Quantity and quality losses of 'Crimson Seedless' grape and 'Packham's Triumph' pear along the supply chain and associated impacts

by Anelle Blanckenberg

Dissertation presented for the degree of
Doctor of Philosophy (Agricultural Sciences)

at
Stellenbosch University
Department of Horticultural Sciences, Faculty of AgriSciences

Supervisor: Professor Umezuruike Linus Opara
Co-Supervisor: Professor Olaniyi Amos Fawole

April 2022

DECLARATION

By submitting this dissertation electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

March 2022

DEDICATION

To Bill Hulme

with love

ACKNOWLEDGEMENTS

The funding of the South African Research Chairs Initiative of the Department of Science and Technology and National Research Foundation for this research is hereby acknowledged.

On a more personal note

First and foremost, I would like to express my sincere gratitude and appreciation to my supervisor Prof. Umezuruike Linus Opara, for granting me the opportunity and for his mentorship.

My co-supervisor Prof. Olaniyi Fawole, for his guidance and support during the course of this research.

Dr Christo Wiese and the Karsten Group for allowing me do research on their farms and trusting me with data not usually shared.

Bill, for your undying love and committed support.

My parents for their love and profuse encouragement.

The Creator for granting me health, strength and walking with me.

This work is based on the research supported wholly by the National Research Foundation of South Africa (Grant Numbers: 64813). The opinions, findings, conclusions, or recommendations expressed are those of the author(s) alone, and the NRF accepts no liability whatsoever in this regard.

SUMMARY

Postharvest loss and waste (often referred to as wastage) is a global problem affecting all produce along the supply chain from farm to plate. These losses not only decrease food supply but also mean that huge amounts of the resources and effort used in the production of horticultural crops are squandered. From an economic perspective, addressing postharvest losses is not only helpful to producers aiming to sell more, but also to consumers who could save money as the available food becomes more affordable. To date, there is little scientific data available on the incidence and magnitude of postharvest losses of fruit and other food crops in South Africa.

The aims of this study were to assess postharvest losses in quantity and quality of 'Crimson Seedless' table grape and 'Packham's Triumph' pear along the supply chain and quantify the associated economic, environmental and resource impacts in order to inform mitigating actions.

The base measurement for table grape losses occurred in the packhouses of four farms in the Western Cape during the commercial harvest. The highest quantity (%) of physical losses in the supply chain was found to occur at this level when compared to the cold storage (2 or 4 weeks at -0.3°C ± 0.7°C and 81.3% ± 4.1% RH), retail (10 days at 5.4°C ± 0.6°C and 83.7% ± 2.9% RH) and consumer/home (ambient) storage (25.1 ± 1.3°C and 46.6 ± 6.0% RH) stages. There were large differences between the 2017 and 2018 seasons, with the 2018 season's losses being half that of the first. The main reason for losses at the packhouse level was mechanical damage (7.1% in 2017 and 3.09% in 2018) due to rough handling of crates and could be improved by making workers more aware of the necessity to handle crates with care. Harvest timing is also essential, as delayed harvesting reduces shelf life and increases postharvest losses, as evidenced by this research. The farm that sustained the highest losses in 2017 (23.3%) harvested later than was optimal, and therefore, the bunches stayed on the vines too long. In 2018 the harvest occurred two weeks earlier than in 2017, and the grapes were in better condition leading to fewer losses on farm level (5.85%).
Among all supply chain scenarios, the main quality problem was rachis and stem browning at temperatures higher than -0.5ºC. This caused berries to drop faster and bunches to look less fresh, as well as causing bunches to weigh less when sold. While

500 g and 1 kg punnets are routinely kept at around 5ºC at the retail level, during peak season 4.5–10 kg cartons are often stacked on the floor under ambient conditions. Therefore, the table grapes would have a maximum shelf life of seven days before the stems have browned and too many berries per bunch are decayed to sell. Therefore, it is advisable to keep cartons at -0.5ºC and high RH and only place bunches in punnets in 5ºC display fridges as the stock sells.

The base measurement for losses of pear occurred in the orchard of two farms in the Western Cape during commercial harvest. It was found that 18% of the harvest on the one farm and 19% of the harvest on the other, did not reach the minimum quality standards. The main reasons were deformed fruit and too small size. The only decay, among all supply chain scenarios, occurred when pears were kept under ambient conditions (25.1 ± 1.3°C, 46.6 ± 6.0% RH) where 3.3% were decayed after seven days and 6.6% after 10 days. The majority of physical losses were due to weight loss with a 3.9%, 3.6 and 3.7% decrease in weight for supply chain Scenario B (to local retail markets), supply chain Scenario C (to export retail markets) and supply chain Scenario D (simulated 'abusive' treatment of fruit within the export chain) respectively.

.

Of the data gaps in the existing knowledge on global food loss and waste, the largest gap is the lack of available data on postharvest losses, retail and household level (shelf-life) food waste data. Therefore, this study contributed to the advancement of new knowledge by generating primary data on postharvest quantity and quality losses along the supply chain to manage the food loss and waste problem better.

OPSOMMING

Na-oes verliese en vermorsing is 'n wêreldwye probleem wat alle produkte in die voorsieningskettings van plaas tot bord beïnvloed. Hierdie verliese verminder nie net die voedselvoorraad nie, maar beteken ook dat groot hoeveelhede van die hulpbronne en moeite wat in die produksie van tuinbougewasse gebruik word, vermors word. Vanuit 'n ekonomiese oogpunt is die vermindering van na-oesverliese nie net nuttig vir produsente wat meer wil verkoop nie, maar ook vir verbruikers wat geld kan bespaar namate die beskikbare voedsel meer bekostigbaar word. Tot op hede is daar min wetenskaplike data beskikbaar oor die voorkoms en omvang van na-oesverliese van vrugte en ander voedselgewasse in Suid-Afrika.

Die doel van hierdie studie was om na-oes verliese in hoeveelheid en kwaliteit van druiwe 'Crimson Seedless' en pere 'Packham's Triumph' deur die verskaffingsketting te meet en die gepaardgaande ekonomiese, omgewings- en hulpbronimpakte te bereken om ingeligte besluite te kan maak wat na-oesverliese verminder.

Die basismeting vir tafeldruifverliese het tydens die kommersiële oes in die pakhuise van vier plase in die Wes -Kaap plaasgevind. Die grootste hoeveelheid (%) fisiese verliese in die voorsieningsketting het op hierdie stadium voorgekom in vergelyking met die verkoelde opberging (2 of 4 weke by -0.3°C ± 0.7°C en 81.3% ± 4.1% RH), kleinhandel (10 dae by 5.4°C ± 0.6°C en 83.7% ± 2.9% RH) en verbruiker (25.1 ± 1.3°C en 46.6 ± 6.0% RH) stadiums. Daar was groot verskille tussen die 2017- en 2018-seisoene met 2018 se verliese die helfte van die gedurende die 2017-seisoen. Die hoofrede vir verliese op pakhuisvlak was meganiese skade (7.1% in 2017 en 3.09% in 2018) as gevolg van rowwe hantering van kratte en kan verbeter word deur werkers meer bewus te maak van die noodsaaklikheid om kratte versigtig te hanteer. Oestydsberekening is ook noodsaaklik, aangesien vertraagde oes raklewe verminder en lei tot verhoogde na-oes verlies soos bewys deur hierdie navorsing. Die plaas wat die hoogste verliese in 2017 gely het (23.3%) het later as optimaal geoes en die trosse het dus te lank aan die stokke gebly. In 2018 het die oes twee weke vroeër as in 2017 plaasgevind, en die druiwe was in 'n beter toestand wat gelei het tot minder verliese op plaasvlak (5.85%). Die belangrikste kwaliteitsprobleem was rachis en stingel verbruining by temperature hoër as -0,5ºC. Dit het veroorsaak dat bessies vinniger val en dat trosse minder vars lyk, asook dat trosse minder weeg as hulle verkoop word.

Terwyl 500 g of 1 kg plastiek bakkies gereeld by ongeveer 5ºC op kleinhandelvlak gehou word, word 4,5 –10 kg kartonne dikwels op die vloer gestapel tydens piek seisoen by kamer temperatuur en humiditeit. Die tafeldruiwe sou dus 'n maksimum rakleeftyd van sewe dae hê voordat die stingels verbruin en te veel bessies per tros vrot om te verkoop. Dit word dus aanbeveel dat kartonne by -0,5ºC en hoë RH gehou word en trosse slegs in bakkies in 5ºC yskaste geplaas word soos die voorraad verkoop.

Die basismeting vir verliese van pere het tydens die kommersiële oes in die boord van twee plase in die Wes-Kaap plaasgevind. Daar is gevind dat 18% van die oes op die een plaas en 19% van die oes op die ander plaas nie die minimum kwaliteitstandaarde bereik het nie. Die hoofredes was misvormde en te klein vrugte. Die enigste bederf, onder alle voorsieningskettingscenario's, het plaasgevind toe pere by kamer-temperatuur en humiditeit (25.1 ± 1.3°C, 46.6 ± 6.0% RH) gestoor is waar 3.3% na 7 dae en 6.6% na 10 dae bederf het. Die meerderheid fisiese verliese was as gevolg van gewigsverlies met 'n 3.9%, 3.6 en 3.7% afname in gewig vir voorsieningsketting Scenario B (na plaaslike kleinhandelmarkte), voorsieningsketting Scenario C (om kleinhandelmarkte uit te voer) en voorsieningsketting Scenario D (gesimuleerde swak hantering van vrugte in die uitvoerketting) onderskeidelik.

Die grootste gaping in die bestaande kennis oor wêreldwye voedselverliese en vermorsing, is die gebrek aan beskikbare data oor na-oesverliese, kleinhandel- en huishoudelike vlak (rakleeftyd). Hierdie studie het dus ten doel gehad om nuwe kennis by te dra deur primêre data oor na-oesvelies hoeveelheid en kwaliteitverliese in die voorsieningsketting te genereer om sodoende die voedselverlies- en afvalprobleem beter te bestuur.

PUBLICATIONS AND CONFERENCE PRESENTATIONS FROM THIS DISSERTATION

Peer reviewed journal publications

Blanckenberg, A., Fawole, O.A., Opara, U.L. (2022). Postharvest losses in quantity and quality of Pear (cv. Packham's Triumph) along the supply chain and associated economic, environmental and resource impacts. Sustainability, 14, 603. https://doi.org/10.3390/su14020603

Blanckenberg, A., Opara, U.L. and Fawole, O.A. (2021). Postharvest losses in quantity and quality of Table Grape (cv. Crimson Seedless) along the supply chain and associated economic, environmental and resource impacts. Sustainability, 13, 4450. https://doi.org/10.3390/su13084450

Blanckenberg, A., Fawole, O.A. and Opara, U.L. (2018). Quantifying postharvest losses of 'Crimson Seedless' table grapes along the supply chain. Acta Horticulturae. 1201, 29-34. https://doi.org/10.17660/ActaHortic.2018.1201.5

Conference presentations

Blanckenberg, A., Fawole, O.A. and Opara, U.L. (2021). Postharvest losses in quantity and quality of Table Grape (cv. Crimson Seedless) along the supply chain and associated economic, environmental and resource impacts. Presented at the 3rd All Africa Postharvest Congress and Exhibition, Addis Ababa, 13-16 September.

Blanckenberg, A., Fawole, O.A. and Opara, U.L. (2017). Quantifying postharvest losses of table grapes 'Crimson Seedless' along the supply chain. Presented at the VII International Conference on "Managing Quality in Chains" & II International Symposium on Ornamentals in association with XIII International Protea Research Symposium, Stellenbosch University, 4-7 September.

TABLE OF CONTENTS

CHAPTER 1
GENERAL INTRODUCTION AND OBJECTIVES

1. Background

High incidence of postharvest loss has been identified as one of the major global challenges of the 21st century as efforts increase to reduce hunger, improve food security, and use natural resources sustainably. Various international organizations conducting research, under the auspices of the Food and Agriculture Organization of the United Nations (FAO), indicated that a third of all food produced globally and almost half of all fruit and vegetables are never consumed (Porat et al., 2018).

In addition, lost and wasted produce consume a quarter of all the water used by agriculture annually, requires farmland area the size of China, and generates an estimated 8% of global greenhouse gas emissions. In effect, if lost and wasted food were a country, it would be the third largest greenhouse gas emitter after China and the United States (Smil, 2004; Parfitt et al., 2010; FLW Protocol, 2016).

The issue of postharvest loss prevention has become very important globally. Reducing postharvest loss is more cost effective and less time consuming than strategies to increase production. Therefore, instead of putting all efforts into increasing food production, reducing the inefficiencies that exist throughout our supply chains will significantly increase food availability and security while also promoting environmental sustainability (FAO, 2011; Shafiee-Jood and Cai, 2016; Munhuweyi et al., 2016).

Clear knowledge of the magnitude of postharvest losses and identifying the causes are a crucial first step without which it is impossible to monitor the results of mitigating actions or policy changes. This knowledge is also essential in order to determine how to control and reduce losses over time and space (Kafa and Jaegler, 2021). The past decades have seen a growing body of literature on the quantification of postharvest losses across supply chains at global, regional, and national levels. Yet, despite these increased efforts, several researchers have highlighted concerns on contradictions and the absence of data, calling for more research (Rutten, 2013; Affognon et al., 2015; Xue et al., 2017).

Measuring postharvest losses and food waste is complex and highly variable depending on the country being considered, which commodity is investigated, the circumstances under which the food is being handled, and the length of time the food is stored (Kitinoja and Kader, 2015). At whatever level of precision postharvest fruit loss is defined, the value will be specific to that time and location (Matare, 2012). It is, therefore, important that research generate accurate data for a specific food product, such as fruit, for a particular region and that these efforts continue over time.

Fruit production and export marketing is a major contributor to the South African economy through the supply of nutrients, employment, and income. Many rural communities in South Africa, such as in the Western Province, depend largely on fruit production, processing, and trade. While it is estimated that fruit and vegetables account for around 47% of the overall postharvest loss in South Africa, that figure does not include losses at the primary production level (Oelofse and Nahman, 2013). Part of the problem lies in sourcing operational data from stakeholders. In addition, the competitive nature of the industry also negatively influences the sharing of information, including the incidence of losses (Louw, 2017).

This study will therefore focus on measuring postharvest losses in quantity and quality of table grape (cv. Crimson Seedless) and pear (cv. Packham's Triumph) along the supply chain in the Western Cape Province of South Africa and calculate the associated economic, environmental and resource impacts thereof.

2. Aim and Specific objectives

2.1. Research Aim

This dissertation aimed to provide the first scientific measurement of postharvest loss of fruit along the supply chain in South Africa.

2.2. Specific Objectives

The specific objectives of this study were to:

a) Analyse farm packhouse data in order to compare it with direct sampling data of losses and determine whether the farm data is accurate or whether losses may be greater than perceived by industry.

b) Measure postharvest losses in quantity and quality of ‘Crimson Seedless’ table grapes at packhouse level, after two weeks of cold storage for the local markets and four weeks cold storage for the international markets followed by 10 days under retail conditions and shelf life of 3, 7 and 10 days.
c) Measure postharvest losses in quantity and quality of ‘Packham’s Triumph’ pears at orchard level, after two weeks of cold storage for the local markets and four weeks cold storage for the international markets followed by 10 days under retail conditions and shelf life of 3, 7 and 10 days.
d) Quantify the impacts of these losses in terms of economic, environmental and resource costs.

3. Thesis structure

This dissertation is structured into five (5) chapters, each addressing a research focus.

Chapter 1 provides a brief background and discusses the research aims and objectives (General introduction).

Chapter 2 is a literature review, which provides an overview of the causes of postharvest losses in fruit, sites where these losses occur, different methods for assessing postharvest losses of fruit, the magnitude of postharvest losses of fruit, as well as the economic and environmental impacts thereof. It is clear from the literature review that there is a dearth of information on scientifically measured losses of fruit through direct sampling, especially studies that start at farm level and continue along the supply chain.

Chapter 3 is a case study of the magnitude of postharvest fruit loss of apples, pears and grapes using historical data provided by eight farms in the Western Cape, South Africa. The data was analysed to evaluate the differences between cultivars and between fruit types. This provided insight into the differences between what farm records state they lose and what is measured through direct sampling.

In **Chapter 4**, the incidence of postharvest losses in quantity and quality of table grape (cv. Crimson Seedless) along the supply chain and the associated economic, environmental and resource impacts were assessed. The base measurement for losses at harvest occurred in the packhouse on each farm after the bunches were trimmed for packaging and the resulting berries sorted into categories based on the reason for being cut from the bunch, 1) berry too green in colour, 2) mechanical damage or 3) decayed. It was quantified as the weight of the berries removed as a percentage of the original weight of the bunches before trimming. At each evaluation date thereafter, physical losses were quantified as the decrease in bunch weight and the amount lost due to decay or SO_2 damage expressed as a percentage of the initial berry numbers per bunch. The data was collected over two seasons and the differences between seasons illustrate how variable these losses can be and why ongoing measurements are important.

Chapter 5 aimed to measure postharvest losses in quantity and quality of pear (cv. Packham's Triumph) along the supply chain and the economic, environmental, and resource impacts. In order to achieve this, farm level losses were measured in the orchards by inspecting full picking bags and quantifying the percentage that would be discarded due to defects or too small size. Thereafter, physical losses were quantified as the decrease in fruit weight as well as the amount lost due to decay. Changes in quality parameters were also measured at each evaluation time.

Chapter 6, the general discussion integrates the results of all the research chapters. It also highlights the practical contribution of the studies to the South African horticultural industry. In particular, it highlights how data obtained in this study can be used by producers, sellers and policymakers to improve the postharvest handling of 'Crimson Seedless' table grape and 'Packham's Triumph' pear.

REFERENCES

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

FAO. (2011) Global Food Losses and Waste. Extent, Causes and Prevention. http://www.fao.org/docrep/014/mb060e/mb060e00.pdf

FLW Protocol (Food Loss and Waste Protocol). (2016). The Food Loss and Waste Accounting and Reporting Standard; World Resources Institute: Washington, DC, USA.

Kafa, N. and Jaegler, A. (2021). Food losses and waste quantification in supply chains: a systematic literature review. British Food Journal, Vol. ahead-of-print No. ahead-of-print. https://doi.org/10.1108/BFJ-09-2020-0879

Kitinoja, L. and Kader, A.A. (2015). Measuring post-harvest losses of fresh fruits and vegetables in developing countries. White paper 15-02, Post-harvest Education Foundation.

Louw, L. (2017). Economic Aspects of Losses and Waste: Case Study of the South African Table Grape Supply Chain. Master' Thesis, Department of Agricultural Economics, Extension and Rural Development, Faculty of Natural and Agricultural Sciences, University of Pretoria, Pretoria, South Africa.

Matare, T., E. (2012). Post-harvest losses and changes in physicochemical properties of fruit (peaches, pears and oranges) at retail and during post-purchase storage. Master Thesis in Food Science, Department of Food Science, Stellenbosch University.

Munhuweyi, K., Opara, U.L. and Sigge, G. (2016). Postharvest losses of cabbages from retail to consumer and the socio-economic and environmental impacts. British Food Journal, 118, 286–300.

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

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

Porat, R., Lichter, A, Terry, L.A., Harker, R. and Buzby, J. (2018). Postharvest losses of fruit and vegetables during retail and in consumers' homes: Quantifications, causes, and means of prevention, Postharvest Biology and Technology, 139, 135-149.

Rutten, M. M. (2013). What economic theory tells us about the impacts of reducing food losses and/or waste: implications for research, policy and practice. Agriculture & Food Security, 2:1, 1−13.

Shafiee-Jood, M and Cai, X. (2016). Reducing food loss and waste to enhance food security and environmental sustainability, Environmental Science & Technology, 50, 8432-8443.

Smil, V. (2004). Improving Efficiency and Reducing Waste in Our Food System. Environmental Sciences, 1, 17-26.

Xue, L., Liu, G., Parfitt, J., Liu, X., Van Herpen, E., Stenmarck, A., O'Connor, C., Ostergren, K. and Cheng, S. (2017). Missing food, missing data? A critical review of global food losses and food waste data, Environmental Science and Technology, American Chemical Society, 51:12, 6618-6633.

CHAPTER 2

LITERATURE REVIEW: QUANTIFYING THE MAGNITUDE AND IMPACT OF POSTHARVEST LOSSES IN THE FRUIT SECTOR

TABLE OF CONTENTS

Abstract

A major challenge to global food security is postharvest losses. With rapidly growing populations, especially in the poorest countries where food is already in short supply, there is an increased urgency to do a better job of preserving humanity's food supply. Besides the loss of produce that impacts food security, postharvest losses also represent wastage of natural resources used in production. When attempting to mitigate this problem, it is important first to understand the causes. Causes may be direct or indirect. Direct losses occur when the commodity disappears because of spoilage or consumption by insects, rodents, and birds, whereas an indirect loss is the lowering of the quality of the product to the extent that it draws a lower price or is

rejected completely. Losses are also classified as primary or secondary. Primary causes directly affect the produce, such as insects, microorganisms or mechanical damage, while secondary causes include inadequate harvesting, packaging and storage. Losses may occur anywhere along the value chain, from the point where the fruit has been harvested up to the point of consumption. Different methods for assessing postharvest loss exist. Estimates and surveys can be faster and cheaper than sampling, but it is also less accurate. Due to their relative high perishability, horticultural products are particularly vulnerable to postharvest losses. Postharvest losses for a single commodity can vary by season, by country and by the data collection method. South Africa produces vast volumes of fruit every year, yet; there is little scientific data available on postharvest losses in South Africa. Further studies are needed to track various fruits from harvest to consumer to provide more information on handling procedures and the origin of defects associated with losses and downgrading.

1. BACKGROUND

Postharvest loss is one of the most critical issues facing the sustainability of food systems around the world. The Sustainable Development Goals (SDGs) announced by the United Nations in 2015 highlighted the international community's immense concern to decrease postharvest loss between the farm and the plate in global supply chains (Kafa and Jaegler, 2021). Feeding the growing world population, predicted to reach 9.1 billion by 2050 sustainably and affordably, has become a dominant challenge of the 21st century. With rapidly growing populations, especially in the poorest countries where food is already in short supply, there is an increased urgency to do a better job of preserving humanity's food supply to alleviate hunger and malnutrition (Hodges et al., 2011; FAO, 2013). The UN Food and Agriculture Organization (FAO) estimates that to feed the growing world population by 2050 sustainably will require a 70% increase in food production. However, the FAO also reports that a massive one-third of the edible portions of the food produced globally is lost or wasted along the way from farm to plate, which amounts to about 1.3 billion tonnes per year, with 38% of the volume consisting of fruit and vegetables (FAO, 2013; Statista, 2019).

Furthermore, postharvest losses mean that huge amounts of the resources used in food production are squandered (FAO, 2013; FLW protocol, 2016; Statista, 2019). It is indeed disturbing to note the amount of effort and resources being dedicated to the cultivation of the plant, including inputs of labour, irrigation, fertilisation, and crop protection, only to be wasted soon after harvest. Minimising the loss of fresh fruit will, therefore, not only increase our food supply without any new inputs, but will also reduce the use of land, chemicals, energy and other inputs needed to produce horticultural crops, thereby conserving natural resources and protecting the environment (Kader, 2005; Munhuweyi et al., 2016).

From an economic point of view, addressing postharvest losses are not only helpful to producers aiming to sell more but also to consumers who could save money as the available food becomes more affordable (Rutten, 2013). It is, therefore, very important that improvement of postharvest chains receive as much attention as production practices. The past decades have seen a growing body of literature on the quantification of postharvest loss across supply chains at global, regional, and national levels. Yet, despite these increased efforts, several researchers have highlighted concerns on contradictions and the absence of data, calling for more research (Xue et al., 2017). Quantifying postharvest loss is a crucial first step, without which it is impossible to monitor the results of mitigating actions or policy changes. Knowing the magnitude and causes of losses is also essential in determining how to control and reduce losses over time and space (Kafa and Jaegler, 2021).

2. CAUSES OF POSTHARVEST LOSSES OF FRUIT – AN OVERVIEW

2.1 Definition of terms

Differing terms, scopes and definitions of postharvest losses have been employed in research studies. Some of these terms include “postharvest loss” (PHL), “postharvest food loss” (PHFL), “post-harvest loss and waste” (PHLAW) and “food loss and waste” (FLW). Chaboud and Davrion (2017) provided an analysis of the numerous ways that loss and waste are grouped with regards to timing, extent, terminology, criteria and category by separate agencies and states, which showed that more consistency in future data collection efforts is required (Kitinoja et al., 2018).

For the purposes of this review, the following definitions are used (de Lucia and Assennato, 1994; Hodges et al., 2010; FAO, 2011; Chaboud and Davrion, 2017):

‘POSTHARVEST’ implies after separation from the medium and site of immediate growth or production of the food. Postharvest begins when the process of collecting or separating food of edible quality from its site of immediate production has been completed. The food need not be removed any great distance from the harvest site, but it must be separated from the medium that produced it by a deliberate human act with the intention of starting it on its way to consumption.

‘FOOD’ denotes the weight of wholesome edible material that would normally be consumed by humans, measured on a moisture-free basis. Inedible portions such as skins, stalks, leaves, and seeds are not food.

‘POSTHARVEST LOSS’ refers to food products produced for human consumption which have undergone a change in availability, wholesomeness or quality, rendering them unfit for human consumption.

‘FOOD LOSS’ the decrease in quantity or quality of food resulting from decisions and actions by food suppliers in the supply chain, excluding retailers, food service providers and consumers.

‘FOOD WASTE’ refers to the decrease in quantity or quality of food resulting from the decisions and actions by retailers, food service providers and consumers.

2.2 Types of loss

Food losses may be direct or indirect. Direct losses occur when the commodity disappears because of spoilage or consumption by insects, rodents, and birds, whereas an indirect loss is the lowering of the quality of the product to the extent that it draws a lower price or is rejected completely. If people consume the food, it is not lost; if people for any reason do not consume it at all, then it is considered a postharvest food loss. It is usual to describe postharvest losses in terms of loss in weight, but at times it can be more helpful to consider the loss in economic terms or as a loss of nutritional units. (Harris and Lindblad, 1978; Boxall, 2001; Hodges et al., 2014; Kumar and Kalita, 2017). For example, there is a difference between 1 kg of beef lost or 1 kg of lettuce lost. Beef contains more calories than lettuce when considered from a food security perspective; however, beef production requires far more resources than lettuce production and will, therefore, have a larger impact on natural resource conservation (Chaboud and Davrion, 2017).

2.3 Causes of losses

Postharvest losses can be *quantitative* (e.g., physical weight losses) and *qualitative* (e.g., loss in edibility, nutritional quality, caloric value, consumer acceptability, etc.) (World Bank et al., 2011). There are so many causes of loss in the postharvest food chain that it helps classify them into two main groups, primary and secondary causes, with sub-groupings.

2.3.1 Primary causes of loss

These are causes that directly affect the food. They may be classified further into the following groups:

Biological

Insects, rodents, birds, monkeys and other animals cause weight losses through direct consumption of the food and quality losses due to their excreta, webbing, and some unpleasant odours that can be imparted the food. Allwood and Le Blanc (1997) conducted host surveys in seven Pacific Island countries, where insecticide use was kept to a minimum, losses of fruit caused by fruit flies (Diptera: Tephritidae) was reported to be 12% for papaya, 35-38% for breadfruit, 45-90% for guava, 4% for Orange, 80% for Surinam cherry, 20-25% for mango and 60% for cumquat. Fuentes et al. (2017) reported that the guava weevil (*Conotrachelus dimidiatus*) damage 37.4% of guava fruit in Calvillo, Aguascalientes, Mexico while the small avocado seed weevil (*Conotrachelus perseae*) could cause losses of up to 85% if appropriate control measures are not applied.

Microbiological

A wide variety of microorganisms can cause degradation of fruit, they usually directly consume only a small amount, but they damage the food to the point that it becomes unacceptable because of rotting or by reducing its palatability by inducing offensive taste. Microorganisms contributing to food loss and waste include bacteria, yeast and mould (Bist and Bist, 2021). Species of *Phytophthora*, *Botrytis*, *Geotrichum*, *Aspergillus*, *Penicillium*, *Alternaria*, and Fusarium have been reported as prevalent pathogens contributing to postharvest food losses 10 – 30% in tomatoes (Etebu et al., 2013). *Penicillium expansum*, which causes blue mold rot, can lead to losses of 10 – 30% of stored pear fruit (Amin et al., 2017).

Chemical

Chemical constituents naturally present in stored foods can spontaneously react, causing loss of colour, flavour, texture and nutritional value. An example is the Maillard reaction, also known as non-enzymatic browning (NEB), the most important chemical reaction responsible for quality and colour changes during prolonged storage of citrus products (Bharate and Bharate, 2012). There can also be accidental or deliberate contamination of food with harmful chemicals such as pesticides or lubricating oil.

Biochemical reactions

Off-flavours, discolouration and softening can occur in foods during storage due to a number of enzyme-activated reactions. A limiting factor influencing the economic value of fruit is the short ripening period and reduced shelf life associated with biochemical changes in the cell walls (Payasi et al., 2009).

Mechanical

The most prevalent type of mechanical damage affecting fresh fruit is bruising. Leading to a downgrade in quality, it contributes to physical and income losses in the fruit industry (Opara and Pathare, 2014). Up to 30–40% of fresh produce may be affected by bruising and other types of mechanical damage from harvest to market (Peleg and Hinga, 1986). This amounts to significant financial losses in the fresh produce industry, as reported by Funt et al. (2000) based on their study on the effects of bruising on total returns in the New Zealand apple industry.

Environmental and atmospheric conditions

Extreme temperatures, too hot or too cold, can spoil the fruit. In a case study on the development of cold chains for fresh fruits and vegetable distribution in Indonesia, Waisnawa et al. (2018) report that without cooling, the rate of decay for fresh fruit and vegetable products is very high due to high temperature and humidity. Conversely, when fruit is stored under too cold temperatures, water in the cells form ice crystals which may cause damage that results in tissue softening and browning (Dongmei et al., 2018). At times, controlled atmosphere (CA) storage facilities with improper atmospheric composition due to negligent supervision can also cause losses. (Atanda et al., 2011).

Physiological

Climacteric fruit (such as pear, apple, banana, and peach) are prone to premature ripening due to the production of ethylene, which is accompanied by an increase in respiration rate (Busatto et al., 2017). Natural respiration, the process by which stored food reserves in the fruit (carbohydrates, proteins, fats) is broken down, generates heat and accounts for a significant level of weight loss. It also hastens senescence, reducing the food value and leading to loss of flavour (Kader, 2002). Changes that occur during ripening may also increase the sensitivity of the product to mechanical damage or infection by pathogens. Consumer acceptance and nutritional level may also be reduced with these changes (Alkan and Fortes, 2015).

Postharvest losses of horticultural crops are caused mainly by microbiological, physiological and mechanical factors during postharvest activities such as harvesting, handling, storing, processing, packaging, transporting and marketing. (Mrema and Rolle, 2002, Idah et al., 2007). For example, in a survey of 120 farmers in four local government areas in Nigeria, it was found that 62.5% of postharvest losses of tomatoes was due to mechanical damage (Olayemi et al., 2010). Similarly, Kasso and Bekele (2018), who assessed the causes of postharvest loss of horticultural crops amongst 296 small-scale farmers in Ethiopia, reported that 43.5% of mango losses were attributable to mechanical damage, 35.5% losses of oranges were caused by abrasion, decay and shrinkage while 19.8% postharvest losses of banana was due to decay, softening, bruising and peel split.

2.3.2 Secondary causes of losses

Inadequate or non-existent postharvest practices, deficient technologies and improper techniques used during harvesting, transportation and storage result in suitable conditions for secondary causes of loss to occur. Some examples are:

i. Inadequate harvesting, packaging and handling skills.

   Kitinoja and AlHassan (2012) reported that during the harvesting of litchis, pineapples and bananas in India and Rwanda, the temperatures were much higher than what is recommended for maintaining the quality of the harvest.

Sharma et al. (2018) shares similar results during grape harvesting in India, reporting that harvesting in the early morning hours is better as increased temperature results in more loss of grapes. Rough handling of bunches during harvesting also caused mechanical damage and leaving filled crates in direct sun light for an extended period of time are practices which lead to higher levels of post-harvest losses at the harvesting stage.

ii. Shortage of suitable containers for the transport and handling of perishables. Flimsy containers, open baskets, cloth sacks and dirty, rough wooden crates lead to high postharvest losses. For bananas, 14.8±21.0% (farm), 35.1±33.1% (wholesale) and 30.1±24.4% (retail market) was measured by Kitinoja and AlHassan (2012). Sosa et al. (2016) likewise reports that in Argentina, harvested pears are usually packed and stored in cardboard boxes with nylon bags at 0/-1°C and 95% RH for short or long periods and decay on packed fruit in these boxes are a major concern. While this is standard industry packaging, Sosa et al. (2016) found that when a percentage of fruit has latent grey mould infections, this becomes inoculum for the formation of nests in the cardboard boxes during high RH storage.

iii. Inadequate storage facilities.

Verma & Singh (2004) and Singh et al. (2009) found that inadequate infrastructure and lack of cold storage in developing countries resulted in fresh fruit losses ranging from 20 - 50%.

iv. Inadequate transportation to move the food to market before it spoils.

Yahaya and Mardiyya (2019) provide an example from Nigeria, stating that the transportation of perishable products was the most precarious stage in the supply chain. Produce delivered to local markets are transported by trolley, motorcycles or on the bus resulting in high levels of losses due to physical and mechanical injury and uncontrollable environmental conditions such as temperature and humidity. The magnitude of such losses were not quantified. Iordăchescu et al. (2019) reported losses of 8% for fresh fruit during transportation in European countries; there was no reference to specific fruit type.

v. Traditional processing and marketing systems can be responsible for high losses. Suitable marketing infrastructure is crucial for the efficient marketing of fruit (Hassan, 2010). In Bangladesh, for example, the majority of horticultural products are produced by smallholders, but due to a weak and fragmented supply chain, only a small percentage of the produce reaches urban markets (Minten et al., 2010).

vi. Legal standards can affect the retention or rejection of food for human use by being too lax or unduly strict. A product standard document contains approved specifications on a given product put in place by a consortium of organisations. These standards include mandatory quality requirements that deal with hygiene and cosmetic quality standards, often addressing the size, shape, and colour of the fruit. These standards are intended to optimise the packaging and logistic process and promote trade; however, high cosmetic requirements are partly responsible for a percentage of the production being downgraded. As such, fruit is often processed into other products, and it does not imply food losses. However, high cosmetic quality standards may cause part of the production to disappear from the human food chain ('outgrading'), resulting in losses (Roels and Van Gijseghem, 2017).

vii. Meticulous, informed management is essential for maintaining food in good condition during marketing and storage. According to Bendeković et al. (2015), the 'from the field to the table' strategy tries to completely manage fresh produce's journey from production to the consumer. Many problems can arise along the way from production, during transport and in storage. Therefore, it is important to establish and maintain effective communication between all the subjects involved to preserve fruit quality along the entire production chain.

viii. A very large crop can overload the postharvest handling system or exceed the consumption need and cause excessive wastage. Producers may leave crops without harvesting if, at the time, demand is low and returns cannot cover the cost of harvest and transportation. Farmers overproducing to guarantee the contractual obligation with the buyers can also lead to oversupply and more crops left unharvested (FAO, 2014).

3. SITES OF LOSSES

Losses may occur anywhere along the value chain (Figure 1), from the point where the fruit has been harvested up to the point of consumption (FAO, 2011, Rezaei and Liu, 2017). Of the food lost or wasted globally, 40% is lost during early-stage postharvest and processing in developing countries, while in developed countries, most is wasted during the latter stages of retail and consumption (Bond et al., 201).

a. Losses may occur right after harvest (described as the removal of the product from the plant that produced it). According to Ludwig-Ohm et al. (2019) easily, perishable fruit incurs higher losses at the farm level; for example, according to farmers' estimates, strawberry losses of 15% to 20% were reported while losses for apples were between 6% and 16%. Opara et al. (2021) reported losses for pomegranate at this level to be between 6.74% and 7.69%. Results may vary greatly between years due to the strong influence of favourable or unfavourable weather conditions and the timing of the harvest (Ludwig-Ohm et al., 2019).

b. Losses in quantity and quality occur during transportation. All forms of transportation are used to convey foods from production to the ultimate point of consumption. Most developing countries need an improved transportation system to reduce the time lag between the site of production and the market. The main problems encountered during this phase of the supply chain is poor infrastructure, lack of appropriate transport systems, lack of refrigerated transport, poor temperature management and loading and unloading practices (Iordãchescu et al., 2019). There are several factors that affect produce quality during transport, and it all starts with the initial quality of the fruit at harvest. Locally produced fruits can be quite mature and ripe because the time to market is short. When produce is shipped over great distances, however, it is less mature and must have no mechanical damage or other defects that predisposes it to perceptible quality loss during a long postharvest handling period. Containing different fruit into the same load during transportation also affects shelf life, particularly where high ethylene-producing fruit and ethylene-sensitive commodities are mixed (Kader and Rolle, 2004). George and Mwangangi (1994) found that greater postharvest losses of bananas (increased physical damage incidence and severity) were associated with longer transport distance on poor roads. Idah et al. (2007) reported that 13.89% of fresh tomato fruits were damaged during transportation from farm to market in Nigeria. Kasso and Bekele (2018) reported that the majority of respondents in their study on postharvest losses in Ethiopia believed that problems related to transportation and road conditions were responsible for losses of 43.53% for mango, 30.31% for papaya, 23.10% for guava and 19.87% for banana.

c. Postharvest losses also occur during storage. Lack of suitable storage facilities compromise quality and can lead to considerable postharvest losses (as much as 25%) of fruit produced (Veena et al., 2011). Poor sanitation of storage rooms and lack of knowledge on temperature requirements also lead to losses (Iordãchescu et al., 2019). While fresh fruit can be stored successfully for periods of weeks up to many months if handled correctly under refrigerated or controlled atmosphere conditions, many developing countries lack such facilities and use common storage (under ambient temperature and humidity). It is estimated that fresh fruit deterioration rate increases two to three-fold with every 10°C increase in temperature (Kader, 2005). Underhill and Kumar (2015) reported losses of 6.2%, 8.2%, and 13.4% of tomatoes under ambient storage conditions after one, two, and three days.

d. Losses at the retail level are much higher in developed countries. Retail stores assume that customers buy more from overflowing displays, preferring to pick their apples from a huge pile rather than from a meagrely filled bin. This leads to overhandling by both staff and customers and damage to fruit on the bottom of the pile due to the accumulated weight (Natural Resources Defense Council, 2017). Amorim et al. (2008) reported incidences of mechanical injuries in peaches of up to 14.5% at the wholesale market in Sao Paulo, Brazil. Munhuweyi (2012) reported losses of tomatoes at the retail level to range from 12.50 – 18.16%, with an average of 14.46%. Matare (2012) measured retail losses of three different fruit types: peach (Yellow Clingstone) losses after two days of storage were 57.85% and 18.91% at ambient and optimum storage conditions, respectively, while the physical loss of pears (Packham's Triumph) were level 0 - 10% with an average of 3.61% and losses of soft citrus (Minneola Tangelo) ranged between 7.67 - 13%.
e. Losses finally occur at the consumer level. In developing countries, this area probably requires minor attention in terms of reducing postharvest losses as it is likely that these in-home losses are low because the cost of food accounts for so much of the family budget that food must be of very poor quality to be discarded. However, in developed countries, household consumption is the primary source of food waste (Bond et al., 2013). A landmark study on loss for

the US, Canada, Australia, and New Zealand collectively reported that 61% of produce is lost at this stage of the supply chain (Reich and Foley, 2014), with 19% of this loss being fresh fruit (Natural Resources Defense Council, 2017). Matare (2012) found losses of peaches during consumer storage of 30.01% to 93.97%, with an average of 57.85% after two days under ambient condition. Refrigeration lowered the losses to between 13.53% to 25.85% with an average of 18.92%. Losses for pears at this level of the supply chain ranged from 2.41% to 25% with an average of 12.29% under ambient conditions and 0.1% to 6.85% with average 2.38% at 0 ºC after four days. The average physical loss of soft citrus after seven days was 13.72% under ambient conditions and 5.29% at 5 ºC (Matare, 2012). Duo et al. (2004) reported decay incidences of 16% in Minneola stored at 22 ºC after 14 days while Nules mandarins stored at ambient temperature had 100% decay after seven days (Perez-Lopez and Carbonell-Barrachina, 2005).

