 2017; Munhuweyi, Lennox, Meitz-Hopkins, Caleb & Opara, 2016), bruise damage (Hussein, Fawole & Opara, 2019), and loss of moisture and weight (Lufu, Ambaw & Opara, 2019; Lufu, Ambaw & Opara, 2020) and mechanical damage (Fadiji, Berry, Coetzee & Opara, 2018). In spite of 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.

4.2 Study location

The study was carried out at Sonlia packhouse, Wellington, in the Western Cape Province of South Africa. Wellington is the second highest pomegranate production area in the country, accounting for 14% of the total cultivated area (POMASA, 2019). Sonlia packhouse is the biggest pomegranate processing packhouse in Wellington and one of the biggest in South Africa. It serves most of the farms in the area in the production of deciduous and citrus fruit. The packhouse has a storage (precooling) facility where fruit are precooled before they are processed. The processing line accommodates about 50 people working simultaneously. At peak production season, about 135 - 215 bins of pomegranate fruit are processed daily. The packhouse operates day and night duty shift in order to reduce storage and processing time of fruit at the packhouse.

4.3 Research methodology

4.3.1 Research design

The study was carried out by assessing the physical quality of fruit sorted out as ‘waste’ from the packhouse production line. The assessment started at about 9:00 am and ended by 3:00 pm daily. The study was carried out in February and March 2020. ‘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 is the bin with the following dimension: length = 125 m x height = 61 m x width = 109 m, and carton box; length = 35 m x height = 25 m x width = 22 m. The carton was used for sample size measurement. A total of 18 bins for all the three cultivars were assessed, six bins for each cultivar. 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.

4.3.2 Research method

The research method for this study is the sampling method, which has been identified as a practical method to conduct a study where there is a large variable of data to consider and also in conditions where data collection is constrained (Bryman, Bell, Hirschsohn, Dos Santos, Du Toit et al., 2014). Because the assessment of this present study was carried out simultaneously with full packhouse operation, 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 (Dome & Prusty, 2017; Munhuweyi, Opara & Sigge, 2016; Opara & Al-Ani, 2010). This present study involved the physical identification of the causes of fruit loss on individual fruit sorted as ‘waste’ at the packhouse. Qualitative data was 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 (R89.99/kg) in Stellenbosch, Western Cape, South Africa. The environmental impacts were estimated using the values from previous studies. The energy used and GHG emission values were estimated using 6.1 MJ/kg and 0.48 CO_2eq/kg, respectively (González et al., 2011). The water footprint was calculated with 910 m^3 ton^{-1} (Mekonnen & Hoekstra, 2011). The nutritional impact was calculated using values from Spiker et al. (2017) and Paul and Shaha

(2004). Furthermore, cropland use was estimated by the size of the farm and the average yield produced.

The magnitude of pomegranate fruit losses at the packhouse was measured by the proportion of bins of discarded fruit to the number of bins initial put in the fruit processing line. Using the following formular, the percentage of discarded fruit was calculated for each cultivar.

$$Loss\ (\%) = \frac{No\ of\ discarded\ bin}{Total\ bins\ put\ into\ processing\ line} * 100 \qquad 1$$

4.3.3 Data collection

The data collection protocol is consistent with the direct measurement method of the Food Loss and Waste Protocol (FLWP) (Hanson, Lipinski, Robertson, Dias, Gavilan, et al., 2016). Data collection involved monitoring fruit bins put in the processing line and the number of 'waste bins' produced for each cultivar. To determine the reason for the loss, a sub-sample of 30 fruit were randomly selected each from the bottom, middle and top respectively, of the 18 'waste bins' studied. The sample fruit were assessed based on physical appearance (presence of rot, Alternaria, crack, injury, sunburn, blemish, insect damage), sorted, and counted according to the category of the defect and recorded.

Data collection for each cultivar was done in three days, and 6 bins (n=6) were assessed per cultivar (Acco, Hershkawitz, and Wonderful). The 'waste bins' were labelled, and 2 bins assessed per day. It is important, however, to mention that pomegranate fruit losses at packhouse level is not necessarily cultivar dependent, rather originate from direct (primary sources) and indirect (secondary sources) (Atanda, Pessu, Agoda, Isong & Ikotun, 2011). But it was important to categorise fruit defects by cultivar for ease of data collection and comparison with historical packhouse data.

4.3.4 Historical packhouse data

Historical packhouse data was collected as secondary data and discussed in the results. Only data for the years 2016 and 2019 was available and was compared to the results of this present study.

4.3.5 Data analysis

Statistical analysis

Microsoft Excel 2013 was used to collate the data collected. 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, France). 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 differences between cultivars and fruit defects. Significant differences between means were separated using Duncan's multiple range test (Fawole & Opara, 2013a).

4.4 Result and discussion

4.4.1 Causes of packhouse pomegranate fruit losses

The causes of packhouse pomegranate fruit losses were assessed based on the quality issues 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) (Atanda et al., 2011). 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 (POMASA, 2019) and 61% of the total export goes to the European markets (POMASA, 2018). The trend of pomegranate marketing in Europe shows that South Africa faces strong competition with other Southern hemisphere countries for the market share (Kahramanoglu, 2019; POMASA, 2019). 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 at the export market are sold locally. The effect of this is that more fruit are lost and 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 in fruit bruises and superficial injuries. However, the two major reasons for physical loss as identified in this study are sunburn and injury. Other reasons are Alternaria, bruise, crack, oversize, insect damage, rot, decay, blemishes and malformation.

Environmental stress

i Sunburn

In the three cultivars assessed, sunburn recorded 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 (Weerakkody, Jobling, Infante & Rogers, 2010). 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 4.1). The highest incidence was in ‘Wonderful’, where it contributed to 34.81% of losses. Sunburn show a positive relationship with oversize fruit in the correlation analysis result (Table 4.2). The relationship is the only positive relationship result in the analysis, which indicates that more oversize 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.

Temperature exceeding 35°C and low relative humidity at the farm level results to sunburn (Yazici & Kaynak, 2006). ‘Wonderful’ produces bigger fruit with larger surface area and is a late cultivar in South Africa. Hence, it hangs on the tree more with most of the fruit exposed to direct sunlight outside the tree canopy at the farm, making them susceptible to sunburn more than ‘Acco’ and ‘Hershkawitz’.

Table 4.1: Packhouse percentage loss of pomegranate fruit due to defects.

	Cultivar		
Defect	**Acco (%)**	**Hershkawitz (%)**	**Wonderful (%)**
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
Oversize	0.00	0.00	2.24

Table 4.2: Pearson correlation coefficient matrix between defects in three pomegranate cultivars (Acco, Hershkawitz and Wonderful).

Defects	Alternaria	Oversize	Bruise	Injury	Sunburn	Crack	Insect damage	Crown rot	Decay	Blemish	Misshapen
Alternaria	**1**										
Oversize	-0.267	**1**									
Bruise	-0.248	-0.179	**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	**1**				
Crown rot	0.067	-0.218	-0.093	0.042	-0.181	-0.063	0.003	**1**			
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 $p<0.05$

ii Cracks and splits

The results show that the amount of fruit affected by crack and splits in the three cultivars studied are similar as they ranked third in the causes of loss in the cultivars. But the highest incidence was in ‘Acco’, where they accounted for 18.70% of losses (Table 4.1). For ‘Hershkawitz’, crack and splits contributed to 18.34% and 17.96% of losses in ‘Wonderful’. Crack and splits have a negative relationship with sunburn according to the correlation analysis result (Table 4.2). This shows the impact of fruit sorting at the farm level; otherwise, it is reasonable to believe that higher sunburn would result to more crack and splits due to the hardening of fruit rinds due to direct sunlight, which aids cracking when moisture content fluctuates. Like sunburn, pomegranate crack and splits as observed at the packhouse, mostly originated from the farm. This is due to environmental stress, specifically soil moisture imbalances (Ghanbarpour, Rezaei & Lawson, 2019; Opara, Studman & Banks, 1997). Also, pomegranate fruit is highly sensitive to variation in soil moisture content (Abd El-Rhman, 2010). So, fruit with crack and splits at the packhouse are due to either oversight by farm fruit sorters or the assumption that the fruit could meet the minimum market standard.