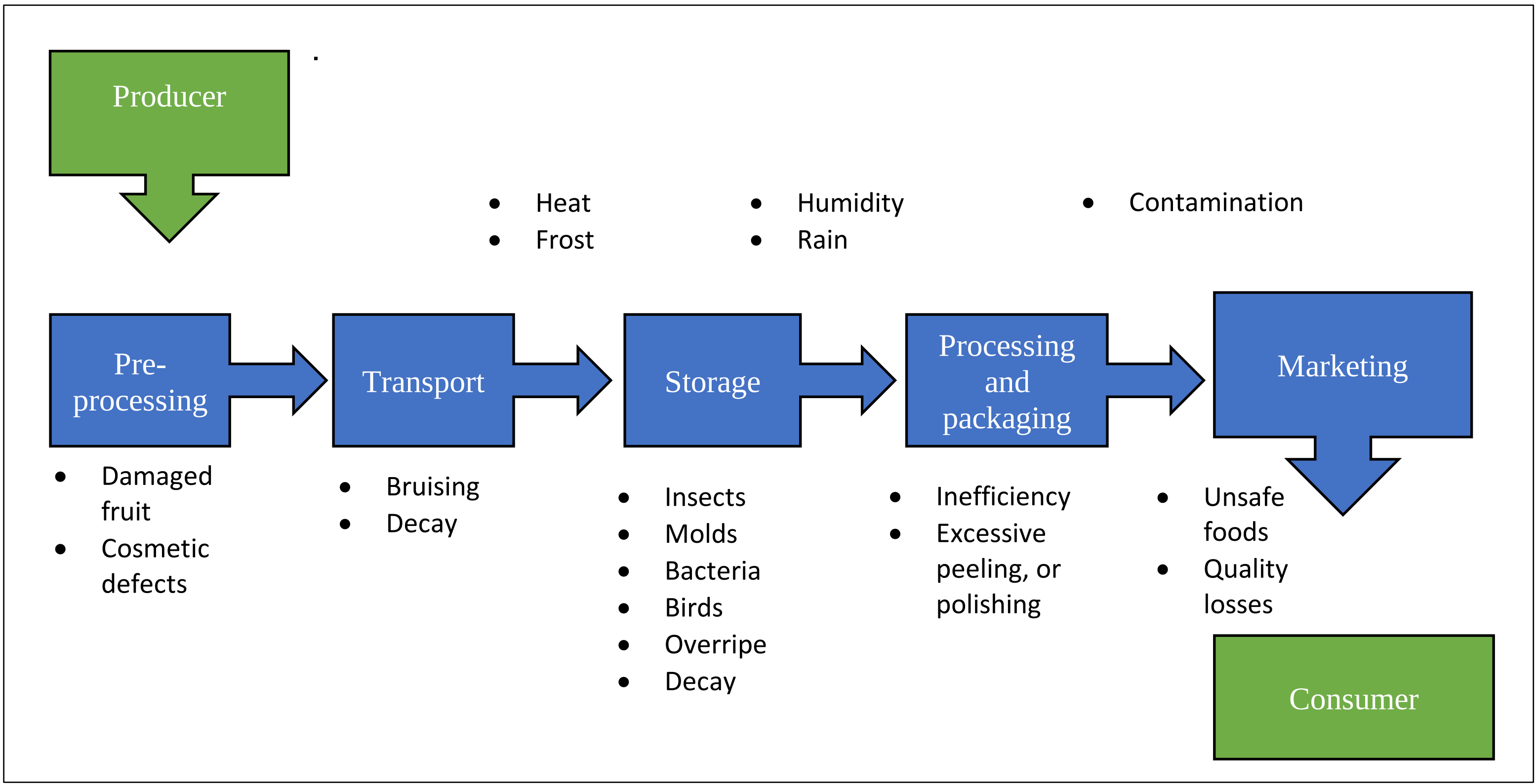

Figure 1. Sites and types of losses along the fresh fruit supply chain. (Adapted from Bourne, 1977).

4. METHODS FOR ASSESSING POSTHARVEST LOSSES OF FRUIT

A major obstacle in achieving postharvest loss mitigation is the lack of clear knowledge of the real magnitudes of losses, which makes it impossible to measure progress against any loss reduction targets (Affognon et al., 2015). Until recently, reliable and systematic estimations of global postharvest loss and waste have been difficult to determine due to an absence of a global and consistent quantification methodology for reporting and managing food removed from the food supply chain (Parfitt et al., 2010; Kitinoja et al., 2011). In response, the Food Loss and Waste Protocol was established in 2013, with the first international Food Loss and Waste Accounting and Reporting Standard formalized in June 2016 during the Global Green Growth Forum (3GF) held in Copenhagen. Quantitative data about postharvest loss is still incomplete as measuring these losses is complex and highly variable depending on the country being considered, which commodity is investigated, the circumstances under which the food is being handled, and the length of time the food is stored (Kitinoja and Kader, 2015). At whatever level of precision postharvest fruit loss is defined, the value will be specific to that time and location (Matare, 2012). Comprehensive, nationally representative assessments of postharvest fruit losses are relatively rare and very expensive (Minor et al., 2019). Instead, many researchers rely on small-scale, detailed studies of postharvest loss for a particular product or region (Dusoruth et al., 2018). This type of analysis can shed light on the individual instances studied and can also help to inform the larger conversation around postharvest loss in general. Researchers have developed many different methods during the past few decades, each focusing on different aspects of the value chain and varying types of food losses (Kitinoja and Kader, 2015). Currently, the primary methods for assessing postharvest fruit losses include estimates, surveys and field sampling of produce.

4.1 Estimates

Estimation is the interpretation of several scientific measurements based on expert knowledge, experience and judgment of the observer (NAS, 1978). Estimating postharvest loss is difficult and unreliable as estimates are based on personal experiences, and the amount of loss given has not been obtained by actual measurements (Hodges et al., 2010, Kitinoja and Kader, 2015). Often quoted data is from the Economic Research Service of the United States Department of Agriculture (ERS). While several estimates have been made on postharvest loss at the retail and consumer level, the ERS report that data limitations prevent estimating total postharvest loss across all commodities at the farm level and the farm to retail levels. Figures between 10–40%, and as high as 50–70% are regularly quoted with fruit and vegetables lumped together in one group and no data on specific fruit reported (Kader, 2005; FAO/World Bank, 2010; Parfitt et al., 2010; Prusky, 2011; UN FAO SAVE FOOD Initiative, 2012). Statements like 'For fruits like apples and citrus losses vary around 10 – 40 percent are not specific or very useful other than providing an idea on the size of the overall problem (Lundqvist et al., 2008). Furthermore, many estimates link to datasets collected 30 years ago and are fragmentary and unconsolidated (Affognon et al., 2015).

During the 1970s and 80s, a few international studies were conducted (Ceponis and Butterfield, 1973; National Academy of Sciences, 1978; Cappellini and Ceponis, 1984; Blond, 1984), and a small number of postharvest systems assessments on fruit were done in the USA (Salunkhe and Desai, 1984; Prussia et al., 1986). A large gap is found in the literature from the 1990s through the early 2000s. Most of the investigations were done by private consultants as quick assessments during the start of postharvest infrastructure development projects, and the results are still considered proprietary information (Kitinoja and Kader, 2015). More recently, a number of meta-analyses (reanalyzing of existing data) and synthesis studies (compiling existing information from different studies) have been done to characterize postharvest losses by INTERPACK (Gustavsson et al., 2011), the World Resources Institute (Lipinski et al., 2013), a United Nations High Level Panel of Experts (HLPE 2014) and International Research Development Center (IDRC) by scientists affiliated with the International Centre of Insect Physiology and Ecology (known as ICIPE) (Affognon et al*.,* 2015). The resulting estimates of postharvest losses for horticultural crops from these widely dispersed studies vary somewhat, and differ by region, country, crop and season, often without much explanation of what is being measured, when, or how (Kitinoja and Kader, 2015). Table 1 lists some examples in the literature where estimates were used to determine postharvest losses of specific fruit. The advantage of using estimates is that it is useful in raising awareness about the problem of postharvest losses (Kitinoja and Kader, 2015). Data from published studies, press reports and interviews with product experts are used so it is less expensive than collecting data through actual measuring and give rapid results. The disadvantage of using estimates is that there are often temptations to cite "worst case" figures to dramatise the problem or “minor cases" figures in trying to defend notions concerning losses (FAO, 1983). Overestimates or underestimates can occur where insufficient information is used in the estimation. Kantor et al. (1995) suggest that the loss estimated for most agricultural commodities are understated due to limitations inherent in the food supply data in the published studies on which these estimates were based.

Table 1: Examples of studies using estimates of postharvest fruit losses

Crop	Country	Farm level	Postharvest handling and storage	Wholesale	Retail level	Total loss	Author
Apple	Armenia	9%	3%	5%	2%	19%	Urutyan, 2013
Apple	Jordan				9.8%	11.2%	Al Hiary, 2012
Apricot	Jordan				14.2%	26.5%	Al Hiary, 2012
Papaya	U.S.				54.9%		Buzby et al., 2009
Peach	Jordan				17.1%	42.3%	Al Hiary, 2012
Mango	Ethiopia					26.3%	Tadesse, 1991
Mango	Benin	17.6%					Vayssières et al., 2009
Mango	Pakistan					0-70%	Stonehouse et al., 1998
Tomato	Bangladesh			10.8%	14%	36.4%	Jasim Uddin, 2010
Oranges	Benin	20%		5.4%	9%		Kitinoja, 2010

4.2 Surveys

Surveys usually comprise questionnaires and interviews with stakeholders in the supply chain within a specific location for a specific fruit (Newman et al., 2008; Barry et al., 2009). Questionnaire loss assessment (QLA), as these surveys are usually called, been widely used to estimate mainly economic losses (NAS, 1978; FFTC, 1994; Murthy et al., 2007; Gangwar et al., 2007; Barry et al., 2009). Information used in policy- and decision-making is usually generated using this method (Ward and Jeffries, 2000). Whether survey data generates reliable estimates of postharvest losses is questionable, and the honest answer is that no one really knows (Sheahan and Barrett, 2015). It relies on a person's ability to accurately recall mounting losses up to the point in time when the survey was conducted. The timing of the survey may also be significant, especially if it does not represent the entire postharvest period, and responses reflect only a portion of the time fruit might be stored. For example, if losses are standard in a community, farmers might subconsciously report only relative loss rates, thereby underestimating the true magnitude of postharvest losses at the farm level (Sheahan and Barrett, 2015).

Table 2 lists some examples in the literature where surveys were used to determine postharvest losses of the specific fruit. Bhattarai et al. (2013) assessed postharvest losses of mandarin orange in Nepal using a systematic survey of oral questionnaires, personal interviews, group discussions and informal observation in the field. The losses were reported as 7, 25, 3, 1 and 5% maximum during harvesting, transportation, grading, packaging, and marketing, but the article does not mention the number of interviewees. Kasso and Bekele (2018) assessed the causes of postharvest loss of several horticultural crops in Ethiopia. Stratified and multistage random sampling techniques were used to sample representative Peasant Associations and respondents (n = 296). The total amount of postharvest losses per crop type and the major reasons for the losses were reported, but the supply chain in these losses occurred was not specified.

Rahiel et al. (2018) assessed production potential and postharvest losses of fruits in Ethiopia through semi-structured questionnaires, focus group discussion and field observation on 120 farmers' cultivation sites via formal and informal surveys. Although the reasons for losses were discussed, no data on losses for specific crops were provided. The advantage of using this method is that questionnaires and interviews are more effective where there are limited resources and time constraints. This method can be used to quantitatively assess postharvest losses of all types except for nutritional losses. Researchers collect data from farmers, pack houses, wholesalers, retailers and consumers (Fehr and Romao, 2000). Researchers also acquire some data from agricultural departments, marketing organisations and municipalities (Murthy et al., 2007; Gangwar et al., 2009). The disadvantages are that surveys and interviews do not always result in gathering accurate information on postharvest losses. When interviewing respondents, they sometimes have difficulties in giving absolute figures in which case relative amounts such as fractions or percentages are used which distorts the actual amount of postharvest loss to be measured. Written surveys and interviews require people to try to remember what happened in the past, sometimes months or even a season earlier than when the data are being collected, and so are largely considered to be less accurate than making direct measurements (Kitinoja and Kader, 2015). As a historical example, sampling the physical losses at Egyptian farms, wholesale and retail markets for grapes and tomatoes was reported to total 28.0 and 43.2%, respectively. Yet, interviews of these same value chain players resulted in reported average total losses of 11.9 and 27.6%, indicating that their perceptions of losses were much lower than was the reality (Blond, 1984; Kitinoja and Kader, 2015).

Table 2: Examples of studies in which questionnaires and interviews (Surveys) were used to measure postharvest fruit losses

Crop	Country	Farm level	Transport	Handling and storage	Wholesale	Retail level	Total loss	Author
Apples	Germany	6-16%						Ludwig-Ohm et al., 2019
Apples	Afghanistan	5.8%		11.2%	19.1%	4.9%		Masood, 2011
Banana	Ethiopia					10%		Minten et al., 2016
Grapes	Pakistan	4.8%	5.2%			11%	20.5%	Aujla et al., 2011
Mango	Kenya						25-44%	Affognon et al., 2015
Mango	Pakistan					31%		Mushtaq et al., 2005
Mango	Ethiopia						45.32%	Kasso and Bekele, 2018
Orange	Nepal	7%	25%	3%		5%		Bhattarai et al., 2013
Orange	Ethiopia						35.58%	Kasso and Bekele, 2018
Plum	Vietnam					28%		Newman et al., 2008
Strawberries	Germany	15-20%						Ludwig-Ohm et al., 2019
Tomato	Vietnam					19%		Weinberger et al., 2008
Tomato	India					35%		Gajbhiye et al., 2008
Tomato	Pakistan					20%		Mujib et al., 2007
Tomato	Pakistan					22%		Zulfiqar et al., 2005

4.3 Sampling

When actual sampling of the produce is used to quantify physical and qualitative losses at specific links in the supply chain, the data generated is more meaningful and reliable (FAO, 2011; Matare, 2012; Munhuweyi, 2012). Sampling is done to carry out laboratory trials to assess the response of fruits under different handling and storage conditions. Laboratory simulations directly identify sources of deterioration quickly and provide corrective measures (Bollen, 2006). However, sampling of specific links in the supply chain gives an incomplete assessment of the supply chain; therefore, tagging and tracing becomes more appropriate in assessing the supply chain. Tagging and tracing is used to obtain statistically valid and meaningful results in which the actual loss are most accurate when data takes the form of a continuous measurable variable (NAS, 1978).

Tagging and tracing involve fieldwork, with both destructive and non-destructive sampling at the points of interest along the supply chain. The accuracy of the results depends on the suitability of the experimental design, principally the sampling method, sample size and data analysis. For example, Dodd (2014), together with two international partners, Sainsbury's in the United Kingdom and BT-9 Tech in Israel, participated in a project to monitor fruit quality (apples, pears, soft citrus and plums) along the export supply chain. The project aimed to illuminate the parts of the supply chain usually unseen by producers/exporters – the final leg of the voyage, from the time the fruit arrives at the foreign port to where it is sold. This entailed gathering information on the storage and fruit pulp temperatures as well as the relative humidity in the fruit export containers. Radio frequency identification (RFID) technology, comprising data recorders, radio receivers and hand-held scanners, made the study possible. Data recorders, known as tags, were inserted into fruit pallets at the start of the journey and the temperature and humidity information recorded was transferred by the radio receivers, via satellite, to a central server from where it could be retrieved through the internet. The study found that the weak links in the supply chain, from a temperature and relative humidity perspective, were the container loading facilities, shipping containers, the receiving distribution centres and the retail distribution centres. Having successfully followed 22 fruit shipments from packhouse to retailer, the data indicated that only 14 shipments adhered to the export protocols. While no quality issues were recorded with any of these shipments, the data gathered provided the exporters and retailers with a new insight into their supply chain, and claims for losses can now be backed up with scientific evidence. Table 3 lists some examples of studies that have used sampling to measure postharvest losses of fruit.

Matare (2012) quantified postharvest losses and changes in physico-chemical properties of fruit at retail and post-purchase storage levels for peach, pear and citrus (Mineola Tangelo) in South Africa. Three different retail outlets were selected representing different handling systems and supply chains. Two of the outlets had a refrigerated facility to store fruit before display, and shelf temperature was controlled by air conditioners. The third outlet was an open market where the fruit was displayed in cartons under a shaded area. While the difference in losses, both quantitively and qualitatively, due to temperature and relative humidity, were discussed in detail. The unknown postharvest factors like harvest date and transport conditions before the fruit reached the retail level limit the study. Kitinoja and AlHassan (2012) assessed postharvest losses for various fruits at three locations, namely at farm, wholesale market and retail level for each crop and in four countries. While US team members briefly joined the local assessment teams in each country to participate in the process at each site, the majority of the loss assessment efforts were carried out by local partners, with over 100 trainees and local supervisors participating in a 6 month long data collection effort. When such a large number of people are involved, many with limited training in data collection, there is inevitably missing data and wrong measurements at times. The protocols developed for measuring these losses in developing countries, however, identified four major factors, namely: temperature, poor quality containers, poor field sanitation and time to reach retail markets. Addressing these could prove invaluable to reduce loss and improve farmer incomes.

The advantage of using the direct sampling method is that data generated is generally regarded as more accurate than other methods and can therefore provide industry specific information that can be used for mitigation strategies (Kitinoja and Kader, 2015). There are also several disadvantages; however, sampling not only is time consuming and expensive, but it also requires the cooperation of many role players in the particular supply chain. One of the critical determinants of reliability is robust sampling; it is, therefore, important for an entity without expertise in sampling to consult a statistician to help guide the sampling design. There is almost always a trade-off between the desired level of certainty and the resources available for the study. For example, increasing the sample size typically reduces sampling error; however, to double confidence in the results, the number of samples must be quadrupled, so reducing uncertainty can quickly become very expensive (FLW protocol, 2016). Kitinoja et al. (2018) state that while direct measurements are generally considered to be more accurate, the data may not be as reliable as expected if there is little or no information on important variables such as crop maturity at harvest, time that have passed since harvesting, temperatures of the produce and ambient air, relative humidity in the storage environment, or the type of containers or packaging used. Each of these factors affects postharvest losses, and it is therefore important to include this data to make sure that the data reliably captures the full extent or causes of losses.

Table 3: Postharvest fruit and vegetable losses measured by sampling

Crop	**Country**	**Sample size**	**% loss at farm**	**% loss at wholesale**	**% loss at retail**	**% Total loss**	**Author**
Peach	South Africa	360 fruit			18.91% (optimum cold storage) 57.85% (Ambient conditions)		Matare, 2012
Pear	South Africa	360 fruit			0-10%; Average: 3.61%		Matare, 2012
Citrus	South Africa	600 fruit			7.67%-13%		Matare, 2012
Litchi	India	500 fruit	18.5±7.4%		18%		Kitinoja and AlHassan, 2012
Banana	Rwanda	200 fruit	14.8±21.0%	35.1±33.1%	30.1±24.4%		Kitinoja and AlHassan, 2012
Pomegranate	South Africa	1630 fruit (540 per cultivar)	6.74%-7.69%				Opara et al., 2021
Mango	Benin	300 fruit per cultivar was assessed				17% (early April) 70% (mid-June)	Vayssieres et al 2008
Mango	Costa Rica					14.1% (dry season) 84.4% (rainy season)	Arauz et al 1994
Mango	Pakistan					36.1%	Malik and Mazhar 2008
Grapes	Egypt		15.1%	6.9%	6.0%	28%	Blond, 1984
Tomato	Australia	3 subsamples of 100 fruits each	28,7%		5,4%	40.3% - 55.9%	McKenzie et al, 2017

5. MAGNITUDE OF POSTHARVEST LOSSES OF FRUIT

The basis for loss measurement can be monetary loss or unit loss (Bell et al., 1999; Kantor et al., 1997). Monetary loss depends upon market prices, and unit loss can be measured as changes in the numbers of items or as weight loss percentages. So, how much fruit is lost in the postharvest food chain? It is known that losses are highly variable depending upon the country as well as the commodity considered, the conditions in which the fruit is being handled, and the length of time the fruit is stored. Higher losses are expected in more perishable fruit, and the extent of loss will increase with time of storage.

The FAO–World Bank "Missing Food" report (World Bank, 2011) made a significant contribution in demonstrating current knowledge on the nature, magnitude, and economic value of postharvest losses, but it also points out that major data gaps exist especially concerning fruit. They concluded there is a pressing need for more quantitative evidence of the actual level and nature of postharvest losses. Postharvest fruit loss is an issue in all the economies in the world. Data on postharvest losses, however, are often reported as a combination of fruit and vegetables, for example, the Food and Agriculture Organization (Gustavsson et al., 2011) reported that 45% of all fruit and vegetables produced is lost or wasted globally, amounting to as much as 644 million tons annually (BCG, 2018).

Rezaei and Liu (2017) lists losses of fruit and vegetables, from production to consumption, for different regions as follows: Europe, 46%; North America and Oceania, 52%; Industrialized Asia, 38%; Sub-Saharan Africa, 51%; North Africa, West and Central Asia, 55%; South and Southeast Asia, 51% and Latin America, 54%. Kitinoja (2016) reports that in developing countries, 44% of fruit and vegetables are lost before even reaching the consumption stage. In India, nearly 30% of the country's fruits and vegetables are lost due to a lack of cold-storage facilities (Murthy et al., 2009; Mukherji and Pattanayak, 2011).

Similarly, Yahaya and Mardiyya (2019) reported that about 30% of fruits and vegetables are rendered unfit for consumption due to spoilage after harvesting in Nigeria. In Australia, 33% of food lost are horticultural products, amounting to 1.32 million tons annually (DEE, 2010; ABC, 2013). Terry et al. (2011) reported losses for fruit and vegetables through the wholesale supply chain in the United Kingdom to be

10%-15% depending on the product. Eriksson et al. (2012) found that the total loss of fresh fruits and vegetables was 4.3%; this study was limited to the retail level, however. However, fruit and vegetables belong to a wide range of products with a large difference in physiology. To obtain more practical information, it is, therefore, better to report the data separately for specific crops (Matare, 2012).

5.1 Magnitude of postharvest losses of specific fruit

Due to their relative high perishability, horticultural products are particularly vulnerable to postharvest losses. Postharvest losses for a single commodity can vary by season, by country and by the data collection method, as shown in Table 4. Ludwig-Ohm et al. (2019) conducted research on postharvest losses of apples in Germany through face-to-face interviews with producers and decision-makers from different levels of the value chain, although only farm level losses were quantified. The main reasons for these losses were identified as unfavourable weather conditions, oversupply, and the very strict quality standards of the food retail sector. Masood (2011) investigated the apple supply chain in Afghanistan. Data was collected through surveys, interviews, and field observation; again, no direct sampling was done. It was concluded that while postharvest losses in apples occur throughout the supply chain, the maximum losses were noticed at the storing stage. The main reasons included poor harvest techniques and packaging materials, such as re-used wooden crates, and the absence of cold storage rooms. Buzby et al. (2011) focused solely on the retail and consumer level and used data from the Economic Research Service/U.S. Department of Agriculture, so again, no direct sampling was done.

However, Argenta et al. (2021) used direct sampling and conducted trials over three years to characterize and quantify apple losses during long-term CA storage and shelf-life. While this study only focused on one part of the supply chain, it did so intensively, and the data obtained was considered sound. Ilyas et al. (2007) investigated the entire apple supply chain in Pakistan and collected data by both surveys and direct sample taking. It was concluded that under a modified and controlled atmosphere, postharvest losses in apples could be minimized greatly by avoiding mechanical damage to fruits and proper storage.

Mebratie et al. (2015) studied the determinants of postharvest banana loss in Ethiopia through structured questionnaires and interviews. The main cause for postharvest loss of bananas at the farm level was mechanical damage while rotting was the main cause at the retail level. Poor postharvest handling practices from farm to retail were the major factors leading to banana losses in the supply chain. White et al. (2011) performed waste audits at banana packing sheds in Australia to quantify the amount of fruit discarded due to cosmetic imperfections. The data gathered, together with production records and interviews with growers, were used to inform a nutritional analysis, a life cycle assessment and an economic analysis to quantify nutritional, environmental and economic impacts. Mvumi et al. (2016) used field and market visits and observations along with structured questionnaires to analyse the banana postharvest supply chain in Zimbabwe. Fernando et al. (2019) assessed the quality of bananas along the entire postharvest supply chain from farm gate to retail store through direct sampling and found that the level of cosmetic damage progressively increased from packhouse to retail and was greatly influenced by package height and pallet positioning during transport. Ilyas et al. (2007) investigated the banana supply chain in Pakistan and collected data by surveys and direct sample taking. It was found that most postharvest losses in bananas are due to mechanical injuries, improper storage and postharvest decay by microorganisms.

Rajabi et al. (2015) quantified grape losses across the supply chain among small-scale grape growers in Iran. Data was collected from government and private data sources, interviews with grape growers and market consultations and no sampling data was recorded. It was reported that most of the losses occurred during the production and processing stages. This is different from the findings of Aujla et al. (2011) that found most losses occurred during the consumer stage in Pakistan. In that study, data were again obtained through questionnaires and government departments. Murthy et al. (2014) used direct sampling to quantify losses of grapes along the supply chain in India. It was concluded that water berries, a physiological disorder that causes affected berries to become watery, soft, and flabby during ripening, were the major causes of loss and suggested further research to sort out this problem.

From these examples, data on postharvest losses for specific fruit can differ greatly between countries (Table 4). Some studies focus on only one part of the supply chain, yet every link in the chain impacts losses down the line. Other studies use existing data from government estimates made years previous. It seems necessary to research direct sampling for specific fruit in specific countries to establish the actual situation and the major contributing factors to a loss for that region and use this knowledge to create bespoke mitigating protocols.

Table 4. Postharvest losses of specific fruit

Crop	Country	Farm level	Transport	Handling and storage	Wholesale	Retail level	Total loss	Author
Apple	Germany	6-16%						Ludwig-Ohm et al., 2019
	Afghanistan	5.8%		11.2%	19.1%	4.9%		Masood, 2011
	United States					8.6%		Buzby et al., 2011
	Brazil			3.9% to 12.1%				Argenta et al., 2021
	Pakistan	8%	4%		5%	7%	24%	Ilyas et al., 2007
Banana	Ethiopia						26.5%	Mebratie et al., 2015
	Australia	10%–30%						White et al., 2011
	Zimbabwe						24-27%	Mvumi et al., 2016
	Australia	1.3%		9%		13.3%		Fernando et al., 2019
	Pakistan	6%	9%		14%	11%	40%	Ilyas et al., 2007
Table grapes	Iran	17.6%	9%	19%		7%	53%	Rajabi et al., 2015
	Pakistan	4.8%	5.2%		6.5%		20.5%	Aujla et al., 2011
	India	3.4%-7.82%		12.13%		4.56%	19.95%	Murthy et al., 2014
Pear	South Africa					0-10%; Average: 3.61%		Matare, 2012
	Nordic countries	10%						Franke et al., 2016
	Hungary	8%						WRAP, 2019
	India	20-30%						Mangaraj et al., 2011

5.2 Magnitude of postharvest loss of fruit in South Africa

South Africa produces vast volumes of fruit every year, significantly more than what the country's population can consume. Most of the fruit produced in South Africa are consequently exported, mainly to European markets, but exports to emerging markets such as the rest of Africa and the Far East has grown substantially and continue to grow.

While we find some worrying anecdotal information, there is little scientific data available on food losses in South Africa. According to the initialt estimate by Oelofse and Nahman (2013), fruit and vegetables account for 47% of the approximately 9.04 million tons of food lost and wasted per year in South Africa. This figure has recently been updated with the new food losses and waste estimate for South Africa being 10.3 million tons per annum (Oelofse et al., 2021). This provides a preliminary estimate, but as no primary data was collected during that research, it indicates the size of the problem but does not provide accurate, reliable data for specific industries. The authors state that these preliminary figures should be used with caution and are subject to verification through primary data collection. This lack of primary data on postharvest losses and the unknown economic, environmental and resource impacts of these losses make it difficult to formulate mitigation strategies.

To date, there is a dearth of information on the incidence and magnitude of postharvest losses of fruit and other food crops in South Africa. Matare (2012) assessed the incidence of postharvest losses of 'yellow clingstone' peach, Packham's Triumph pear and soft citrus 'Minneola Tangelo' at the retail level in South Africa. This study showed that postharvest losses of fruit at the retail level is variable depending on the season, type of retail outlet, type of fruit, maturity, whether the fruit is climacteric or not (climacteric fruit can be harvested at a lower maturity stage when they can withstand rigors of postharvest handling and distribution), and storage condition. Losses of peaches were measured at 18.91% under optimum cold storage and 57.85% under ambient conditions, while average pear losses, where 3.61% and 7.67%-13% of the soft citrus were lost. Higher losses of pear were expected as the fruit is on the market during the summer when high temperature and low relative humidity are associated with high levels of water loss and rapid respiration, and it also has a thin peel predisposing it to injury, but the study showed that pears had the lowest incidence of losses. The sampling method used in this study gives more accurate data on postharvest losses than surveys and estimations. However, the results obtained in this study can only refer to the supply chains where samples were drawn and the 2011 marketing seasons of the studied fruit types. It was also concluded that further studies are needed to track the studied fruits from harvest to consumer to provide more information on handling procedures and origin of defects associated with losses and downgrading.

Opara et al. (2021) quantified the magnitude of pomegranate fruit losses at packhouse level, identified the causes, and estimated the impacts of losses. The results showed that losses ranged between 6.74% to 7.69%. Environmental stress (sunburn, cracks and splits) accounted for the highest incidence of loss, with 49.44% of the total losses, with mechanical damage accounting for 37.84% of total fruit losses, microbial and pathological spoilage accounted for 7.84%, insect damage contributed 2.96% while irregular fruit size and shape contributed least to losses with 1.92%. This study also points out that losses between cultivars vary as losses in ‘Acco’ were lower than in ‘Herskawitz’ and ‘Wonderful’ and that market standards (especially the export market) greatly influence the amount of losses recorded at packhouse level. While these studies provide a start for quantifying postharvest losses of fruit in South Africa, much more research needs to be done on the wide variety of fruit produced in this country to limit losses and promote sustainable use of resources.

6. ENVIRONMENTAL AND ECONOMIC IMPACTS OF POSTHARVEST LOSS

Postharvest loss not only reduces the amount of food available, but also constitutes a substantial waste of economic and environmental resources (Kummu et al., 2012; FAO, 2013). Agricultural production contributes copious amounts of greenhouse gases to the phenomenon of global warming, consumes unsustainable amounts of resources with detrimental environmental impacts such as deforestation, loss in biodiversity and water scarcity, and contaminates the environment (Chapagain and James, 2013). The demand for food is projected to increase by 50% in the next 30 years because of the growing population. Under these circumstances, it will become progressively more difficult to meet sustainable development goals, especially from an environmental perspective regarding the use of natural resources and the production of greenhouse gas emissions (Nicastro and Carillo, 2021). Reducing postharvest loss is therefore a key part in utilising environmental resources more sustainably. Cattaneo et al. (2021) estimated that preventing postharvest losses can reduce GHG emissions by 8% and water use by a quarter. Simply put, reducing postharvest losses means more food for all, less greenhouse gas emissions, less pressure on the environment, and increased productivity and economic growth.

Life cycle assessment approaches have been used in a number of studies to assess the impact of postharvest losses. Two main methods are typically used to perform this assessment: top-down approaches, using for example input-output tables and related figures for the impacts, or bottom-up approaches, using more detailed products databases (Tonini et al., 2018). Reutter et al., (2017) discussed the advantages and disadvantages of the two methods. Life cycle assessment (LCA) is an extremely data-intensive methodology. The typical life cycle of a product covers numerous human activities, each of which needs to be understood and documented in terms of environmentally relevant material and energy flows (Wernet et al., 2016). Due to the high cost of primary data collection, this information is usually not gathered within each specific LCA project. It is therefore common practice to focus data collection efforts on selected activities that fall within the actual scope for action and to use generic data from Life Cycle Inventory (LCI) databases to model the remaining activities (Bourgault et al. 2012). By first understanding the climatic impact of fruit production, the impacts of the postharvest losses can be calculated.

Karlsson (2017) did a systematic review and meta-analysis on climate impact of fresh fruit production that included nine types of fruit (apple, apricot, banana, grapes, kiwi fruit, peach, pear, pineapple and orange). The result from the meta-analysis showed that apple production had the smallest climate impact of 0.11 kg CO_2eq/kg, followed by Oranges 0.13 kg CO_2eq/kg, Peach 0.177 kg CO_2eq/kg Kiwi fruit 0.19 kg CO_2eq/kg, Grapes 0.2 kg CO_2eq/kg, Pineapples 0.211 kg CO2eq/kg, Pears 0.225 kg CO_2eq/kg, Bananas 0.275 kg CO_2eq/kg and that apricot production had the largest impact with 0.36 kg CO_2eq/kg. The system boundaries for that study, however stopped at the farm gate. Janse van Vuuren (2015) included storage and transportation to the retail markets in calculations that led to much higher values for grape production for example of 0.91 kg CO_2eq/kg. To determine the specific impact for a given fruit, the entire supply chain has to be taken into consideration along with the energy cost for producing and marketing lost produce as well as the water that was required to produce the lost fruit in the first place. The economic impact is calculated by multiplying the amount of fruit lost by weight with the current value of the product on the market it was destined for.

Measuring the impact of pomegranate losses at packhouse level, Opara et al. (2021) found that the annual average loss of 7.16% translated to 328.79 tons with a monetary loss of the total annual production estimated at ZAR 29.5 million (USD 1,754,984) per annum. These losses also emitted 157 819 CO_2eq greenhouse gases into the atmosphere that would require about 4 million trees at 0.039 metric ton CO_2 per tree planted to sink this amount. 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 people in a year at 0.05 m^3 utilised per person per day.

7. SUMMARY AND FUTURE PROSPECTS

The problem of postharvest losses remains a global issue. Data on combined fruit and vegetable losses show that all regions across the world lose more than 30% of their fresh produce from production to consumption with the average being 49.5% (Rezaei and Liu 2017). The range of reported losses can be enormous and is often due to the nature of the produce (whether it is highly perishable e.g. berries or more robust e.g. apples), along with many other contributing factors (such as initial disease incidence in the field, harvest time, weather conditions, temperature during storage and marketing, type of packages used as well as the distance from production site to market) (Kitinoja, 2015). Besides the loss of produce that impacts food security, postharvest losses also represent wastage of natural resources used in production such as the water, land and energy as well as contributing greenhouse gas emissions that further impact climate change. They also represent the waste of investment capital and opportunity cost that reduces farmers' incomes and increase consumers' expenses. Reducing postharvest loss throughout the supply chain then, should be considered an effective solution to reduce the environmental impacts of agriculture, to improve the income and livelihood of the chain actors and to improve food and nutrition security for low-income consumers (Berjan et al., 2018).

The current high rate of postharvest loss is not merely the consequence of the various causes leading to losses, but also a result of lack of measurement. Information from one location cannot be generalised as the losses reflect the time and situation when they are taken, and these vary with time and the prevailing conditions in each place (Munhuweyi, 2012). Postharvest loss data is often not measured by direct sampling, considered the most accurate method, and also not frequently enough. If one does not know how much or where postharvest loss is occurring, how can one take measures to reduce it? It needs to be an ongoing process to determine if mitigation strategies are working (Dora et al., 2020). It is therefore important that future research generate accurate data for specific fruit and for a particular region.

8. REFERENCES

ABC. (2013). Do Australians Waste $8 Billion Worth of Edible Food Each Year? Australian Broadcasting Corporation. Available online: http://www.abc.net.au/news/factcheck/2013-10-08/food-waste-value-australia/4993930 (accessed on 7 Oct 2018).

Affognon, H., Mutungi, C., Sanginga, P. and Borgemeister, C. (2015). Unpacking postharvest losses in Sub-Saharan Africa: A Meta-analysis. World Development, 66, 49-68.

Ajay, V., Singh, K.P. and Avnish, K. (2003). Postharvest losses of vegetables: an assessment. Annals of Agricultural Research, 24:4, 815-818.

Ajay, V. and Singh, K.P. (2004). Postharvest loss of vegetables: a study. Journal of Horticultural Science, 33:1/2, 152-153.

Al Hiary, M. (2012). Estimation of postharvest losses of some fruit crops in Jordan. Journal of King Saud University - Science, 24:2, 151-162.

Alkan, N. and Fortes, A.M. (2015). Insights into molecular and metabolic events associated with fruit response to post-harvest fungal pathogens. Frontiers in Plant Science, 6, 889. doi: 10.3389/fpls.2015.00889

Allwood, A.J. and Leblanc, L. (1997). Losses Caused by Fruit Flies (Diptera: Tephritidae) in Seven Pacific Island Countries. pp. 208-211 In: Allwood, A.J., and Drew, R.A.I. Management of Fruit Flies in the Pacific. A Regional Symposium, Nadi, Fiji 28-31 October 1996. ACIAR Proceedings No. 76, 267

Amin, S. A., Ahmed, A. I., Sidiq, S. A. and Mahmood, H. A., (2017). Biological control of post-harvest disease of blue mould (*Penicillium expansum*) of pear fruit by using antagonist microorganisms under laboratory and cold storage conditions. International Journal of Current Research in Biosciences and Plant Biology, 4:1, 20-31.

Amorim, L., Martins, M. C., Lourenco, S. A., Guitierrez, A. S. D., Abreu, F. M. and Goncalves, F. P. (2008) . Stone fruit injuries and damages at wholesale market of Sao Paulo, Brazil. Journal of Postharvest Biology and Technology, 47, 353-357.

Argenta, L.C., de Freitas, S.T., Mattheis, J.P., Vieira, M.J. and Ogoshi, C. (2021). Characterization and Quantification of Postharvest Losses of Apple Fruit Stored under Commercial Conditions. HortScience, 56:5, 608–616.

Atanda S. A., Pessu P. O., Agoda S., Isong I. U. and Ikotun I. (2011). The concepts and problems of post–harvest food losses in perishable crops. African Journal of Food Science, 5:11, 603-613.

Aujla, K. M., Shah, N. A. Ishaq, M. and Farooq, A. (2011). Post-harvest losses and marketing of grapes in Pakistan. Sarhad J. Agric 27:3, 485-490.

Bani, R.J., Josiah, M.N. and Kra, E.Y. (2006). *Postharvest losses of tomatoes in transit.* Agricultural Mechanization in Asia (AMA), Africa and Latin America 37,2, 84-86.

Barry, I.N., Jaenicke, H., Pichop, G.N. and Virchow, D. (2009). Production and marketing of African vegetables in the Ameru district of Tanzania: Assessing postharvest loss and processing potential. Acta Horticulturae, 806, 481-488.

BCG (Boston Consulting Group). (2018). Tackling the 1.6-billion-ton food loss and waste crisis. Available online: https://www.bcg.com/publications/2018/tackling-1.6-billion-ton-food-loss-and-waste-crisis. (accessed on 7 Oct 2020).

Bhattarai, R.R., Rijal, R.K. and Mishra, P. (2013). Post-harvest losses in mandarin orange: A case study of Dhankuta District, Nepal. African Journal of Agricultural Research. 8:9, 763-767.

Bell, A., Maraud, F. and Muck, O. (1999). Guidelines for the analysis of post-production systems. FAO, Rome, Italy and GTZ, Eschborn, Germany, 102.

Bendeković, J., Naletina, D. and Nola, I. (2015). Food safety and food quality in the supply chain. Conference Paper, Trade perspectives 2015: Innovations in Food Retailing, Zagreb. https://www.researchgate.net/publication/324389840.

Beretta, C., Stoessel, F., Baier, U. and Hellweg, S. (2013). Quantifying food losses and the potential for reduction in Switzerland. Waste Management, 33, 764-773.

Berjan, S., Capone, R., Debs, P and El Bilali, H. (2018). Food Losses and Waste: A Global Overview with a Focus on Near East and North Africa Region. International Journal of Agricultural Management and Development, 8:1,1-16.

Bharate, S.S. and Bharate, S.B. (2014). Non-enzymatic browning in citrus juice: chemical markers, their detection and ways to improve product quality. Journal of Food Science and Technology, 51:10, 2271–2288.

Bist, N.S. and Bist, P. (2021). Role of microorganisms in post-harvest loss of agricultural products: a review. Sustainability in Food and Agriculture, 2:1,1-4.

Blond, R.D. (editor). (1984). The Agricultural Development Systems Project in Egypt, pp.42-48 (Fruit and Vegetable Postharvest Losses) and pp.190-194 (Economic Evaluation of Postharvest Losses). University of California, Davis.

Bollen, A.F. (2006). Technological innovations in sensors for assessment of postharvest mechanical handling systems. International Journal of Postharvest Technology and Innovation, 1:1, 16-31.

Bond, M., Meacham, T., Bhunnoo, R. and Benton, T.G. (2013) Food waste within global food systems. A Global Food Security report (www.foodsecurity.ac.uk).

Bourgault ,G., Lesage, P. and Samson, R. (2012). Systematic disaggregation: a hybrid LCI computation algorithm enhancing interpretation phase in LCA. International Journal of Life Cycle Assessment, 17, 774–786.

Bourne, M.C. (1977). Post-harvest food losses – The neglected dimension in increasing the world food supply. Cornell International Agriculture Mimeograph 53.

Boxall, R.A. (2001). Post-harvest losses to insects – a world overview. International Biodeterioration and Biodegradation, 48, 137-152.

Busatto, N., Tadiello, A., Trainotti, L. and Costaa, F. (2017). Climacteric ripening of apple fruit is regulated by transcriptional circuits stimulated by cross-talks between ethylene and auxin. Plant Signaling and Behaviour, 12:1, e1268312.

Buzby, Jean C., Wells, H.F., Axtman, B. and Mickey, J. (2009). Supermarket Loss Estimates for Fresh Fruit, Vegetables, Meat, Poultry, and Seafood and Their Use in the ERS Loss-Adjusted Food Availability Data. EIB-44, U.S. Dept. of Agriculture, Economic Research Service.

Buzby, J.C., Hyman, J., Stewart, H. and Wells, H.F. (2011). The value of retail- and consumer-level fruit and vegetable losses in the United States. The Journal of Consumer Affairs, 45:3, 492-515.

Buzby, J.C. and Hyman, J. (2012). Total and per capita value of food loss in the United States. Journal of Food Policy, 37, 561-570.

Buzby, J.C., Wells, H.F. and Hyman, J. (2014) The Estimated Amount, Value, and Calories of Postharvest Food Losses at the Retail and Consumer Levels in the United States, EIB-121, U.S. Department of Agriculture, Economic Research Service.

Cappellini, R.A. and Ceponis, M.J. (1984). Postharvest losses in fresh fruits and vegetables. p. 24-30. In: H.E. Moline (ed.), Postharvest pathology of fruits and vegetables: postharvest losses in perishable crops. University of California Bulletin 1914.

Cattaneo, A.; Federighi, G.; Vaz, S. (2021). The environmental impact of reducing food loss and waste: A critical assessment. Food Policy, 98, 101890.

Ceponis, M.J. and Butterfield, J.E. (1973). The nature and extent of retail and consumer losses in apples, oranges, lettuce, peaches, strawberries, and potatoes marketed in greater New York. USDA Mktg. Res. Rpt. No. 996, 23 p.

Chaboud, G. and Daviron, B. (2017). Food losses and waste: Navigating the inconsistencies. Global Food Security, 12: 1-7.

Chapagain, A. and James, K. (2011). The Water and Carbon Footprint of Household Food and Drink Waste in the UK. Banbury, Oxon: Waste & Resources Action Programme. Available at: http://www.wrap.org.uk/retail_supply_chain/research_tools/research/report_water_and.html (accessed 6 October 2018).

Chapagain, A.K. andJames, K. (2013). Accounting for the Impact of Food Waste on Water Resources and Climate Change M.R. Kosseva, C. Webb (Eds.), Food Industry Wastes, Academic Press, San Diego, 217-236, 10.

Choudhury, M.M. and da Costa, T.S. (2004). Perdas na cadeia de comercializacao da manga (Losses in the commercialization network of mango). Documentos-da-Embrapa-Semi-Arido, 186, 41.

Coursey, D.G. and Proctor, F.J. (1975). Towards the quantification of post-harvest loss in horticultural produce. Acta Horticulturae, 49, 55-66.

de Lucia, M. and Assennato, D. (1994). Agricultural Engineering in Development: Post-harvest Operations and Management of Foodgrains. FAO Agricultural Services Bulletin No. 93. Rome: FAO.

Department of Environment and Energy (DEE). (2010). National Waste Report 2010; ACT: Canberra, Australia.

Dongmei, L., Zhu, Z., & Sun, D. (2018). Effects of freezing on cell structure of fresh cellular food materials: A review. Trends in Food Science and Technology, 75, 46-55.

Dora, M., Wesana, J., Gellynck, X., Seth, N., Dey, B. and De Steur, H. (2020). Importance of sustainable operations in food loss: evidence from the Belgian food processing industry. Annals of Operations Research, 290, 47–72.

Dou, H., Gmitter, F. G. & Coates, G. (2004). Postharvest internal and external evaluation of LB8-9 in comparison to „Sunburst" and „Minneola". Proceedings of the Florida State Horticultural Society, 117, 362-364.

Dusoruth, V., Peterson, H.H. and Schmitt, J. (2018). Estimating a local food waste baseline. Journal of Food Products Marketing, 25:5, 654-680.

Eriksson, M., Strid, I., and Hansson, P. A. (2012). Food losses in six Swedish retail stores: Wastage of fruit and vegetables in relation to quantities delivered. Resources, Conservation and Recycling, 68, 14–20.

Etebu, E., Nwauzoma, A., Bawo, D. (2013). Postharvest spoilage of tomato and control strategies in Nigeria. Journal of Biology, Agriculture and Healthcare, 3:10, 51-61

FAO. (1981). Food loss prevention in perishable crops. FAO Agricultural Services Bulletin, 43.

FAO. (2009). State of food insecurity in the world: economic crises — impacts and lessons learned. Food and Agriculture Organization of the United Nations.

FAO. (2011). Global food losses and food waste - Extent, causes and prevention. (available at http://www.fao.org/docrep/014/mb060e/mb060e00.pdf).

FAO. (2013). Food losses and waste in Europe and Central Asia. Food and Agriculture Organization of the United Nations.

FAO. (2013). Food Wastage Footprint: Impacts on Natural Resources. Rome, Italy. (available at: http://www.fao.org/3/i3347e/i3347e.pdf)

FAO. (2014). Food Wastage Footprint: Full-Cost Accounting, Final Report; FAO: Rome, Italy.

Fehr, M. and Romano, D.C. (2001). Measurement of fruit and vegetable losses in Brazil- A case study. Environment, Development and Sustainability, 3, 253-263.

Fernando, I., Fei, J., Stanley, R., Enshaei, H. and Eyles, A. (2019). Quality deterioration of bananas in the post-harvest supply chain- an empirical study, Modern Supply Chain Research and Applications, 1:2, 135-154.

FLW Protocol (Food Loss and Waste Protocol). The food loss and waste accounting and reporting standard, 2016, Washington, DC. Available online: https://flwprotocol.org/wpcontent/uploads/2016/05/FLW_Protocol_Guidance_on_FLW_Quantification_Methods.pdf

Franke, U., Hartikainen, H, Mogensen, L. and Svanes, E. (2016). Food losses and waste in primary production. Data collection in the Nordic countries, TemaNord, Nordic Council of Ministers. www.norden.org/nordpub

Fuentes, L.M.H., Vildozola, A.C. and Urías-López, M.A. (2017). Weevil Borers in Tropical Fruit Crops: Importance, Biology and Management, Insect Physiology and

Ecology, Vonnie D.C. Shields, IntechOpen, DOI: 10.5772/66635. Available from: https://www.intechopen.com/books/insect-physiology-and-ecology/weevil-borers-in-tropical-fruit-crops-importance-biology-and-management

Funt, R., Cameron, E. and Banks, N. (2000). The effect of apple fruit bruising on total returns. Good Fruit Grower, 51, 37-40.

Gangwar, L. S., Singh D., and Singh, D.B. (2007). Estimation of post-harvest losses in Kinnow Mandarin in Punjab using a modified formula. Agricultural Economics Research Review, 20, July-December, 315-331.

Gajbhiye, D.T., Kukade, N. N., Bagde, N.T. and Burade, A.L. (2008). An economic analysis of post-harvest losses of selected vegetables in Nagpur district. Journal of Soils and Crops 18:2, 469-472.

George, J.B. and Mwangangi, B.M. (1994). Some factors affecting banana storage and ripening: A case study of banana handling and ripening in Kenya. Acta Horticulturae, 368, 628-633.

Ghosh, P., Fawcett, D., Perera, D., Sharma, S., Poinern, G. (2017). Horticultural loss generated by wholesalers: A case study of the canning vale fruit and vegetable markets in Western Australia, Horticulturae, 3, 34.

Gustavsson, J., Cederberg, C., Sonesson, U., van Otterdijk, R., and Meybeck, A. (2011). Global food losses and food waste. Rome: Food and Agriculture Organization of the United Nations. http://www.fao.org/fileadmin/user_upload/ags/publications/GFL_web.pdf

Harris, K.L. and Lindblad, C.J. (1978). Post-harvest grain loss assessment methods. A manual of methods for the evaluation of post-harvest losses. American association of Cereal Chemists.

Hassan, K. (2010). A guide to postharvest handling of fruits and vegetables. Department of Horticulture, Bangladesh Agricultural University, Mymensingh, Bangladesh.

Hodges, R.J., Buzby, J.C. and Bennett, B. (2010). Post-harvest losses and waste in developed and less developed countries: opportunities to improve resource use. Journal of Agricultural Science, 149, 37-45.

Hodges, R.J, Bernard, M. and Rembold, F. (2014). APHLIS – Postharvest cereal losses in Sub-Saharan Africa, their estimation, assessment and reduction. JRC Technical reports, Institute for Environment and Sustainability, Joint Research Centre, European Commission. Available online: https://publications.jrc.ec.europa.eu › JRC92152. (accessed: 10 June 2021).

Idah, P.A., Ajisegiri, E.S.A. and Yisa, M.O. (2007). Fruits and vegetables handling and transportation in Nigeria. AU Journal of Technology, 10: 3, 175 – 183.

Ilyas, M.B., Ghazanfar, M.U., Khan, M.A., Khan, C.A., Bhatti, M.A.R. (2007). Post-harvest losses in apple and banana during transport and storage. Pakistan Journal of Agricultural Sciences, 44, 534-539

Iordăchescu, G., Ploscuțanu, G., Pricop, E.M., Baston, O. and Barna, O. (2019). Postharvest losses in transportation and storage for fresh fruits and vegetables sector. Journal of International Scientific Publications, Agriculture & Food, 7, 244-251.

Kader, AA (ed). (2002). Postharvest Technology of Horticultural Crops (3rd Edition). UC Publication 3311. University of California, Division of Agriculture and Natural Resources, Oakland, California 94608, 39-47.

Kader, A.A. (2005). Increasing availability by reducing post-harvest losses of fresh produce. Acta Horticulturae, 682, 2169-2175.

Kader, A.A. and Rolle S.R. (2004).The role of post harvest management in assuring quality and safety of horticultural produce. FAO Agricultural Support Systems Division 152, 1010-1365.

Kafa, N. and Jaegler, A. (2021). Food losses and waste quantification in supply chains: a systematic literature review. British Food Journal, Vol. ahead-of-print No. ahead-of-print. https://doi.org/10.1108/BFJ-09-2020-0879

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

Karlsson, A.E. (2017). Climate impact from fresh fruit production - a systematic review and meta-analysis. Master of Science in Environmental Science, Department of Biological and Environmental Sciences, University of Gothenburg.

Kasso, M. and Bekele, A. (2018). Post-harvest loss and quality deterioration of horticultural crops in Dire Dawa Region, Ethiopia. Journal of the Saudi Society of Agricultural Sciences,17:1, 88-96.

Kepler, E. F. (2004). Supply chain approach to sustainable beef production from a Brazilian perspective. Livestock Production Science, 90, 53-61.

Kitinoja, L. (2010). Identification of appropriate postharvest technologies for improving market access and incomes for small horticultural farmers in sub-Saharan Africa and south Asia. WFLO Grant Final Report, 323.

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

Kitinoja, L. and Al Hassan, H.Y. (2012). Identification of appropriate postharvest technologies for small scale horticultural farmers and marketers in Sub-Saharan Africa and South Asia – Part 1. Postharvest losses and quality assessments. Acta Horticulturae, 934, 31-40.

Kitinoja, L. and Kader, A.A. (2015). Measuring post-harvest losses of fresh fruits and vegetables in developing countries. White paper 15-02, Post-harvest Education Foundation.

Kitinoja, L. (2016). “Innovative Approaches to Food Loss and Waste Issues,” Frontier Issues Brief submitted to the Brookings Institution’s Ending Rural Hunger project. https://www.endingruralhunger.org/

Kitinoja, L., Tokala, V.Y. and Brondy, A. (2018). Challenges and opportunities for improved postharvest loss measurements in plant-based food crops. Journal of Postharvest Technology, 6:4,16-34.

Kuhr, R.J. (1979). Integrated pest management. A new strategy in an old war. New York's Food and Life Science, 12:2, 3.

Kumar, D. and Kalita, P. (2017). Reducing postharvest losses during storage of grain crops to strengthen food security in developing countries. Foods, 6:1, 8.

Kummu, M., de Moel, H., Porkka, M., Siebert, S., Varis, O. and Ward, P.J. (2012). Lost food, wasted resources: Global food supply chain losses and their impacts on freshwater, cropland and fertiliser use. Science of the total environment, 438, 477-489.

Ludwig-Ohm, S., Dirksmeyer, W. and Klockgether, K. (2019). Approaches to reduce food losses in German fruit and vegetable production. Sustainability, 11, 6576. doi:10.3390/su11236576

Lundqvist, J., de Fraiture, C. and Molden, D. (2008). Saving Water: From field to fork – Curbing losses and wastage in the food chain. SIWI Policy Brief. Stockholm International Water Institute.

Masood, M. (2011). An assessment of apple post-harvest losses the case of Nerkh district, Afghanistan. Master Thesis in Agriculture Production Chain Management, University of Applied Sciences, Wageningen, The Netherlands.

Matare, T. E. (2012). Post-harvest losses and changes in physicochemical properties of fruit (peaches, pears and oranges) at retail and during post-purchase storage. Master Thesis in Food Science, Department of Food Science, Stellenbosch University.

Mangaraj, S., Sadawarti, M.J. and Prasad, S. (2011) Assessment of Quality of Pears Stored in Laminated Modified Atmosphere Packages, International Journal of Food Properties, 14:5, 1110-1123

Mebratie, M.A., Haji, J., Woldetsadik, K. and Ayalew, A. (2015). Determinants of postharvest banana loss in the marketing chain of Central Ethiopia. Food Science and Quality Management, 37, 52-64.

Minor, T., Hitaj, C., Kuchler, F., Skorbiansky, S.R., Roe, B and Thornsbury, S. (2019). Exploring food loss from farm-to-retail in the produce industry. Choices, a publication of the Agricultural and Applied Economics Association, 34:1, 1-7.

Minten, B., Alam, A.Z.M.S., Deb, U.K., Kabir, A.Z., Laborde, D., Hasanullah, M. and Murshed. K.A.S. (2010). Agricultural marketing, price stabilization, value chains, and global/regional trade. Paper presented for the Bangladesh Food Security Investment Forum.

Munhuweyi, K. (2012). Postharvest losses and changes in quality of vegetables from retail to consumer: a case study of tomato, cabbage and carrot. MSc thesis, Department of Food Science, Faculty of AgriSciences, Stellenbosch University, South Africa.

Morisaki, I. (2011). Pattern of Food Losses in Households: A Case Study in Oita-Prefecture, Japan. Oita, Japan: Ritsumeikan Asia Pacific University. Available at: http://rcube.ritsumei.ac.jp/bitstream/10367/2585/1/MORISAKI%20Ikuko.pdf

Mrema, C.G. and Rolle, S.R., (2002). Status of the postharvest sector and its contribution to agricultural development and economic growth. In: 9th JIRCAS International Symposium – Value Addition to Agricultural Product, 13-20.

Mujib, U. R., Naushad, K., and Inayatullah, J. (2007). Postharvest losses in tomato crop (a case of Peshawar valley). Sarhad Journal of Agriculture, 23:4, 1279-1284.

Mukherji, B., Pattanayak, B. (2011). New Delhi Starts Drive to Root Out Hunger. The Wall Street Journal. Available at: http://online.wsj.com/article/SB10001424052702304259304576372813010336844.html (accessed 7 Oct 2018).

Murthy, D.S., Gajanana, T.M., Sudha, M. and Dakshinamoorthy, V. (2009). Marketing and post-harvest losses in fruits: Its implications on availability and economy. Indian Journal of Agricultural Economics, 64:2, 259-275.

Murthy, M.R K., Reddy, G. P. and Rao, K. H. (2014). Retail marketing of fruits and vegetables in India: A case study on export of grapes from Andhra Pradesh, India. European Journal of Logistics Purchasing and Supply Chain Management, 2:1, 62 - 70.

Mushtaq, K., Javed, M.S., and Bari, A. (2005). Postharvest losses in mango: the case of Pakistani Punjab. Proceedings of the International Conference on Postharvest Technology and Quality Management in Arid Tropics, Sultanate of Oman, 89-94.

Mvumi, B., Matsikira, L.T. and Mutambara, J. (2016), “The Banana postharvest value chain analysis in Zimbabwe”, British Food Journal, 118:2, 272-285.

National Academy of Sciences. (1978). Postharvest food losses in developing countries. Board on Science & Technology for International Development, NAS, Washington, D.C., 202.

Natural Resources Defense Council. (2017). Wasted: How America is losing up to 40 percent of its food from farm to fork to landfill.

Newman, S.M., Ku, V.V.V., Hetherington, S.D., Chu, T.D., Tran, D.L. and Nissen, R.J. (2008). Mapping stone fruit supply in North West Vietnam. Acta Horticulturae, 794, 261-267.

Next Generation Food (2010). The impact of domestic food waste on climate change. Retrieved August 30, 2018, from http://www.nextgenerationfood.com/news/looking-at-food-waste

Next Generation Food. (2010). Food waste in the food chain. Available online: http://www.nextgenerationfood.com/article/food-waste-in-the-food-chain (accessed on 30 August 2018)

Nicastro, R.; Carillo, P. (2021). Food Loss and Waste Prevention Strategies from Farm to Fork. Sustainability, 13, 5443. (available at: https://doi.org/10.3390/su13105443)

Nilsson, H. (2012). Integrating sustainability in the food supply chain – Two measures to reduce the food wastage in a Swedish retail store, Master Thesis in Sustainable Development, Department of Earth Sciences, Uppsala University.

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

Oelofse, S.H.H, Polasi, T., Haywood, L and Musvoto, C. (2021). Increasing reliable, scientific data and information on food losses and waste in South Africa. Briefing note, CSIR, South Africa. (available at: https://wasteroadmap.co.za/wp-content/uploads/2021/06/17-CSIR-Final_Briefing-Note_Food-waste.pdf)

Olayemi, F.F., Adegbola, J.A., Bamishaiye, E.I. and Daura, A.M. (2010). Assessment of post-harvest challenges of small scale farm holders of tomatoes, bell and hot pepper in some local government areas of Kano State, Nigeria. Bayero Journal of Pure and Applied Sciences, 3, 39-42

Okah, R.N. (1997). Economic evaluation of losses in yams stored in traditional barns. Tropical Science, 38,125-127.

Opara, U. L. and Pathare, P.B. (2014). Bruise damage measurement and analysis of fresh horticultural produce—A review. Postharvest Biology and Technology, 91, 9-24.

Opara, I.K., Fawole, O.A. and Opara, U.L. (2021). Postharvest Losses of pomegranate fruit at the packhouse and implications for sustainability indicators. Sustainability, 13:9, 5187; https://doi.org/10.3390/su13095187.

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

Payasi, A., Mishra, N.N, Chaves, A.L.S. and Singh, R. (2009). Biochemistry of fruit softening: an overview. Physiology and Molecular Biology of Plants, 15:2,103-113.

Peleg, K. and S. Hinga, S. (1986). Simulation of vibration damage in produce [fruit and vegetables] transportation.Transactions of the American Society of Agricultural and Biological Engineers, 29, 633-641.

Pelletier, N. and Tyedmers, P. (2010). Forecasting potential global environmental costs of livestock production 2000–2050. Proceedings of the National Academy of Sciences, 107, 18371–4.

Perez-Lopez, A. J. & Carbonell-Barrachina, A. A. (2005). Fibre content in the edible portions of eight mandarin cultivars. Journal of Food Quality, 28, 154-162.

Rahiel, H.A., Zenebe, A.K., Leake, G.W. and Gebremedhin, B.W. (2018). Assessment of production potential and post-harvest losses of fruits and vegetables in northern region of Ethiopia. Agriculture & Food Security, 7, 29.

Rajabi, S., Lashgarara, F., Omidi, M. and Hosseini, S.J.F. (2015). Quantifying the grapes losses and waste in various stages of supply chain. Biological Forum, 7:1, 225-229.

Reich, A. and Foley, J. (2014). Food loss and waste in the US: The science behind the supply chain. Food Policy Research Center. Retrieved from the University of Minnesota Digital Conservancy. https://hdl.handle.net/11299/170087.

Reutter, B., Lant, P., Reynolds, C., Lane, J. (2017). Food waste consequences: environmentally extended input-output as a framework for analysis. Journal of Cleaner Production, 153, 506–514.

Rezaei, M. and Liu, R. (2017). Food loss and waste in the food supply chain. Nutfruit, 26-27.

Rizou, M., Galanakis, I.M., Aldawoud, T.M.S. and Galanakis, C.M. (2020),"Safety of foods, food supplychain and environment within the COVID-19 pandemic", Trends in Food Science and Technology, 102, 293-299.

Food losses and waste quantification in supply chains: a systematic literature review. Available from: https://www.researchgate.net/publication/350197080_Food_losses_and_waste_quantification_in_supply_chains_a_systematic_literature_review (accessed 4 Aug 2021).

Rockström, J., Falkenmark, M., Karlberg, L., Hoff, H. ,Rost, S. and Gerten, D. (2009). Future water availability for global food production: the potential of green water for increasing resilience to global change. Water Resources Research, 45:7. https://doi.org/10.1029/2007WR006767

Roels K. and Van Gijseghem D. (2017). The impact of cosmetic quality standards on food losses in the Flemish fruit and vegetable sector, summary report, Department of Agriculture and Fisheries, Brussels.

Rutten, M.M. (2013). What economic theory tells us about the impacts of reducing food losses and/orwaste: implications for research, policy and practice. Agriculture and Food Security, V 2:1, 13.

Salunkhe, D. K. and Desai, B.B., (1984). Posthrvest biotechnolgy of fruits, Vol 1. CRC Press, Inc., Boca Raton, Fl.

Sheahan, M., and C.B. Barrett. (2015). Food loss and waste in Sub-Saharan Africa: Magnitudes, remedial strategies and alternative approaches. Food Policy, 70, 1–12.

Singh, S. P., Sikka, B. K., & Singh, A. (2009). Supply chain management and Indian fresh produce supply chain: opportunities and challenges. International Food & Agribusiness Management Association, 19th Annual World Symposium, June 20-23, Budapest, Hungary.

Smil, V. (2004). Improving efficiency and reducing waste in our food system. Environmental Sciences, 1:1, 17-26.

Sosa, M.C. Lutz, M.C., Lefort, N.C. and Sanchez, A. (2016). Postharvest losses by complex of Phytophthora sp. and Botrytis cinerea in long storage pear fruit in the North Patagonia, Argentina. Acta Horticulturae, 1144, 237-244.

Sreenivasa Murthy, D., Gahanna, T.M., Sudha, M. and Dakshinamoorthy, V. (2009). Marketing and post-harvest losses in fruits: Its implications on availability and economy. Indian Journal of Agricultural Economics, 64:2, 259-275.

Statista. (2019). Global volume of wasted food as of 2017, by food category, Global waste generation dossier, Statista, Available online: https://www.statista.com/study/58790/global-waste-generation/(accessed on 10 Sept 2020).

Stenmarck, Å., Jensen, C., Quested, T. and Moates, G. (2016). Estimates of European food waste levels. Fusions: Stockholm, Sweden. Available at: <https://www.eu-

fusions.org/index.php/publications/266-establishing-reliable-data-on-food-waste-and-harmonising-quantification-methods> (accessed Oct 2018).

Stonehouse, J.M., Mumford, J.D. and Mustafa, G. (1998). Economic losses to tephritid fruit flies (Diptera: Tephritidae) in Pakistan. Crop protection, 17:2, 159-164.

Tadesse, F. (1991). Post-harvest losses of fruits and vegetables in horticultural state farms. Acta Horticulturae 270, 261–270

Terry, L. A., Mena, C., Williams, A., Jenney, N., and Whitehead, P. (2011). Fruit and vegetable resource maps: Mapping fruit and vegetable waste through the retail and wholesale supply chain. WRAP, RC008.

Tonini, D., Albizzati, P.F. and Astrup, T.F. (2018). Environmental impacts of food waste: Learnings and challenges from a case study on UK. Waste Management, 76, 744–766

Underhill, S.J.R. and Kumar, S. (2015). Quantifying postharvest losses along a commercial tomato supply chain in Fiji: A case study. Journal of Applied Horticulture, 17:3, 199-204.

Urutyan, V. (2013). Food Losses and Wastes along Selected Agri-food Chains in Armenia. Country Study. Prepared for the Food and Agriculture Organization of the United Nations.

Vayssières, J-F., Korie, S. and Ayegnon, D. (2009). Correlation of fruit fly (Diptera Tephritidae) infestation of major mango cultivars in Borgou (Benin) with abiotic and biotic factors and assessment of damage. Crop Protection, 28:6, 477-488.

Veena, Babu, K. N., and Venkatesha, H. R. (2011). Supply Chain: A Differentiator in marketing fresh produce. The IUP Journal of Supply Chain Management, VIII:I, 23-36.

Venkat, K. (2011). The climate change and economic impacts of food waste in the United States. International Journal of Food System Dynamics 2:4, 431–446.

Verma, A. (2003). Post-harvest losses of vegetables: an assessment. Indian Institute of Research, Varansi, India.

Verma, A., & Singh, K. (2004). An economic analysis of post harvest losses in fresh vegetables. Indian Journal of Agricultural Marketing, 18:1, 134-139.

Vigneault, C., Thompson, J., Wu, S., Hui, K.P.C. and LeBlanc, D.I. (2009). Transportation of fresh horticultural produce. Postharvest Technologies for Horticultural Crops, 2, 1-24.

Vilela, N.J, Lana, M.M., Nascimento, E.F., Makishima, N. (2003) Losses in the in the commercialisation of vegetables in a net retail of the Federal District of Brazil. Journal of Science & Technology, Brasilia, 20:3, 521-541.

Waisnawa, I. N. G. S., Santosa, I. D. M. C., Sunu, I. P. W. and Wirajati, I.G.A.B. (2018). Model development of cold chains for fresh fruits and vegetables distribution: A case study in Bali Province. Journal of Physics: Conference Series, 953.

Wallace, T.C., Bailey, R.L., Blumberg, J.B., Burton-Freeman, B., Chen,C-y.O., Crowe-White, K.M., Drewnowski, A., Hooshmand, S., Johnson, E., Lewis, R., Murray, R., Shapses, S.A. and Wang, D.D. (2020). Fruits, vegetables, and health: A comprehensive narrative, umbrella review of the science and recommendations for enhanced public policy to improve intake, Critical Reviews in Food Science and Nutrition, 60:13, 2174-2211. DOI: 10.1080/10408398.2019.1632258

Ward, A.R, and Jeffries, D.J. (2000). A manual for assessing post-harvest fisheries losses. DFID Projects R5027 Post-harvest fisheries research Programme.

Weinberger, K. & Lumpkin, T.A. (2005). Challenge Program: High value crops-fruits and vegetables. Horticulture of poverty alleviation-the unfunded revolution, Shanhua Taiwan. AVDARC –The world vegetable centre, 15, 1-4.

White, A., Gallegos, D. and Hundloe, T. (2011), "The impact of fresh produce specifications on the Australian food and nutrition system: a case study of the north Queensland banana industry", Public Health Nutrition,14:8, 1489-1495.

Weinberger, K., Genova, C. & Acedo, A. (2008). Quantifying postharvest loss in vegetables along the supply chain in Vietnam, Cambodia and Laos. International Journal of Postharvest Technology Innovation, 1, 288-97.

Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E. and Weidema, B., (2016). The Ecoinvent database version 3 (part I): overview and methodology. International Journal of Life Cycle Assessment, 21:9, 1218–1230. (available at: <http://link.springer.com/10.1007/s11367-016-1087-8>)

Woldu, Z., Mohammed, A., Belew, D., Shumeta, Z. and Bekele, A. (2015). Assessment of banana postharvest handling practices and losses in Ethiopia. Journal of Biology, Agriculture and Healthcare, 5:17, 82-97.

World Bank, FAO and NRI. (2011). Missing Food: the case of post-harvest grain losses in Sub-Saharan Africa. Economic Sector Work Report No. 60371-AFR. World Bank, Washington, DC.

WRAP (2019). Banbury, Food waste in primary production in the UK, Prepared by Bojana Bajzelj, William McManus and Andrew Parry.

Xue, L., Liu, G., Parfitt, J., Liu, X., Van Herpen, E., Stenmarck, A., O'Connor, C., Ostergren, K. and Cheng, S. (2017). Missing food, missing data? A critical review of global food losses and foodwaste data, Environmental Science and Technology, American Chemical Society, 51:12, 6618-6633.

Yahaya, S.M. and Mardiyya, A.Y. (2019). Review of post-harvest losses of fruits and vegetables. Biomedical Journal of Scientific & Technical Research,13:4, 10192-10200.

Zulfiqar, M., Khan, D. and Bashir, M. (2005). An assessment of marketing margins and physical losses at different stages of marketing channels for selected vegetable crops of Peshawar Valley. Journal of Applied Sciences, 5:9, 1528-1532.

CHAPTER 3

QUANTIFYING THE MAGNITUDE OF POSTHARVEST FRUIT LOSSES: A CASE STUDY OF INDUSTRY PACKHOUSE DATA IN THE WESTERN CAPE, SOUTH AFRICA

TABLE OF CONTENTS

Abstract

While it is estimated that 10 – 30% of the production volume of fruit are lost at primary production level, these estimates are not based on measurements. Few articles provide measured losses at primary production level. Sourcing operational data from stakeholders and the lack of adequate data with regard to the classification of different types of losses and waste can hamper efforts. This paper investigates the current situation for pears, grapes and apples, by reviewing data received from farms in the Western Cape, South Africa. The more delicate a fruit is, the higher the losses at farm level will be, this can be seen by apples and pears having production level losses with means of 0.87 ± 0.8% and 0.59 ± 0.38%, respectively, while grapes have mean production level losses of 13.55 ± 4.01%. The amount of 'missing fruit' (classified as 'variance' in farm records) is also worrisome as this is an indication that either the method for measuring harvested fruit is faulty or that staff carry away or eat around 1.53 ± 0.87%, 3.20 ± 1.68% and 3.40 ± 1.68% of the harvested apples, pears and grapes, respectively. While the concept of 'shrinkage' is well known and researched in the retail industry with an average of 1.62% loss of inventory per year across all

industries, little is known and nothing published about ‘shrinkage’ in fruit packhouses. Since the magnitude of ‘missing’ fruit on farm level is higher than that reported for other sectors in the global retail industry, further research could investigate minimising these losses as well as quantifying primary production site losses, as it could make a marked difference to the income of farms.

1. INTRODUCTION

Global interest in the problem of food loss and waste has increased tremendously in recent years, however, losses occurring at the primary production level is often overlooked (Johnson et al. 2018). It is estimated that between 10 – 30% of the production volume of fruit are lost at primary production level (FAO, 2009; Gustavsson et al. 2011; FAO, 2013; Kitinoja and Kader, 2015; Hartikainen et al. 2020). These estimates are not based on measurements, but cites other literature which is also not based on field measurements. There are few articles that provide specific numbers for specific fruits or cultivars like Murthy et al, (2014) does for ‘Thompson Seedless’ grapes.

Fruit and vegetables account for around 47% of the overall food waste in South Africa, a figure that does not include losses at the primary production level (Oelofse and Nahman, 2013). Part of the problem lies in sourcing operational data from stakeholders. A lack of adequate data with regard to the classification of different types of losses and waste can also hamper efforts. In addition, the competitive nature of the industry also negatively influence the availability of information at the production level (Louw, 2017).

To limit on-farm losses, it is necessary to know what the status quo is. This chapter analyses packhouse data for pears, grapes and apples received from farms in the Western Cape, South Africa to later be able to compare it against direct sampling data and determine whether the farm data is accurate or whether losses are greater than perceived by industry.

2. MATERIALS AND METHODS

The data presented and the methods used were received directly from the farms.

2.1 *G*eographical location

The apple and pear data originate from the same two farms in Somerset-West (latitude: 34° 04'S longitude: 18° 53'E) and in the Overberg area (latitude: 34°22' S; longitude: 20°34' E), while the grapes were harvested on six farms near Somerset West (Latitude: -34° 04' 60.00" S: Longitude: 18° 50' 59.99" E), De Doorns (Latitude: -33° 28' 59.99" S; Longitude: 19° 40' 59.99" E), Robertson (Latitude: -33° 47' 59.99" S; Longitude: 19° 52' 59.99" E) and Piketberg (Latitude: -32° 53' 59.99" S; Longitude: 18° 45' 59.99" E) in the Western Cape Region of South Africa.

*2.*2 Cultivars and harvest times

Apples
'Fuji', 'Golden Delicious', 'Granny Smith', Pink Lady', 'Royal Beaut', 'Sundowner' and 'Top Red' were harvested during the commercial harvest from February to May, depending on the cultivar, in 2014 and 2015.