Crack and splits create an open wound that enhances moisture loss and disease infestation, which lowers the affected fruit quality (Singh, Shukla & Meghwal, 2020). Fruit discarded from the packhouse due to crack and splits were sold locally for industrial use.

Mechanical and physical damage

i Superficial injuries

Superficial injuries are the second highest cause of pomegranate fruit loss at the packhouse after sunburn. Injuries constituted 23.33% of the total loss in ‘Acco’ (Table 4.1). For ‘Hershkawitz’, injury contributed 23.70% of 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 oversize fruit in the correlation matrix (Table 4.2). 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 in suspect of internal disease by packhouse fruit sorters with false results. Also, 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, the chilling injury was not observed.

ii 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 4.1). Bruise damage contributed to 12.80% of losses recorded for 'Hershkawitz' and 10.94% of losses in 'Wonderful'. Bruise damage showed no significant relationship with any other defect in the correlation analysis result (Table 4.2), 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 (Hussein, Fawole & Opara, 2019). 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 from bruising damage (Hussein, Fawole & Opara, 2020; Hussein, Fawole & Opara, 2018). Also, 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, depicting 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 for the softness of the affected parts. Bruised fruit does not meet both the export and local market standards, therefore, are sold at a low price for industrial use.

iii Blemish

Blemish is one of the least 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. Fruit with blemishes result from oversight from the farm fruit sorters as they are unlikely to be caused by packhouse operation (handling). Blemish is mostly as 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 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 blemish-free appearance (Czieczor, Bentkamp, Damerow & Blanke, 2018).

Biological damage

i Insect damage

The results show that insect damage contribution to pomegranate fruit losses at the packhouse is 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 4.1). 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 has no significant relationship with other defects assessed in the correlation analysis (Table 4.2). This indicates that insect damage in this present study, occurred independent 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, resulting in a partial loss of the affected fruit and 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 manufacturing of dye and animal feed.

Microbial and pathological spoilage

i Decay and rots

Decay and rots are one of the lowest causes of pomegranate fruit loss among the three cultivars assessed at the packhouse. For 'Acco', it accounted for 2.22% of losses (Table 4.1). They contributed to 1.90% of losses in 'Hershkawitz' and 2.22% in 'Wonderful'. Decay and rots have no significant relationship with other defects in the correlation analysis (Table 4.2). This indicates that decay at the packhouse, in this present study, was not as a result of packhouse operation (handling). Therefore, the decayed fruit were because of sorting oversight at the farm level. Decay and rots result from microbial pathogens that breakdown the rind of the affected fruit, resulting in partial or total decay and rots (Munhuweyi et al., 2016). Decayed fruit do not meet market standard and are often buried or composted.

ii *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 4.1). 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 sorting oversight at the farm because it is often difficult to dictate infected fruit physically.

Alternaria is a pomegranate fruit disease caused by *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 (Munhuweyi et al., 2016). The affected fruit is light in weight, making them float on top during chlorine bath 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.

iii 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 4.1). The highest occurrence of crown rot was in ‘Hershkawitz’, where it accounted for 2.96% of loss and ranked seventh in loss causes. 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 4.2), which suggests that it occurred for reasons outside the packhouse. Like Alternaria, crown rot is a farm disease and did not originate at the packhouse, rather was found due to sorting oversight at the farm.

Crown rot is caused by *Coniella granati*, a fungi pathogen (Munhuweyi et al., 2016), which mostly affect pomegranate fruit on the farm. The rind of the affected fruit shows the presence of pycnidia with rotten crown (Munhuweyi et al., 2016). Fruit affected by crown rot were discarded for not meeting the market standard, as such, were sold at cheap price for industrial products such as ink and dye.

Irregular fruit size and shape

i Oversize

Oversize fruit were only observed among 'Wonderful' and in very small quantity. So, oversize fruit contributed little to overall pomegranate fruit loss in the cultivar. Oversize fruit accounted for 2.24% of loss (Table 4.1). The oversize fruit could not fit comfortably into the 3.8kg equivalent carton used for pomegranate fruit packaging, therefore, were sorted out to be sold and used for other purposes such as juicing.

ii Misshapen

Pomegranate fruit discarded for misshapen are 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 1.66% in 'Wonderful' (Table 4.1). The misshapen fruit was good fruit with irregular shapes, hence, it does not appear appealing for the shelves but could be used to produce juice, jam and dye.

Comparative analysis of pomegranate fruit based on defects

Fruit were discarded from the processing line for not meeting market standard due to bruise and injury (during handling), and other defects such as sunburn and microbial and pathological diseases that originate 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 a biplot axes, which shows a relationship by the clustering of active variables (defects) around active observations (cultivars) (Figure 4.1). The result revealed that oversize and mishappen fruit was highest in 'Wonderful'. At the same time, insect damage and Alternaria was predominant in 'Acco'. Decay and crown rot were majorly 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 crack) 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 each cultivar handling (Figure 4.2). The result suggests that different packhouse management practices are not necessary for each cultivar. 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 and handling practices. Cluster 1 consists only of 'Wonderful', and this could be attributed to misshapen and oversize fruit, which were majorly associated with the cultivar.

The causes of pomegranate fruit loss at the packhouse in the three cultivars assessed varied and 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 4.3). The results show that environmental stress is 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. 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 was mostly in 'Wonderful'. Lastly, microbial and pathological spoilage accounted for 7.84% of total losses.

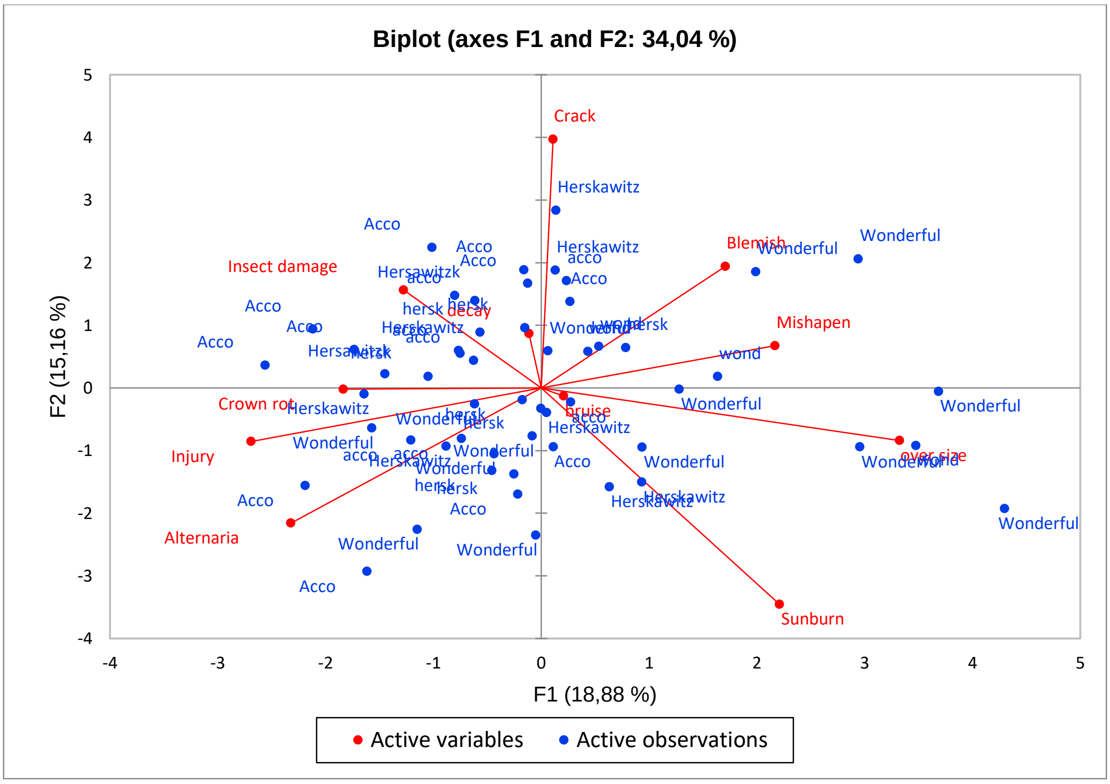
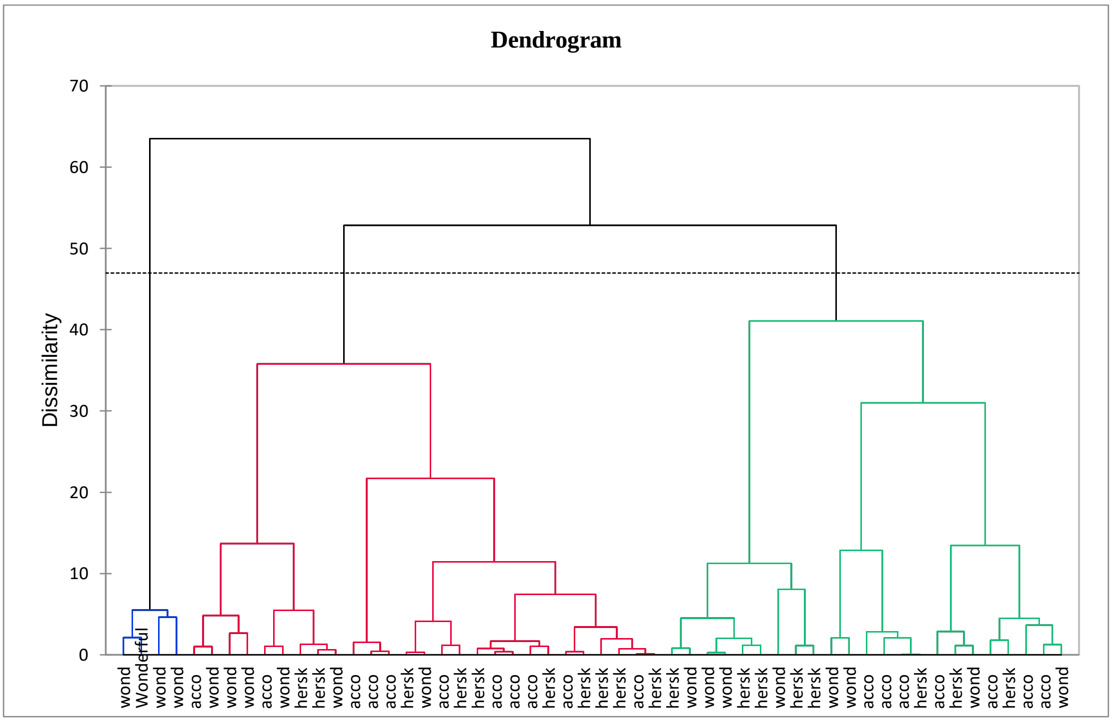


Figure 4.1: Observation chart showing pomegranate fruit defects according to cultivars.



Key: wond = 'Wonderful', acco = 'Acco', hersk = 'Hershkawitz'

Figure 4.2: Dendrogram of clusters analysis of three pomegranate cultivars studied based on defects.

Table 4.3: Comparison of the origin and reasons for packhouse pomegranate fruit loss at Sonlia packhouse, Wellington, in the Western Cape Province of South Africa.

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

Mean values in the same row, followed by different letters, indicate significant differences ($P < 0.05$).

Historical packhouse data on pomegranate fruit losses at Sonlia packhouse, Wellington, Western Cape, South Africa

Historical packhouse data for 2016 and 2019 was analysed in comparison with the results of this present study and presented in Figure 4.3. The trend of 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 accounts for a significant amount of fruit loss at the packhouse according to both the packhouse historical data and result obtained from the present study.

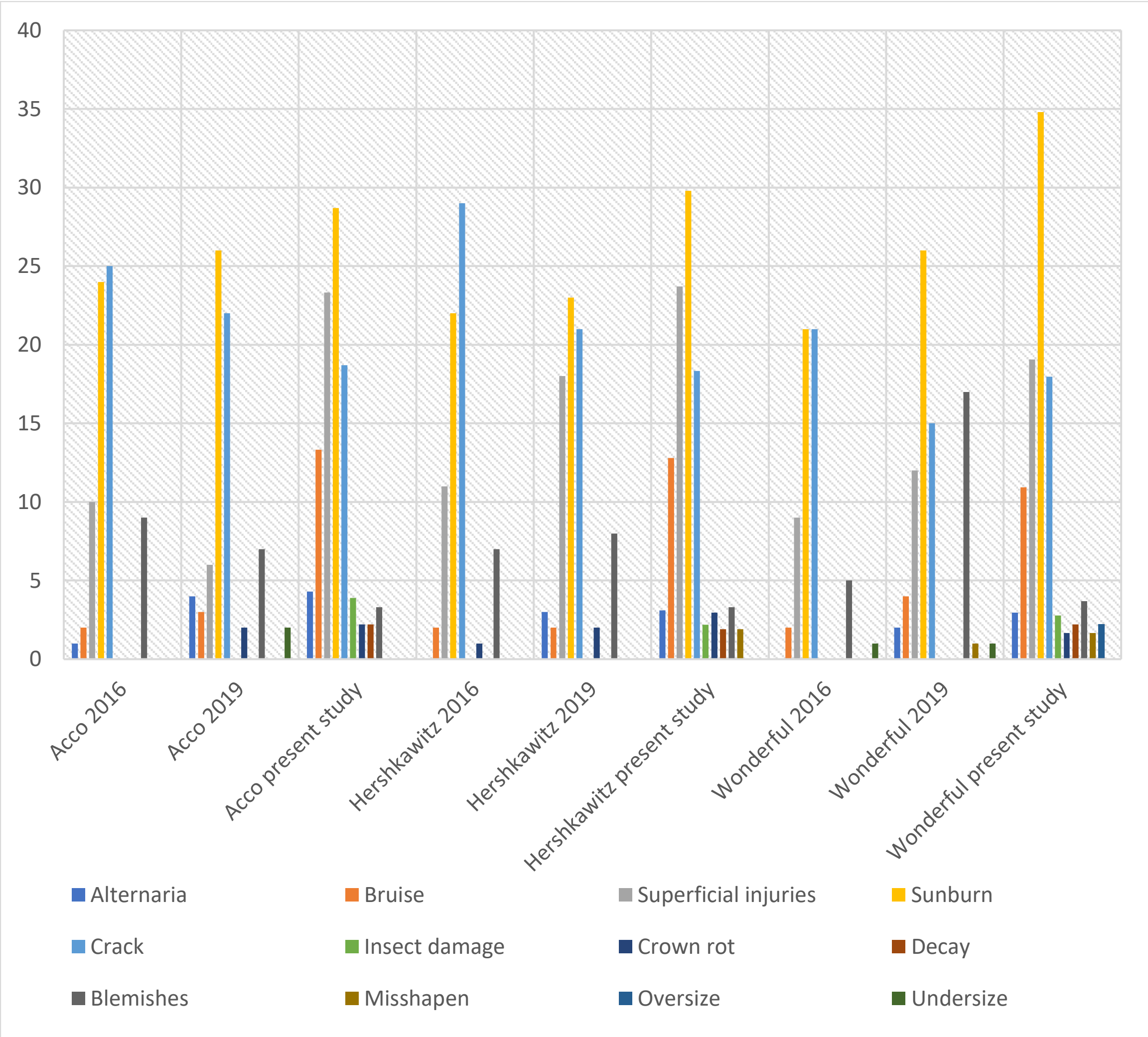


Figure 4.3: Comparison of historical packhouse pomegranate fruit defect data (2016 & 2019) and the present study

4.4.2 Magnitude of packhouse pomegranate fruit losses

Quantification of loss 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 4.4). '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 4.4: Percentages of discarded (lost) fruit based on the amount of fruit put into the packhouse processing line.