Pears
William's Bon Chretien'; 'Packham's Triumph' and 'Forelle' were harvested during the commercial harvest in February 2014 and 2015.

Grapes
'Crimson Seedless', harvested during the commercial harvest in February and March of 2015 and 2016.

2.3 Harvest and packing techniques

Apples and pears were harvested using picking bags (20 L) to gather the fruit from the trees, after which the bags were emptied into bins (*External* Dimensions: 1270 mm X 1070 mm; Total height: 720 mm; Weight: 68 kg). The bins were then transported to the packing shed where they were emptied (tipped) into a grading machine (Pomone system, Agrobotic, MAF RODA RSA) this is referred to as the tipped amount in kg on the packing reports. The fruit were electronically scanned and sorted by the grading machine. Similar size and quality fruit were then channeled to the various packing stations (Figure 1). Damaged and decayed fruit were collected in separate bins and weighed at the end of each day.

Grapes were cut from the vines and packed into crates in the vineyards. They were then transported to the packing sheds where crates were placed on a central conveyor line from where crates were taken by the packers to their work tables. The grape bunches were trimmed and packed according to commercial practice and resulting losses (dropped, decayed, damaged or green berries) were collected into bins and weighed at the end of each day (Figure 2).

3. RESULTS AND DISCUSSION

3.1 Apples

Tables 1 and 2 summarises the 2014 and 2015 harvest data for apples received from two different farms. To remain anonymous, the farms are labelled Farm 1 and Farm 2.

Postharvest losses per cultivar per farm

Farm 1:
‘Fuji’: In 2014, 20 kg or 2.04% was classified as loss, due to damage or deformity, and 18 kg or 1.83% classified as missing fruit. Only 2014 data was available.

‘Golden Delicious’: In 2014, 2 400 kg or 0.93% was classified as loss and 2 850 kg or 1.11% was missing after harvest. A total of 5 250 kg or 2.04% was therefore lost. In 2015, 1 160 kg or 0.35% was loss and 376 kg or 0.11% missing with a total amount of 1 536 kg or 0.46%.

'Granny Smith': In 2014, 920 kg or 0.64% was loss and 2 073 kg or 1.45% classified as missing. A total of 2 993 kg or 2.10% of the harvest was lost. In 2015, 940 kg or 0.27% was classified as loss and 4 299 kg or 1.21% was missing adding up to a total of 5 239 kg or 1.48% of the harvest.

'Pink Lady': In 2014, 10 820 kg or 0.77% was classified as loss and 27 266 kg or 1.93% classified as missing. The total amount lost was 38 086 kg or 2.70%. No data for 2015 was provided.

'Sundowner': In 2014, 4 640 kg or 0.95% was loss with 488 kg or 0.10% missing fruit. A total of 5 128 kg or 1.05% of this cultivar was lost at farm level. In 2015, 1 160 kg or 0.16% was loss and 13 177 kg or 1.80% of the harvest went missing. A total of 14 337 kg or 1.95% of the harvest was therefore lost.

Farm 2:

'Royal Beaut': 460 kg or 3.02% was classified as loss and 330 or 2.16% was missing after packing. A total of 790 kg or 5.18% of the harvest was lost.

'Golden Delicious': 3 720 kg or 0.64% of the harvest was loss and 7 756 kg or 1.33% of the harvest was missing. A total of 11 476 kg or 1.96% was lost at farm/packhouse level. In 2015, 2 730 kg or 0.32% was classified as loss and 1 062 kg or 0.13% was missing. A total of 3 792 kg or 0.45% was lost.

'Granny Smith': 1 420 kg or 0.83% was classified as loss and 3 705 kg or 2.16% was missing after reaching the packhouse. A total of 5 125 kg or 2.99% of the harvest was thus lost at farm level. In 2015,1 620 kg or 0.36% was loss and 10 968 kg or 2.41% was missing. A total of 12 588 kg or 2.76% was lost.

'Top Red': In 2014, 80 kg or 0.71% was classified as loss and 340 kg or 3.04% went missing. A total of 420 kg or 3.75% of the harvest was lost. Only the one year's data was available.

The largest amount of loss generated by a single cultivar, in terms of percentage, was on 3.02% for 'Royal Beaut', while the largest amount of missing fruit was 3.04% for

‘Top Red’. On Farm 1 the mean amount of apples across all cultivars, and for both years, classified as loss was 0.76% ± 0.59% and the mean for missing fruit was 1.19% ± 0.73% while on Farm 2 the mean amount of loss generated was 0.97% ± 0.67% while the mean amount of apples that went missing in the packhouse was 1.87% ± 1.01%. Losses was lower than the average losses of 5.8% reported by Masood, (2011) for ‘Jawrasi’, ‘Golden Delicious’ and ‘Red Delicious’. Masood, (2011) also reported that the main reasons for these losses were absence of proper harvesting materials and that little care is taken by the unskilled pickers during harvesting. Ludwig-Ohm et al. (2019) reported higher losses at farm level of 6 -16% in Germany though the cultivar is not specified. While Ilyas et al. (2007) reports farm level losses in Pakistan to be 8%, also with no cultivar specified.

The amount of apples lost through theft in the packhouse is more than double that lost through damage or decay. While the concept of ‘shrinkage’ is well known and researched in the retail industry with an average of 1.62% loss of inventory per year across all industries (these include: supermarkets and groceries, men’s and women’s apparel, jewelry and watches, pharmacies, home improvement, building, hardware, lumber and garden supply, consumer electronics, computers and appliances, pets and animal supplies, shoes and footwear amongs others) in the United States (Mishra and Prasad, 2006; National Retail Security Survey, 2020), little is known or published about shrinkage in fruit packhouses. Since the mean magnitude of ‘missing’ apples on farm level was 2.05%, further research could focus on minimising these losses as it is higher than levels reported in the retail sector and could make a marked difference in farm income.

3.2 Pears

Tables 3 and 4 summarises the 2014 and 2015 harvest data for pears also received from Farms 1 and 2.

Postharvest losses per cultivar per farm

Farm 1:

'William's Bon Chretien': The amount of loss generated during packing was 820 kg or 0.24% while the amount classified as variance, i.e. missing fruit was 9 932 kg or 2.91%. The total amount of fruit lost was therefore, 3.15% of the harvest during 2014. In 2015 no fruit of this cultivar were harvested or alternatively no records were kept.

'Packham's Triumph': In 2014, 10 111 kg or 0.73% was classified as loss and 22 626 kg or 1.64% was classified as missing fruit. The total amount of fruit lost was 2.37%. In 2015, 9 990 kg or 0.68% was classified as loss and 47 869 kg or 3.26% classified as missing fruit. This brings the total amount of fruit lost at harvest to 3.94%.

'Forelle': In 2014, 760 kg or 0.93% of the harvest was classified as loss and 594 kg or 0.72% of the harvest was missing after packaging with the total amount of fruit lost at harvest 1.65%. In 2015, 388 kg or 0.48% of the harvest was loss and 3 767 kg or 4.71% of the harvest was missing after packaging. A total of 5.19% of the harvest was therefore lost.

Farm 2:
'Packham's Triumph': This is the only cultivar grown. 231 kg or 1.08% was loss and 817 kg or 3,82% was classified as missing fruit. The total amount of lost fruit was 4.90% at harvest in 2014. In 2015, according to farm records, 0 kg or 0% was classified as loss during this season and 1 492 kg or 5.56% was classified as missing fruit, so the total loss at harvest was 5.56%.

In 2014 the mean for pears classified as loss from both farms was 0.74% ± 0.36% and 0.38% ± 0.34% in 2015. The highest amount of loss recorded was 1.08% of 'Packham's Triumph' on Farm 2 in 2014. This is much lower than the measured data of Franke et al. (2016) of 10% loss of pears at farm level in Nordic countries though no specific cultivars were mentioned.The mean for missing fruit was 2.27% ± 1.36% in 2014 and 4.89% ± 0.84% in 2015. The highest amount of missing fruit was also 'Packham's Triumph' on Farm 2 with 5.56%. That is a large amount of fruit that disappeared after harvested fruit are tipped in the packhouse and will have an impact of the farms profitability.

3.3 Grapes

Tables 5, 6 and 7 summarises the 2015 and 2016 harvest data for 'Crimson Seedless' received from six different farms. To remain anonymous, the farms are labelled Farm 3 – 8.

Postharvest losses of 'Crimson Seedless' per farm

Farm 3:

In 2015, 61 633 kg or 10.3% was classified as loss and 19 294 kg or 3.2% was classified as variance that means it is missing fruit. The total amount of grapes lost at harvest was therefore 13.5%. In 2016, 141 458 kg or 14.0% was classified as loss and 27 465 kg or 2.7% was classified as missing. 16.7% of grapes was therefore lost at harvest.

Farm 4:

In 2015, 89 368 kg or 11.1% was classified as loss and 50 007 kg or 6.2% was classified as missing fruit. In total, 17.4% was lost at harvest. In 2016, 109 700 kg or 14.9% was classified as loss and 46 152 kg or 6.3% was classified as missing fruit. A total of 21.2% was therefore lost at harvest.

Farm 5:

In 2015, 290 776 kg or 19.9% was classified as loss and 67 787 kg or 4.6% was missing fruit. 24.5% of the harvest was therefore lost at harvest. In 2016, 147 941 kg or 16.6% was classified as loss and 26 729 kg or 3.0% was missing fruit. A total of 19.6% of the harvest was therefore lost at harvest.

Farm 6:

In 2015, 64 428 kg or 6.6% were classified as loss and 33 354 kg or 3.4% was missing. A total of 10.0% of the harvest was lost. In 2016, 170 331 kg or 15.4% was classified as loss and 27 780 kg or 2.5% was missing. A total of 17.9% of the harvest was therefore lost.

Farm 7:

In 2015, 98 263 kg or 18.2% was classified as loss and 14 649 kg or 2.7% was classified as missing. A total of 21% of this harvest was lost at farm/packhouse level.

In 2016, 135 673 kg or 16.1% was classified as loss and 31 566 kg or 3.8% was classified as missing. 19.9% of this harvest was lost.

Farm 8:
In 2015, 73 646 kg or 10.4% was classified as loss and 2 687 kg or 0.4% was missing. A total of 10.8% of harvested grapes was therefore lost. In 2016, 66 035 kg or 9.1% was classified as loss and 14 959 kg or 2.1% was missing. A total of 11.2% of harvested grapes was therefore lost.

The mean % of grapes classified as loss across all six farms and for both years was 13.55% ± 4.02%, ranging from 9.75% to 18.22% between farms. This is much higher, than the 3.40% for 'Thompson Seedless' grapes headed for the domestic market in India, and also higher than the 7.82% reported for the same cultivar headed for the export market reported by Murthy et al, (2014). The mean amount of grapes classified as missing was 3.42 ± 1.68%.

4. CONCLUSION

The more delicate a fruit is, the higher the losses at farm level will be, this can be seen by the production level losses of apples with means of 1.17 ± 0.81% in 2014 and 0.29 ± 0.08% in 2015 and production level losses of pears with means of 0.74 ± 0.36% 2014 and 0.38 ± 0.34% in 2015, while grapes have mean production level losses of 12.75 ± 5.15% in 2015 and 14.35 ± 2.72% in 2016. Grapes are more delicate than pears and apples and this contributes much to the larger loss recorded for grapes on farm level. The rough handling of crates has the effect of causing many berries to fall off the bunches and as workers are paid according to how much they pack in a given time period, their haste in getting more crates onto their worktable could be a big reason for the higher magnitude of losses. Making the workers more aware of the need to work carefully with the product could lead to a decrease in lost berries. These finding show that every fruit type, indeed, every cultivar, therefore, must be investigated to make appropriate recommendations as to how these losses can be reduced.

It is advisable for farm managers to make a greater effort towards better record keeping methods as the data is often incomplete or obviously incorrect. For example, in one of the records, it was stated that 118% of the harvest was tipped in the packhouse, this is clearly not possible and throws doubt upon the rest of the data. The amount of 'missing' fruit (called 'variance' in farm records) is also worrisome as this is an indication that either the method for measuring harvested fruit is faulty or that staff often carry away or eat around 1.53 ± 0.87%, 3.20 ± 1.68% and 3.40 ± 1.68% of the harvest for apples, pears and grapes, respectively. It seems important, therefore, to do further intensive research on the losses at farm level as it is the starting point for the whole fresh fruit supply chain.

5. REFERENCES

Blanckenberg, A., Opara, U.L. and Fawole, O.A. (2021). Postharvest losses in quantity and quality of Table Grape (cv. Crimson Seedless) along the supply chain and associated economic, environmental and resource impacts. Sustainability, 13, 4450. https://doi.org/10.3390/su13084450

FAO. (2009). State of food insecurity in the world: economic crises — impacts and lessons learned. Food and Agriculture Organization of the United Nations.

FAO. (2013). Food losses and waste in Europe and Central Asia. Food and Agriculture Organization of the United Nations.

Gustavsson, J., Cederberg, C., Sonesson, U., van Otterdijk, R. and Meybeck, A. (2011). Global food losses and food waste. Rome: Food and Agriculture Organisation of the United Nations. http://www.fao.org/docrep/014/mb060e/mb060e00.pdf. Accessed 10 June 2020.

Hartikainen, H., Riipi, I., Katajajuuri, JM. and Silvennoinen, K. (2020). From Measurement to Management: Food Waste in the Finnish Food Chain. In: Närvänen E., Mesiranta N., Mattila M., Heikkinen A. (eds) Food Waste Management. Palgrave Macmillan, Cham. https://doi.org/10.1007/978-3-030-20561-4_16

Johnson, L.K., Dunning, R.D., Gunter, C., Bloom, J.D., Gunter, C.C., Boyette, M.D. and Creamer. N.G (2018). Estimating on-farm food loss at the farm-level: A methodology and applied case study on a North Carolina farm. Resources, Conservation & Recycling, 137, 243-250.

Kader, A.A. (2005). Increasing availability by reducing post-harvest losses of fresh produce. Acta Horticulturae, 682, 2169-2175.

Kitinoja, L.; Kader, A.A. (2015). Measuring Post-Harvest Losses of Fresh Fruits and Vegetables in Developing Countries; White paper 15-02; Post-harvest Education Foundation: La Pine, OR, USA.

Louw, L. (2017). Economic Aspects of Losses and Waste: Case Study of the South African Table Grape Supply Chain. Master' Thesis, Department of Agricultural Economics, Extension and Rural Development, Faculty of Natural and Agricultural Sciences, University of Pretoria, Pretoria, South Africa.

Masood, M. (2011). An assessment of apple post-harvest losses the case of Nerkh district, Afghanistan. Master' Thesis, Van Hall Larenstein University of Applied Sciences, Wageningen, The Netherlands.

Mishra, B.K. and Prasad, A. (2006), Minimizing retail shrinkage due to employee theft. International Journal of Retail & Distribution Management, 34:1, 817-832.

Murthy, M.R.K.; Reddy, G.P.; Rao, K.H. (2014).Retail marketing of fruits and vegetables in India: A case study on export of grapes from Andhra Pradesh, India. European Journal of logistics, Purchasing and Supply Chain Management, 2, 62–70.

National Retail Security Survey. (2020). National retail federation. Available online: https://cdn.nrf.com/sites/default/files/2020-07/RS-105905_2020_NationalRetailSecuritySurvey.pdf (accessed 3 June 2021).

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

Figure 1. Flow diagram of pear harvest from picking to packing

Pears harvested into picking bags.

Picking bags emptied into bins.

Bins waiting to be loaded into sorting machine.

Bins tipped onto sorting machine.

Pears electronically scanned and sorted.

Pears channeled to the packing stations.

Pears rejected due to size

Figure 2. Flow diagram of grape harvest from picking to packing

Grapes cut from the vines and packed into crates.

Grapes ready for transport to packing shed.

Central conveyor line in packing shed.

Grape bunches being trimmed and packed

Lost berries (dropped, decayed, damaged or green berries)

Table 1. Collation of packing reports for apples, 'Fuji', 'Pink Lady', 'Golden Delicious', 'Granny Smith', 'Sundowner', 'Royal Beaut', 'Golden Delicious', 'Granny Smith' and 'Top Red', harvested on two farms in the Western Cape, South Africa for two years (2014 and 2015) according to the farms' own records.

Year	Farm	Cultivar	Tipped kg	Grade 1 kg	Grade 1 %	Grade 2 kg	Grade 2 %	Grade 3 kg	Grade 3 %	Loss kg	Loss %	Variance (Missing fruit) kg	Variance (Missing fruit) %	Total % lost
2014	1	Fuji	982	554	56.42	390	39.71	0	0.00	20	2.04	18	1.83	3.87
2014	1	Pink Lady	1 409 246	1 116 132	79.20	147 073	10.44	107 956	7.66	10 820	0.77	27 266	1.93	2.70
2014	1	Golden Delicious	257 292	196 546	76.39	30 675	11.92	24 821	9.65	2 400	0.93	2 850	1.11	2.04
2014	1	Granny Smith	142 637	108 087	75.78	18 659	13.08	12 898	9.04	920	0.64	2 073	1.45	2.10
2014	1	Sundown er	487 216	392 128	80.48	52 163	10.71	37 486	7.69	4 640	0.95	488	0.10	1.05
2014	2	Royal Beaut	15 248	12 800	83.95	1 285	8.43	373	2.45	460	3.02	330	2.16	5.18
2014	2	Golden Delicious	584 674	466 726	79.83	62 607	10.71	43 866	7.50	3 720	0.64	7 756	1.33	1.96
2014	2	Granny Smith	171 440	136 202	79.45	17 342	10.12	12 770	7.45	1 420	0.83	3 705	2.16	2.99
2014	2	Top Red	11 195	9 717	86.80	897	8.01	161	1.44	80	0.71	340	3.04	3.75
2015	1	Sundown er	733 998	624 150	85.03	32 051	4.37	63 460	8.65	1 160	0.16	13 177	1.80	1.95
2015	1	Granny Smith	354 332	260 445	73.50	11 466	3.24	77 182	21.78	940	0.27	4 299	1.21	1.48
2015	1	Golden Delicious	332 847	242 660	72.90	17 576	5.28	71 075	21.35	1 160	0.35	376	0.11	0.46
2015	2	Golden Delicious	845 216	585 492	69.27	95 969	11.35	159 963	18.93	2 730	0.32	1 062	0.13	0.45
2015	2	Granny Smith	455 627	354 331	77.77	21 861	4.80	68 847	15.11	16 20	0.36	10 968	2.41	2.76

Table 2. Mean values per apple cultivar for two farms in the Western Cape, South Africa.

Cultivar	Tipped kg	Grade 1 kg	Grade 1 %	Grade 2 kg	Grade 2 %	Grade 3 kg	Grade 3 %	Loss kg	Loss %	Variance (Missing fruit) in kg	Variance (Missing fruit) %	Total % lost
Fuji	982	554	56.42	390	39.71	-	-	20	2.04	18	1.83	3.87
Golden Delicious	505 007	372 856	74.59	51 706	9.81	74 931	14.35	2 502	0.56	3 011	0.66	1.22
Granny Smith	281 009	214 766	76.62	17 332	7.80	42 924	13.34	1 225	0.52	5 261	1.80	2.33
Pink Lady	1409 246	1 116 132	79.20	147 073	10.43	107 956	7.66	10 820	0.76	27 266	1.93	2.70
Royal Beaut	15 248	12 800	83.94	1 285	8.42	373	2.44	460	3.01	330	2.16	5.18
Sundowner	610 607	508 139	82.75	42 107	7.53	50 473	8.16	2 900	0.55	6 832	0.94	1.50
Top Red	11 195	9 717	86.79	897	8.01	161	1.43	80	0.71	340	3.03	3.75

Table 3. Collation of packing reports for pears, 'Packham's Triumph' and 'Forelle', harvested on two farms in the Western Cape, South Africa for two years (2014 and 2015) according to the farms' own records.

Year	Farm	Cultivar	Tipped kg	Grade 1 kg	Grade 1 %	Grade 2 kg	Grade 2 %	Grade 3 kg	Grade 3 %	Loss kg	Loss %	Variance (Missing fruit) kg	Variance (Missing fruit) %	Total % lost
2014	1	William's Bon Chretien	341 671	266 918	78.12	7 793	2.28	56 208	16.45	820	0.24	9 932	2.90	3.14
2014	1	Packham's Triumph	1 383 066	1 180 898	85.38	102 107	7.38	67 324	4.87	10 111	0.73	22 626	1.64	2.37
2014	1	Forelle	82 048	58 012	70.70	10 471	12.76	12 211	14.88	760	0.93	594	0.72	1.65
2014	2	Packham's Triumph	21 385	16 689	78.04	1 827	8.54	1 821	8.52	231	1.08	817	3.82	4.90
2015	1	Packham's Triumph	1 469 592	1 207 264	82.15	100 378	6.83	104 091	7.08	9 990	0.68	47 869	3.26	3.94
2015	1	Forelle	79 968	60 953	76.22	12 450	15.57	2 418	3.02	380	0.48	3 767	4.71	5.19
2015	2	Packham's Triumph	26 833	19 847	73.96	2 918	10.87	2 576	9.60	0	0.00	1 492	5.56	5.56

Table 4. Mean values per pear cultivar for both years and both farms.

Cultivar	Tipped kg	Grade 1 kg	Grade 1 %	Grade 2 kg	Grade 2 %	Grade 3 kg	Grade 3 %	Loss kg	Loss %	Variance (Missing fruit) kg	Variance (Missing fruit) %	Total % lost
William's Bon Chretien	341 671	266 918	78.12	7 793	2.28	56 208	16.45	820	0.24	9 932	2.90	3.14
Packham's Triumph	725 219	606 174	79.88	51 807	8.40	43 953	7.51	5 083	0.62	18 201	3.56	4.19
Forelle	81 008	59 482	73.46	11 460	14.16	7 314	8.95	570	0.70	2 180	2.71	3.41

Table 5. Collation of packing reports for grapes, 'Crimson Seedless', harvested on six farms in the Western Cape, South Africa for two years (2015 and 2016) according to the farms' own records.

Year	Farm	Crates harvested	Cartons packed 4.5 kg	Grapes packed in kg	Loss in kg	Loss %	Variance (Missing fruit) in kg	Variance (Missing fruit) %	Total % lost
2015	3	43 005	118 153	599 436	61 633	10.3	19 294	3.2	13.5
2015	4	65 143	153 560	802 067	89 368	11.1	50 007	6.2	17.4
2015	5	106 978	249 750	1 464 296	290 776	19.9	67 787	4.6	24.5
2015	6	79 150	194 778	976 412	64 428	6.6	33 354	3.4	10.0
2015	7	33 957	97 288	538 868	98 263	18.2	14 649	2.7	21.0
2015	8	53 884	140 681	708 401	73 646	10.4	2 687	0.4	10.8
2016	3	119 989	190 918	1 009 912	141 458	14.0	27 465	2.7	16.7
2016	4	81 306	142 199	735 497	109 700	14.9	46 152	6.3	21.2
2016	5	103 419	161 754	893 367	147 941	16.6	26 729	3.0	19.6
2016	6	119 808	215 696	1 107 172	170 331	15.4	27 780	2.5	17.9
2016	7	92 715	160 267	840 178	135 673	16.1	31 566	3.8	19.9
2016	8	80 228	146 507	724 150	66 035	9.1	14 959	2.1	11.2

Table 6. 'Crimson Seedless' packhouse data for 2015 and 2016 on six farms in the Western Cape, South Africa.

	Crates harvested	Cartons packed 4.5 kg	Grapes packed in kg	Loss in kg	Variance (Missing fruit) in kg	Loss%	Variance (Missing fruit) %	Total % lost
Means for 2015	63 686	159 035	848 246	113 019	31 296	12.75	3.43	16.18
Means for 2016	99 577	169 556	885 046	128 523	29 108	14.35	3.40	17.75

Table 7. Mean values per farm for 'Crimson Seedless' packhouse data (over two years) from six farms in the Western Cape, South Africa.

Farm	Crates harvested	Cartons packed 4.5 kg	Grapes packed in kg	Loss in kg	Variance (Missing fruit) in kg	Loss %	Variance (Missing fruit) %	Total % lost
3	105 198	205 752	1 178 831	219 358	47 258	18.22	3.81	22.04
4	81 497	154 535	804 674	101 545	23 379	12.15	2.95	15.10
5	99 479	205 237	1 041 792	117 379	30 567	10.99	2.95	13.95
6	67 056	143 594	716 275	69 840	8 823	9.74	1.23	10.98
7	63 336	128 777	689 523	116 968	23 107	17.16	3.25	20.42
8	73 224	147 879	768 782	99 534	48 079	13.02	6.26	19.28

CHAPTER 4

POSTHARVEST LOSSES IN QUANTITY AND QUALITY OF TABLE GRAPE (CV. *CRIMSON SEEDLESS*) ALONG THE SUPPLY CHAIN AND ASSOCIATED ECONOMIC, ENVIRONMENTAL AND RESOURCE IMPACTS*[1]

TABLE OF CONTENTS

Abstract

High incidence of postharvest losses is a major challenge to global food security. Addressing postharvest losses is a better strategy to increase business efficiency and improve food security rather than simply investing more resources to increase production. Global estimates show that fruit and vegetables are the highest contributors to postharvest losses and food waste, with 45% of production lost. This represents 38% of total global food losses and waste. However, the lack of primary data on postharvest losses at critical steps in the fruit value chain and the unknown

[1]*Blanckenberg, A., Opara, U.L. and Fawole, O.A. (2021). Postharvest losses in quantity and quality of Table Grape (cv. Crimson Seedless) along the supply chain and associated economic, environmental and resource impacts. Sustainability, 13, 4450. https://doi.org/10.3390/su13084450

economic, environmental and resource impacts of these losses make it difficult to formulate mitigation strategies. This paper quantified postharvest losses (quantity and quality) of 'Crimson Seedless' table grapes at farm and simulated retail levels. Table grapes were sampled from four farms in the Western Cape Province of South Africa, the largest deciduous fruit production and export region in Southern Africa. Mean on-farm losses immediately after harvest were 13.9% in 2017 and 5.97% in 2018, ranging from 5.51% to 23.3% for individual farms. The main reason for on-farm losses was mechanical damage (7.1%). After 14 days in cold storage (-0.3 ± 0.7°C, 81.3 ± 4.1% RH), mean grape losses were 3.05% in 2017 and 2.41% in 2018, which increased to 7.41% in 2017 and 2.99% in 2018, after 28 days. After 10 days of further storage under simulated market conditions (5.4 ± 0.6°C, 83.7 ± 2.9% RH), fruit losses were 3.65% during retail marketing and 4.36% during export. Storing grapes under ambient conditions (25.1 ± 1.3°C and 46.6 ± 6.0% RH) resulted in a higher incidence of losses, increasing to 7.03, 9.59 and 14.29% after 3, 7 and 10 days, respectively. The socio-economic impacts of the postharvest physical losses amounted to financial losses of over R 279 million (US$ 17 million according to the conversion rate of 20 October 2020) annually, and this was associated with the loss of 177.43 million MJ of fossil energy, 4.8 million m^3 of fresh water and contributed to the emission of approximately 52 263 tonnes of CO_2 equivalent.

1. INTRODUCTION

Interest in the mitigation of postharvest losses is heightened due to global concern about food insecurity. Preserving the food supply after production has since the earliest times been a problem for humankind (Kuhr, 1979). However, a dominant challenge of the 21st century is how to feed the growing world population sustainably, predicted to reach 9.1 billion by 2050, affordably while using the natural resources required equitably and sustainably (FAO, 2009; Hodges et al., 2010).

The UN Food and Agriculture Organisation (FAO) estimated that feeding the growing world population by 2050 would require 70% increase in food production (Alexandratos, 2009). However, the FAO also reports that approximately one-third of the edible portions of the food produced globally is lost or wasted along the supply chain, from farm to plate, (FAO, 2013) with a total of 38% of the volume consisting of fruits and vegetables (Statista, 2019). Lost and wasted food consumes a quarter of all the water used by agriculture annually, requires farmland area the size of China, and generates an estimated 8% of global greenhouse gas emissions. In effect, if lost and wasted food were a country, it would be the third-largest greenhouse gas emitter on the planet after China and the United States (Smil, 2009; Parfitt et al., 2010; FLW Protocol, 2016).

While 95% of all agricultural research investment focuses on increasing crop production strategies, only 5% focuses on postharvest issues (Lipinski et al., 2013). Reducing postharvest loss and waste is more cost effective and less time consuming than production strategies. Therefore, the improvement of postharvest chains must receive as much attention as production practices. Furthermore, limiting the loss of fresh fruit will reduce the use of land, chemicals, energy, and other inputs needed to produce horticultural crops, thereby conserving natural resources and protecting the environment (Kader, 2005; Munhuwey et al., 2015).

A major obstacle in achieving postharvest loss mitigation is a lack of clear knowledge of the real magnitudes of losses, making it impossible to measure progress against any loss reduction targets (Affognon et al., 2015).

Apart from worrying anecdotal information, there is little scientific data available about food losses in South Africa. A study (Oelofse and Nahman, 2013) provided a preliminary estimate of the magnitude of food loss and waste generation in South Africa of around 9.04 million tonnes per year. However, this study was based on available data as reported by FAO and further assumptions as no primary data was collected. While estimates do indicate the size of the problem, they do not provide accurate and reliable data for specific supply chains.

The lack of primary data on postharvest losses at critical steps in the fruit value chain and the unknown economic, environmental and resource impacts makes it challenging to formulate mitigation strategies. There is a lack of standard methods to measure postharvest losses of food crops, including fruit and vegetable crops. Researchers have developed many different methods during the past few decades, focusing on different aspects of the value chain and varying types of food losses (Kitinoja and Kader, 2015). The lack of accurate and reliable postharvest loss data may result in inaccurate assumptions on food wastage (Gustavsson, 2011).

In South Africa, fruit and vegetables account for 47% of food wastage (Oelofse and Nahman, 2013). In the first South African study generating primary data on postharvest losses of vegetables at the retail level, (Munhuwey et al., 2015) found vegetable losses for carrot, tomato and cabbages to be on average 17.93%, 15.33% and 21.21%, respectively. The availability of primary research data on the magnitude of losses in the fresh fruit value chain is very limited. Fruit is a major contributor to the agricultural industry, considering foreign exchange earnings and employment creation.

Table grapes account for 32% of the total area planted to deciduous fruits in South Africa (DAFF, 2017), with 'Crimson Seedless' cultivar accounting for 20% of all vines (SATI, 2016). 'Crimson Seedless' is a mid to late season red seedless grape cultivar with firm berries characterized by its crisp texture and intensely sweet flavour. The main quality problems during postharvest handling are moisture loss leading to loss of mass, fungal infection and shrivelled rachis, which then become brittle and break easily, and the browning of the stems, which reduces the visual appeal and price of the product (Lichter et al., 2011; Ngcobo et al., 2012a; Ngcobo et al., 2013).

Although table grapes are non-climacteric fruit with a relatively low rate of physiological activity (Crisosto et al., 2001), they are subject to severe postharvest losses during storage and long distance transport (Li et al., 2015). Rapid moisture loss, which results in rachis (cluster stem) drying and browning (Crisosto et al., 2002; Jiang et al., 2015), mass loss (Ngcobo et al., 2012b), berry shatter, wilting and shrivelling of berries (Sabir and Sabir, 2013) are some of the main quality problems experienced during postharvest handling causing quantitative and quality losses. It has been suggested that inappropriate handling processes are the main reason for weakening the natural defences of grapes and making fresh grapes more susceptible to decay and subsequent deterioration (Sabir and Sabir, 2017).

As the gross value of production of table grapes has increased significantly from R2 billion in 2006/07 to R7.1 billion in 2015/16, an increase of 248% (DAFF, 2017), reduction of postharvest losses by even a few percentage points will not only reduce the cost of production, trade and distribution but will also have significant financial implications for all involved in the supply chain by lowering the price for the consumer and increasing the farmers' income. Therefore, this research aimed to generate primary data on postharvest losses in quantity and quality of 'Crimson Seedless' table grape through direct sampling at critical steps in the supply chain to inform future action to reduce and better manage the postharvest loss problem.

2. MATERIALS AND METHODS

2.1 Harvesting techniques and berry preparation

Data collection protocols were similar to those used by Kitinoja and Al Hassan, (2012). Grapes were harvested from four farms during the last week of February and the first week of March in 2017, and during the first three weeks of February in 2018. Both times were during the commercial harvest. In 2017, a total sample size of 1200 bunches (300 bunches per farm) were collected, while 1600 bunches (400 bunches per farm) were collected in 2018. The grapes were collected from four farms that each have their own packhouse on site, near De Doorns, Robertson and Piketberg in the Western Cape Region of South Africa. Bunches were weighed in the packhouse as they came in from the vineyard, each bunch was then tagged with a unique label identifying the farm of origin (V; K; R or D), the supply chain scenario the bunch was destined for (A; B; or C in 2017 and A; B; C or D in 2018) and the bunch number (1 – 100) e.g. VA29 (Table 1).

The grape bunches were then trimmed by expert packers according to commercial practice and packed into standard 9 kg cartons (internal dimensions of the 9 kg cartons were 58 cm long × 34 cm wide × 13.2 cm high) with a riffled sheet at the bottom, a plastic liner as well as an SO_2 cover pad on top with a slow release of sodium metabisulfite ($Na_2S_2O_5$) (Uvasys®, Cape Town, South Africa). Sodium metabisulfite generates sulphurous anhydride gas (SO_2) when in contact with humidity, inhibiting the development and growth of fungi in table grapes during refrigerated packaging and transport.

2.2 Supply chains simulated

In 2017, eighteen cartons per farm were collected and divided equally into three simulated supply chain scenarios. In 2018, twenty-four cartons per farm were collected and divided into four simulated supply chain scenarios. From each farm and for both years, 100 bunches were used for each supply chain scenario simulated, i.e. 400 bunches per scenario. Four supply chain scenarios were studied (Table 1), representing the range of postharvest handling practices that occur in local and export marketing of Table grapes in the South African fresh fruit industry. According to export grape producers (pers. communication Amelia Vorster, Technical Advisor (Quality) –

Karsten Western Cape), Scenario D is a common occurrence and leads to tension between role-players as to whether the fruit was mishandled before the report was written and who is responsible for the losses if it is higher than expected.

2.3 Fruit loss evaluation and quality measurements

2.3.1 Postharvest losses

The base measurement for losses at harvest occurred in the packhouse on each farm after the bunches were trimmed for packaging and the resulting berries sorted into categories based on the reason for being cut from the bunch, 1) berry too green in colour, 2) mechanical damage or 3) decayed. It was quantified as the weight of the berries removed as a percentage of the original weight of the bunches before trimming. At each evaluation date thereafter, physical losses were quantified as the decrease in bunch weight and the amount lost due to decay or SO_2 damage (a high concentration of SO_2 can damage table grapes by causing bleaching, cracking or causing early browning of the rachis) expressed as a percentage of the initial berry numbers per bunch.

2.3.2 Quality attributes

The following attributes were measured at each evaluation time:

1.Weight loss

Expressed as a percentage of the initial bunch weight. A total of 30 bunches x 4 farms = 120 bunches per supply chain scenario.

2. Stem browning

Rated on a 5-point scale, with 1 being fresh/green and 5 being dry/brown (Kitinoja and Kader, 2015; Gustavsson et al., 2011). A total of 30 bunches x 4 farms = 120 bunches per supply chain scenario.

3. Total soluble solids (TSS) concentration

Fruit juice was extracted using a manual juice extractor (TMS® hand press commercial pro manual juice squeezer). TSS of juice was measured with a digital refractometer (Atago, Tokyo, Japan). Twelve bunches per supply chain scenario were used.

4. Titratable acidity (TA)

TA of juice was determined by titration to pH 8.2 using a Metrohm 862 compact titrosampler (Herisau, Switzerland). 12 bunches per supply chain scenario were used.

5. Peel colour

Colour was assessed using a colorimeter (Minolta CR-400, Minolta Corp, Osaka, Japan) and expressed as CIE L*, a*, b* coordinate where L* defines lightness, a* denotes the red/green value and b* the yellow/blue value (Pathare et al., 2013). A total of 120 berries per supply chain scenario were evaluated for peel colour.

6. Firmness

Berry firmness (N) was measured by compression (TA.XT.plus, Stable Micro Systems Ltd, Surrey, United Kingdom) (Chen and Opara, 2013). 120 berries per supply chain scenario were evaluated for firmness.

2.4 Environmental and economic impacts of postharvest losses

Total greenhouse gas emissions were calculated using values provided by Janse van Vuuren (2015). That study examined the annual cycle for grape production, beginning with establishment costs, raw material extraction for production of inputs used on the vineyard and included the factors of fertilizer, tillage, irrigation, pest management, electricity and fuel consumption, ending at delivery of grapes. For every ton of grapes produced, stored and transported to the retail market, approximately 0.91 ton of CO_{2eq} is emitted into the atmosphere. The energy cost for producing and marketing the lost produce was obtained using a reference value of 6 529 MJ/ton provided by Steenwerth et al. (2015), and the water footprint was determined by multiplying the quantity of lost produce with the reference water footprint value of 210.35 m^3/ton provided by Kangueehi (2018). The value of table grapes lost was calculated using values provided by SATI (2016), R13 134/ton for locally sold produce and R21 002/ton for exported produce.

2.5 Statistical analysis

Data on farm losses at harvest were subjected to a one-way analysis of variance (ANOVA) and the physicochemical analysis data for firmness, total soluble solids (TSS), titratable acidity (TA), peel colour, weight loss, decay, SO_2 damage and stem browning were subjected to mixed model analysis of variance (ANOVA) using Statistica version 13.2 (TIBCO Software Inc., Palo Alto, CA) with 'farm' and 'time' as fixed effect and cartons as a random effect.

3. RESULTS

3.1 Physical losses at farm level

In 2017, the measured losses at harvest for individual farms were 7.5%, 9.7%, 15.7% and 23.3% for V; K; R or D respectively, while in 2018 the same farms lost 6.17%, 6.39%, 5.51% and 5.85%. The average loss in 2017 was 13.9% and 5.97% in 2018. The main reasons for the losses in 2017 were mechanical damage (7.1%), poor berry colour (5%), and decay (1.8%). In 2018 the reasons remained the same, although the amounts lost differed with mechanical damage (3.09%), poor berry colour (1.77%), and decay (1.11%).