Cultivar	Initial bin	Discarded 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

Pomegranate fruit losses are quantified at the packhouse level in South Africa in recent years by the Pomegranate Producers Association of South Africa (POMASA). The results of the studies are similar to this present study in the magnitude of pomegranate fruit lost at the packhouse. In 2017, POMASA reported 11% loss in 'Wonderful', 13% loss in 'Hershkawitz', and 11% loss in 'Acco' (POMASA, 2017). In 2018, a 7% loss of 'Wonderful' was reported, 8% loss in 'Hershkawitz' and 9% loss in 'Acco' (POMASA, 2018). Additionally, in 2019, 9% of 'Wonderful was reported as a loss with a 25% loss in 'Hershkawitz' and 13% loss in 'Acco' (POMASA, 2019). 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 conveyed to the packhouse and the amount of loss recorded. So, this explains the small variation in magnitude in the POMASA results and the result of this present study.

Bond (2016) reported a 20% loss in carrot at the packinghouse level in Norway. The estimation was done using secondary data from experts in the carrot industry and survey 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 wound for decay and diseases 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, Alemayehu, Abera, and Bizuayehu (2017). The results show that 18-28% of losses occurred during harvesting, storage and transportation while 18%-25% of losses was 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 questionnaire and interview were used for data collection in the study. Furthermore, a study in Nepal reported 35% of losses in carrots (Bhattarai, Subedi, Gautam & Chauhan, 2017). 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 (Bhattarai et al., 2017). Irrespective of the magnitude of loss reported in the studies, losses due to environmental stress and mechanical damage have remained dominant in the causes of fruit loss, which are similar to the results of this present study.

4.4.3 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 Sonlia packhouse, Wellington, Western Cape Province, South Africa 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. This is particularly important with sustainability challenges facing the world, which require prudent use of resources today to create a future with sufficient material and natural resources (Swilling & Annecke, 2012).

The retail price of pomegranate fruit at the supermarket means that R88.99 ($5.26) is lost per 1 kg of lost pomegranate fruit in South Africa. Based on the annual average loss of 7.16% at the packhouse (Table 4.5), which translates to 328.79 tonnes, the monetary loss of the total annual production was estimated at R29.5 million ($1,754,984). During the production of pomegranate fruit, 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, it would require planting about 4 million trees at 0.039 metric ton CO_2 per tree planted (U.S. DOE, 1998). 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 (Gleick & Iwra, 1996). 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 shopping complex.

Table 4.5: Economic, environmental and resource impacts of pomegranate fruit losses at Sonlia packhouse, Wellington, Western Cape Province, South Africa.

Production statistics and impacts	Cultivars				
	Acco	**Hershkawitz**	**Wonderful**	**Total of three cultivars**	**Total of all cultivars**
Production volume (tonnes)*	596.96	551.04	3398.08	4546.08	4592.00
Average loss (%)	6.74	7.14	7.69	7.16	7.16
Retail price (R/kg)[a]	89.99	89.99	89.99	89.99	89.99
Estimated physical and economic losses					
Physical loss (tonnes)	40.24	39.34	261.31	325.49	328.79
Monetary loss (ZAR×10⁶)	3.62	3.54	23.51	29.29	29.58
Environmental impacts					
Estimated GHG emission (CO_2 eq × 10^3)[b]	19.31	18.88	125.42	156.23	157.81
Estimated energy used (MJ)[c]	245×10^3	239×10^3	1×10^6	1×10^6	2×10^6
Resource impact					
Water footprint ($m^3 \times 10^3$)[d]	36.61	35.79	237.79	296.19	299.19
Equivalent land used to produce lost fruit (ha)	1.05	1.02	6.79	8.45	8.54

*Production statistics are estimated from Sonlia packhouse - Muller (2020).

[a] Supermarket retail price in Stellenbosch, Western Cape, South Africa.

[b,c] Impacts per unit fruit produced estimated from González et al. (2011).

[d] Impact per unit fruit produced estimated from Mekonnen & Hoekstra (2011).

The economic and environmental impacts of pomegranate fruit losses at packhouse was also estimated at the national (South Africa) level. Losses at the national level was estimated at 2332.16 tonnes (Table 4.6), which translates to an estimated R209.87 million ($12.64 million) annual revenue loss. Losses at the national level were found to emit about 1.11 million CO_2 eq. To sink this amount of CO_2 eq, it would require planting at least 28 million trees at 0.039 metric ton CO_2 per tree planted (U.S. DOE, 1998). Furthermore, about 14.22 million MJ of energy and 2.12 million m^3 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 m^3 consumed per person per day (Gleick & Iwra, 1996). Lastly, land used to produce the lost fruit was estimated at 60.58 ha of land.

Table 4.6: Economic, environmental and resource impacts of pomegranate fruit losses at packhouse level in South Africa.

Production statistics and impacts	**Cultivar**				
	Acco	**Hershkawitz**	**Wonderful**	**Total of three cultivars**	**Total of all cultivars**
Production volume (tonnes) [*]	4234.37	3908.65	24103.36	32246.38	32572.11
Average loss (%)	6.74	7.14	7.69	7.16	7.16
Retail price (R/kg)[a]	89.99	89.99	89.99	89.99	89.99
Estimated physical and economic losses					
Physical loss (tonnes)	285.39	279.07	1853.55	2308.84	2332.16
Monetary loss ($ZAR \times 10^6$)	25.68	25.11	166.80	207.77	209.87
Environmental impacts					
Estimated GHG emission (CO_2 *eq*)[b]	136×10^3	133×10^3	889×10^3	1×10^6	1×10^6
Estimated energy used ($MJ \times 10^6$)[c]	1.74	1.70	11.30	14.08	14.22
Resource impact					
Water footprint (m^3)[d]	259×10^3	253×10^3	1×10^6	2×10^6	2×10^6
Equivalent land used to produce lost fruit (ha)	7.41	7.25	48.14	59.97	60.58

[*] Production statistics are estimated from farm volume of production at the national level.

[a] Supermarket retail price in Stellenbosch, Western Cape, South Africa.

[b,c] Impacts per unit fruit produced estimated from González et al. (2011).

[d] Impact per unit fruit produced estimated from Mekonnen & Hoekstra (2011).

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 4.7) and retail price of R88.99/kg ($5.26/kg). The revenue loss due to the lost fruit was estimated at R20.22 billion ($1.2 billion). Based on the estimation, about 107.90 million CO_2 eq were emitted annually due to losses of pomegranate fruit. To sink this amount of CO_2 eq, it would require planting at least 2.7 billion trees at 0.039 metric ton CO_2 per tree planted (U.S. DOE, 1998). Additionally, about 1.37 billion MJ of energy and 204.56 million m^3 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 m^3 utilised per person per day (Gleick & Iwra, 1996). 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.

Table 4.7: Estimated economic, environmental and resource impacts of pomegranate fruit losses at the packhouse level globally based on the incidence of losses and retail price in South Africa.