3.2 Physical losses along the simulated supply chain

3.2.1 Weight loss, decay and SO_2 damage

Supply chain Scenario A (handling and marketing fruit under ambient conditions)

There was no statistically significant weight loss (P=0.28) after harvest in 2017 (Table 2); however, there was a decrease in weight of 2.34% after 3 days, 4.47% after 7 days and 7.6% after 10 days, while in 2018 a decrease of 1.55% was noted after 3 days, 1.83% after 7 days and 4.43% after 10 days. (P=0.19). While not statistically significant, this decrease in weight is important in terms of losses as it could affect the profit margin as fruit are sold by weight. The incidence of decay increased significantly (P<0.01) over time from 1% after 3 days to 3.3% after 7 days and 7.6% after 10 days in 2017 and from 0.85% after 3 days to 1.67% after 7 days and 2.67% 10 days after harvest in 2018 (P<0.01). The incidence of SO_2 berry damage increased significantly over time from 1.85% after 3 days to 2.31% after 7 days and 2.57% after 10 days in 2017 and from 0.37% after 3 days to 0.92% after 7 days and 1.19% after 10 days in 2018 (P<0.01).

Supply chain Scenario B (to local retail markets)

There was no statistically significant weight loss (Table 3) in both seasons (2017; P=0.91, 2018; P=0.99). However, the weight decreased by 1.41% after 14 days in cold storage, 1.87% after 10 days at retail conditions, and then by 2.53%, 3.78 and 5.36% after 3, 7 and 10 days under ambient conditions respectively in 2017. While in 2018, the decrease in weight were 1.85% after 14 days in cold storage, 2.57% after 10 days at retail conditions, and then 4.03%, 4.40 and 6.76% after 3, 7 and 10 days under ambient conditions. The incidence of berry decay increased significantly (P<0.01) over time, although it remained at zero for the 14 days duration in cold storage (-0.3 ± 0.7°C, 81.3 ± 4.1% RH) in 2017 with a small incidence of 0.4% in 2018. After 10 days at local retail conditions (5.4 ± 0.6°C, 83.7 ± 2.9% RH), there was a decay incidence of 2.1% in 2017 and 1.2% in 2018. After 3 days under ambient conditions (25.1 ± 1.3°C and 46.6 ± 6.0% RH), the incidence of decay increased significantly (P<0.01) to 2.5% in 2017 and 2.2% in 2018. After 7 days, this increased to 5.5% in 2017 and 3.3% in 2018, and after 10 days to 8.6% and 4.7% in 2017 and 2018, respectively. The incidence of SO_2 berry damage in this study was 1% after 14 days in cold storage in 2017 (P=0.02) and 0.8% in 2018 (P<0.01). SO_2 damage increased significantly after 10 days at local retail conditions from 1.8% in 2017 and 1.7% in 2018 to 2.1% after 3 days at ambient conditions in both years, after which there was no further significant change.

Supply chain Scenario C (to international retail markets)

In 2017, weight decreased by 4.82% after 28 days in cold storage, 5.50% after 10 days at retail conditions and 6.61%, 7.90% and 10.22% after 3, 7 and 10 days under ambient conditions respectively. In 2018, percentage decreases in weight was 1.89% after 28 days in cold storage, 2.45% after 10 days at retail conditions and 2.64%, 3.95% and 5.18% after 3, 7 and 10 days under ambient conditions respectively. (Table

4). Percentage decay increased significantly over time ($P<0.01$). After 28 days in cold storage (-0.3 ± 0.7°C, 81.3 ± 4.1% RH), there was a 2.14% incidence of decay in 2017 and 0.94% in 2018. After 10 days at retail display conditions (5.4 ± 0.6°C, 83.7 ± 2.9% RH) this increased to 3.2% in 2017 and 2.6% in 2018. After being moved to ambient temperature and humidity conditions (25.1 ± 1.3°C and 46.6 ± 6.0% RH) for 3 days, decay increased to 4.44% in 2017 and 3.16% in 2018. After 7 days, decay increased to 6.53% in 2017 and 4.95% in 2018, and after 10 days, it reached 9.92% in 2017 and 8.30% in 2018. SO_2 damage remained low. After 28 days in cold storage plus 10 days at retail conditions, less than 0.5% damage was visible. In 2017 it increased significantly ($P<0.01$) after removal from cold storage to 1.39% after 3 days at ambient conditions, 1.68% after seven days and 1.85% after 10 days, but remained below 2% overall. In 2018, however, it did not increase significantly ($P=0.26$) over time and remained below 1% overall.

Supply chain Scenario D (simulated 'abusive' treatment of fruit within the export chain)

There was no statistically significant difference in bunch weight over time ($P=0.19$), although a 1.35% decrease in weight is noted after 28 days in cold storage, 2.17% after two days at 'abusive' ambient conditions, 3.04% after 10 days at retail conditions and 3.96%, 4.74% and 5.70% after 3, 7 and 10 days under ambient conditions respectively. (Table 5). Percentage decay increased significantly over time ($P<0.01$). After 28 days in cold storage, there was a 0.84% incidence of decay, increasing to 1.34% after breaking the cold chain with two days at 'abusive' ambient conditions, 10 days at retail conditions increased this to 2.35%, and decay kept increasing significantly at ambient conditions to 3.24% after 3 days, 4.46% after 7 days and 6.7% after 10 days. SO_2 damage remained low, with only 0.88% visible after 28 days in cold storage and did not increase significantly ($P=0.99$) over time, remaining around 1%.

3.2.2 Total amount of physical losses

When the amount of weight loss, decay and SO_2 damage are combined, the total amount of losses along the different supply chain scenarios are as follows (Fig 1 and 2).

Supply chain Scenario A (marketing at ambient conditions): In 2017, 13.9% was lost at harvest, followed by 5.25% after 3 days, 7.83% after 7 days and 13.47% after 10 days. The total losses were 27.37%. In 2018 only 5.97% were lost at harvest. 2.77% after 3 days, 2.87% after 7 days and 6.51% after 10 days. The total losses were 12.48%, less than half that of the previous season.

Supply chain Scenario B (to local retail markets): After 14 days in cold storage in 2017, 2.41% were lost, 4.36% after 10 days at retail condition followed by an additional 5.27% after 3 days at ambient conditions (shelf-life), 8.98% after 7 days and 12.64% after 10 days. When this is added to the initial 13.9% lost at harvest, the total for this supply chain simulation is 26.54%. In 2018, 3.05% were lost after 14 days in cold storage, 3.65% after 10 days under retail conditions, 5.80% after 3 days under ambient conditions and remained thus after 7 days while increasing again to 10.22% after 10 days. The total loss along this simulated supply chain in 2018 was 16.19%.

Supply chain Scenario C (to international markets): In 2017, 7.41% were lost after 28 days in cold storage, another 4.36% after 10 days under retail conditions and a further 7.03% after 3 days under ambient conditions, 9.59% after 7 days and 14.29% after 10 days. A total of 28.19% was lost in this export supply chain simulation in 2017. In 2018, 2.99% were lost after 28 days in cold storage, 3.79% after 10 days under retail conditions, 3.97% after 3 days under ambient conditions, 6.92% after 7 days and 10.22% after 10 days. A total of 16.99% were lost in 2018.

Supply chain Scenario D (simulated 'abusive' storage conditions of fruit within the international supply chain): This simulation was done during the 2018 season only. It was found that 3.03% was lost after 28 days in cold storage 3.19% after 2 days of 'abusive' ambient condition, 4.27% after 10 days at retail conditions. After 3 days under ambient condition losses increased to 5%, 6.66% after 7 days, and 8.91% after 10 days.

3.3 Quality losses along the supply chain

Supply chain Scenario A (marketing at ambient conditions)

In the 2017 season (Table 6), berry colour became lighter (L*) over time, although the change was not statistically significant (P=0.06), during the 2018 season (Table 7), however, the change in lightness (L*) of berry colour became statistically significant (P<0.01). The measurements for a* denoting the red/green values (P=0.45) and b* indicating the yellow/blue values (P=0.98) in 2017 and a* (P=0.21) and b* (P=0.75) in 2018, did not change significantly. There was no significant difference in firmness in 2017 or 2018 (P=0.79), although the values decreased over time. The TSS (P=0.85) and TA (P=0.50) values did not change significantly in 2017 or in 2018, TSS (P=0.75) and TA (P=0.73). For both seasons, the stem colour changed from fresh and green to mostly dry and brown within 7 days after harvest (P<0.01).

Supply chain Scenario B (to local retail markets)

In 2017, there were no significant changes in any colour attributes for Lightness (L*) denoting black/white values (P=0.79), a* denoting the red/green values (P=0.49) or b* indicating the yellow/blue values (P=0.25) (Table 8). In 2018 no significant differences were measured for a* (P=0.31) and b* (P=0.19). However, lightness (L*) values increased (P<0.01), although this only became significant after 10 days at ambient conditions as there was no significant difference between baseline measurements, 14 days in cold storage, 10 days at retail conditions or even after a week at ambient temperature and humidity (Table 9). Berry firmness (P=0.21) in 2017 and (P=0.49) in 2018, showed no statistically significant changes. While TA (P=0.27) and TSS (P=0.73) showed no significant changes in 2017, in 2018 the values did indicate an increase for both TA (P<0.01) and TSS (P<0.01) over the storage period. For both seasons, bunch stems and rachi remained fresh and green during the 14 days in cold storage (-0.3 ± 0.7°C, 81.3 ± 4.1% RH), but changed significantly (P<0.01) during 10 days at retail display conditions (5.4 ± 0.6°C, 83.7 ± 2.9% RH), and after 7 days storage under ambient conditions (25.1 ± 1.3°C and 46.6 ± 6.0% RH), the stems were mostly dry and brown.

Supply chain Scenario C (to international retail markets)

No significant difference in any colour attributes (Table 10) was observed in 2017, L* (P=0.12), a* (P=0.15) and b* (P=0.72). In 2018, however, the attribute for lightness

(L*) changed significantly (P<0.01), with berries becoming a bit lighter after removal from cold storage but darkening again after 7 days under ambient conditions (Table 11), while a* (P=0.26) and b* (P=0.22) remained the same. The average berry firmness remained unchanged in 2017 (P=0.90) and in 2018 (P=0.11). No changes were observed in TSS in 2017 (P=0.67) or in 2018 (P=0.30). There is a trend, however, indicating that TA may decrease somewhat over time, but with a P-value of 0.06, it was just not statistically significant in 2017, while it was significant in 2018 (P<0.01). Stem colour exhibited the same pattern for both years, remaining mostly fresh and green during the 28 days cold storage (-0.3 ± 0.7°C, 81.3 ± 4.1% RH) only changing significantly (P<0.01) during the 10 days at retail display conditions (5.4 ± 0.6°C, 83.7 ± 2.9% RH) to mostly green with some smaller stems that have turned brown. After 3 days at ambient temperature and humidity (25.1 ± 1.3°C and 46.6 ± 6.0%RH), most of the smaller stems (rachi) are brown, but the main stem is still green, after 7 days, however, most stems are dry and brown.

Supply chain Scenario D (simulated ‘abusive’ treatment of fruit within the export chain)

Significant changes (P<0.01) in colour attribute (L*) for lightness was observed, (Table 12), with berries becoming lighter with increased temperature and lower humidity and darker when returned to lower temperatures and increased humidity. No significant difference in colour attributes a* (P=0.86) and b* (P=0.21) were observed. The average berry firmness remained unchanged (P=0.23). There were significant changes observed in TSS (P<0.01) with values increasing and TA values (P<0.01) that decreased during storage. Stem colour changed significantly over time (P<0.01). While stems remained fresh and green during the 28 days in cold storage, the 2 days at ambient conditions, to simulate the abusive treatment, affected the stems to such an extent that by the time they reached retail conditions, most of the stems were already brown.

3.4 Socio-economic impacts of postharvest losses

Based on the percentage losses along the simulated supply chains, estimates were made to determine the volume of table grapes that could be lost at the national level (Table 13). In 2017, South Africa produced approximately 325061 tons, of which

20046 tons were sold locally, and 305015 tons were exported (DAFF, 2017). The ranges provided in the following data are estimates made from the lowest losses which were recorded in the 2018 season to the highest losses that were recorded in 2017. It thus provides a range of losses that could occur in any given season.

Supply chain Scenario A (marketing at ambient temperatures and relative humidity)

Losses translate were between 555 and 1 052 tons after 3 days. This equates to a financial loss of R7.3 million – R13.8 million, 3 623 595 – 6 868 508 MJ of energy, 116 744 – 221 288 m^3 water used in production and 505 – 957 tons CO_2eq emissions. After 7 days, the losses increase to 575 – 1 904 tons, R7.5 million – R25 million, 375 417 – 12 431 216 MJ, 120 951 – 400 466 m^3 and 523 – 1 733 tons CO_2eq. After 10 days, 1 305 – 2 068 tons were lost, R17.1 million – R27.1 million, 8 520 345 – 13 461 972 MJ of energy, 274 507 – 435 003 m^3 and 1 188 – 1 882 tonnes CO_2eq.

Supply chain Scenario B (to local retail markets)

After 14 days in cold storage, the losses were between 493 – 611 tons with a financial loss of R6.5 million – R8 million, lost energy of 3 218 797 – 3 989 219 MJ, a water footprint of 103 703 – 128 524 m^3 and 449 – 556 tons CO_2eq. After 10 days at retail conditions, losses were 728 – 874 tons, R9.6 million – R11.5 million, 4 753 112 – 5 706 346 MJ, 153 135 – 183 846 m^3 water lost and 663 – 795 tons CO_2eq.

Once moved to ambient conditions, the losses after 3 days were 1 163 – 1 431 tons, R15.2 million – R18.8 million, 7 593 227 – 9 342 999 MJ, 244 637 – 301 011 m^3 and 1 058 – 1 302 tons CO_2eq. After 7 days, 1 303 – 2 074 tons, R17.1 million – R27.2 million, 8 507 287 – 13 541 146 MJ, 274 086 – 436 266 m^3 and 1 186 – 1 887 tons CO_2eq. After 10 days, 1 856 – 2 534 tons, R24.3 million –R33.3 million, 12 117 824 – 16 544 486 MJ, 390 410 – 533 027 m^3 and 1 689 – 2 306 tons CO_2eq.

Supply chain Scenario C (to export retail markets)

After 28 days in cold storage, the losses were between 13 299 – 29 861tons with a financial loss of R279.3 million – R627.1 million, 86 829 171 –194 962 469 MJ of energy, 2 797 445 - 6 281 261 m^3 of water and 12 102 – 27 174 tons CO_2eq. After 10 days at retail conditions, 11 560 – 21 443 tons, R242.8 million – R450.3 million, 75 475 240 – 140 001 347 MJ, 2 431 646 – 4 510 535 m^3 and 10 520 – 19 513 tons CO_2eq. After 3 days at ambient conditions, losses were 12 109 – 22 602 tons, R254.3 million – R474.7 million, 79 059 661 – 147 568 458 MJ, 2 547 128 - 4 754 331 m^3 and 11 019 – 20 568 tons CO_2eq. After 7 days: 21 107 – 29 251 tons, R443.3 million – R614.3 million, 137 807 603 – 190 979 779 MJ, 4 439 857 – 6 152 948 m^3 and 19207 – 26 618 tons CO_2eq. 10 Days at ambient, and the losses were 31 173 – 43 587 tons, R654.7 million - R915.4 million, 203 528 517 – 284 579 523 MJ, 6 557 241 – 9 168 525 m^3 and 28 367 – 39 664 tons CO_2eq.

Supply chain Scenario D (simulated ‘abusive’ treatment of fruit within the export chain)

After 28 days in cold storage, the losses were 9 242 tons with a financial value of R194.1 million, 60 341 018 MJ of energy, 1 944 055 m^3 water and 8 410 tons CO_2eq. After 2 days at ‘abusive’ ambient temperature and humidity before entering retail conditions, the losses were 9 730 tons, R204.3 million, 63 527 170 MJ, 2 046 706 m^3 water and 8 854 tons CO_2eq. After 10 Days at retail conditions, losses were 13 024 tons, R273.5 million, 85 033 696 MJ, 2 739 598 m^3 and 11 852 tons CO_2eq. At 3 days of ambient conditions, losses were 15 251 tons, R320.3 million, 99 573 779 MJ, 3 208 048 m^3 and 13 878 tons CO_2eq. 7 days ambient: 20 314 tons, R426.6 million, 132 630 106 MJ, 4 273 050 m^3 and 18 486 tons CO_2eq. After 10 days at ambient conditions, the losses were 27 177 tons, R570.8 million, 177 438 633 MJ, 5 716 682 m^3 and 24 731 tons CO_2eq

4. DISCUSSION

Physical losses at farm level

The losses measured on farm level in 2017 were higher than the findings of Louw (2017), who concluded in an economic analysis of the South African table grape supply chain that approximately 9.5% was lost between farm and intake. However, the data used in that study was based on perception data gathered from different role-players in the table grape industry, the authors own elaborations and from SATI (2016) as no primary data was collected.

Rajab et al. (2015) reported similar losses at agricultural production level of 15%, where table grape losses were quantified along the supply chain in Iran. The materials and methods of that study are unclear, however, as it divides the supply chain into production, postharvest, processing, distribution and consumption stages without clearly describing the various stages. In the present study, the losses at farm level include what it seems they refer to as production, postharvest and processing into one. If that is the case, the losses experienced in Iran was much higher than our findings and amounted to 46% of total production. Rajab et al. (2015) used data from government and private sources with estimates and interviews, and no primary data was collected in that study.

In the present study, the average loss measured on farm level in 2018 was 5.97%. This is less than reported by Rajab et al. (2015) and Louw (2017) but very similar to the findings of Aujla et al. (2011) that reported losses of table grapes in Pakistan of 4.8% at farm level and Murthy et al. (2014) where losses of table grapes at farm level in India were reported as 3.4% for grapes prepared for the domestic market while grapes prepared for the export market sustained losses of 7.82% as the requirements for export produce are stricter.

The losses measured in 2017 are similar to that of Murthy et al. (2014) for export grapes (Thomson Seedless), but the reasons for the losses differ, water berries (6.72%), harvest injury (0.57%), mummies (0.02%) and immature (0.26%). Sharma et al. (2018) report losses of table grape (Nana Purple) on farm level as 8-10% due to insufficient colouring, while Aujla et al. (2011) and Rajab et al. (2015) did not specify the reasons for losses.

The large differences between farms in 2017, were unexpected and although it was initially thought that it could have been due to different climatic conditions or soil types it appears to have been related to different vineyard management practices as there was no statistical difference between losses on the farms in the 2018 season and the average losses were less than half recorded in 2017. The reasons for this could be two-fold. Firstly, by having been made aware of how high the losses where during the previous season, the farm managers took steps to reduce this during the 2018 season, workers were trained to be more careful when handling the crates after harvest. Secondly, the farm that sustained the highest losses (23.3%) in 2017 harvested later than was optimal and therefore the bunches stayed on the vines too long. The 2018 harvest occurred two weeks earlier than in 2017, and the grapes were in better condition leading to fewer losses on farm level.

Physical losses along the simulated supply chain

Supply chain Scenario A (handling and marketing fruit under ambient conditions)

These results support the research of Pereira et al. (2018) that reported the mass of grapes cv. 'Crimson Seedless' always decreased with time at all combinations of storage temperature and RH. Grapes stored at higher temperature lost weight faster than those maintained at lower temperatures. The increased vapor pressure deficit and respiration rates of the stems of grapes stored at higher temperatures accelerated transpiration rates of fruit. Lichter et al. (2011) further found a linear profile for the mass decreasing in grapes of cv. 'Thompson' and 'Superior'. Similar findings were also reported by Sharma et al. (2018), noting a 5% weight loss in grapes transported in trucks in temperatures of 35-40°C before reaching the wholesale market.

The findings on the incidence of decay were similar to the findings of Ngcobo et al. (2012a), who found severe incidence of decay (2 – 5 infected berries per carton) of 'Regal Seedless' table grapes after 7 days shelf life at 24.33 ± 0.04°C in similar packaging to that used in this study. Mlikota et al. (2006) reported much higher levels of 40.5% after 7 days at 15°C for cv 'Thompson Seedless'. Visible decay in a carton could make the carton hard to sell, even though less than 10% of the berries are affected, as from the consumer's perspective, appearance is the first factor that influences purchase decision, followed by perceived value for money and fruit eating quality (Eccher Zerbini, 2012). This is similar to the findings of Ngcobo et al. (2012a), who found severe incidence of decay (2 – 5 infected berries per carton) of 'Regal Seedless' table grapes after 7 days shelf life at 24.33 ± 0.04°C in similar packaging to that used in this study. Mlikota et al. (2006) reported much higher levels of 40.5% after 7 days at 15°C for cv 'Thompson Seedless'. Visible decay in a carton could make the carton hard to sell, even though less than 10% of the berries are affected, as from the consumer's perspective, appearance is the first factor that influences purchase decision, followed by perceived value for money and fruit eating quality (Eccher Zerbini, 2012).

Supply chain Scenario B (to local retail markets)

The decrease of 5.4% and 6.8% in weight noted for the two seasons were more than double the amount of 2% weight loss after 14 days of cold storage for cv. ‘Thompson Seedless’ reported by Sabir et al. (2018), while findings on decay during cold storage were similar to the 0% decay reported. After 10 days at retail conditions, the reported decay was less than half the amount of 4.56% reported by Murthy et al. (2014). Similar to Sortino et al. (2017) reporting 1% SO_2 damage for cv 'Red Globe’ after 15 days in cold storage, the incidence of SO_2 berry damage in this study was 1% after 14 days in cold storage. Ngcobo et al. (2012a) and Zoffoli et al. (2008) reported that the combination of free water (100% RH), as occurs with the formation of condensation when cartons are removed from cooler conditions to ambient conditions, combined with SO_2 in non-perforated liners may result in the formation of acidic conditions that may increase SO_2 injury, this seems to be the case in this study also. It is suggested that after a few days at ambient conditions, the free water evaporates, and the damage stops.

Supply chain Scenario C (to export retail markets)

The measured weight loss was similar to the 5% after 10 days and 10% after 14 days at room temperature (25°C) and 45–70% relative humidity reported by Xu et al. (2013) for cv ‘Victoria’. After 28 days in cold storage (-0.3 ± 0.7°C, 81.3 ± 4.1% RH), there was a 2.14% incidence of decay in 2017 and 0.94% in 2018. These results were similar the mean of 1.28% decay reported by Klaasen et al. (2006) for cultivars ‘Red Globe’, ‘Sunred Seedless’ and ‘Thompson Seedless’ under similar conditions for the same time period. After 10 days at retail display conditions (5.4 ± 0.6°C, 83.7 ± 2.9% RH) this increased to 3.2% in 2017 and 2.6% in 2018. These results are slightly higher than the 2.5% reported by Louw (2017) for the perceived losses of table grapes at retail level and correspond to the lowest end of the 3 – 7% range of loss reported for fresh fruit under retail conditions in the UK and Spain by Mena et al. (2011). Both Louw (2017) and Mena et al. (2011), however, used data collected through interviews with managers in food manufacturing and questionnaires completed by other role players in the table grape supply chain while no primary sampling data was collected. 3 days after being moved to ambient temperature and humidity conditions (25.1 ± 1.3°C and 46.6 ± 6.0%RH), decay increased to 4.44% in 2017 and 3.16% in 2018. Lichter et al. (2002) reported decay of more than a hundred berries per kg after 4 weeks at 0°C and 3 days shelf-life at 20°C for cv. 'Thompson Seedless'. Taking the average weight of a 'Thompson Seedless' berry as 5 g reported by Peacock et al. (2017), the data translates to 500 g infected berries per kg or 50%, which is much higher than the decay rate measured in this study.

The results for SO_2 damage seem similar to the rating of 4 (11 – 20 berries per replicate consisting of 10 bunches) with SO_2 damage after 65 days at 0°C and 3 days at 20°C reported by Lichter et al. (2008) although it is not easy to compare as that study used a rating of 1 - 5 for describing SO_2 damage and not % and it is unknown exactly how many berries were in a replicate of 10 bunches.

Supply chain Scenario D (simulated 'abusive' treatment of fruit within the export chain)

The 5.7% decrease in weight noted is half the weight loss of around 12% reported by Palou et al. (2010) for 'Crimson Seedless' table grapes under similar conditions and for the same period. Decay and $S0_2$ damage are disorders that can be caused or aggravated by wet berries in combination with elevated temperature (Du Plessis, 2003). Results indicate that the decay in this trial was lower than that recorded for supply chain scenario C, which was the same in all regards except for the two days under ambient conditions. This could be due to condensation evaporating, leaving less free moisture that would exacerbate decay.

Total amount of physical losses

Supply chain Scenario A (marketing at ambient conditions): For both years, the losses were considerably less than the 53% reported by Rajabi et al. (2015) for table grape losses along the supply chain under ambient conditions in Iran. No sampling data was recorded in that study. However, the data used for their calculations were collected through government and private data sources with horticulture expert estimates, grape growers interviews, agriculture cooperation interviews and markets consultations.

Supply chain Scenario B (to local retail markets): When these losses are taken only from harvest to retail level, it translates to 18.26% loss in 2017 and 9.62% in 2018. The result for 2018 is similar to Murthy et al. (2014), who reported losses of 7.96% from the field to retailer in India.

Supply chain Scenario C (to export retail markets): The 2018 data was similar to Murthy et al. (2014) reporting export supply chain losses for table grapes in India, of 19.95%, as well as the approximate figure of 15.5% reported by Louw (2017) for the South African table grape supply chain, although no sampling data was collected for those studies. The 2017 data of this study was significantly higher and showed how variable the yearly losses could be.

Supply chain Scenario D (simulated 'abusive' treatment of fruit within the export chain): In terms of quantity of losses, therefore, the 2 days at ambient conditions in the middle of the cold chain did not cause a significant difference. It did, however, create a difference in quality, as will be illustrated in the next section.

Quality losses along the supply chain

Supply chain Scenario A (marketing at ambient conditions): Results for firmness over time supports the findings of Li et al. (2015) reporting no difference in firmness for cv. 'Mystery' after 6 days under ambient conditions (22 – 28°C) but contrasts with the findings of Tamizheezham et al. (2018) for cv. 'Muscat Hamburg' reporting a significant decrease of firmness over time under ambient conditions. Similar findings of unchanging TSS and TA values were reported for both cv. Müşküle and cv. Red Globe by Sabir and Sabir (2013) during the first week of that research project. The results on change in stem colour support the report by Lichter et al. (2011). The author reported major rachis browning during marketing at ambient temperatures and relative humidity.

Supply chain Scenario B (to local retail markets): The increase in lightness measured in 2018 differ to the findings of Sabir et al. (2018) that found the L* values for the black table grape cv. 'Alphonse Lavallée' decrease during cold storage, indicating that the grapes became darker over time. Berry firmness results that showed no significant difference over time is similar to findings of Ahmed et al. (2018) reporting no significant difference in firmness for cv. 'Italia' after cold storage and 7 days shelf life. The increase in TA measured during the 2018 season is similar Sabir and Sabir (2013) also describing such a significant increase in TA after 2 and 3 weeks in storage for cv. Müşküle and cv. Red Globe. Li et al. (2015) and Sabir et al. (2011) describe increases in TSS of grapes during cold storage due to water loss. In contrast to the 2018 findings, yet similar to the 2017 findings of this study, TSS levels could remain stable under different storage conditions and for different cultivars. Crisosto et al. (2002) reported that TSS levels in cv. Red Globe, after up to 12 weeks in storage under different controlled atmosphere (CA) conditions at 0°C, was almost equal to that measured at harvest.

Supply chain Scenario C (to export retail markets): No significant difference in any of the colour attributes was found in 2017, similar to findings of Colombo et al. (2018) for cv. 'BRS Isis' after 50 days in cold storage plus 5 days under ambient conditions. In 2018, however, results indicated that berry colour became lighter, which differs from Sabir and Sabir (2017) reporting that L* decreased with storage time for cv. 'Thompson Seedless', while Ahmed et al. (2018) reported no significant changes in colour for cv. 'Italia' after 50 days of cold storage and 7 days under ambient conditions. No change in firmness was observed. Similarly, Ahmed et al. (2018) reported no significant difference in firmness for cv. Italia after up to 50 days in cold storage and 7 days shelf life. No changes were observed in TSS, similar to findings of Sortino et al. (2017) for cv. 'Red Globe'. Results for changes in TA are similar to findings reported by Sabir and Sabir (2017) that berry TA underwent a progressive decrease during storage for cv. 'Thompson Seedless'. Stem colour changes support the findings of Du Plessis (2003) and Ngcobo et al. (2013) also noted for cv. 'Thompson Seedless' that the average stem condition deteriorated more during the shelf life period than cold storage.

Supply chain Scenario D (simulated 'abusive' treatment of fruit within the export chain): Unchanged berry firmness was also reported by Li et al. (2015) for cv. 'Mystery' and Sortino et al. (2017) for cv. 'Red Globe'. Lichter et al. (2011), however, reported a decrease in firmness during shelf life trials for the white grape cultivars 'Superior' and 'Thompson' held in high (>95%) and low (70%) relative humidity at 20°C or 10°C for up to 11 days. Several researchers similarly reported general increases in TSS of grapes during cold storage, including Li et al. (2015) and Sabir and Sabir (2011). This is attributed to the gluconeogenesis pathway or water loss. Li et al. (2015) also reported similar findings on stem browning for cv. 'Mystery' where cooling delays of 48 hrs resulted in a rachis browning score of 5, indicating very severe damage.

Socio-economic impacts of postharvest losses

The socio-economic impacts of these postharvest losses indicate a financial loss of between R 279 million to over R600 million annually for the table grape export industry. Louw (2017) estimated losses of approximately 9.5% between production and intake stages for the South African table grape industry, translating into a financial loss of R270.5 million with an additional 2.2% or R93.2 million between intake and export and 3.8% or R400 000 between the importer to retail depot. It is unclear how 3.8% equals R400 000 when it was also stated that 2.2% equals R93 200 000, the accuracy of the estimates are therefore uncertain. The values given for losses between production and intake does, however, approximate the values this current study recorded for the 2018 season, while the losses during the 2017 season were more than double that amount.

Additionally, as much as 177.43 million MJ of fossil energy and 4.8 million m^3 of fresh water resources were lost. At the Eskom tariff rate of R0.90 per kWh, the lost energy is worth R44.36 million (Eskom, 2019). The fresh water lost could sustain at least 263 013 individuals daily for a whole year at daily minimum usage rate of 0.05 m^3 per day. Losses also contribute to unwanted emission of approximately 52 263 tons of CO_2eq, contributing to environmental degradation from greenhouse gases.

5. CONCLUSIONS

The highest loss in the supply chain was measured at the farm level. It is therefore important to include this stage when studies are conducted on the quantification of postharvest losses. As the main reason for losses at this stage was mechanical damage due to the rough handling of bunches and crates causing berries to drop off the bunches as well as the crushing of berries due to loading too many bunches in

crates, these losses could be improved by making workers more aware of the necessity to handle crates with care. The harvest timing is also essential, as delayed harvesting reduces shelf life and results in an increased postharvest loss.
The main quality problem, among all supply chain scenarios, were rachis and stem browning at temperatures higher than -0.5°C. This caused berries to drop faster and bunches to look less fresh, as well as causing bunches to weigh less when sold. While 500g or 1kg punnets are routinely kept at around 5°C at the retail level, during peak season 4.5 kg – 10 kg cartons are often stacked on the floor under ambient conditions. Therefore, the table grapes would have a maximum shelf-life of 7 days before the stems have browned, and too many berries per bunch are decayed to sell. It would be advisable to keep cartons at -5°C and high RH and only place bunches in punnets in 5°C display fridges as the stock sells.
The increase in weight loss and especially stem browning recorded in Scenario D **(**'Abusive' treatment of fruit within the export chain), compared to Scenario C (Shipping to export markets) indicated the importance of eliminating the delay between reefer delivery and quality checking as a break in the cold chain of two days have a significant impact on the quality of the bunches and therefore also the price it can be sold at.

This study was conducted on farms with good infrastructure, cultivation practices and cooling facilities, where nonetheless, farm-level losses of up to 23% were recorded. It is significant that during pre-season interviews with farm management, the highest estimate of losses was 13%, most of them lower. As 'Crimson Seedless' is a high value crop, even relatively small improvements in future could have a large financial impact for producer-exporters. In the changing local agricultural environment of many more upcoming farmers entering the industry, this situation deserves much more attention than what was the case so far.

6. REFERENCES

Affognon, H., Mutungi, C., Sanginga, P. and Borgemeister, C. (2015). Unpacking postharvest losses in Sub-Saharan Africa: A meta-analysis, World Development, 66, 49-68.

Ahmed, S., Roberto, S.R., Domingues, A.R., Shahab, M., Junior, O.J.C., Sumida, C.H. and de Souza, R.T. (2018). Effects of different sulfur dioxide pads on botrytis mold in 'Italia' table grapes under cold storage. Horticulturae, 4, 29.

Alexandratos, N. (2009). How to feed the world in 2050. Expert meeting. FAO headquarters, 24-26 June 2009, Rome.

Aujla, K.M., Shah, N.A., Ishaq, M. and Fraooq, A. (2011). Post-harvest losses and marketing of grapes in Pakistan, Sarhad Journal of Agriculture, 27:3, 485-490.

Chen, L and Opara, U.L. (2013). Texture measurement approaches in fresh and processed foods – A review. Food Research International, 51, 823-835.

Colombo, R.C., Carvalho, D.U., da Cruz, M.A., Sumida, C.H., Ahmed, S., Bassoli, P.A., de Souza, R.T. and Roberto, S.R. (2018). Cold storage and biocontrol agents to extend the storage period of 'BRS Isis' seedless table grapes. Horticulturae, 4, 18.

Crisosto, C.H., Smilanick, J.L., Dokoozlian, N.K. (2001). Table grapes suffer water loss, stem browning during cooling delays. California Agriculture, 55:1, 39 – 42.

Crisosto, C.H., Garner, D., Crisosto, G. (2002). Carbon dioxide-enriched atmospheres during cold storage limit losses from Botrytis but accelerate rachis browning of 'Red Globe' table grapes. Postharvest Biology and Technology, 26, 181–189.

DAFF. (2017). A Profile of the South African table grapes market value chain. Available online: http://webapps.daff.gov.za. (accessed on 31 Aug 2019).

Du Plessis, S.F. (2003). Effects of packaging and postharvest cooling on quality of table grapes (Vitis vinifera L.). MSc thesis, Department of Horticulture, Faculty of AgriSciences, Stellenbosch University, South Africa.

Eccher Zerbini, P. (2002). The quality of pear fruits. *Acta Horticulturae*, 596, 805–810.

Eskom. (2019). Available online: www.eskom.co.za › TariffsAndCharges › Documents. (accessed on 10 October 2019.)

FAO. (2009). State of food insecurity in the world: economic crises — impacts and lessons learned. Food and Agriculture Organization of the United Nations. www.fao.org

FAO. (2013). Food losses and waste in Europe and Central Asia. Food and Agriculture Organization of the United Nations. www.fao.org

FLW Protocol (Food Loss and Waste Protocol) (2016). The food loss and waste accounting and reporting standard, Washington, DC.

Gustavsson, J., Cederberg, C., Sonesson, U., van Otterdijk, R., and Meybeck, A. (2011). Global food losses and food waste section 3.2 (Study conducted for the international congress “Save Food!” at Interpack2011, Düsseldorf, Germany), FAO Rural Infrastructure and Agro-Industries Division, 38.

Hodges, R.J., Buzby, J.C. and Bennett, B. (2010). Postharvest losses and waste in developed and less developed countries: opportunities to improve resource use. Journal of Agricultural Science, 149, 37-45.

Janse van Vuuren, P. F. (2015). Regional resource flow model: Fruit sector report: GreenCape. https://www.green-cape.co.za/assets/Bioeconomy/RRFM-Fruit-sector-report-2014-15.pdf

Jiang, L., Jin, P., Wang, L., Xuan, Y., Wang, H. and Zheng, Y. (2015). Methyl jasmonate primes defense responses against Botrytis cinerea and reduces disease development in harvested table grapes. Scientia Horticulturae,192, 218–223.

Kader, A.A. (2005). Increasing availability by reducing post-harvest losses of fresh produce. Acta Horticulturae, 682, 2169-2175.

Kangueehi, G. N. (2018). Water footprint analysis to improve water use efficiency in table grape (Vitis vinifera L. cv. Crimson Seedless) production. A South African case study. PhD thesis, Department of Viticulture and Oenology, Faculty of AgriSciences, Stellenbosch University, South Africa.

Kitinoja, L. and Al Hassan, H.Y. (2012). Identification of appropriate postharvest technologies for small scale horticultural farmers and marketers in Sub-Saharan Africa and South Asia – Part 1. Postharvest losses and quality assessments. Acta Horticulturae, 934, 31-40.

Kitinoja, L. and Kader, A.A. (2015). Measuring post-harvest losses of fresh fruits and vegetables in developing countries. White paper 15-02, Post-harvest Education Foundation.

Klaasen, J.A., van der Merwe, J.A., Vries, F.A. and Calitz, F.J. (2006). Long-erm storage quality of table grapes as influenced by pre-harvest yeast applications and post-harvest use of controlled atmosphere. South African Journal for Enology and Viticulture, 27: 2, 187-195.

Kuhr, R.J. (1979). Integrated pest management. A new strategy in an old war. New York's Food and Life Science, 12 (2):3.

Li, L., Kaplunov, T., Zutahy, Y., Daus, A., Porat, R. and Lichter, A. (2015) The effects of 1-methylcyclopropane and ethylene on postharvest rachis browning in table grapes. Postharvest Biology and Technology,107, 16–22.

Lichter A., Zutahy, Y., Sonego, L., Dvir, O., Kaplunov, T., Sarig, P. and Ben-Arie, R. (2002). Ethanol controls postharvest decay of table grapes. Postharvest Biology and Technology, 24, 301–308.

Lichter A., Zutahy Y., Kaplunov T., Lurie S. (2008). Evaluation of table grape storage in boxes with sulfurdioxide releasing pads with either an internal plastic liner or external wrap, HortTechnology, 18, 206–214.

Lichter, A., Kaplunov, T., Zutahy, Y., Daus, A., Alchanatis, V., Ostrovsky, V., Lurie, S. (2011). Physical and visual properties of grape rachis as affected by water vapour pressure deficit. Postharvest Biology and Technology, 59, 25–33.

Lipinski, B., Hanson, C., Lomaw, J., Kitinoja, L., Waite, R., Searchinger, T. (2013). Reducing food loss and waste. Working Paper, Installment 2 of Creating a Sustainable Food Future, World Resources Institute, Washington, DC., Available online: http://www.worldresourcesreport.org. (accessed on 23 Dec 2020).

Louw, L. (2017). Economic aspects of losses and waste: Case study of the South African table grape supply chain. MCom thesis, Department of Agricultural Economics, Extension and Rural Development, Faculty of Natural and Agricultural Sciences, University of Pretoria, South Africa.

Mena, C., Adenso-Diaz, B., Yurt, O. (2011). The causes of food waste in the supplier–retailer interface: Evidences from the UK and Spain. Resources, Conservation and Recycling, 55, 648–658.

Mlikota Gabler, F., Fassel, R., Mercier, J., and Smilanick, J. L. (2006). Influence of temperature, inoculation interval, and dosage on biofumigation with Muscodor albus to control postharvest gray mold on grapes. Plant Disease, 90, 1019-1025.

Munhuweyi, K., Opara, U.L., Sigge, G. (2016). Postharvest losses of cabbages from retail to consumer and the socio-economic and environmental impacts, British Food Journal, 118:2, 286 – 300.

Murthy, M.R K., Reddy, G. P. and Rao, K. H. (2014). Retail marketing of fruits and vegetables in India: A case study on export of grapes from Andhra Pradesh, India. European Journal of Logistics Purchasing and Supply Chain Management, 2:1, 62 - 70.

Ngcobo, M.E.K., Opara, U.L., Thiart, G.D. (2012a). Effects of packaging liners on cooling rate and quality attributes of table grape (cv Regal Seedless). Packaging Technology and Science, 25, 73–84.

Ngcobo, M.E.K., Delele, M.A., Pathare, P.B., Chan, L., Opara, U.L., Meyer, C.J. (2012b). Moisture loss characteristics of fresh table grapes packed in different film liners during cold storage. Biosystems Engineering, 113, 363– 370.

Ngcobo, M.E.K., Delele, M.A., Opara, U.L., Meyer, C.J. (2013). Performance of multipackaging for table grapes based on airflow, cooling rates and fruit quality. Journal of Food Engineering, 116, 613–621.

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

Palou, L., Serrano, M., Martínez-Romero, D. and Valero, D. (2010). New approaches for quality retention of table grapes. Fresh Produce, 4:1, 103-110.

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

Pathare, P.B., Opara, U.L. and Al-Said, F.A.-J. (2013). Colour measurement and analysis in fresh and processed foods: a review. Food and Bioprocess Technology, 6, 36-60.

Peacock, B. and Simpson, T. (2017). The Relationship Between Berry Weight, Length and Width for Five Table Grape Varieties, Cooperative Extension Pub.-TBI 95; Available online: http://cetulare.ucanr.edu/ files/82015.pdf (accessed on 10 July 2020).

Pereira, E., e Silva, R.G.B., Spagnol, W.A., and Silveira Junior, V. (2018). Water loss in table grapes: model development and validation under dynamic storage conditions. Food Science and Technology, Campinas, 38:3, 473-479.

Rajabi, S., Lashgarara, F., Omidi, M. and Hosseini, S.J.F. (2015). Quantifying the grapes losses and waste in various stages of supply chain. Biological Forum, 7:1, 225-229.

Sabir, A., Sabir, F.K. and Kara, Z. (2011). Effects of modified atmosphere packing and honey dip treatments on quality maintenance of minimally processed grape *cv*. Razaki (*V. vinifera* L.) during cold storage. Journal of Food Science and Technology, 48, 312–318.

Sabir, F.K. and Sabir, A. (2013). Quality response of table grapes (Vitis vinifera L.) during cold storage to postharvest cap stem excision and hot water treatments. International Journal of Food Science and Technology, 48, 999–1006.

Sabir, F.K. and Sabir, A. (2017). Extending postharvest quality attributes of grapes (V. vinifera L. cv. 'Thompson Seedless') by preharvest calcium pulverizations. Acta Scientiarum Polonorum Hortorum Cultus, 16:5, 29–38

Sabir, F.K., Sabir, A., Unal, S., Taytak, M., Kucukbasmaci, A. and Bilgin, O.F. (2018). Postharvest quality extension of minimally processed table grapes by chitosan coating. International Journal of Fruit Science, 1-12.

SATI. (2016). South African Table Grape Industry Statistics Booklet, Available online: http://www.satgi.co.za/Media/Default/Documents/Booklets/SATI_BOOK_2016.pdf (accessed on 19 Aug 2020).

Sharma, A.K., Sawant, S.D., Somkuwar, R.G. and Naik, S. (2018). Postharvest losses in grapes: present Indian status. Technical report ICAR-National Research Centre for Grapes, Pune, India. Available online: https://www.researchgate.net/publication/311693568 (accessed on 5 Aug 2020).

Smil, V. (2004). Improving efficiency and reducing waste in our food system, Environmental Sciences, 1:1, 17-26.

Sortino, G., Allegra, A., Passafiume, R., Gianguzzi, G., Gullo, G. and Gallotta, A. (2017). Postharvest application of sulphur dioxide fumigation to improve quality and storage ability of "Red Globe" grape cultivar during long cold storage. Chemical Engineering Transactions, 58, 403-408.

Statista. (2019). Global volume of wasted food as of 2017, by food category, Global waste generation dossier, Statista, Available online: https://www.statista.com/study/58790/global-waste-generation/(accessed on 10 Sept 2020).

Steenwerth, K.L., Strong, E.B., Greenhut, R.F., Williams, L. and Kendall, A. (2015). Life cycle greenhouse gas, energy and water assessment of wine grape production in California. The International Journal of Life Cycle Assessment, 20, 1243-1253.

Tamizheezham, U., Muthuvel, I. and Subbiah, A. (2018). Effect of temperature on shelf life of Muscat Hamburg Grapes under storage. Madras Agricultural Journal, 105, 426-429.

Xu, W., Li, D., Fu, Y., Liu, Z., Wang, Y., Yu, X. and Shang, W. (2013). Chinese Packaging Institute - 2012 Conference extending the shelf life of Victoria table grapes by high permeability and fungicide packaging at room temperature. Packaging Technology and Science, 26:1, 43–50.

Zoffoli, F.P., Latorre, B.A. and Naranjo, P. (2008). Hairline, a postharvest cracking disorder in table grapes induced by sulfur dioxide. Postharvest Biology and Technology, 47, 90–97.

Table 1. Description of the supply chain scenarios studied

Supply chain scenario	Description	Environmental condition
A	Table grapes were harvested and stored under ambient conditions, typical in areas that lack cold storage facilities Measurements were taken at harvest and after 3, 7 and 10 days.	Under ambient conditions for 10 days: 25.1 ± 1.3 °C 46.6 ± 6.0% RH
B	Handling of table grapes for domestic supply chain Measurements were taken at harvest, after 14 days in cold storage, after 10 days at retail conditions and then after 3, 7 and 10 days at ambient conditions.	Cold store for 2 weeks: -0.3°C ± 0.7°C and 81.3% ± 4.1% RH Retail store for 10 days: 5.4°C ± 0.6°C and 83.7% ± 2.9% RH Consumer/home (ambient) store: 25.1 ± 1.3 °C and 46.6 ± 6.0% RH
C	Shipping to export markets Measurements were taken at harvest, after 28 days in cold storage, after a further 10 days at retail conditions and then at 3, 7 and 10 days at ambient conditions.	Cold storage for 4 weeks at -0.3 ± 0.7°C, 81.3 ± 4.1% RH Retail store for 10 days: 5.4°C ± 0.6°C and 83.7% ± 2.9% RH Consumer/home (ambient) 'shelf' store: 25.1 ± 1.3°C and 46.6 ± 6.0% RH
D	Reefer container containing export fruit are left open on arrival for two days before fruit is unloaded. 'Abusive' treatment of fruit within the export chain. Measurements were taken at harvest, after 28 days in cold storage then after 2 days exposure to ambient conditions, after a further 10 days at retail conditions and then at 3, 7 and 10 days at ambient conditions	Cold store for 2 weeks: -0.3°C ± 0.7°C and 81.3% ± 4.1% RH; Ambient storage for 2 days: 25.1 ± 1.3°C, 46.6 ± 6.0% RH ; Retail store display for 10 days: 5.4°C ± 0.6°C and 83.7% ± 2.9% RH; Consumer/home (ambient) 'shelf' store: 25.1 ± 1.3°C and 46.6 ± 6.0% RH

Table 2. Physical losses of 'Crimson Seedless' table grapes measured as weight loss (%) and decayed and SO_2 damaged berries (%) after 3, 7 and 10 days at ambient conditions (25.1 ± 1.3°C and 46.6 ± 6.0% RH). Mean values with different letter(s) in the same column indicate statistically significant differences (P<0.05).

Season	2017			2018		
Time	Weight loss (%)	Decay (%)	SO_2 (%)	Weight loss (%)	Decay (%)	SO_2 (%)
Harvest	-	0	0	-	0	0
3 Days	2.34 ^{a}	1.05^{b}	1.85 ^{b}	1.55 ^{a}	0.85^{b}	0.37 ^{b}
7 Days	4.47 ^{a}	3.34^{b}	2.31 ^{a}	1.83 ^{a}	1.67^{b}	0.92 ^{a}
10 Days	7.63 ^{a}	7.60^{a}	2.57 ^{a}	4.43 ^{a}	2.67^{a}	1.19 ^{a}
P-Value	0.28	<0.01	<0.01	0.19	<0.01	<0.01

Table 3. Physical losses of 'Crimson Seedless' table grapes measured as weight loss (%) and decayed and SO_2 damaged berries (%) after 14 days cold storage (-0.3 ± 0.7°C, 81.3 ± 4.1% RH), after another 10 days at retail conditions (5.4 ± 0.6°C, 83.7 ± 2.9% RH) and then 3, 7 and 10 days at ambient conditions (25.1 ± 1.3°C and 46.6 ± 6.0% RH). Mean values with different letter(s) in the same column indicate statistically significant differences (P<0.05).

Season	2017			2018		
Time	Weight loss (%)	Decay (%)	SO_2 (%)	Weight loss (%)	Decay (%)	SO_2 (%)
Harvest	-	0	0	-	0	0
14 Days (-0.5°C)	1.41 ^{a}	0	1.0 ^{b}	1.85 ^{a}	0.4 ^{e}	0.8 ^{b}
10 Days (5°C)	1.87 ^{a}	2.1 ^{c}	1.8^{ab}	2.57 ^{a}	1.2 ^{d}	1.7^{ab}
3 Days	2.53 ^{a}	2.5 ^{c}	2.1 ^{a}	4.03 ^{a}	2.2 ^{c}	2.1 ^{a}
7 Days	3.78 ^{a}	5.5 ^{b}	2.2 ^{a}	4.40 ^{a}	3.3 ^{b}	2.1 ^{a}
10 Days	5.36 ^{a}	8.6 ^{a}	2.4 ^{a}	6.76 ^{a}	4.7 ^{a}	2.1 ^{a}
P-Value	0.91	<0.01	0.02	0.99	<0.01	<0.01

Table 4. Physical losses of 'Crimson Seedless' table grapes measured as weight loss (%), decayed and SO_2 damaged berries (%) after 28 days cold storage (-0.3 ± 0.7°C, 81.3 ± 4.1% RH), after another 10 days at retail conditions (5.4 ± 0.6°C, 83.7 ± 2.9% RH) and then for 3, 7 and 10 days at ambient conditions (25.1 ± 1.3°C and 46.6 ± 6.0% RH). Mean values with different letter(s) in the same column indicate statistically significant differences (P<0.05).

Season	2017			2018		
Time	Weight loss (%)	Decay (%)	SO_2 (%)	Weight loss(%)	Decay (%)	SO_2 (%)
Harvest	-	0	0	-	0	0
28 Days (-0.5°C)	4.82 [a]	2.14 [d]	0.47 [c]	1.89 [a]	0.94 [d]	0.25 [a]
10 Days (5°C)	5.50 [a]	3.20 [cd]	0.94 [c]	2.45 [a]	2.60 [c]	0.62 [a]
3 Days	6.61 [a]	4.44 [c]	1.39 [b]	2.64 [a]	3.16 [c]	0.62 [a]
7 Days	7.90 [a]	6.53 [b]	1.68 [ab]	3.95 [a]	4.95 [b]	0.62 [a]
10 Days	10.22 [a]	9.92 [a]	1.85 [a]	5.18 [a]	8.30 [a]	0.62 [a]
P-Value	0.85	<0.01	<0.01	0.84	<0.01	0.26

Table 5. Physical losses of 'Crimson Seedless' table grapes measured as weight loss (%), decayed and SO_2 damaged berries (%) after 28 days cold storage (-0.3 ± 0.7°C, 81.3 ± 4.1% RH), 2 days 'abusive' temperature and humidity (25.1 ± 1.3°C and 46.6 ± 6.0% RH), another 10 days at retail conditions (5.4 ± 0.6°C, 83.7 ± 2.9% RH) and then for 3, 7 and 10 days at ambient conditions (25.1 ± 1.3°C and 46.6 ± 6.0% RH). Mean values with different letter(s) in the same column indicate statistically significant differences (P<0.05).

Season	2018		
Time	Weight loss (%)	Decay (%)	SO_2 (%)
Harvest	-	0	0
28 Days (-0.5°C)	1.31 [a]	0.84 [e]	0.88 [a]
2 Days (ambient)	2.17 [a]	1.33 [e]	0.98 [a]
10 Days (5°C)	3.04 [a]	2.35 [d]	1.06 [a]
3 Days	3.96 [a]	3.24 [c]	1.09 [a]
7 Days	4.74 [a]	4.46 [b]	1.10 [a]
10 Days	5.70 [a]	6.70 [a]	1.21 [a]
P-Value	0.19	<0.01	0.99

Table 6. Supply chain Scenario A (2017): Changes in quality attributes of colour (L*, a* and b*), Firmness (N), TSS (°Brix), TA (%) and stem browning index for 'Crimson Seedless' table grapes at harvest and after 3, 7 and 10 days at ambient conditions (25.1 ± 1.3°C and 46.6 ± 6.0% RH). Mean values with different letter(s) in the same column indicate statistically significant differences (P<0.05).

Year	2017						
Time	L*	a*	b*	Firmness (N)	TSS (°Brix)	TA (%)	Stem browning index
Harvest	29.55 [a]	5.85 [a]	6.77 [a]	98.22 [a]	18.72 [a]	0.89 [a]	1 [d]
3 Days	30.81 [a]	4.98 [a]	6.56 [a]	97.80 [a]	18.16 [a]	0.75 [a]	2.4 [c]
7 Days	31.07 [a]	5.08 [a]	6.59 [a]	96.87 [a]	18.34 [a]	0.73 [a]	4.4 [b]
10 Days	30.91 [a]	4.88 [a]	6.75 [a]	95.47 [a]	19.15 [a]	0.80 [a]	5.0 [a]
P-Value	0.06	0.45	0.98	0.79	0.85	0.50	<0.01

Table 7. Supply chain Scenario A (2018): Changes in quality attributes of colour (L*, a* and b*), Firmness (N), TSS (°Brix), TA (%) and stem browning index for 'Crimson Seedless' table grapes at harvest and after 3, 7 and 10 days at ambient conditions (25.1 ± 1.3°C and 46.6 ± 6.0% RH). Mean values with different letter(s) in the same column indicate statistically significant differences (P<0.05).

Year	2018						
Time	L*	a*	b*	Firmness (N)	TSS (°Brix)	TA (%)	Stem browning index
Harvest	27.46 [c]	7.91 [a]	6.95 [a]	98.15 [a]	20.88 [a]	0.86 [a]	1 [c]
3 Days	27.64 [bc]	6.80 [a]	6.74 [a]	97.73 [a]	16.77 [a]	0.76 [a]	2.5 [b]
7 Days	27.96 [b]	6.84 [a]	6.83 [a]	96.96 [a]	18.60 [a]	0.79 [a]	4.6 [a]
10 Days	28.94 [a]	7.85 [a]	7.00 [a]	95.55 [a]	19.15 [a]	0.85 [a]	4.8 [a]
P-Value	<0.01	0.45	0.98	0.79	0.85	0.50	<0.01

Table 8. Supply chain Scenario B (2017): Changes in quality attributes of colour (L*, a* and b*), Firmness (N), TSS (°Brix), TA (%) and stem browning index for 'Crimson Seedless' table grapes at harvest after 14 days cold storage (-0.3 ± 0.7°C, 81.3 ± 4.1% RH), after another 10 days at retail conditions (5.4 ± 0.6°C, 83.7 ± 2.9% RH) and then for 3, 7 and 10 days at ambient conditions (25.1 ± 1.3°C and 46.6 ± 6.0%RH). Mean values with different letter(s) in the same column indicate statistically significant differences (P<0.05).

			2017				
Time	L*	a*	b*	Firmness (N)	TSS (°Brix)	TA (%)	Stem browning index
Harvest	33.65 [a]	7.76 [a]	7.28 [a]	98.23 [a]	17.34 [a]	0.99 [a]	1 [d]
14 Days (-0.5°C)	30.78 [a]	6.60 [a]	7.08 [a]	100.14 [a]	19.39 [a]	0.91 [a]	1.4 [d]
10 Days (5°C)	29.78 [a]	7.64 [a]	7.74 [a]	106.59 [a]	18.97 [a]	0.75 [a]	2.4 [c]
3 Days	30.61 [a]	6.11 [a]	7.41 [a]	92.02 [a]	19.63 [a]	0.77 [a]	3.5 [b]
7 Days	30.52 [a]	6.70 [a]	8.44 [a]	87.59 [a]	19.52 [a]	0.70 [a]	4.7 [a]
10 Days	31.38 [a]	6.86 [a]	9.20 [a]	88.88 [a]	17.10 [a]	0.68 [a]	4.9 [a]
P-Value	0.79	0.49	0.24	0.21	0.73	0.27	<0.01

Table 9. Supply chain Scenario B (2018): Changes in quality attributes of colour (L*, a* and b*), Firmness (N), TSS (°Brix), TA (%) and stem browning index for 'Crimson Seedless' table grapes at harvest after 14 days cold storage (-0.3 ± 0.7°C, 81.3 ± 4.1% RH), after another 10 days at retail conditions (5.4 ± 0.6°C, 83.7 ± 2.9% RH) and then for 3, 7 and 10 days at ambient conditions (25.1 ± 1.3°C and 46.6 ± 6.0%RH). Mean values with different letter(s) in the same column indicate statistically significant differences (P<0.05).

			2018				
Time	L*	a*	b*	Firmness (N)	TSS (°Brix)	TA (%)	Stem browning index
Harvest	27.46 [b]	7.91 [a]	2.23 [a]	111.06 [a]	17.84 [b]	0.72 [c]	1 [d]
14 Days (-0.5°C)	27.88 [b]	8.22 [a]	2.87 [a]	114.59 [a]	17.99 [b]	0.85 [b]	1.3 [d]
10 Days (5°C)	27.32 [b]	7.32 [a]	4.05 [a]	121.69 [a]	19.14 [a]	0.82 [b]	2.7 [c]
3 Days	27.84 [b]	7.05 [a]	2.19 [a]	115.23 [a]	18.95 [a]	0.78 [c]	3.7 [b]
7 Days	27.56 [b]	6.56 [a]	1.94 [a]	119.03 [a]	19.13 [a]	0.89 [a]	4.6 [a]
10 Days	30.30 [a]	6.01 [a]	3.45 [a]	120.27 [a]	18.95 [a]	0.85 [b]	4.8 [a]
P-Value	<0.01	0.31	0.19	0.49	<0.01	<0.01	<0.01

Table 10. Supply chain Scenario C (2017): Changes in quality attributes of colour (L*, a* and b*), Firmness (N), TSS (°Brix), TA (%) and stem browning index for 'Crimson Seedless' table grapes at harvest after 28 days cold storage (-0.3 ± 0.7°C, 81.3 ± 4.1% RH), after another 10 days at retail conditions (5.4 ± 0.6°C, 83.7 ± 2.9% RH) and then for 3, 7 and 10 days at ambient conditions (25.1 ± 1.3°C and 46.6 ± 6.0%RH). Mean values with different letter(s) in the same column indicate statistically significant differences (P<0.05).

2017							
Time	L*	a*	b*	Firmness (N)	TSS (°Brix)	TA (%)	Stem browning index
Harvest	30.04 ^{a}	10.37 ^{a}	9.36 ^{a}	98.69 ^{a}	17.80 ^{a}	1.13 ^{a}	1 ^{e}
28 Days (-0.5°C)	29.94 ^{a}	8.80 ^{a}	9.16 ^{a}	94.41 ^{a}	18.56 ^{a}	0.74 ^{a}	1.14 ^{e}
10 Days (5°C)	28.61 ^{a}	7.89 ^{a}	9.54 ^{a}	98.70 ^{a}	19.15 ^{a}	0.64 ^{a}	1.97 ^{d}
3 Days	31.41 ^{a}	6.81 ^{a}	8.72 ^{a}	97.00 ^{a}	19.28 ^{a}	0.73 ^{a}	3.08 ^{c}
7 Days	31.78 ^{a}	6.52 ^{a}	8.10 ^{a}	99.70 ^{a}	19.17 ^{a}	0.67 ^{a}	4.53 ^{b}
10 Days	31.69 ^{a}	5.76 ^{a}	8.10 ^{a}	97.20 ^{a}	18.57 ^{a}	0.67 ^{a}	5.00 ^{a}
P-Value	0.12	0.15	0.72	0.90	0.67	0.06	<0.01

Table 11. Supply chain Scenario C (2018): Changes in quality attributes of colour (L*, a* and b*), Firmness (N), TSS (°Brix), TA (%) and stem browning index for 'Crimson Seedless' table grapes at harvest after 28 days cold storage (-0.3 ± 0.7°C, 81.3 ± 4.1% RH), after another 10 days at retail conditions (5.4 ± 0.6°C, 83.7 ± 2.9% RH) and then for 3, 7 and 10 days at ambient conditions (25.1 ± 1.3°C and 46.6 ± 6.0% RH). Mean values with different letter(s) in the same column indicate statistically significant differences (P<0.05).

2018							
Time	L*	a*	b*	Firmness (N)	TSS (°Brix)	TA (%)	Stem browning index
Harvest	27.45 ^{b}	7.91 ^{a}	2.23 ^{a}	106.60 ^{a}	17.80 ^{a}	0.72 ^{b}	1 ^{e}
28 Days (-0.5°C)	27.75 ^{b}	7.06 ^{a}	1.76 ^{a}	106.02 ^{a}	18.69 ^{a}	0.77 ^{a}	1.97 ^{e}
10 Days (5°C)	28.09 ^{ab}	7.20 ^{a}	2.47 ^{a}	104.34 ^{a}	18.58 ^{a}	0.77 ^{a}	2.67 ^{d}
3 Days	28.42 ^{a}	6.96 ^{a}	2.36 ^{a}	110.07 ^{a}	18.77 ^{a}	0.72 ^{b}	3.61 ^{c}
7 Days	27.30 ^{c}	6.60 ^{a}	2.10 ^{a}	110.21 ^{a}	18.55 ^{a}	0.69 ^{c}	4.45 ^{b}
10 Days	27.79 ^{b}	7.23 ^{a}	2.41 ^{a}	112.65 ^{a}	18.53 ^{a}	0.73 ^{b}	4.78 ^{a}
P-Value	<0.01	0.26	0.22	0.11	0.30	<0.01	<0.01

Table 12. Supply chain Scenario D (2018): Changes in quality attributes of colour (L*, a* and b*), Firmness (N), TSS (°Brix), TA (%) and stem browning index for 'Crimson Seedless' table grapes at harvest after 28 days cold storage (-0.3 ± 0.7°C, 81.3 ± 4.1% RH), after 2 days 'abusive' temperature and humidity (25.1 ± 1.3°C and 46.6 ± 6.0%RH), after another 10 days at retail conditions (5.4 ± 0.6°C, 83.7 ± 2.9% RH) and then for 3, 7 and 10 days at ambient conditions (25.1 ± 1.3°C and 46.6 ± 6.0%RH). Mean values with different letter(s) in the same column indicate statistically significant differences (P<0.05).

2018							
Time	L*	a*	b*	Firmness (N)	TSS (°Brix)	TA (%)	Stem browning index
Harvest	27.46 b	7.91 a	9.36 a	116.60 a	17.80 d	0.79 a	1 e
28 Days (-0.5°C)	27.49 b	7.89 a	9.16 a	118.54 a	18.54 c	0.76 b	1.89 e
2 Days (ambient)	28.21 a	7.65 a	9.23 a	115.72 a	17.75 d	0.75 b	3.25d
10 Days (5°C)	27.71 b	7.88 a	9.54 a	123.01 a	19.55 ab	0.72 c	4.01 c
3 Days	27.60 b	8.02 a	8.72 a	121.96 a	17.27 d	0.72 c	4.62 b
7 Days	28.23 a	7.69 a	8.34 a	116.28 a	19.11 b	0.75 b	4.94 a
10 Days	27.82 b	7.83 a	8.12 a	123.24 a	19.74 a	0.76b	4.94 a
P-Value	<0.01	0.86	0.21	0.23	<0.01	<0.01	<0.01

Table 13. Impact of postharvest losses in terms of magnitude, monetary value, energy used, water footprint and greenhouse gas emissions in the production and distribution of table grapes along different supply chains.

Year	Supply Chain Scenario	Storage Condition		Estimated physical and economic losses		*Estimated environmental and resource impacts		
		Time	Temp (°C) and Humidity (%)	Physical (ton)	Value (ZAR)	Energy (MJ)	Water footprint (m^3)	Emissions CO_2eq (ton)
2017	A	3 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	1 052[a]	13 816 968[a]	6 868 508[a]	221 288[a]	957[a]
2017	A	7 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	1 904[b]	25 007 316[b]	12 431 216[b]	400 466[b]	1 733[b]
2017	A	10 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	2 068[b]	27 161 112[b]	13 461 972[b]	435 003[b]	1 882[b]
2017	B	14 Days	-0.3 ± 0.7°C; 81.3 ± 4.1%RH	493[a]	6 475 062[a]	3 218 797[a]	103 703[a]	449[a]
2017	B	10 Days	5.4 ± 0.6°C; 83.7 ± 2.9%RH	874[ab]	11 479 116[ab]	5 706 346[ab]	183 846[ab]	795[ab]
2017	B	3 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	1 431[bc]	18 794 754[bc]	9 342 999[bc]	301 011[bc]	1 302[bc]
2017	B	7 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	2 074[cd]	27 239 916[cd]	13 541 146[cd]	436 266[cd]	1 887[cd]
2017	B	10 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	2 534[d]	33 281 556[d]	16 544 486[d]	533 027[d]	2 306[d]
2017	C	28 Days	-0.3 ± 0.7°C; 81.3 ± 4.1%RH	13 299[a]	279 305 598[a]	86 829 171[a]	2 797 445[a]	12 102[a]
2017	C	10 Days	5.4 ± 0.6°C; 83.7 ± 2.9%RH	21 443[b]	450 345 886[b]	140 001 347[b]	4 510 535[b]	19 513[b]
2017	C	3 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	22 602[b]	47 467 204[b]	147 568 458[b]	4 754 331[b]	20 568[b]
2017	C	7 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	29 251[b]	614 329 502[b]	190 979 779[b]	6 152 948[b]	26 618[b]
2017	C	10 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	43 587[c]	915 414 174[c]	284 579 523[c]	9 168 525[c]	39 664[c]
2018	A	3 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	555[a]	7 289 370[a]	3 623 595[a]	116 744[a]	505,05[a]
2018	A	7 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	575[a]	7 552 050[a]	3 754 175[a]	120 951[a]	523,25[a]
2018	A	10 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	1 305[b]	17 139 870[b]	8 520 345[b]	274 507[b]	1 187,55[b]
2018	B	14 Days	-0.3 ± 0.7°C; 81.3 ± 4.1%RH	611[a]	8 024 874[a]	3 989 219[a]	128 524[a]	556[a]
2018	B	10 Days	5.4 ± 0.6°C; 83.7 ± 2.9%RH	728[ab]	9 561 552[ab]	4 753 112[ab]	153 135[ab]	663[ab]
2018	B	3 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	1 163[bc]	15 274 842[bc]	7 593 227[bc]	244 637[bc]	1 058[bc]
2018	B	7 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	1 303[cd]	17 113 602[cd]	8 507 287[cd]	274 086[cd]	1 186[cd]

2018	B	10 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	1 856[d]	24 376 704[d]	12 117 824[d]	390 410[d]	1 689[d]
2018	C	28 Days	-0.3 ± 0.7°C; 81.3 ± 4.1%RH	29 861[a]	627 140 722[a]	194 962 469[a]	6 281 261[a]	27 174[a]
2018	C	10 Days	5.4 ± 0.6°C; 83.7 ± 2.9%RH	11 560[b]	242 783 120[b]	75 475 240[b]	2 431 646[b]	10 520[b]
2018	C	3 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	12 109[b]	254 313 218[b]	79 059 661[b]	2 547 128[b]	11 019[b]
2018	C	7 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	21 107[ab]	443 289 214[ab]	137 807 603[ab]	4 439 857[ab]	19 207[ab]
2018	C	10 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	31 173[a]	654 695 346[a]	203 528 517[a]	6 557 241[a]	28 367,43[a]
2018	D	28 Days	-0.3 ± 0.7°C; 81.3 ± 4.1%RH	9 242[a]	194 100 484[a]	60 341 018[a]	1 944 055[a]	8 410[a]
2018	D	2 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	9 730[a]	204 349 460[a]	63 527 170[a]	2 046 706[a]	8 854[a]
2018	D	10 Days	5.4 ± 0.6°C; 83.7 ± 2.9%RH	13 024[ab]	273 530 048[ab]	85 033 696[ab]	2 739 598[ab]	11 852[ab]
2018	D	3 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	15 251[bc]	320 301 502[bc]	99 573 779[bc]	3 208 048[bc]	13 878[bc]
2018	D	7 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	20 314[c]	426 634 628[c]	132 630 106[c]	4 273 050[c]	18 486[c]
2018	D	10 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	27 177[d]	570 771 354[d]	177 438 633[d]	5 716 682[d]	24 731[d]

a,b,c Values in a column without a common superscript are significantly different (P<0.05).

*Estimated values obtained using the volume of table grapes sold locally, 20 046 t and exported, 305 015 t. [17] This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation as well as the experimental conclusions that can be drawn.

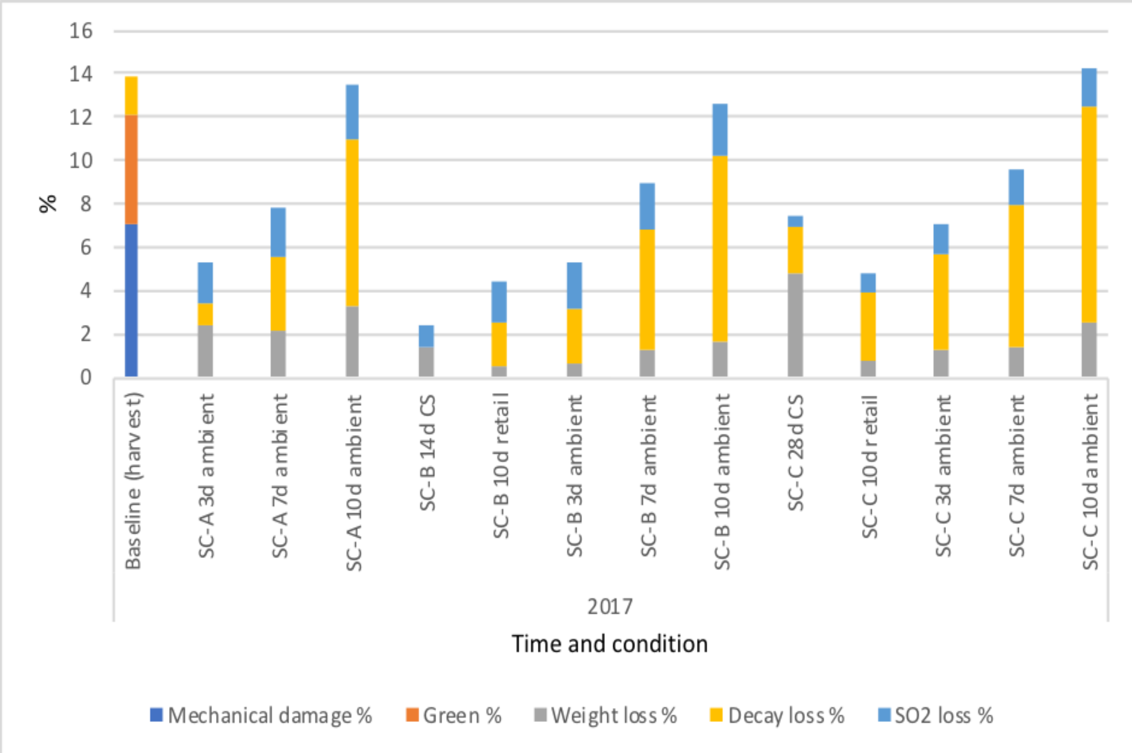

Figure 1. Total physical losses of grape 'Crimson Seedless' at harvest 2017 along different supply chain (SC) scenarios where SC-A represents marketing at ambient conditions, SC-B represents the supply chain to the local retail market, SC-C represents the international supply chain and SC-D represents the international supply chain including 2 days 'abusive' ambient temperature and humidity.

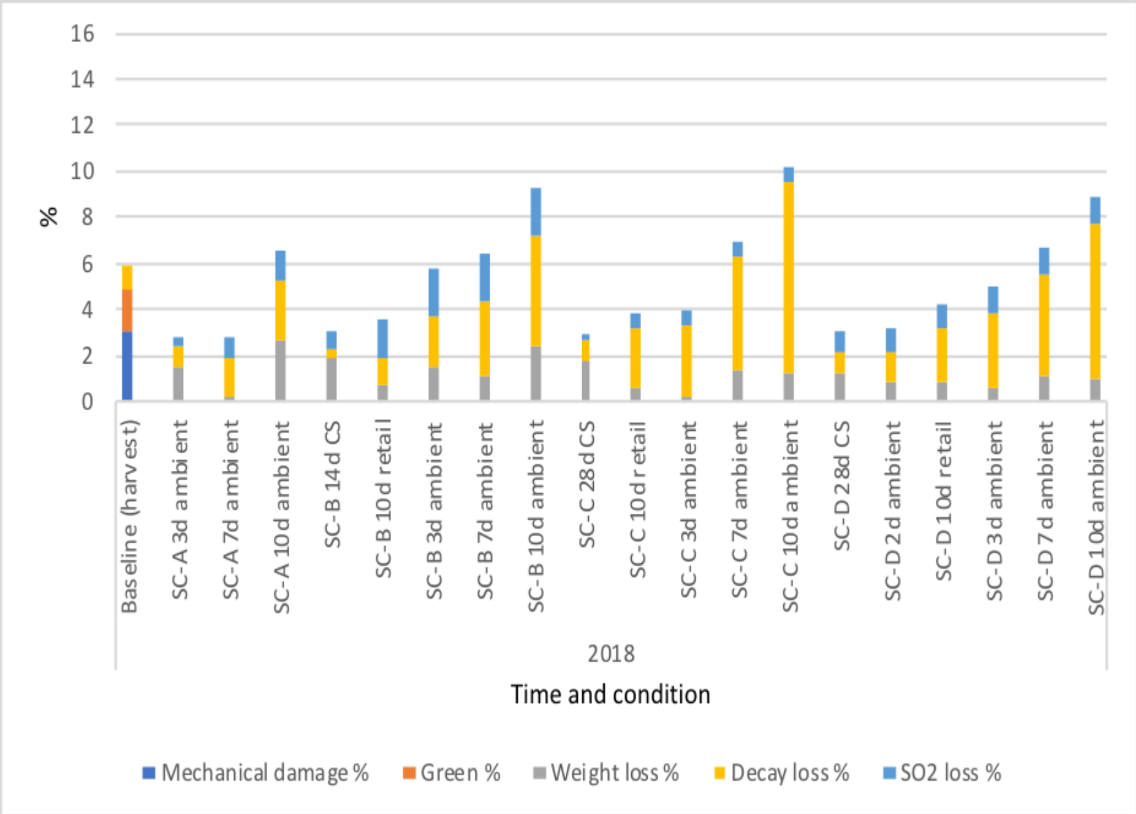

Figure 2. Total physical losses of grape ‘Crimson Seedless’ at harvest 2018 along different supply chain (SC) scenarios where SC-A represents marketing at ambient conditions, SC-B represents the supply chain to the local retail market, SC-C represents the international supply chain and SC-D represents the international supply chain including 2 days ‘abusive’ ambient temperature and humidity.