Factor	**Statistics of impacts**
Production volume (tonnes × 10^6)*	3.13
Average loss (%)	7.16
Retail price (R/kg)[a]	89.99
Estimated physical and economic losses	
Physical loss (tonnes)	224,792.50
Monetary loss (ZAR×10^9)	20.22
Environmental impacts	
Estimated GHG emission (CO_2 eq × 10^6)[b]	107.90
Estimated energy used (MJ × 10^9)[c]	1.37
Resource impact	
Water footprint (m^3 × 10^6)[d]	204.56
Equivalent land used to produce lost fruit (ha)	5838.77

*Production statistics are estimated from farm volume of production based on Kahramanoglu (2019)

[a] Supermarket retail price in Stellenbosch, Western Cape, South Africa.

[b,c] Impacts per unit fruit produced estimated from González et al. (2011).

[d] Impact per unit fruit produced estimated from Mekonnen & Hoekstra (2011)

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4.4.4 Nutritional impacts

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 Sonlia packhouse, Wellington, in the Western Cape Province of South Africa during the past season (2020) are presented in Table 4.8. The nutritional impacts of fruit and vegetable cannot be overemphasised, 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 at the packhouse level, the amount of fruit lost could meet the daily recommended nutrition intake of 1-66 people in varying proportion according to the various nutrients.

Table 4.8: Selected nutritional impacts of pomegranate fruit losses at Sonlia packhouse, Wellington, in the Western Cape Province of South Africa.

Nutrition factor	**Content ($mg100^{-1}g$)[*]**	**Amount lost ($mg100^{-1}g$)**	**Daily recommended intake (mg)[**]**	**Nutritional loss (per capita/day)**
Fibre	0.50[##]	164.39[##]	25.00[##]	7.00
Carbohydrate	9.90[##]	3255.02[##]	130.00[##]	25.00
Protein	1.40[##]	460.30[##]	46.00[##]	10.00
Iron	0.30	98.64	18.00	5.00
Ascorbic acid	15.00	4931.85	75.00	66.00
Calcium	30.00	9863.70	1,000.00	10.00
Magnesium	12.00	3945.48	310.00	13.00
Sodium	4.00	1315.16	<2,000.00[a]	1.00
Potassium	171.00	56223.09	4,700.00	12.00

[*] Paul & Shaha (2004).

[**] Spiker et al. (2017).

[a] WHO (2012). Guideline: Sodium intake for adults and children. Geneva. (online). Available: https://www.who.int/nutrition/publications/guidelines/sodium_intake_printversion.pdf (23 August 2020).

[##] Pomegranate fruit content and the amount lost are estimated in $g100^{-1}g$ while the daily recommended intake is in gram.

The nutritional impacts of pomegranate fruit losses were also estimated at the national (South Africa) level using the incidence of losses at Sonlia packhouse, in the Western Cape Province of South Africa (Table 4.9). Based on the annual losses of pomegranate fruit at the packhouse level, the amount of fruit lost could meet the daily recommended intake of 5-466 people in the country for selected nutrients.

Table 4.9: Selected nutritional impacts of pomegranate fruit losses at the packhouse level in South Africa.

Nutrition factor	**Content ($mg100^{-1}g$)***	**Amount lost ($mg100^{-1}g$)**	**Daily recommended intake (mg)****	**Nutritional loss (per capita/day)**
Fibre	0.50##	1166.08##	25.00##	47.00
Carbohydrate	9.90##	23088.38##	130.00##	178.00
Protein	1.40##	3265.02##	46.00##	71.00
Iron	0.30	699.65	18.00	39.00
Ascorbic acid	15.00	34982.40	75.00	466.00
Calcium	30.00	69964.80	1,000.00	70.00
Magnesium	12.00	27985.92	310.00	90.00
Sodium	4.00	9328.64	<2000.00[a]	5.00
Potassium	171.00	398799.40	4,700.00	85.00

* Paul & Shaha (2004)

** Spiker et al. (2017).

[a] WHO (2012). Guideline: Sodium intake for adults and children. Geneva. (online). Available: https://www.who.int/nutrition/publications/guidelines/sodium_intake_printversion.pdf (23 August 2020).

Pomegranate fruit content and the amount lost are estimated in $g100^{-1}g$ while the daily recommended intake is in gram.

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 impact negatively on the quality of life (Keating et al., 2010). 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 4.10). The amount of fruit lost could meet the daily recommended nutrition intake of 450-44,959 people in varying proportion according to the various nutrients. The findings revealed that postharvest losses of pomegranate fruit at the packhouse level also contribute to global food and nutrition insecurity.

Table 4.10: Selected nutritional impacts of pomegranate fruit losses at the packhouse level globally based on the incidence of losses in South Africa.

Nutrition factor	Content ($mg100^{-1}g$)*	Amount lost ($mg100^{-1}g$)	Daily recommended intake (mg)**	Nutritional loss (per capita/day)
Fibre	0.50##	112×10^{3}##	25.00##	4496.00
Carbohydrate	9.90##	222×10^{4}##	130.00##	17119.00
Protein	1.40##	314×10^{3}##	46.00##	6842.00
Iron	0.30	67×10^{3}	18.00	3747.00
Ascorbic acid	15.00	337×10^{4}	75.00	44959.00
Calcium	30.00	674×10^{4}	1,000.00	6744.00
Magnesium	12.00	269×10^{4}	310.00	8702.00
Sodium	4.00	899×10^{3}	<2000.00[a]	450.00
Potassium	171.00	384×10^{5}	4,700.00	8179.00

* Paul & Shaha (2004)

** Spiker et al. (2017).

[a] WHO (2012). Guideline: Sodium intake for adults and children. Geneva. (online). Available: https://www.who.int/nutrition/publications/guidelines/sodium_intake_printversion.pdf (23 August 2020).

Pomegranate fruit content and the amount lost are estimated in $g100^{-1}g$ while the daily recommended intake is in gram

4.5 Conclusion

This study found that pomegranate fruit loss at Sonlia packhouse, Wellington, in the 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 in the case study packhouse. 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 crack), microbial and pathological diseases were also contributors to loss. Losses due to environmental stress are the highest in the causes of packhouse pomegranate fruit loss and accounted for 49.44%, followed by mechanical damage, which contributed 37.84% of losses. Microbial and pathological factors accounted for 7.84% of losses, while biological factors and irregular fruit shape and sizes ranked least in the causes of loss with 2.96% and 1.92%

respectively. Interestingly, result of the causes of loss in this present study is similar to the historical packhouse report as analysed.

The result of the magnitude of losses shows that the incidence of loss was least in 'Acco' with 6.74% of losses. The amount of loss in 'Herskawitz' and 'Wonderful' are similar with 7.14% and 7.69% respectively. Market standard (especially the export market) is greatly influential to the amount of losses recorded at Sonlia packhouse. This is because the majority 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 and resource impact. The economic impact reflects the loss of revenue by farmers and other actors along the value chain. The estimated annual economic loss at Sonlia packhouse, Wellington, in the Western Cape Province of South Africa is R29.5 million ($1,754,984). At national (South Africa) and global levels, economic loss was estimated at R209.87 million ($12.64 million) and R20.22 billion ($1.2 billion) respectively. The environmental impact entails the GHG emission and the energy wasted to produce the lost fruit. The estimated GHG emission is about 157,819 CO_2 eq at the packhouse level. At national and global levels, GHG emission was estimated at 1.11 million CO_2 eq and 107.90 million CO_2 eq respectively. Energy wasted to produce lost fruit was estimated at 2.00 million MJ at packhouse level. At the national and global levels, energy wasted was estimated at 14.22 million MJ and 1.37 billion respectively. Resource impact involved the water and land wasted to produce lost pomegranate fruit, which would have otherwise been put to other beneficial use. The water wasted to produce lost fruit at the packhouse was estimated at 299,198.9 m^3. At the national and global levels, water use was estimated at 2.12 million m^3 and 204.56 million m^3, respectively. The land used to produce the wasted fruit at the packhouse level was estimated at 8.54 ha. Based on the estimates, about 60.58 ha was wasted to produce the lost fruit at the national level and 5838.77 ha wasted at the global level.