CHAPTER 5

POSTHARVEST LOSSES IN QUANTITY AND QUALITY OF PEAR (CV. *PACKHAM'S TRIUMPH*) ALONG THE SUPPLY CHAIN AND ASSOCIATED IMPACTS*[2]

TABLE OF CONTENTS

ABSTRACT

Approximately one third of the food produced globally is lost or wasted along the supply chain. Reducing this would be an important measure to increase the global food supply as the world continuous the struggle to feed its people sustainably. Not merely a waste of food, these losses al-so represent a waste of human effort and agricultural inputs from expensive fertilizers to natural resources as well as contributing to global greenhouse gas emissions. Measuring the extent of, and understanding the reasons

---

[2] Citation: Blanckenberg, A.; Fawole, O.A.; Opara, U.L. Postharvest Losses in Quantity and Quality of Pear (cv. Packham's Triumph) along the Supply Chain and Associated Economic, Environmental and Resource Impacts. Sustainability 2022, 14, 603. https:// doi.org/10.3390/su14020603

for these losses can assist in developing appropriate measures re-quired to prevent or reduce such losses. Therefore, the objective of this research was to quantify postharvest losses in quantity and quality of 'Packham's Triumph' pears at farm and simulated retail levels. Pears were sampled from two farms in the Western Cape Province of South Africa, the largest deciduous fruit production and export region in Southern Africa. The greatest losses measured along the supply chain were on-farm immediately after harvest, with 18% recorded. The main reasons for on-farm losses were small size (65%), deformity (26%), and chafed peel (9%). After 14 days in cold storage (-0.3 ± 0.7°C, 81.3 ± 4.1% RH), mean pear losses were 0.86% which increased to 1.49% after 28 days. After 10 days of further storage under simulated mar-ket conditions (5.4 ± 0.6°C, 83.7 ± 2.9% RH), fruit losses were 1.52% during retail marketing and 2.09% during export. Storing pears under ambient conditions (25.1 ± 1.3°C and 46.6 ± 6.0% RH) resulted in a higher incidence of losses, increasing from 0.90 to 1.55 and 2.25% after 3, 7 and 10 days, respectively. The socio-economic impacts of these postharvest losses amounted to financial losses of between ZAR 492 million (USD 34.1 million according to the conversion rate of 14 April 2021) to over ZAR 831 million (USD 57.6 million) annually, and this was associated with the loss of 301 million MJ of fossil energy, 69 million m^3 of fresh water and contributed to the emission of approximately 19 690 tonnes of CO_2 equivalent. The fresh water lost could sustain 3.7 million individuals daily for a whole year at a daily minimum usage rate of 0.05 m^3 per day while it will require planting 0.5 million trees to sink the 19 690 tons GHG emissions of the pear losses (0.039 metric ton per urban tree planted). Decreasing postharvest losses will conserve resources as well as improve food security and nutrition, objectives of the post-2015 sustainable development agenda led by the United Nations.

1. INTRODUCTION

Around one billion people are currently malnourished as the world continuous the struggle to feed its people sustainably (Tilman et al., 2001; FAO, 2009; Pelletier and Tyedmers, 2010). The projected increase in the global population together with the impact of climate change will further affect food production in the near future (Schmidhuber and Tubiello, 2007; Nelson et al., 2010). Several methods have been suggested to meet these growing challenges in a balanced way: stemming farmland expansion, especially in the tropics; increasing cropping efficiency; altering diets; and reducing losses and waste (Godfray et al., 2010; Foley et al., 2011; Kummu et al., 2012). By employing these measures jointly, food production could be doubled with our available resources without increasing environmental impacts (Foley et al., 2011). This study focuses on the last of those measures, i.e. reducing losses and waste. As approximately one third of the food produced globally (in terms of weight) is lost or wasted, reducing this would certainly be an important measure to increase global food supply (Gustavson et al., 2011).

The loss of horticultural produce in the supply chain is a major problem that has only recently began to receive the worldwide recognition and attention it deserves. These losses can be the result of many different factors that range from growing conditions to rough handling at retail level. Not merely a waste of food, these losses also represent a waste of human effort and agricultural inputs from expensive fertilizers to natural resources like water and soil (Debela et al., 2011). Postharvest losses are difficult to measure and very little scientifically quantified data is available on this topic. A number of attempts, over several decades, have been made to quantify global food waste, this has been motivated in part by the desire to highlight the scale of 'waste' in relation to global malnutrition in an attempt to jolt people into changing their behaviour (Lundqvist et al., 2011; Parfitt et al., 2010). However, such assessments rely on limited datasets collected across the food supply chains at different times and extrapolated to the larger picture.

In terms of foreign exchange earnings, employment creation and linkages with support institutions, pears (Pyrus communis L.) are among the most important deciduous fruits grown in South Africa (Matare, 2012; DAFF, 2019). During the 2016/17 season, pears accounted for 14.1% (R2.7 billion) of the total gross value for deciduous fruits (R19 billion) in South Africa.

The leading pear cultivar grown in South Africa by area planted and exportation is 'Packham's Triumph' accounting for 33% (4 072 ha) of the total area planted (12 265 ha) (DAFF, 2019; Kawhena et al., 2018). Pear production in South Africa is export oriented, and as the export markets for South African pears are geographically distant, the fruit has to be stored for extended periods. Maintaining the quality of the fruit while moving through the postharvest handling chain from the orchard all the way to the consumer is therefore very important (Dodd et al., 2010; DAFF, 2019).

As pears are climacteric, they are usually harvested at a lower maturity to enable them to withstand the demands of postharvest handling and distribution (Crisosto, 1994). Even so, being highly perishable products, considerable losses of pears can occur (Mari et al., 2003). Even a minor loss can be very costly because of the accumulated expenses of growing, harvesting and storing these high value products (Janisiewicz, 1996). Harvested pears are prone to physical damage leading to moisture loss and infection that affects fruit appearance (Slaughter et al., 1998). Postharvest diseases can be a limiting factor for the long-term storage of fruits with losses as high as 50-60% having been observed in storage bins prior to packing (Xiao and Boal, 2004). Losses cause less food to be available for consumption and therefore contribute to food insecurity. In addition, these losses also lead to unnecessary CO_2 emissions and represent a waste of human effort and agricultural inputs from expensive fertilizers to natural resources like water and soil (Debela et al., 2011). The reduction of postharvest losses is, therefore, important to increase food security (Mrema and Rolle, 2002; Hailu and Derbew, 2015). Information on the characteristics and extent of losses in pears reaching the export markets as well as the South African local fresh fruit markets could help in ascertaining the factors responsible for the losses and provide guidelines in developing appropriate measures required to prevent or reduce such losses.

The aim of this study, therefore, was to assess postharvest losses of pears along the supply chain, from harvest to both export and local retail level and during post-purchase storage. The specific objectives were to measure the extent of postharvest physical losses, quantify the changes in physico-chemical properties related to quality during storage, and estimate the economic and environmental impacts of the fruit losses.

2. MATERIALS AND METHODS

Harvesting and sampling techniques

Data collection protocols were similar to those used by Kitinoja and AlHassan (2012). Pears were collected during the commercial harvest on 5 February 2018 at Lourensford farm (latitude: 34° 04'S longitude: 18° 53'E) in Somerset-West and on 20 February 2018 at Uitvlugt farm (latitude: 34°22' S; longitude: 20°34' E) in the Overberg area, both farms are located in the Western Cape, South Africa. At harvest, ten full 20 L picking bags were selected at each farm and the contents carefully inspected to quantify the percentage of fruit that would be discarded due to defects or too small size (if it falls through a 75 mm ring). Subsequently, 400 pears per farm were selected and packed into standard Multi-Layer Telescopic Cartons 12.5 kg M12T (MK6) (dimensions: 300x400x220 mm; internal trays: 383x281 mm and a liner bag: length 410 mm; width 310 mm and depth 775mm) based on industry practice.

Supply chains simulated

From each farm, 100 pears were used for each supply chain scenario simulated i.e. 200 pears per scenario. From each farm, 100 pears were used for each supply chain scenario simulated, i.e. 200 pears per scenario. Four supply chain scenarios were studied (Table 1), representing the range of postharvest handling practices that occur in local and export marketing of pears in the South African fresh fruit industry. According to export pear producers (pers. communication Amelia Vorster, Technical Advisor (Quality) – Karsten Western Cape), Scenario D is a common occurrence and leads to tension between role-players as to whether the fruit was mishandled before the report was written and who is responsible for the losses if it is higher than expected.

Fruit loss evaluation and quality measurements

Postharvest losses

The base measurement for losses at harvest occurred in the orchards, ten full 20 L picking bags were selected at each farm and the contents carefully inspected to quantify the percentage of fruit that would be discarded due to defects or too small size (if it falls through a 75 mm ring).
At each evaluation time thereafter, physical losses were quantified as the decrease in fruit weight expressed as percentage fresh weight loss from harvest and the amount of fruit lost due to decay, expressed as the percentage of fruit with the disorder. For supply chain Scenario A, loss measurements were taken at harvest and after 3, 7 and 10 days under ambient conditions (25.1 ± 1.3°C, 46.6 ± 6.0% RH).

Quality attributes

1.Weight loss

For weight loss, 30 pears from two farms were selected, which gave 60 pear samples per supply chain scenario. Weight loss was expressed as a percentage of the initial fruit weight.

2. Total soluble solids (TSS) concentration

Fruit juice was extracted using a juice extractor (Mellerware - 600W Liqua Fresh Juice Extractor, South Africa). TSS of juice was measured with a digital refractometer (Atago, Tokyo, Japan). For the total soluble solids (TSS) concentration, samples of 18 pears per supply chain were used.

4. Titratable acidity (TA)

TA of juice was determined by titration to pH 8.2 using a Metrohm 862 compact titrosampler (Herisau, Switzerland). For TA, samples of 18 pears per supply chain were used.

5. Peel colour

Colour was assessed using a colorimeter (Minolta CR-400, Minolta Corp, Osaka, Japan) and expressed as CIE L*, a*, b* coordinate where L* defines lightness, a* denotes the red/green value and b* the yellow/blue value (Pathare et al*.,* 2013).

6. Firmness

Pear firmness (N) was measured using a penetrometer fitted with an 8 mm diameter probe (Sugar and Einhorn, 2011; Matare, 2012) (Güss Manufacturing, Strand, South Africa). Measurements were made on the widest part of the fruit after a 1–2 cm diameter area of peel was removed from the area to be tested using a vegetable peeler. Eighteen pears per supply chain scenario were evaluated for firmness.

7. Ethylene production

Ethylene production was measured as described by Oz (2011) and Mditshwa et al. (2016). Nine pears were weighed with an accuracy of up to 1 g and sealed, three per chamber, in 3200 mL air-tight glass chambers for 1 h at ambient conditions (25.1 ± 1.3°C, 46.6 ± 6.0% RH). The conncentration of ethylene in the container was then measured using an ICA 56 ethylene meter (International Controlled Atmosphere Ltd. Instrument Division UK) with an accuracy of up to 0.1 ppm, within a time of 15 s, at a flow of 0.8 $L.min^{-1}$. Based on the results and having measured the specific gravity of the pears as 1.06, ethylene production per 1 kg of fruit per hour was calculated (Li et al., 2013; Łysiak, 2014). The ethylene production rate was measured in ppm and expressed as C_2H_4 µL.kg.h

8. Respiration rates

Respiration rate was measured as described by Belay et al., 2018) with slight adaptations. Nine pears were weighed with an accuracy of up to 1 g and transferred to 3 200 mL air-tight glass chambers, three per chamber, for 1 h at ambient conditions (25.1 ± 1.3°C, 46.6 ± 6.0% RH). The CO_2 and O_2 concentrations were then measured using a combined CO_2/O_2 analyzer (CheckMate 9900, PBI-Dansensor, Denmark) with a syringe through a rubber septum attached to the top of the 3200 ml chambers. The following equation was used to calculate the CO_2 concentrations:

:

$$RCO_2 = \frac{(CO_{2f} - CO_{2i})}{(\Delta t)} \times \frac{Vf}{W}$$

Where RCO_2 is the respiration rate expressed in CO_2 mL.kg.h, CO_{2i} is the initial concentration of CO_2 in the chamber at the beginning of the experiment, CO_{2f} is the concentration of CO_2 at time *t*, *W* is fresh weight, and *Vf* is free volume.

Environmental and economic impacts of postharvest losses

Total greenhouse gas emissions were calculated using values provided by Janse van Vuuren and Pineo (2015). That study examined the annual cycle for pear production, beginning with establishment costs, raw material extraction for production of inputs used on the orchard and included the factors of fertilizer, tillage, irrigation, pest management, electricity and fuel con-sumption, ending at delivery of pears. For every ton of pears produced, stored and transported to the retail market approximately 0.25 ton of CO_2eq is emitted into the atmosphere. The energy cost for producing and marketing the lost produce was obtained using a reference value of 3 703 MJ/ton provided by (Tabatabaie et al., 2013) and the water footprint was determined by multiplying the quantity of lost produce with the reference water footprint value of pear 920 m^3/ton provided by Mekonnen and Hoekstra (2010). The value of pears lost was calculated using values provided by DAFF (2019), R5 871/ton for locally sold produce, and R11 366/ton for exported produce.

3. STATISTICAL ANALYSIS

The statistical significance of the difference in total loss at harvest across the farms was examined via a one-way analysis of variance (ANOVA). The physicochemical analysis data [weight loss, peel colour, firmness, total soluble solids (TSS), titratable acidity (TA), respiration rate and ethylene production] were subjected to mixed model analysis of variance (ANOVA) using Statistica version 13.2 (TIBCO Software Inc., Palo Alto, CA) with ‘farm’ and ‘time of measurement’ as fixed effect and cartons as random effect.

4. RESULTS

Physical losses at farm level

The measured loss of pears at harvest for individual farms were 18% and 19%, respectively. The average loss at harvest on the farm level was 18%. Of the 18% lost at harvest, the main reasons were due to deformed fruit (50%), too small size (48%) and chafed peel (2%) on the first farm while on the other farm the main reasons were the same, but the proportions differed, the majority of the losses were due to too small size (80%), chafed peel (18%) and deformed (2%). The average values for both farms together were small size (65%), deformity (26%), and chafed peel (9%).

Physical losses along the supply chain

Weight loss and decay

Supply chain Scenario A (handling and marketing under ambient conditions)

There was no statistically significant difference in fruit weight up to 10 days after harvest (P=0.42) as shown in Table 2. However, there was a 2.2% decrease in weight which would affect the profit margin, as fruit are sold by weight. No decay was present up to 7 days when 3.3% of the fruit showed visible signs of decay, increasing to 6.6% after 10 days.

Supply chain Scenario B (to local retail markets)

There was no statistically significant weight loss (P=0.97), Table 3. However, the weight decreased by 0.86% after 14 days in cold storage, 1.52% after 10 days at retail conditions, and then by 1.86%, 3.32 and 3.90% after 3, 7 and 10 days under ambient conditions, respectively. No decay was present during the measurements.

Supply chain Scenario C (to export retail markets)

There was no statistically significant difference in weight after storage or during shelf life of 10 days (P=0.93). However, weight decreased by 1.49% after 28 days in cold storage, 1.77% after 10 days at retail conditions and 2.24%, 2.97% and 3.60% after 3, 7 and 10 days under ambient conditions, respectively (Table 4). No decay was present during the course of the measurements.

Supply chain Scenario D (simulated 'abusive' treatment of fruit within the export chain)

There was no statistically significant difference in fruit weight over time (P=0.94), although a 0.98% decrease in weight is noted after 28 days in cold storage, 1.36% after two days at 'abusive' ambient conditions, 2.09% after 10 days at retail conditions and 2.91%, 3.26% and 3.71% after 3, 7 and 10 days under ambient conditions respectively. (Table 5). No decay was present during the measurements.

Quality losses along the supply chain

Supply chain Scenario A (marketing at ambient temperatures and relative humidity:

Pear colour became lighter (L*) over time (Table 6) and the change was statistically significant (P<0.01). The measurements for a* (P<0.01) denoting the red/green values and b* (P<0.01), indicating the yellow/blue values also changed significantly, indicating that the fruit became less green and more yellow over time. There were also significant differences in firmness, the values decreased with time as the fruit became softer as they ripened from 89.83 N at harvest to 71.29 N after 7 days and down to 4.71 N after 20 days (P<0.01). Although the TSS values increased over time, the increase was not statistically significant (P=0.45). TA values also did not change significantly for the duration of the trial (P=0.15). Respiration dropped to its lowest after 7 days and then rose again to peak at 17 days (P=0.02), while Ethylene levels remained quite low for the first 7 days and then increased significantly from 14 days to 20 days after harvest (P<0.01).

Supply chain Scenario B (to local retail markets)

Pear colour (L*) indicates that the lightness of the fruit did not change significantly (Table 7) during the time measurements were taken (P=0.25). The measurements for a* denoting the red/green values indicate that the pears retained their harvest colour during the two weeks in cold storage and at 10 days at retail conditions, after 10 days at ambient conditions. However, it became significantly (P<0.01) less green. The b* values, indicating the yellow/blue colour component, changed significantly (P<0.01) and showed that the fruit became yellower during the initial two weeks in -0.5°C cold storage and continuing the trend during its shelf-life period. Firmness decreased from 89.83 N to 79.53 N during cold storage and retail conditions when removed to ambient conditions; however, the firmness decreased rapidly to 37.66 N after 3 days, 20.10 N after 7 days and 10.2 N after 10 days. The TSS (P=0.38) values did not change significantly during the duration of the trial. The TA values also did not change significantly (P=0.80). The respiration rate dropped during cold storage, although it was not significantly different from that at harvest. At ambient conditions, the respiration rate increased significantly (P<0.01), peaking at 7 days. Ethylene levels remained low from harvest, through storage at both cold-room and retail conditions and then increased significantly (P<0.01) and quickly from 7 to10 days at ambient conditions

Supply chain Scenario C (to export retail markets)

Pear colour (L*), indicating lightness, darkened slightly, yet significantly (P=0.02), during cold storage and became lighter again with increases in temperature and relative humidity (Table 8). The measurements for a* (P<0.01) denoting the red/green values indicate that the pears retained their harvest colour during the four weeks in cold storage and during the 10 days at retail conditions, becoming significantly less green at ambient conditions. The b* values, indicating the yellow/blue colour component, also changed significantly (P<0.01), indicating that the fruit became considerably yellower during the four weeks in -0.5°C cold storage, after which it stayed the same until exposed to ambient conditions when it yellowed further. Firmness decreased from 89.83 N to 78.65 N during four weeks in cold storage and remained did not significantly change during 10 days at retail conditions. However, when moved to ambient conditions, the firmness decreased rapidly to 23.93 N after 3 days, 12.06 N after 7 days, and 9.41 N after 10 days. The TSS (P=0.12) and TA (P=0.20) values did not change significantly during the duration of the trial. The respiration rate dropped right down to no discernible activity during the four weeks in cold storage and was significantly different from that at harvest, it picked up slightly during storage at retail conditions and significantly when placed at ambient conditions where the respiration rate peaked at 7 days. Ethylene levels remained low after harvest and cold storage of 28 days. While it increases during retail conditions, it was not statistically significant until moved to ambient conditions when it increased significantly (P<0.01) and quickly during its 3 to10 days shelf life.

Supply chain Scenario D (simulated 'abusive' treatment of fruit within the export chain)

Pear colour (L*), darkened slightly, yet significantly, during cold storage (Table 8) and became lighter again with increases in temperature and relative humidity. The measurements for a* (P<0.01) denoting the red/green values indicate that the pears retained their green harvest colour during the four weeks in cold storage. No significant change occurred during the 2 days at ambient conditions or when placed at retail conditions for 10 days, but they did become significantly less green after 3, 7 and 10 days shelf life at ambient conditions.

The b* values, indicating the yellow/blue colour component also changed signifi-cantly (P<0.01), meaning that the fruit became considerably yellower during the four weeks in -0.5°C cold storage after which it did not change significantly, although the values show a trend of becoming more yellow under ambient shelf life conditions. After four weeks in cold storage, firmness decreased by around 9.81 N, from 90.12 N to 81.49 N and remained at that firmness during the 2 days at ambient conditions. During the 10 days at retail conditions, however, the firmness dropped with another 19.61N to 62.47 N, and when moved to ambient conditions, the firmness decreased rapidly to below 19.12 N firmness. There were no significant differences in TSS (P=0.45) or TA (P=0.51) during the whole supply chain. Fruit respiration rate dropped right down to no measurable activity during the four weeks in cold storage. After 2 days at ambient conditions, the respiration rate was again similar to that at harvest, dropping once more during the 10 days at retail conditions, but not significantly different from harvest or ambient conditions. During the 3, 7 and 10 days shelf life measurements, The respiration rate peaked after 3 days, albeit not significantly different between 3, 7 and 10 days at ambient conditions. Ethylene levels remained low and statistically the same after harvest, cold storage of 28 days, 2 days ambient and 10 days retail conditions. When moved to ambient conditions again, it in-creased significantly (P<0.01) and quickly during its 3 to10 days shelf life.

Socio-economic impacts of postharvest losses

Based on the percentage losses along the simulated supply chains, estimates were made to determine the volume of pears that could be lost at the national level (Table 10). In 2018, South Africa produced approximately 406 644 tons of which 49 926 tons were sold locally and 212 149 tons were exported (DAFF, 2019). The 18% loss measured at harvest translated to an estimated 73 196 tons at national level with a value of R 429 733 716 (USD 28 445 436) if it were sold on the local market and R 831 945 736 (USD 55 069 125) if it could have been exported. In addition, 271 044 788 MJ of energy has been lost, 67 340 320 m^3 of water and 18 299 tons of CO_{2eq} has been released into the atmosphere.

Supply chain Scenario A (marketing at ambient temperatures and relative humidity)

After 3 days 659 tons lost. This equates to a financial loss of R 3 868 989 (USD 252 781), 2 440 277 MJ of energy, 606 280 m^3 of water and 165 tons $CO_{2eq.}$ After 7 days the losses increase to 2 415 tons worth R 14 178 465 (USD 926 355), 8942 745 MJ of energy, 2 221 800 m^3 of water and 604 tons $CO_{2eq.}$ After 10 days, 6 441 tons worth R 37 815 111 (USD 2 470 663), 23 851 023 MJ of energy, 5 925 720 m^3 of water and 1610 tons $CO_{2eq.}$

Supply chain Scenario B (to local retail markets)

After 14 days in cold storage the losses were 585 tons worth R 3 434 535 (USD 224 396), 2 166 255 MJ of energy, 538 200 m^3 of water and 146 tons $CO_{2eq.}$ After 10 days at retail condition (if it were kept at 5.4 ± 0.6°C; 83.7 ± 2.9%RH, which not all retailers do) 1 098 tons were lost worth R 6 446 358 (USD 421 175), 4 076 874 MJ of energy 1 010 160 m^3 of water and 275 tons of $CO_{2eq.}$ After 3 days under ambient conditions 1391 tons were lost worth R8 166 561 (USD 533 565), 5 150 873 MJ of energy, 1 279 720 m^3 of water and 348 tons $CO_{2eq.}$ After 7 days shelf life, 2415 tons worth R 14 178 465 (USD 926 355), 8 942 745 MJ of energy, 2 221 800 m^3 of water and 604 tons of $CO_{2eq.}$ After 10 days 2 855 tons were lost worth R 16 761 705 (USD 1 095 132), 10 572 065 MJ of energy, 2 626 600 m^3 of water and 714 tons of $CO_{2eq.}$

Supply chain Scenario C (to export retail markets)

After 28 days in cold storage the losses were 1098 tons worth R 12 479 868 (USD 815 376), 4 065 894 MJ of energy, 1 010 160 m^3 of water and 275 tons $CO_{2eq.}$ After 10 days at retail condition 1 244 tons were lost worth R 14 139 304 (USD 923 796), 4 606 532 MJ of energy 1 144 480 m^3 of water and 311 tons of $CO_{2eq.}$ After 3 days under ambient conditions 1 610 tons were lost worth R 18 299 260 (USD 1 195 588), 5 961 830 MJ of energy, 1 481 200 m^3 of water and 403 tons $CO_{2eq.}$ After 7 days shelf life, 2196 tons worth R 24 959 736 (USD 1 630 753), 8 131 788 MJ of energy, 2 020 320 m^3 of water and 549 tons of $CO_{2eq.}$ After 10 days 2635 tons were lost worth R 29 949 410 (USD 1 956 755), 9 757 405 MJ of energy, 2 424 200 m^3 of water and 659 tons of $CO_{2eq.}$

Supply chain Scenario D (simulated 'abusive' treatment of fruit within the export chain)

After 28 days in cold storage the losses were 732 tons with a financial value of R 8 319 912 (USD 543584, 2 710 596 MJ of energy, 673 440 m^3 water and 183 tons CO_{2eq}. After 2 days at 'abusive' ambient temperature and humidity before entering retail conditions the losses were 1 025 tons worth R 11 650 150 (USD 761 166), 3 795 575 MJ, 943 000 m^3 water and 256 tons CO_{2eq}. After 10 Days at retail conditions losses were 1464 tons, R 16 639 824 (USD 1 087 168), 5 421 192 MJ, 1 346 880 m^3 water and 366 tons CO_{2eq}. At 3 days of ambient conditions losses were 2 123 tons were lost worth R 24 130 018 (USD 1 576 543), 7 861 469 MJ of energy, 1 953 160 m^3 water and 531 tons of CO_{2eq}. After 7 days under ambient conditions, 2 415 tons worth R 27 448 890 (USD 1 793 383) were lost along with 8 942 745 MJ of energy, 2 221 800 m^3 of water and 604 tons of CO_{2eq}. After 10 days at ambient conditions the losses were 2 708 tons worth R 30 779 128 (USD 2 010 965), 10 027 724 MJ of energy, 2 491 360 m^3 of water and 677 tons CO_{2eq}.

The socio-economic impacts of these losses, from harvest to shelf life, indicate a financial loss of between R 492 million to over R831 million annually for the South African pear industry. Additionally, as much as 301 million MJ of fossil energy and 69 million m^3 of freshwater resources were lost. The fresh water lost could sustain 3,7 million individuals daily for a whole year at daily minimum usage rate of 0.05 m^3 per day (Peter and Gleik, 1996)**,** while it will require planting 0.5 million trees to sink the 19 690 tons GHG emissions of the pear losses (0.039 metric ton per urban tree planted) (U.S. DOE, 1998).

5. DISCUSSION

Physical losses at farm level

The measured loss at harvest of 18% was almost double the 10% reported by Franke et al. (2016) measured in a study on food loss in primary production of the Nordic countries of Denmark, Finland, Sweden and Norway. As well as findings by Nótári and Ferencz (2014) who measured losses of 8% for Packham's Triumph pears in Hungary. Losses of 5% were reported by The United Kingdom's Waste and Resources Action Programme (WRAP) (2019). However, that study collected no primary data for pears, and their estimates were based on 'expert judgment'. While Mangaraj et al. (2011) reported that postharvest losses of pears in India were in the range of 20–30%, this was due to inadequate facilities and improper handling, packaging, and storage techniques.

Physical losses along the supply chain

Supply chain Scenario A (marketing at ambient temperatures and relative humidity)

These results differed and were much lower than the 8% weight loss reported by Dave et al. (2017) for cv. 'Babughosha' after 8 days under ambient conditions, 8.81% weight loss after 7 days for cv. 'Shahmive' reported by Akbari et al. (2019) as well as the 4.69% reported by Dhillon et al. (2017) for cv. 'Punjab Beauty'.

The decay rates were also lower than the 5% after 6 days and 12% after 9 days reported for cv. 'Punjab Beauty' by Dhillon et al. (2017). Nath et al. (2012), however, reported no decay for the first 3 days and then 9% decay after 6 days for cv. 'Lagoon'.

Supply chain Scenario B (to local retail markets)

Results indicate a higher percentage of weight loss than the 2% reported by Zucoloto et al. (2016) for cv. 'Abate Fetel' and was closer to the weight loss of 2.65 ± 0.64% reported for cv. 'Red Clapp's' after 15 days in cold storage plus 7 days at 20°C by Calvo and Sozzi (2004). Also similar to findings of Matare (2012), reporting average losses of 3.61% at the retail level for the 'Packham's Triumph' in South Africa. No decay was present during the experiment, corresponding to findings reported by Dhillon et al. (2017) for cv. 'Punjab Beauty'.

Supply chain Scenario C (to export retail markets)

Results were similar to the 3.9% loss in weight reported by Burger (2004) for cv. 'Packham's Triumph' after shipping to export markets and shelf life. No decay was present during the measurements, which is similar to Kahwena et al. (2018) finding no decay present up to 4 months in cold storage under regular atmosphere followed by seven days shelf life conditions (20°C).

Supply chain Scenario D (simulated 'abusive' treatment of fruit within the export chain)

Similar to supply chain Scenario C, the weight loss percentage was similar to that reported by Burger (2004) for cv. 'Packham's Triumph' after shipping to export markets and shelf life. No decay was present during the experiment.

Quality losses along the supply chain

Supply chain Scenario A (marketing at ambient temperatures and relative humidity

Results for firmness over time contrasts with the findings of Dave et al. (2017) reporting on cv. 'Babughosha', after 8 days under ambient conditions, found that firmness became as low as 3.96 N. This indicates that cv 'Packham's Triumph' has a longer shelf life and that posharvest loss quantification should be done for every cultivar separately. Results showing no significant TSS increase differs from previous studies on pears by Elgar et al. (1997) for cv 'Buerre Bose' and 'Doyenne du Cornice' pears and cv. 'Lagoon' by Nath et al. (2012), where a significant increase in TSS during the storage period were found. Dave et al. (2017) also reports an increase in TSS for cv. 'Babughosha', however, the data for the control in that study does not show a significant increase. Similarly, Błaszczyk and Łysiak (2001) also reported no significant increase in TSS for cvs. 'Erica' and 'Dicolor'. Results for TA values differ from those reported by Błaszczyk and Łysiak (2001) of a significant decrease in TA, although that only occurred after 120 and 150 days in cold storage for cvs. 'Erica' and 'Dicolor', respectively. A significant decrease in acidity for cv. 'Babughosha' after 4 and 8 days under ambient conditions were, however, reported by Dave et al. (2017). Results on respiration were similar to Porritt (1964), describing the respiration rate of cv 'Bartlett' at 22°C as decreasing during the first 4 days after harvest and then increasing in a normal climacteric rise. Ethylene production levels took much longer to increase when compared to those reported by Villalobos-Acuña et al. (2011) for cv. 'Bartlett' after 4, 6 and 8 days after harvest stored under ambient conditions.

Supply chain Scenario B (to local retail markets)

The changes in colour correlate with the results published by Antoniolli and Czermainski (2012) for cv. 'Packham's Triumph'. The initial decrease in firmness during two weeks of cold storage corresponds to findings of Antoniolli and Czermainski (2012) reporting on cv. 'Packham's Triumph' but after 5 days at room temperature (24±1°C) in that study, the firmness only decreased to around 60 N, from a starting firmness of 75 N, which is much firmer than reported in this study. The results for TSS values were similar to findings by Kawhena et al. (2018) for cv. 'Packham's Triumph', no significant differences in TSS between harvest and 4 or 8 months of storage were found, although differences were found after 2, 6 and 10 months in that study. The TA, similarly correlates to results of Kawhena et al. (2018) where no significant differences were found during the first season while differences were found in the second season, but only in one treatment of 6 months storage and 7 days shelf life. Calvo and Sozzi (2004) also reported no significant difference in TA levels for cv. ‘Red Clapp’s’ after 15 days at -0.5°C and 7 days at 20°C. Results for respiration rate were similar to findings for cv. ‘Conference’ published by Brandes and Zude-Sasse (2019) reported that the respiration rate increased after removal from storage with a decrease at the end of shelf-life.

Supply chain Scenario C (to export retail markets)

These results are similar to those reported by Antoniolli and Czermainski (2012) for the same cultivar, Packham’s Triumph, grown in Brazil. With regard to firmness, results were similar to those reported by Antoniolli and Czermainski (2012), a 10 N drop in firmness during cold storage of 15 days and a rapid decline in firmness during the simulated shelf life period. Moya-Léon et al. (2006) also reported remarkable decrease in fruit firmness of ‘Packham’s Triumph’ after 5 days under ambient condition subsequent to being stored under regular cold storage (0°C, 90-95% RH), although it is not reported what the firmness was after cold storage but prior to the 5 days shelf life. Findings on TSS and TA were similar to findings by Kawhena et al. (2018) and Moya-Léon et al. (2006) while Antoniolli and Czermainski (2012) reported significant increases in TSS and a decrease in TA during cold storage. Respiration rates confirm reports of Porritt (1964), Streif (1994) and Saquet (2019) stating that lower temperature drastically slows respiration rate. Ethylene production levels were similar to those reported by Brandes and Zude-Sasse (2019), an increase in ethylene production after 4 days shelf life subsequent to cold storage of either 6 or 8 weeks, for cv. ‘Conference’.

Supply chain Scenario D (simulated ‘abusive’ treatment of fruit within the export chain)

The results were similar to those described for supply chain Scenario C, with the main difference being a faster increase in respiration rate and ethylene production.

Socio-economic impacts of postharvest losses

The socio-economic impacts of these losses, from harvest to shelf life, indicate a financial loss of between R492 million to over R831 million annually for the South African pear industry.

Additionally, as much as 301 million MJ of fossil energy and 69 million m^3 of fresh water resources were lost. At the Eskom tariff rate of R0.90 per kWh, the lost energy is worth R75.25 million (Eskom, 2019). The fresh water lost could sustain 3.7 million individuals daily for a whole year at a daily minimum usage rate of 0.05 m^3 per day (Peter and Gleik, 1996), while it will require planting 0.5 million trees to sink the 19 690 tons GHG emissions of the pear losses (0.039 metric ton per urban tree planted) (U.S. DOE, 1998).

6. CONCLUSIONS

The results of this research reveal that postharvest losses of pears, from harvest along the supply chain to retail level and shelf-life (consumer storage), have a serious impact on food security, profitability, and the sustainable management of natural resources. Worldwide interest in the food loss and the waste problem has soared; however, losses that occur on farm level are often overlooked. In this study, the greatest loss measured along the supply chain, 18%, was at harvest. As the majority of losses were due to small size and not any deformity or mechanical damage, industry size standards could be part of the problem. With a shift in perception, smaller fruit could also be sold as fresh fruit and not downgraded for juicing. Smaller fruit are also known to be sweeter and sweeter fruit tends to be more popular. One example is a line of child-sized pears centered on flavour that could transform the way consumers view small pears.

In addition, fruit losses in quantity and quality under ambient conditions (25.1 ± 1.3°C; 46.6 ± 6.0% RH) were much higher than under refrigeration. While the retail sim-ulation in this study was done at 5°C, many retailers exhibit fruit on open shelves where the temperature is much higher, essentially ambient conditions that can reach up to 26.68 ± 0.92°C and 59.79 ± 4.86% RH. This shortens the shelf life significantly and increases the amount of fruit lost due to decay.

Despite the huge lack of data in existing knowledge on global food loss and waste, the largest gap in knowledge presents the lack of available data on postharvest losses, data on food waste at the retail, household levels and shelf life. Therefore, the present study aimed to contribute to the advancement of new knowledge by generating primary data on quantity and postharvest quality losses along the pear supply chain to better manage the food loss and waste problem. However, more studies are needed to gain information and insights on the handling procedures and origin of defects associated with losses for the supply chains of every product.

6. REFERENCES

Akbari, E., Gholami, M. and Ghobadi, C. (2019). Shelf-life and quality attributes in fresh-cut pear cv. Shahmive treated with different kinds of antioxidants. Journal of Food Science and Technology, 56:9, 3998–4008.

Antoniolli, L.R. and Czermainski, A.B.C. (2012). Maturity Index and Cold Storage Effects on Postharvest Quality of ‘Packham’s Triumph’ and ‘Rocha’ Pears. Proc. XXVIIIth IHC – IS on Postharvest Technology in the Global Market, Acta Horticulturae. 934, 856-870.

Belay, Z.A., Caleb, O.J., Mahajan, P.V. and Opara, U.L. (2018). Design of Active Modified Atmosphere and Humidity Packaging (MAHP) for ‘Wonderful’ Pomegranate Arils. Food and Bioprocess Technology, 11, 1478–1494.

Błaszczyk, J. and Łysiak, G. (2001). Storage properties of czech pear cultivars Erica and Dicolor. Journal of Fruit and Ornamental Plant Research, 9:1-4, 71-76.

Brandes, N and Zude-Sasse, M. (2019). Respiratory patterns of European pear (*Pyrus communis* L. ‘Conference’) throughout pre- and postharvest fruit development. Heliyon, 5, e01160. doi: 10.1016/j.heliyon.2019.e01160

Burger, G.E. (2004). Factors affecting shrivelling and friction discolouration of pears (*Pyrus communis* L.), MSc thesis, Department of Horticulture, Faculty of AgriSciences, Stellenbosch University, South Africa.

Calvo, G and Sozzi, G.O. (2004). Improvement of postharvest storage quality of 'Red Clapp's' pears by treatment with 1-methylcyclopropene at low temperature, The Journal of Horticultural Science and Biotechnology, 79:6, 930-934.

Crisosto, C. H., Garner, D., Crisosto, G. M., Sibbett, S. and Day K. R. (1994). Late harvest and delayed cooling induce internal browning of „Ya Li" and „Seuri" Chinese pears. American Society for Horticultural Science, 29:6, 667-670.

DAFF. (2019). A Profile of the South African pear market value chain. https://www.dalrrd.gov.za/doaDev/sideMenu/Marketing/Annual%20Publications/Pear%20Market%20Value%20Chain%20Profile%202019.pdf. Accessed 2 April 2021.

Dave, R.K., Ramana Rao, T.V. and Nandane, A.S. (2017). Improvement of post-harvest quality of pear fruit with optimized composite edible coating formulations. Journal of Food Science and Technology, 54:12, 3917–3927.

Debela, A, Dada, G, Bane, D and Tolessa, K. (2011). Identification of major causes of postharvest losses among selected fruits in Jimma zone for proffering veritable solutions. International Journal of Current Research, 3:11, 40 – 43.

Dhillon, W.S., Mahajan, B.V.C., Gill, P.P.S, Tandon, R and Kumar, M. (2017). Shelf-life extension of pear with coatings under ambient and super market conditions. Indian Journal of Horticulture, 74:3, 429-435.

Dodd, M., Cronje, P., Taylor, M., Huysamer, M., Kruger, F., Lotz, E. and van der Merwe, K. (2010). A review of the post harvest handling of fruits in South Africa over the past twenty five years, South African Journal of Plant and Soil, 27:1, 97-116

Elgar HJ, Watkins CB, Murray SHF, Gunson A (1997) Quality of 'Buerre Bose' and 'Doyenne du Cornice' pears in relation to harvest date and storage period. Postharvest Biol Technol 10:29–37

Eskom. Available online: www.eskom.co.za › TariffsAndCharges › Documents. (accessed on 10 October 2019.)

FAO. (2009). State of food insecurity in the world: economic crises — impacts and lessons learned. Food and Agriculture Organization of the United Nations.