Furthermore, a significant amount of nutrition was lost as a result of fruit losses. The nutrition lost at the packhouse level is enough to meet the daily recommended nutritional intake of 1-66 people in varying proportion according to the various nutrients. Losses at the national level could meet the daily recommended nutritional intake of about 5-466 people, and at the global level, the nutrient lost is enough to meet the daily recommended nutritional intake of 450-

44959 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. Also, reducing postharvest losses and waste would help mitigate the effects of global warming and increase revenue for the food value chain actors.

Chapter 5 - General summary and conclusions

5.1 Introduction

Fruit and vegetables are important in the human diet, given their high content of essential nutrients that are necessary for healthy living (Paul & Shaha, 2004). They ensure food and nutritional security and at the same time, are source of revenue to farmers and food value chain actors. Inadequate consumption of the essential nutrients found in fruit and vegetables results in malnutrition and its associated problems such as stunting (Keatinge et al., 2011). Overall, the strong linkages between fruit and vegetable consumption and better health outcome have been reported (Van Duyn & Pivonka, 2000).

A major challenge limiting the availability of fruit and vegetables for consumption is their susceptibility to deterioration leading to postharvest losses and waste (Opara, 2006, 2010). Although there has been significant progress in some countries and regions due to commitment from food growers, researchers, food businesses and government (WRAP, 2019), it is worrisome that postharvest losses of fruit and vegetables persist despite innovations and efforts to reduce losses.

Postharvest losses and waste along the value chain impose a huge cost on farmers, food value chain actors, the environment, natural resources, and enhance food and nutritional insecurity as exemplified in this study. This manifests in the form of monetary loss, energy loss, GHG emission, waste of water and land that, otherwise, would have been used for beneficial purposes. Also, postharvest losses mean loss of essential nutrient contents of produce that are needed for good human health and well-being. These impacts of postharvest losses and waste inhibit the efforts to attain some of the Sustainable Development Goals (SDGs) as set by the United Nations such as Goal 2 (Zero hunger), Goal 3 (Good Health and Well-being), Goal 6 (Sustainable water management), Goal 13 (Climate change) and Goal 12.3 which seek to "halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including postharvest losses" by 2030 (UN, 2015). It, therefore, means that if the SDGs must be attained and in time too, reducing postharvest losses and waste of food, especially fruit and vegetables, is paramount. Furthermore, there have been arguments that food production would need to increase by 70% and that production in the developing countries would almost double to feed the over 9 billion people projected to live in the world by 2050 (FAO, 2009). However, the results of this study have shown that increasing food production without a conscious effort to reduce postharvest losses and waste would amount to waste of resources and investment needed to produce the harvest that is utilised.

5.2 Study implications

Like other fruit, the pomegranate is highly susceptible to postharvest losses. The losses are due to preharvest, and postharvest factors such as diseases attack (Munhuweyi, Lennox, Meitz-Hopkins, Caleb & Opara, 2016), bruise damage (Hussein et al., 2019), high rates of transpiration and respiration of fruit resulting to weight loss and quality loss during storage (Lufu, Ambaw & Opara, 2019 and 2020; Fawole & Opara, 2013a). To ensure that losses are reduced on-farm and along the value chain, technological innovations in maturity management (Fawole & Opara, 2013b, 2014; Arendse, Fawole & Opara, 2015), postharvest handling and packaging (Mukama, Ambaw & Opara, 2020; Hussein, Fawole & Opara, 2019; Arendse, Fawole, Magwaza, Nieuwoudt & Opara, 2018; Belay, Caleb & Opara, 2017; Fawole & Opara, 2013), cold storage (Arendse et al., 2015; O'Grady, Sigge, Caleb & Opara, 2014), controlled atmosphere storage (Mugode, 2017), sensors for non-destructive measurement of quality attributes and internal defects (Magwaza & Opara, 2014; Arendse, Fawole, Magwaza & Opara, 2018) and postharvest treatments (Fawole, Atukuri, Arendse & Opara, 2020; Atukuri, Fawole & Opara, 2017), have proven to be important in the pomegranate industry.

In the South African pomegranate industry, postharvest fruit losses is only assessed at the packhouse level (POMASA, 2019). This has made it difficult to have comprehensive data on the magnitude of losses and waste along the value chain. The lack of reliable data on pomegranate fruit losses and causes at local and global levels (Kahramanoglu, 2019) limits the development of evidence-based solutions that could be tailored to specific hotspots to reduce losses and waste. However, it is important to mention that whether postharvest losses and waste of pomegranate fruit are measured or not, the impacts of the losses and waste remain and are proportionate to the amount lost or wasted. This study identified the causes and magnitude of postharvest losses of pomegranate fruit at farm and packhouse levels and estimated the implications on revenue, the environment, natural resources, food and nutritional security.

5.2.1 Implication of on-farm postharvest losses

At the farm level, environmental factors resulting in fruit with sunburn, cracks and splits were the leading causes of loss in the three pomegranate cultivars (Acco, Hershkawitz and Wonderful) studied. Environmental factors accounted for 43.9% of all on-farm losses. Mechanical damage, including bruises, superficial injuries and microbial factors (causing decay and spoilage) also contributed to significant fruit loss. The huge losses of 'Wonderful' estimated at 19.7 to 20.1% at the farm were because of the anticipated national lockdown due to the Covid-19 pandemic, which forced the farmer to strip the 'Wonderful' trees in one harvest instead of the usual practice of three harvests (early, mid and late).

The magnitude of pomegranate fruit losses at the farm level ranged from 15.3 to 20.1%, and for individual cultivar, ranging from 15.8 to 16.5% for 'Acco', 15.3 to 16.2% for 'Hershkawitz', and 19.7 to 20.1% for 'Wonderful'. Evidence on the causes of loss indicated that 'Acco' has the highest incidence of fruit loss due to insect damage, bruise and Alternaria. The highest incidence of injury, crown rot, and decay occurred in 'Hershkawitz' while losses due to misshapen and undersize, over-size, sunburn, crack, and blemishes were highest in 'Wonderful'. These findings underscore the need for a cultivar-specific approach in efforts to reduce pomegranate fruit losses and waste.

The implication of pomegranate fruit losses on the capital invested for production, the environment, natural resources, food and nutritional security are enormous and cannot be overemphasized. Based on the findings of this study, the economic, environmental and resources impacts of pomegranate losses at the farm level (Blydeverwacht farm, Wellington, Western Cape Province, South Africa), the national level (South Africa) and global level are summarised in Table 5.1. The total physical loss at the global level was estimated at 660,440 tonnes with a revenue loss of R59.43 billion ($3.4 billion). The GHG emission associated with the loss was about 317 million CO_2 eq and energy wasted to produce the lost fruit estimated at 4.02 billion MJ. Water was also wasted to produce the lost fruit. The total water wasted was estimated at 601 million m^3 and land used to produce lost fruit estimated to be about 17,174.02 ha. These represent a huge loss of revenue and natural resources that would, otherwise, been utilised for other beneficial purposes.

Additionally, the impacts of the losses on food and nutritional security are summarised on selected essential nutrients and estimated at the farm level (Blydeverwacht farm, Wellington, Western Cape Province, South Africa), national level (South Africa) and global level based on the incidence of losses in South Africa and presented in Table 5.2. A substantial amount of essential nutrients were lost at the global level due to postharvest losses. The amount of fruit lost could meet the daily recommended nutrition intake of 1,322-132,240 people in varying proportion according to the various nutrients. Nutrients such as ascorbic acid, dietary fibre, calcium, magnesium and iron have a very important role in human health and are needed in a time that a third of the world population suffer from malnutrition (Keatinge et al., 2010). Also, the negative impacts of the Covid-19 pandemic on food system globally has reduced food availability; therefore, reducing postharvest wastage would mean that more food would be available to meet the global food demand.

Strategies to reduce pomegranate postharvest losses at farm level should be tailored towards reducing the damage caused by environmental factors on fruit since sunburn, crack and splits accounted for the highest incidence of losses. Mechanical damage such as bruise and superficial injuries also contributed to significant losses at the farm. Therefore, more cautious harvesting and handling techniques are required at the farm level. Also, preharvest practices such as pruning and application of pesticides may cause mechanical damage and skin blemish, respectively, and therefore should be done more prudently.

Table 5.1: Summary of the magnitude of pomegranate fruit losses impacts at the farm, South Africa and global levels.

Factor	Blydeverwacht farm	South Africa	Global
Production area (ha)	17.60	1024.00	98,701.29
Production volume (tonnes)[*]	677.60	39424.00	3.80×10^6
Average loss (%)	17.38	17.38	17.38
Retail price (R/kg)[a]	89.99	89.99	89.99
Estimated physical and economic losses			
Physical loss (tonnes)	117.76	6,851.89	660,440.00
Monetary loss (ZAR)	10.50×10^6	616.60×10^6	59.43×10^9
Environmental impacts			
Estimated GHG emission (CO_2 eq)[b]	56.50×10^3	$3{,}288.00 \times 10^3$	317.01×10^6
Estimated energy used (MJ)[c]	718.00×10^3	41.79×10^6	4.02×10^9
Resource impact			
Water footprint (m^3)[d]	107.10×10^3	$6{,}235.20 \times 10^3$	601.00×10^6
Equivalent land used to produce lost fruit (ha)	3.00	177.97	17,174.02

[*] Production statistics is based on POMASA (2019).

[a] Supermarket retail price in Stellenbosch, Western Cape, South Africa.

[b,c] Impacts per unit fruit produced estimated from González et al. (2011).

[d] Impact per unit fruit produced estimated from Mekonnen & Hoekstra (2011).

Table 5.2: Summary of selected nutritional impacts of pomegranate fruit losses at Blydeverwacht farm, national level (South Africa) and global levels.

	Blydeverwacht farm		**National (South Africa)**		**Global**		
Nutrition factor	Amount lost ($mg100^{-1}g$)*	Nutritional loss (per capita/day)**	Amount lost ($mg100^{-1}g$)*	Nutritional loss (per capita/day)**	Amount lost ($mg100^{-1}g$)*	Nutritional loss (per capita/day)**	Role of nutrient in human health
Fibre	58.88##	2.00	3425.94##	137.00	330×10^{3}##	13224.00	Digestibility (Grundy et al., 2016)
Carbohydrate	1165.82##	9.00	67833.71##	522.00	654×10^{4}##	50353.00	Energy source (Smith et al., 2017)
Protein	164.86##	4.00	9592.64##	209.00	925×10^{3}##	20123.00	Energy source (Evans et al., 1983)
Iron	35.32	2.00	2055.56	114.00	198×10^{3}	11020.00	Oxygen transport (Brussaard et al., 1997)
Ascorbic acid	1766.40	24.00	102778.35	1370.00	991×10^{4}	132240.00	Antioxidant (Xu et al., 2017)
Calcium	3532.80	4.00	205556.70	206.00	198×10^{5}	19836.00	Bone formation (Flynn, 2003)
Magnesium	1413.12	5.00	82222.68	265.00	793×10^{4}	25595.00	Better lung function (Britton et al., 1994)
Sodium	471.04	1.00	27407.56	14.00	264×10^{4}	1322.00	Blood pressure regulation (Chen et al., 2016)
Potassium	20136.96	4.00	1171673.19	249.00	113×10^{6}	24056.00	Fluid regulation (Seifter, 2019)

* Amount lost is based on Paul & Shaha (2004).

** Nutritional loss is based on Spiker et al. (2017).

Amount lost are estimated in $g100^{-1}g$.

5.2.2 Implications of packhouse postharvest loss

The results at the packhouse level showed that losses are majorly due to market standard and handling (bruises and superficial injuries). Fruit with a slight sunburn, blemish decay, superficial injuries, cracks and misshapen fruit does not meet market standards, and therefore, are not marketable. This is an indirect (secondary) source of postharvest loss. Losses due to handling are direct and affect the fruit physically as primary sources of loss.

Environmental factors such as sunburn and crack accounted for the highest incidence of loss at the packhouse and contributed to 49.44% of total losses. Mechanical damage also contributed to significant losses of 37.84%. Other factors such as microbial and pathological, biological, irregular fruit shape and sizes accounted for a small amount of losses. The results agree with the historical packhouse records in recent years.

The magnitude of loss ranged from 6.74 to 7.69% at the packhouse, and the incidence of loss was highest in 'Wonderful' with 7.69% and 7.14% in 'Herskawitz'. 'Acco' accounted for the least incidence of loss with 6.74%. Losses at the packhouse seem low but could reach up to 328.79 tonnes annually because of the volume of pomegranate fruit handled at the packhouse. This amount of loss has a huge cost on the farmers and food value chain actors, the environmental, natural resources, food and nutritional security. The implication of pomegranate losses at Sonlia packhouse, Wellington, in the Western Cape Province of South Africa was summarised and presented in Table 5.3. Losses at the packhouse level globally was estimated at 224,792 tonnes, which translates to about R20.22 billion ($1.2 billion). The energy used to produce the lost fruit was estimated at 1.37 billion MJ, and the GHG emitted estimated at 107.90 million CO_2 eq. Water wasted to produce the lost fruit was estimated at 204.56 million m^3, and about 5838.77 ha of land was used to produce the lost fruit. Although most of the losses at the packhouse level originated from the farm, where the fruit were deemed marketable, there was a considerable amount of loss from packhouse operation that resulted in bruise damage and superficial injuries.

Additionally, the impacts of the losses on food and nutritional security were summarised on selected essential nutrients and estimated at the packhouse level (Sonlia packhouse, Wellington, Western Cape Province, South Africa), national level (South Africa) and global level based on the incidence of losses in South Africa and presented in Table 5.4. The amount of nutrition loss at the global level could meet the daily recommended nutrition intake of 450-

44,959 people in varying proportion according to the various nutrients. This means that the loss of pomegranate fruit at the global level contributes to global food and nutrition insecurity.

Strategies to reduce pomegranate postharvest losses at the packhouse level should be tailored towards reducing the damage caused by mechanical damage such as bruise and superficial injuries. This could involve the use of innovative technologies to dictate internal diseases along the packhouse processing line rather than fruit sorters opening fruit in suspect of diseases, which often is false. Additionally, adequate training is required generally about improved pomegranate fruit handling to reduce bruise damage and fruit losses.

Table 5.3: Summary of the magnitude of pomegranate fruit losses impacts at packhouse, South Africa and global levels.

Factors	**Sonlia Packhouse**	**South Africa**	**Global**
Production volume (tonnes)[*]	4592.00	32572.11	3139 x 10^3
Average loss (%)	7.16	7.16	7.16
Retail price (R/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 $\times 10^6$	209 $\times 10^6$	20229 x 10^6
Environmental impacts			
Estimated GHG emission (CO_2 eq)[b]	157 $\times$ 10^3	1 $\times$ 10^6	107 $\times$ 10^6
Estimated energy used (MJ)[c]	2 $\times$ 10^6	14 $\times$ 10^6	1371 $\times$ 10^6
Resource impact			
Water footprint (m^3)[d]	299 $\times$ 10^3	2122 $\times$ 10^3	204,561 $\times$ 10^3
Equivalent land used to produce lost fruit (ha)	8.54	60.58	5838.77

[*] Production statistics is estimated from Sonlia packhouse - Muller (2020).