Franke, U., Hartikainen, H, Mogensen, L. and Svanes, E. (2016). Food losses and waste in primary production. Data collection in the Nordic countries, TemaNord, Nordic Council of Ministers. www.norden.org/nordpub

Foley, J., Ramankutty, N., Brauman, K., Cassidy, E.S., Gerber, J.S., Johnston, M., Mueller, N.D., O'Connell, C., Ray, D.K., West, P.C., Balzer, C., Bennett, E.M., Carpenter, S.R., Hill, J., Monfreda, C., Polasky, S., Rockström, J., Sheehan, J., Siebert, S.,Tilman, D. and Zaks, D.P.M. (2011). Solutions for a cultivated planet. Nature 478, 337–342. https://doi.org/10.1038/nature10452

Fonseca, S. C., Oliveira, F.A.R., Brecht, J. K. (2002). Modelling respiration rate of fresh fruits and vegetables for modified atmosphere packages: a review. Journal of Food Engineering 52: 99–119

Gustavsson, J., Cederberg, C., Sonesson, U., van Otterdijk, R., and Meybeck, A. (2011). Global food losses and food waste section 3.2 (Study conducted for the international congress “Save Food!” at Interpack2011, Düsseldorf, Germany), FAO Rural Infrastructure and Agro-Industries Division, 38.

Godfray, H.C.J., Beddington. J.R., Crute, I.R., Haddad, L., Lawrence, Lawrence, D, Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M. and Toulmin, C. (2010). Food Security: The Challenge of Feeding 9 Billion People. Science 327, 812.

Hailu, G. and Derbew, B. (2015). Extent, Causes and Reduction Strategies of Postharvest Losses of Fresh Fruits and Vegetables – A Review. Journal of Biology, Agriculture and Healthcare, 5:5, 49-65.

Janisiewicz, W.J. (1996) Ecological diversity, niche overlap, and coexistence of antagonists used in developing mixtures for biocontrol of post-harvest diseases of apples. Phytopathology 86, 473–479.

Janse van Vuuren, P.F. and Pineo, C. (2015). Analysing the carbon and resource intensity of the Western Cape economy, GreenCape - Regional Resource Flow Model Project 2014/2015 Synthesis Report, Department of Economic Development and Tourism Western Cape Government.
Johnson, L.K., Dunning, R.D., Gunter, C., Bloom, J.D., Gunter, C.C., Boyette, M.D. and Creamer. N.G (2018). Estimating on-farm food loss at the farm-level: A methodology and applied case study on a North Carolina farm. Resources, Conservation & Recycling, 137, 243-250.

Kantor, L.S., Lipton, K., Manchester, A. and Oliveira, V. (1997). Estimating and Addressing America's Food Losses. Food Review/ National Food Review, United States Department of Agriculture, Economic Research Service, 20:1, 1-11.

Kappel, F, Fisher-Fleming, R. and Hogue, E.J. (1995). Ideal pear sensory attributes and fruit characteristics. HortScience 30(5): 988-993.

Kawhena, T.G., Opara, U.L., Botes, W.J. and Fawole, O.A. (2018). Effect of repeated low oxygen stress (RLOS) on physiological disorders, physico-chemical properties and sensory parameters of 'Packham's Triumph' pears. Acta Horticulturae, 1201, 65 – 74.

Kheiralipour K., Tabatabaeefar A., Mobli H., Rafiee S., Sahraroo A., Rajabipour A., Jafari A., (2008). Some physical properties of apple. Pak. J. Nutr. 7(5): 667-672.

Kitinoja, L. and Al Hassan, H.Y. (2012). Identification of appropriate postharvest technologies for small scale horticultural farmers and marketers in Sub-Saharan Africa and South Asia – Part 1. Postharvest losses and quality assessments. Acta Horticulturae, 934, 31-40.

Kummu, M., de Moel, H., Porkka, M., Siebert, S., Varis, O., Ward, P.J. (2012). Lost food, wasted resources: Global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use. Science of the total environment, 438, 477-489.

Little, C. and Holmes, R. (2000) Storage technology for apples and pears: a guide to production, postharvest treatment and storage of pome fruit in Australia Dept. of Natural Resources and Environment, Victoria.

Lundqvist, J., de Fraiture, C. and Molden, D. (2008). Saving water: from field to fork — curbing losses and wastage in the food chain SIWI Policy Brief, Stockholm International Water Institute (SIWI) (2008), p. 36. http://hdl.handle.net/10535/5088. Accessed 11 May 2021.

Łysiak, G. (2014). Measurement of ethylene production as a method for determining the optimum harvest date of 'Jonagored' apples. Folia Horticulturae, 26:2, 117-124.

Mangaraj, S., Sadawarti, M.J. and Prasad, S. (2011) Assessment of quality of pears stored in laminated modified atmosphere packages, International Journal of Food Properties, 14:5, 1110-1123

Mari, M., Bertolini, P. and Pratella, G.C. (2002). A REVIEW: Non-conventional methods for the control of post-harvestpear diseases. Journal of Applied Microbiology 2003, 94, 761–766.

Matare, T.E. (2012). Postharvest losses and changes in physico-chemical properties of fruit (peaches, pears and oranges) at retail and during post-purchase storage master's thesis Stellenbosch University, Stellenbosch, South Africa.

Mditshwa, A., Fawole, O. A., Vries, F., Van Der Merwe, K., Crouch, E. and Opara, U.L. (2016). Classification of 'Granny Smith' apples with different levels of superficial scald severity based on targeted metabolites and discriminant analysis, Journal of Applied Botany and Food Quality, 89, 49 – 55.

Mekonnen, M.M. and Hoekstra, A.Y. (2010). The green, blue and grey water footprint of crops and derived crop products. Value of Water Research Report Series No. 47, UNESCO-IHE, Delft, the Netherlands.

Moya-Léon, M.A., Vergara, M., Bravo, C., Montes, M.E. and Moggia, C. (2006). 1-MCP treatment preserves aroma quality of 'Packham's Triumph' pears during long-term storage. Postharvest Biology and Technology, 42:185-197.

Mrema, G.C. and Rolle, R.S. (2002). Status of the postharvest sector and its contribution to agricultural development and economic growth. Proc. 9th JIRCAS Intl. Symp. 2002. Value-addition to agricultural products, Ibaraki, Japan.

Munhuweyi, K., Opara, U.L., Sigge, G. (2016). Postharvest losses of cabbages from retail to consumer and the socio-economic and environmental impacts. British Food Journal, 118, 286–300.

Nath, A, Deka, B.C., Singh, A, Patel, R.K., Paul, D. Misra, L.K. and Ojha, H. (2012). Extension of shelf life of pear fruits using different packaging materials. Journal of Food Science and Technology, 49:5, 556-563.

Nelson, G.C., Rosegrant, M.W., Palazzo, A., Gray, I., Ingersoll, C., Robertson, R., Tokgoz, S., Zhu, T., Sulser, T.B., Ringler, C., Msangi, S. and You, L. (2010). Food security, farming, and climate change to 2050: scenarios, results, policy options. International Food Policy Research Institute (IFPRI), Washington DC.

Nótári, M. and Ferencz, A. (2014). The Harvest and Post-Harvest of Traditional Pear Varieties in Hungary. Asia-Pacific Chemical, Biological & Environmental Engineering Society, APCBEE, Procedia 8, 305 – 309

Oz, A.T. (2011). Combined effects of 1-methyl cyclopropene (1-MCP) and modified atmosphere packaging (MAP) on different ripening stages of persimmon fruit during storage. African Journal of Biotechnology, 10, 807-814

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

Pathare, P.B., Opara, U.L., Al-Said Al-Julanda, F. (2013). Colour Measurement and Analysis in Fresh and Processed Foods: A Review. Food and Bioprocess Technology, 6, 36–60.

Pelletier, N. and Tyedmers, P. (2010). Forecasting potential global environmental costs of livestock production 2000–2050. Proceedings of the National Academy of Sciences, 107, 18371–4.

Peter, H. and Gleik, M. (1996). Basic Water Requirements for Human Activities: Meeting Basic Needs. Water International, 21, 83-92.

Porritt, S.W. (1964). The effect of temperature on postharvest physiology and storage life of pears. Canadian Journal of Plant Science, 44:6, 568-579.

Quaggio, J.A., Jr. Mattos, D., Cantarella, H. (2006). Fruit yield and quality of sweet oranges affected by nitrogen, phosphorus and potassium fertilization in tropical soils. Fruits, 61:5, 293-301.

Saquet, A.A. (2019). Storage of pears. Scientia Horticulturae, 246, 1009–1016.

Schmidhuber, J. and . Tubiello, F. N. (2007). Global food security under climate change Proceedings of the National Academy of Sciences,104:50, 19703-19708.

Slaughter, D.C., Thompson, J.F. and Hinsch, R.T. (1998). Packaging Bartlett pears in polyethylene film bags to reduce vibration injury in transit. Transactions of the American Society of Agricultural and Biological Engineers, 41:1,107-114.

Streif, J. (1994). Respiration of apple fruits under different storage conditions. Proceedingsof the Sixth International Symposium of the European Concerted Action Program COST 94, 133–136.

Sugar, D. and Einhorn, T. C. (2011). Conditioning temperature and harvest maturity influence induction of ripening capacity in ‘d’Anjou’ pear fruit. Postharvest Biology and Technology, 60:2, 121-124.

Tabatabaie, S.M.H., Rafiee, S., Keyhani, A. and Heidari, M.D. (2013). Energy use pattern and sensitivity analysis of energy inputs and input costs for pear production in Iran. Renewable Energy, 51, 7-12.

Tilman, D., Fargione, J., Wolff, B., D'Antonio, C., Dobson, A., Howarth, R., Schindler, D., Schlesinger, W.H., Simberloff, D., Swackhamer, D. (2001). Forecasting agriculturally driven global environmental change. Science, 292, 281-284.

Tilman, D., Balzer, C., Hill, J. and Befort B.L. (2011). Global food demand and the sustainable intensification of agriculture. Proceedings of the National Academy of Science, 108, 20260-20264.

U.S. DOE (1998). Method for Calculating Carbon Sequestration by Trees in Urban and Suburban Settings. Voluntary Reporting of Greenhouse Gases, U.S. Department of Energy, Energy Information Administration in: Environmental Protection Agency (EPA), (2012). Clean energy. [WWW document] URL http://www.epa.gov/cleanenergy/energy-resources/refs.html

Villalobos-Acuña,M.G., Biasi, W.V., Floresa, S., Jiang, C-Z., Reida, M.S., Willits, N.H. and Mitchama, E.J. (2011). Effect of maturity and cold storage on ethylene biosynthesis and ripening in 'Bartlett' pears treated after harvest with 1-MCP. Postharvest Biology and Technology, 59, 1-9.

WRAP (2019). Banbury, Food waste in primary production in the UK, Prepared by Bojana Bajzelj, William McManus and Andrew Parry.

Xiao, C. L., and Boal, R. J. (2004). Prevalence and incidence of Phacidiopycnis rot in d'Anjou pears in Washington State, Plant Disease, 88:413-418.

Zucoloto, M, Antoliolli, L.R., Siqueira, D.L., Czermainski, A.B.C. and Salomão, L.C.C. (2016). Conditioning temperature for inducing uniform ripening of 'Abate Fetel' pears. Revista Ciência Agronômica, v. 47, n. 2, p. 344-350.

7. TABLES

Table 1. Description of the supply chain scenarios studied

Supply chain Scenario	Description	Environmental condition
A	Pears were harvested and stored under ambient conditions, typical in areas that lack cold storage facilities	25.1 ± 1.3 °C 46.6 ± 6.0% RH
B	Handling of pears for domestic supply chain	Cold store for 2 weeks: -0.3°C ± 0.7°C and 81.3% ± 4.1% RH Retail store for 10 days: 5.4°C ± 0.6°C and 83.7% ± 2.9% RH Consumer/home (ambient) store: 25.1 ± 1.3°C and 46.6 ± 6.0%RH
C	Shipping to export markets	Cold storage for 4 weeks at -0.3 ± 0.7°C, 81.3 ± 4.1% RH Retail store for 10 days: 5.4°C ± 0.6°C and 83.7% ± 2.9% RH Consumer/home (ambient) 'shelf' store: 25.1 ± 1.3°C and 46.6 ± 6.0%RH
D	Reefer container containing export fruit are left open on arrival for two days before fruit is unloaded. 'Abusive' treatment of fruit within the export chain.	Cold store for 2 weeks: -0.3°C ± 0.7°C and 81.3% ± 4.1% RH; Ambient storage for 2 days: 25.1 ± 1.3°C, 46.6 ± 6.0% RH Retail store display for 10 days: 5.4°C ± 0.6°C and 83.7% ± 2.9% RH; Consumer/home (ambient) 'shelf' store: 25.1 ± 1.3°C and 46.6 ± 6.0%RH

Table 2. Physical losses of 'Packham's Triumph' table pears measured as weight loss (%) and decayed (%) after 3, 7 and 10 days at ambient conditions (25.1 ± 1.3°C and 46.6 ± 6.0%RH). Mean values with different letter(s) in the same column indicate statistically significant differences (P<0.05).

Time	Weight Loss (%)	Decay (%)
Harvest	-	0^{a}
3 Days	0.90^{a}	0^{a}
7 Days	1.55^{a}	3.3^{b}
10 Days	2.25^{a}	6.6^{c}
P-Value	0.42	<0.01

Note: Mean values within the same column with different letters are significantly (P< 0.05) different by Duncan's Multiple Range test (DMRT).

Table 3. Physical losses of 'Packham's Triumph' table pears measured as weight loss (%) after 14 days cold storage (-0.3 ± 0.7°C, 81.3 ± 4.1% RH), after another 10 days at retail conditions (5.4 ± 0.6°C, 83.7 ± 2.9% RH) and then 3, 7 and 10 days at ambient conditions (25.1 ± 1.3°C and 46.6 ± 6.0% RH). Mean values with different letter(s) in the same column indicate statistically significant differences (P<0.05).

Time	Weight Loss (%)
Harvest	-
14Days (-0.5°C)	0.86^{a}
10Days (5°C)	1.52^{a}
3Days	1.86^{a}
7Days	3.32^{a}
10Days	3.90^{a}
P-Value	0.97

Note: Mean values within the same column with different letters are significantly (P< 0.05) different by Duncan's Multiple Range test (DMRT).

Table 4. Physical losses of 'Packham's Triumph' pears measured as weight loss (%) after 28 days cold storage (-0.3 ± 0.7°C, 81.3 ± 4.1% RH), after another 10 days at retail conditions (5.4 ± 0.6°C, 83.7 ± 2.9% RH) and then 3, 7 and 10 days at ambient conditions (25.1 ± 1.3°C and 46.6 ± 6.0% RH). Mean values with different letter(s) in the same column indicate statistically significant differences (P< 0.05).

Time	Weight (%)
Harvest	-
28 Days (-0.5°C)	1.49 [a]
10 Days (5°C)	1.77 [a]
3 Days	2.24 [a]
7 Days	2.97 [a]
10 Days	3.60 [a]
P-Value	0.93

Note: Mean values within the same column with different letters are significantly (P< 0.05) different by Duncan's Multiple Range test (DMRT).

Table 5. Physical losses of 'Packham's Triumph' table pears measured as weight loss (%) after 28 days cold storage (-0.3 ± 0.7°C, 81.3 ± 4.1% RH), 2 days 'abusive' temperature and humidity (25.1 ± 1.3°C and 46.6 ± 6.0% RH) after another 10 days at retail conditions (5.4 ± 0.6°C, 83.7 ± 2.9% RH) and then 3, 7 and 10 days at ambient conditions (25.1 ± 1.3°C and 46.6 ± 6.0% RH). Mean values with different letter(s) in the same column indicate statistically significant differences (P< 0.05).

Time	Weight Loss (%)
Harvest	-
28 Days (-0.5°C)	0.98 [a]
2 Days (ambient)	1.36 [a]
10 Days (5°C)	2.09 [a]
3 Days	2.91 [a]
7 Days	3.26 [a]
10 Days	3.71 [a]
P-Value	0.94

Note: Mean values within the same column with different letters are significantly (P< 0.05) different by Duncan's Multiple Range test (DMRT).

Table 6. Supply chain Scenario A: Changes in quality attributes of colour (L*, a* and b*), Firmness (N), TSS (°Brix), TA (%), respiration rate (CO_2mL.kg.h) and ethylene production (C_2H_4uL.kg·h) of 'Packham's Triumph' pears at harvest and after 3, 7 and 10 days at ambient conditions (25.1 ± 1.3°C and 46.6 ± 6.0% RH). Mean values with different letter(s) in the same column indicate statistically significant differences (P<0.05).

Season				2018				
Time	L*	a*	b*	Firmness (N)	TSS (°Brix)	TA (%)	Respiration rate (CO_2mL.kg.h)	Ethylene (C_2H_4uL.kg.h)
Harvest	64.18 ab	-15.91 a	40.59 a	89.83 a	10.99 a	0.29 a	12.91 ab	2.06 a
3 Days	63.24 b	-15.36 a	41.48 ab	77.28 b	11.53 a	0.30 a	11.88 ab	4.48 a
7 Days	63.81 b	-15.04 ab	41.77 b	76.59 b	11.24 a	0.52 a	9.78 a	4.93 a
10 Days	63.60 b	-14.85 ab	42.02 b	71.29 b	11.65 a	0.44 a	10.54 ab	8.57 a
14 Days	64.19 ab	-13.65 bc	43.51 c	56.39 c	12.43 a	0.26 a	12.57 ab	30.09 ab
17 Days	65.62 bc	-12.54 cd	45.49 d	22.16 d	13.80 a	0.52 a	17.46 b	66.93 b
20 Days	67.16 c	-11.07 d	47.89 e	4.71 e	13.06 a	0.39 a	15.47 ab	130.46 c
P-Value	<0.01	<0.01	<0.01	<0.01	0.45	0.15	0.02	<0.01

Note: Mean values within the same column with different letters are significantly (P< 0.05) different by Duncan's Multiple Range test (DMRT).

Table 7. Supply chain Scenario B: Changes in quality attributes of colour (L*, a* and b*), Firmness (N), TSS (°Brix), TA (%), respiration rate (CO_2mL.kg.h) and ethylene production (C_2H_4uL.kg·h) of 'Packham's Triumph' pears at harvest, after 14 days cold storage (-0.3 ± 0.7°C, 81.3 ± 4.1% RH), after another 10 days at retail conditions (5.4 ± 0.6°C, 83.7 ± 2.9% RH) and then 3, 7 and 10 days at ambient conditions (25.1 ± 1.3°C and 46.6 ± 6.0% RH). Mean values with different letter(s) in the same column indicate statistically significant differences (P< 0.05).

2018								
Time	L*	a*	b*	Firmness (N)	TSS (°Brix)	TA (%)	Respiration (CO_2mL.kg.h)	Ethylene (C_2H_4uL.kg.h)
Harvest	63.62 ^{a}	-14.66 ^{bc}	38.53 ^{e}	89.83 ^{a}	10.99 ^{a}	0.29 ^{a}	12.91 ^{bc}	2.06 ^{c}
14 Days (-0.5°C)	63.02 ^{a}	-14.81 ^{bc}	44.32 ^{c}	79.83 ^{b}	12.44 ^{a}	0.34 ^{a}	2.86 ^{c}	1.36 ^{c}
10 Days (5°C)	64.35 ^{a}	-16.35 ^{c}	44.56 ^{bc}	79.53 ^{b}	13.15 ^{a}	0.29 ^{a}	6.72 ^{c}	3.77 ^{c}
3 Days	66.54 ^{a}	-14.97 ^{bc}	41.57 ^{d}	37.66 ^{c}	12.13 ^{a}	0.30 ^{a}	22.22 ^{ab}	42.82 ^{c}
7 Days	63.62 ^{a}	-13.70 ^{b}	46.56 ^{ab}	20.10 ^{d}	12.63 ^{a}	0.30 ^{a}	25.26 ^{a}	122.23 ^{b}
10 Days	64.72 ^{a}	-11.47 ^{a}	47.48 ^{a}	10.20 ^{e}	13.10 ^{a}	0.29 ^{a}	19.19 ^{ab}	197.34 ^{a}
P-Value	0.25	<0.01	<0.01	<0.01	0.38	0.80	<0.01	<0.01

Note: Mean values within the same column with different letters are significantly (P< 0.05) different by Duncan's Multiple Range test (DMRT).

Table 8. Supply chain Scenario C: Changes in quality attributes of colour (L*, a* and b*), Firmness (N), TSS (°Brix), TA (%), respiration rate (CO_2mL.kg.h) and ethylene production (C_2H_4uL.kg·h) of 'Packham's Triumph' pears at harvest, after 28 days cold storage (-0.3 ± 0.7°C, 81.3 ± 4.1% RH), after another 10 days at retail conditions (5.4 ± 0.6°C, 83.7 ± 2.9% RH) and then 3, 7 and 10 days at ambient conditions (25.1 ± 1.3°C and 46.6 ± 6.0%RH). Mean values with different letter(s) in the same column indicate statistically significant differences (P< 0.05).

2018								
Time	L*	a*	b*	Firmness (N)	TSS (°Brix)	TA (%)	Respiration (CO_2mL.kg.h)	Ethylene (C_2H_4uL.kg.h)
Harvest	64.33 ^{a}	-15.01 ^{c}	37.78 ^{d}	89.83 ^{a}	10.99 ^{a}	0.29 ^{a}	12.91 ^{bc}	2.06 ^{c}
28 Days (-0.5°C)	62.47 ^{b}	-14.81 ^{c}	43.03 ^{bc}	78.65 ^{b}	13.05 ^{a}	0.49 ^{a}	0.00 ^{d}	4.84 ^{c}
10 Days (5°C)	63.55 ^{ab}	-14.90 ^{c}	42.75 ^{c}	78.26 ^{b}	13.35 ^{a}	0.51 ^{a}	7.40 ^{cd}	14.75 ^{bc}
3 Days	62.59 ^{b}	-13.54 ^{bc}	42.86 ^{c}	23.93 ^{c}	13.05 ^{a}	0.31 ^{a}	18.63 ^{ab}	62.96 ^{b}
7 Days	63.37 ^{ab}	-12.22 ^{ab}	44.35 ^{b}	12.06 ^{cd}	12.18 ^{a}	0.26 ^{a}	22.36 ^{a}	226.84 ^{a}
10 Days	64.64 ^{a}	-10.79 ^{a}	45.80 ^{a}	9.41 ^{d}	13.36 ^{a}	0.25 ^{a}	18.81 ^{ab}	273.43 ^{a}
P-Value	0.02	<0.01	<0.01	<0.01	0.12	0.20	<0.01	<0.01

Note: Mean values within the same column with different letters are significantly (P< 0.05) different by Duncan's Multiple Range test (DMRT).

Table 9. Supply chain Scenario D: Changes in quality attributes of colour (L*, a* and b*), Firmness (N), TSS (°Brix), TA (%), respiration rate (CO_2mL.kg.h) and ethylene production (C_2H_4uL.kg·h) of 'Packham's Triumph' pears at harvest, after 28 days cold storage (-0.3 ± 0.7°C, 81.3 ± 4.1% RH), after 2 days 'abusive' temperature and humidity (25.1 ± 1.3°C and 46.6 ± 6.0% RH), after another 10 days at retail conditions (5.4 ± 0.6°C, 83.7 ± 2.9% RH) and then 3, 7 and 10 days at ambient conditions (25.1 ± 1.3°C and 46.6 ± 6.0%RH). Mean values with different letter(s) in the same column indicate statistically significant differences (P< 0.05).

				2018				
Time	L*	a*	b*	Firmness (N)	TSS (°Brix)	TA (%)	Respiration (CO_2mL.kg.h)	Ethylene (C_2H_4uL.kg.h)
Harvest	64.76 ^{abc}	-14.75 ^{de}	38.40 ^{c}	89.83 ^{a}	10.99 ^{a}	0.29 ^{a}	12.91 ^{bc}	2.06 ^{c}
28 Days (-0.5°C)	62.71 ^{c}	-15.08 ^{e}	43.65 ^{ab}	82.67 ^{b}	12.89 ^{a}	0.39 ^{a}	0.00 ^{d}	5.43 ^{c}
2 Days (ambient)	63.65 ^{bc}	-14.68 ^{de}	41.96 ^{b}	81.49 ^{b}	12.82 ^{a}	0.37 ^{a}	14.72 ^{abc}	9.34 ^{c}
10 Days (5°C)	63.73 ^{abc}	-13.56 ^{cd}	44.33 ^{ab}	62.47^{c}	13.45 ^{a}	0.29 ^{a}	8.36 ^{c}	16.80 ^{c}
3 Days	61.43 ^{c}	-12.46 ^{bc}	42.40 ^{b}	19.12 ^{d}	12.82 ^{a}	0.26 ^{a}	21.01 ^{a}	163.92 ^{b}
7 Days	66.84 ^{ab}	-11.10 ^{ab}	45.53 ^{a}	9.71 ^{d}	12.72 ^{a}	0.26 ^{a}	17.26 ^{ab}	258.77 ^{ab}
10 Days	67.78 ^{a}	-10.07 ^{a}	46.17 ^{a}	9.51 ^{d}	13.25 ^{a}	0.23 ^{a}	14.83 ^{ab}	292.32 ^{a}
P-Value	0.019	<0.01	<0.01	<0.01	0.45	0.51	<0.01	<0.01

Note: Mean values within the same column with different letters are significantly (P< 0.05) different by Duncan's Multiple Range test (DMRT).

Table 10. Impact of postharvest losses in terms of magnitude, monetary value, energy used, water footprint and greenhouse gas emissions in the production and distribution of pears along different supply chains.

a,b,c Values in a column without a common superscript are significantly different ($P<0.05$). *Estimated values obtained using the volume of pears sold locally, 49 926 t and exported, 212 149 t (DAFF, 2019).

		Storage Condition		Estimated physical and economic losses		*Estimated environmental and resource impacts		
Year	Supply Chain Scenario	Time	Temp (°C) and Humidity (%)	Physical (ton)	Value (ZAR)	Energy (MJ)	Waterfootprint (m^3)	Emissions CO_2eq (ton)
2018	Harvest			73 196	429 733 716 (local market) 831 945 736 (export)	271 044 788	67 340 320	18 299
2018	A	3 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	659 [a]	3 868 989 [a]	2 440 277 [a]	606 280 [a]	165 [a]
2018	A	7 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	2 415 [b]	14 178 465 [b]	8 942 745 [b]	2 221 800 [b]	604 [b]
2018	A	10 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	6 441 [c]	37 815 111 [c]	23 851 023 [c]	5 925 720 [c]	1610 [c]
2018	B	14 Days	-0.3 ± 0.7°C; 81.3 ± 4.1%RH	585 [a]	3 434 535 [a]	2 166 255 [a]	538 200 [a]	146 [a]
2018	B	10 Days	5.4 ± 0.6°C; 83.7 ± 2.9%RH	1 098 [a]	6 446 358 [a]	4 076 874 [a]	1 010 160 [a]	275 [a]
2018	B	3 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	1 391 [b]	8 166 561 [b]	5 150 873 [b]	1 279 720 [b]	348 [b]
2018	B	7 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	2 415 [b]	14 178 465 [b]	8 942 745 [b]	2 221 800 [b]	604 [b]
2018	B	10 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	2 855 [c]	16 761 705 [c]	10 572 065 [c]	2 626 600 [c]	714 [c]

2018	C	28 Days	-0.3 ± 0.7°C; 81.3 ± 4.1%RH	1 098 [a]	12 479 868 [a]	4 065 894 [a]	1 010 160 [a]	275 [a]
2018	C	10 Days	5.4 ± 0.6°C; 83.7 ± 2.9%RH	1 244 [a]	14 139 304 [a]	4 606 532 [a]	1 144 480 [a]	311 [a]
2018	C	3 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	1 610 [b]	18 299 260 [b]	5 961 830 [b]	1 481 200 [b]	403 [b]
2018	C	7 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	2 196 [b]	24 959 736 [b]	8 131 788 [b]	2 020 320 [b]	549 [b]
2018	C	10 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	2 635 [c]	29 949 410 [c]	9 757 405 [c]	2 424 200 [c]	659 [c]
2018	D	28 Days	-0.3 ± 0.7°C; 81.3 ± 4.1%RH	732 [a]	8 319 912 [a]	2 710 596 [a]	673 440 [a]	183 [a]
2018	D	2 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	1 025 [a]	11 650 150 [a]	3 795 575 [a]	943 000 [a]	256 [a]
2018	D	10 Days	5.4 ± 0.6°C; 83.7 ± 2.9%RH	1 464 [a]	16 639 824 [a]	5 421 192 [a]	1 346 880 [a]	366 [a]
2018	D	3 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	2 123 [b]	24 130 018 [b]	7 861 469 [b]	1 953 160 [b]	531 [b]
2018	D	7 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	2 415 [b]	27 448 890 [b]	89 42 745 [b]	2 221 800 [b]	604 [b]
2018	D	10 Days	25.1 ± 1.3°C; 46.6 ± 6.0%RH	2 708 [c]	30 779 128 [c]	10 027 724 [c]	2 491 360 [c]	677 [c]

a,b,c Values in a column without a common superscript are significantly different ($P<0.05$).
*Estimated values obtained using the volume of pears sold locally, 49 926 t and exported, 212 149 t. (DAFF, 2019)

Chapter 6

GENERAL DISCUSSION AND CONCLUSIONS

High levels of postharvest loss are a major challenge to food security. Furthermore, postharvest losses mean that huge amounts of the resources used in food production are squandered (Smil, 2004; Parfitt et al., 2010; FLW Protocol, 2016; Porat et al., 2018). Minimising the loss of fresh fruit will, therefore, not only increase the food supply without any new inputs, but will also reduce the use of land, chemicals, energy and other inputs needed to produce horticultural crops, thereby conserving natural resources and protecting the environment (Kader, 2005; Munhuweyi et al., 2016). From an economic point of view, addressing postharvest losses are not only helpful to producers aiming to sell more, but also to consumers who could save money as the available food becomes more affordable (Rutten, 2013).

Quantifying postharvest loss, and identifying the causes, is a crucial first step without which it is impossible to monitor the results of mitigating actions or policy changes. It is essential in order to determine how to control and reduce losses over time and space (Kafa and Jaegler, 2021). Porat et al. (2018) highlighted the lack of postharvest research that addresses the interconnected networks of supply chains "from farm to fork". Stating that most postharvest research does not take into account the intricate interactions and connections between postharvest biology and the impact of logistics and supply-chain management systems.

To date, there is a dearth of information on the incidence and magnitude of postharvest losses of fruit and other food crops in South Africa. Before this study, there was no primary research data on the magnitude of losses in the fresh fruit value chain in South Africa. The main aim of this study, therefore, was to fill a part of the information void surrounding this important but not widely researched problem.

As a case study, the first research chapter investigated production level losses of apples, pears and grapes using data received from eight farms in the Western Cape, South Africa. It could clearly be seen that the more delicate a fruit is, the higher the losses at farm level will be as apples and pears had mean production level losses of around 1% while grapes had mean losses of around 13.5%. It was also found that the amount of missing fruit, fruit that were tipped in the packhouse but consequently disappeared, were almost double, in the case of apples and pears, than the amount of fruit lost due to damage or decay, while an additional 3-5% of grapes were lost in this way. Incomplete or obviously incorrect record keeping makes it difficult to have confidence in the data and is also an important area for improvement, that will allow farms to better manage postharvest losses.

In the second research chapter, losses in quantity and quality of table grapes (cv. Crimson Seedless) along the supply chain were measured and the associated economic, environmental and resource impacts reported. The results indicated that, similar to research done in Iran by Rajabi et al. (2015), the highest incidence of losses occur postharvest in the farm packhouse. It is therefore important to include this stage when studies are conducted on the quantification of postharvest losses. As the main reason for losses at this stage was mechanical damage due to the rough handling of bunches and crates causing berries to drop off the bunches as well as the crushing of berries due to loading too many bunches in crates, these losses could be improved by making workers more aware of the necessity to handle crates with care. The harvest timing is also essential, as delayed harvesting reduces shelf life and results in an increased postharvest loss.

The main quality problem, among all supply chain scenarios, was rachis and stem browning at temperatures higher than -0.5 ºC. This caused berries to drop faster and bunches to look less fresh, as well as causing bunches to weigh less when sold. While 500 g or 1 kg punnets are routinely kept at around 5 ºC at the retail level, during peak season 4.5–10 kg cartons are often stacked on the floor under ambient conditions. Therefore, the table grapes would have a maximum shelf-life of 7 days before the stems have browned, and too many berries per bunch are decayed to sell. It would be advisable to keep cartons at -0.5 ºC and high RH and only place bunches in punnets in 5 º C display fridges as the stock sells. The increase in weight loss and especially stem browning recorded in Scenario D (‘abusive’ treatment of fruit within the export chain), compared to Scenario C (shipping to export markets under ideal conditions) indicated the importance of eliminating the delay between reefer delivery and quality checking as a break in the cold chain of 2 days has a significant impact on the quality of the bunches and therefore also the price it can be sold at. This study was conducted on farms with good infrastructure, cultivation practices and cooling facilities, where nonetheless, farm-level losses of up to 23% were recorded. It is significant that during preseason interviews with farm management, the highest estimate of losses was 13%, most of them lower. As ‘Crimson Seedless’ is a high value crop, even relatively small improvements in future could have a large financial impact for producer-exporters.

The third research chapter measured losses in quantity and quality of pear (cv. Packham’s Triumph) along the supply chain and the associated economic, environmental and resource impacts. The measured loss of pears at harvest for individual farms were 18% and 19% respectively. The average loss at harvest on farm level was 18%. This is almost double the amount of 10% reported by Franke et al. (2016) as were measured in a study on food loss in primary production of the Nordic countries of Denmark, Finland, Sweden and Norway. As well as findings by Nótári and Ferencz (2014) who measured losses of 8% for Packham’s Triumph pears in Hungary. The United Kingdom’s Waste and Resources Action Programme (WRAP) (2019) reported losses of pears as 5%, however, no primary data for pears was collected in that study and their estimates were based on ‘WRAP expert judgement’. While Mangaraj et al. (2011) reported that postharvest losses of pears in India were in the range of 20–30%, this was due to inadequate facilities and improper techniques of handling, packaging, and storage. Of the 18% lost at harvest, the main reasons were due to deformed fruit (50%), too small size (48%) and chafed peel (2%) on the first farm while on the other farm the main reasons were the same, but the proportions differed, with the majority of the losses due to too small size (80%), chafed peel (18%) and deformed (2%). The average for both farms together were small size (65%), deformity (26%), and chafed peel (9%).

The socio-economic impacts of the postharvest losses of grapes indicate a financial loss of over R 204 million annually. Additionally, as much as 177.43 million MJ of fossil energy and 4.8 million m^3 of freshwater resources were lost. At the Eskom tariff rate of R0.90 per kWh, the lost energy is worth R44.36 million (Eskom 2019). The fresh water lost could sustain at least 263 013 individuals daily for a whole year at daily minimum usage rate of 0.05 m^3 per day. Losses also contribute to unwanted emission of approximately 52 263 tons of CO_2eq, contributing to environmental degradation from greenhouse gases. To sink these volumes of CO_2 would require planting 1.3 million trees (at 0.039 t CO_2 per urban tree planted) (U.S. DOE, 1998). The postharvest losses measured for pears translated to an estimated financial loss of up to R 831 million annually. In addition, 271.04 million MJ of energy and 67.3 million m^3 of water are embedded in the lost fruit, and about 18 300 tons of CO_2eq released into the atmosphere.

This study reveals the importance of quantifying postharvest losses along the supply chain and the necessity of measuring these losses from the site of production as losses that occur on farm level are often overlooked (Johnson et al., 2018). It highlights the necessity of measuring losses along the supply chain for different fruit as losses occur at different stages in the supply chain and for different reasons depending on whether the fruit is climacteric or non-climacteric, harvested ripe or less mature. It can further be seen that postharvest losses not only remove food from the supply chain, but also represents a waste of water and energy resources that severely impact efforts to protect the environment. Further studies need to be done to measure losses in quantity and quality for all products in the South African fresh value chain, so that a holistic image can be formed of how much fresh produce go to waste and create awareness around the urgent need to mitigate these losses.

REFERENCES

Eskom. (2019). Available online: www.eskom.co.za › TariffsAndCharges › Documents. (accessed on 10 October 2019.)

FLW Protocol (Food Loss and Waste Protocol). (2016). The Food Loss and Waste Accounting and Reporting Standard; World Resources Institute: Washington, DC, USA.

Franke, U., Hartikainen, H, Mogensen, L. and Svanes, E. (2016). Food losses and waste in primary production. Data collection in the Nordic countries, TemaNord, Nordic Council of Ministers. www.norden.org/nordpub

Johnson, L.K., Dunning, R.D., Gunter, C., Bloom, J.D., Gunter, C.C., Boyette, M.D. and Creamer. N.G (2018). Estimating on-farm food loss at the farm-level: A methodology and applied case study on a North Carolina farm. Resources, Conservation & Recycling, 137, 243-250.

Kader, A.A. (2005). Increasing availability by reducing post-harvest losses of fresh produce. Acta Horticulturae, 682, 2169-2175.

Kafa, N. and Jaegler, A. (2021). Food losses and waste quantification in supply chains: a systematic literature review. British Food Journal, Vol. ahead-of-print No. ahead-of-print. https://doi.org/10.1108/BFJ-09-2020-0879

Mangaraj, S., Sadawarti, M.J. and Prasad, S. (2011) Assessment of Quality of Pears Stored in Laminated Modified Atmosphere Packages, International Journal of Food Properties, 14:5, 1110-1123

Nótári, M. and Ferencz, A. (2014). The Harvest and Post-Harvest of Traditional Pear Varieties in Hungary. Asia-Pacific Chemical, Biological & Environmental Engineering Society, APCBEE, Procedia 8, 305 – 309

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

Porat, R., Lichter, A, Terry, L.A., Harker, R. and Buzby, J. (2018). Postharvest losses of fruit and vegetables during retail and in consumers' homes: Quantifications, causes, and means of prevention, Postharvest Biology and Technology, 139, 135-149.

Rajabi, S., Lashgarara, F., Omidi, M. and Hosseini, S.J.F. (2015). Quantifying the grapes losses and waste in various stages of supply chain. Biological Forum, 7, 225–229.

Smil, V. (2004). Improving Efficiency and Reducing Waste in Our Food System. Environmental Sciences, 1, 17–26.

U.S. DOE (1998). Method for calculating carbon sequestration by trees in urban and suburban settings. Voluntary Reporting of Green house Gases, U.S. Department of Energy, and Information Administration. In: Environmental Protection Agency (EPA), (2012).

WRAP (2019). Banbury, Food waste in primary production in the UK, Prepared by Bojana Bajzelj, William McManus and Andrew Parry.