[a] Supermarket retail price in Stellenbosch, Western Cape, South Africa.

[b,c] Impacts per unit fruit produced estimated from González et al. (2011).

[d] Impact per unit fruit produced estimated from Mekonnen & Hoekstra (2011).

Table 5.4: Summary of selected nutritional impacts of pomegranate fruit losses at Sonlia packhouse, national level (South Africa) and global levels.

	Sonlia packhouse		**National (South Africa)**		**Global**	
Nutrition factor	Amount lost ($mg100^{-1}g$)*	Nutritional loss (per capita/day)**	Amount lost ($mg100^{-1}g$)*	Nutritional loss (per capita/day)**	Amount lost ($mg100^{-1}g$)*	Nutritional loss (per capita/day)**
Fibre	164.39##	7.00	1166.08##	47.00	112×10^{3}##	4496.00
Carbohydrate	3255.02##	25.00	23088.38##	178.00	222×10^{4}##	17119.00
Protein	460.30##	10.00	3265.02##	71.00	314×10^{3}##	6842.00
Iron	98.64	5.00	699.65	39.00	67×10^{3}	3747.00
Ascorbic acid	4931.85	66.00	34982.40	466.00	337×10^{4}	44959.00
Calcium	9863.70	10.00	69964.80	70.00	674×10^{4}	6744.00
Magnesium	3945.48	13.00	27985.92	90.00	269×10^{4}	8702.00
Sodium	1315.16	1.00	9328.64	5.00	899×10^{3}	450.00
Potassium	56223.09	12.00	398799.40	85.00	384×10^{5}	8179.00

* Amount lost is based on Paul & Shaha (2004).

** Nutritional loss is based on Spiker et al. (2017).

Amount lost are estimated in $g100^{-1}g$.

5.2.3 Cumulative postharvest loss implications

The study has revealed the potential impacts of postharvest losses of pomegranate fruit at farm, packhouse, national (South Africa) and global levels. The estimated cumulative impacts of pomegranate fruit losses at farm and packhouse at the national and global levels are summarised in Table 5.5. This showed significant implications on the economy as huge revenue is lost. There are also implications for the environment and natural resources.

The annual cumulative physical loss at national (South African) level is estimated at 9184.05 tonnes. This amount of loss is double the export from South Africa in 2015, where total export was 4172.13 tonnes (POMASA, 2016). The cumulative revenue loss due to lost fruit was estimated at R826,472,659.50 ($50,219,211.90). The amount is equal to 43% of the R1,906,538,769 anticipated revenue in the 2019/2020 Special Adjustments Budget of the Stellenbosch Municipality (Stellenbosch Municipality, 2020). The implication of this is that a large amount of revenue is lost to the detriment of farmers and the value chain actors. Additionally, about 4,408,344 CO_2 eq of GHG is estimated to be emitted annually by the production of lost pomegranate fruit in South Africa. Getting rid of the GHG emitted by lost pomegranate fruit is equivalent to removing 2,626 cars off South African roads in a year at 4.6 metric tons per passenger vehicle (EPA, 2018). The energy wasted to produce the lost fruit was estimated at 56,022,705 MJ. Given the crisis in the South African energy sector, which leads to frequent load shedding, the amount of energy wasted to produce lost fruit could benefit 6,877 households in a year at 6.20 kWh per day per household (Eskom, 2020). The cumulative water wasted to produce lost fruit was estimated at 8,357,485.5 m^3, and this amount of water could meet the daily water requirement of about 91,588 households of 5 persons in the country for a year at 0.05 m^3 consumed per person per day (Gleick & Iwra, 1996). Furthermore, about 238.55 ha of land is used to cultivate lost fruit. This is equivalent to the total pomegranate cultivated land area of Limpopo, Eastern Cape and Free State Provinces of South Africa (POMASA, 2020).

Table 5.5: Summary of estimated cumulative on-farm and packhouse losses in South Africa and globally.

Factors	South Africa	Global
Estimated physical and economic losses		
Physical loss (tonnes)[*]	9,184.05	885,232.50
Monetary loss (ZAR)[a]	826×10^6	$79{,}662 \times 10^6$
Environmental impacts		
Estimated GHG emission (CO_2 eq)[b]	$4{,}408 \times 10^3$	$424{,}911 \times 10^3$
Estimated energy used (MJ)[c]	$56{,}022 \times 10^3$	$5{,}399 \times 10^6$
Resource impact		
Water footprint (m^3)[d]	8357×10^3	$805{,}561 \times 10^3$
Equivalent land used to produce lost fruit (ha)	238.55	23, 012.79

[*] Production statistics are estimated from farm and packhouse volume of production and Kahramanoglu (2019).

[a] Supermarket retail price in Stellenbosch, Western Cape, South Africa.

[b,c] Impacts per unit fruit produced estimated from González et al. (2011).

[d] Impact per unit fruit produced estimated from Mekonnen & Hoekstra (2011).

5.3 Limitations and assumptions of the study and future research prospects

This study was conducted on one farm and one packhouse in the Western Cape, the major pomegranate fruit growing region, which accounts for over 81 percent of total production in South Africa (POMASA, 2019). It would be interesting to see how the causes and the magnitude of pomegranate fruit loss interact between several farms and packhouses with different preharvest and postharvest practices. The incidence of fruit losses at the farm and packhouse levels were extrapolated to the national and global and the mean retail price of pomegranate fruit in supermarkets in Stellenbosch was used to estimate the monetary return and financial value of fruit losses at farm, national and global level. However, in practice, both the magnitude of fruit losses and the retail price will vary due to cultivar, geographical location, season, and type of supply chain. These assumptions permit useful estimation of losses and their impacts to inform food loss reduction policy and the implementation of reduction strategies. The methodology used in this study can be readily adopted and applied for an in-depth analysis of specific fruit type and supply chain. Furthermore, to simplify the analysis, fruit quality losses such as loss of characteristic colour, texture and content of nutrients, which often result in downgrading, were not quantified.

The scope of the current research study was at the farm and packhouse levels; however, it is well documented that considerable amount of fruit losses and waste also occur at retail (Mattsson, Williams & Berghel, 2018) and consumer (Porat et al., 2018) levels. The future prospect would be to conduct similar studies down the value chain to include distribution/wholesale, retail and consumer homes. This would provide a comprehensive data at the national (South African) level and identify the hotspots for losses down the value chain so that loss reduction strategies would be tailored to the identified hotspots.

5.4 Conclusion

This study has shown that more than 17% of the pomegranate fruit produced in South Africa may be lost annually due to a combination of losses immediately after harvest (15.3 to 20.1%) and at the packhouse (6.74 to 7.69 %). A wide range of preharvest (environmental and orchard management) and postharvest handling factors contribute to these losses. Overall, environmental stresses resulting in sunburn, cracks and splits, as well as harvesting and postharvest handling practices resulting in bruises and other superficial blemishes account the majority of losses and downgrading of pomegranate fruit. These losses result in considerable monetary losses as well as negative impacts on the environment and natural resources used in agriculture and other socio-economic sectors. These findings have highlighted the need for action to reduce postharvest loss of pomegranate fruit as well as the negative impacts on revenue, climate change, resource conservation, energy security, and nutrition security. While this study has provided valuable data on pomegranate fruit losses in South Africa based on the physical appearance of the fruit, it is that actual magnitude of losses will be higher if internal fruit quality is considered. Assessing fruit loss by manually or mechanically cutting open will amount to a huge waste of otherwise wholesome fruit; however, recent advances in non-destructive quality inspection (Magwaza & Opara, 2014; Arendse et al., 2018) offer considerable promise to contribute for more accurate and reliable estimation of postharvest food losses from farm to fork because they offer the ability to assess fruit both externally and internally.

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