Understanding the influence of context characteristics, logistics control and quality control on postharvest losses

A case study of Zimbabwean tomato supply chains

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Thesis

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Chapter 1

General introduction

1.1 Background

Approximately 1.3 billion tonnes of fresh food crops produced in the world for human consumption, amounting to roughly US$ 680 billion in developed countries and US$ 310 billion in developing countries, is lost after harvest every year (Gustavsson *et al.*, 2011). Agriculture, especially the production of fruit and vegetables, is the mainstay of the economy for most Sub-Saharan African countries. Production of fruit and vegetables in Sub-Saharan Africa as of 2014, is approximated at 34.22 and 31.95 million tonnes, respectively (FAOSTAT, 2016). However, fresh produce chains are characterised by high postharvest losses (PHL), which can occur at all stages and processes between harvesting and consumption (James & Zikankuba, 2017). PHL in fresh produce chains in Sub-Saharan Africa ranges from 30 to 50% (Kitinoja *et al.*, 2011; Affognon *et al.*, 2015). The high PHL are a major obstacle in achieving sustainable fresh produce chains (Hodges *et al.*, 2010).

Sustainable food supply chains consider the environmental, social, and economic aspects of supply chain operations (Soysal *et al.*, 2012; Mota *et al.*, 2015; Zhu *et al.*, 2018). The UK Sustainable Development Commission (DEFRA, 2002) described sustainable food supply chains as those that: (i) produce safe, healthy products in response to market demands, (ii) enable viable livelihoods to be made from sustainable land management, (iii) respect and operate within the biological limits of natural resources, (iv) achieve consistently high standards of environmental performance, (v) ensure a safe and hygienic working environment and high social welfare, and (vi) sustain the resource available for growing food. Considering this description of sustainable food chains, PHL have repercussions on sustainability of fresh produce chains as they translate to loss of production resources, such as water and crop land used for production, and loss in income for the various actors in the supply chain (Prusky, 2011).

With the world population expected to balloon to nine billion by 2050, food insecurity is likely to worsen if measures are not put in place to minimise loss of the available food (Parfitt *et al.*, 2010). PHL reduction can contribute to increasing food availability, eliminating hunger and improving farmers' livelihoods (Kasso & Bekele, 2016; Kumar & Kalita, 2017). However, the complexity of PHL requires to get insight into the multiple factors causing PHL. Despite many intervention strategies having been proposed in literature, PHL still remain a persistent problem, presenting an enormous threat to food security (Affognon *et al.*, 2015). Hence, there is an urgent need for understanding the multiple causes of PHL to develop strategies for reduction.

1.1.1 Multiple causes of postharvest losses in fresh produce chains

Fruit and vegetables are highly perishable in nature and are characterised by high moisture content, active metabolism, and are highly prone to mechanical damage, leading to pathological decay. These characteristics set high requirements to achieve availability of high quality fresh produce to the consumer, without increasing the quantity of PHL along the chain (Kaipia *et al.*, 2013). Once fresh fruit and vegetables are harvested, physiological processes such as respiration, transpiration, and ethylene biosynthesis, continue to take place, limiting the postharvest-life of fresh produce (Akkerman *et al.*, 2010; Wu, 2010). The rate at which these physiological processes take place is influenced by environmental conditions such as temperature and humidity (Dris *et al.*, 2004). At temperatures above the optimum (10-15 ^{0}C), the rate of deterioration increases 2-3 fold for every 10 ^{0}C rise in the temperature (Kader, 2013). Therefore, to minimise the problem of PHL, it is important to understand factors that influence pathological decay. Such understanding could support the identification of improvement opportunities.

1.1.2 Interventions for postharvest loss reduction

PHL reduction can contribute to improved food security in three different pathways (van Gogh *et al.*, 2017): (1) increasing the availability of food at farm gate and market level, (2) reducing the price of food and thus enhancing potential access, and (3) reducing the volatility and the quality of food availability. According to a report by GIZ (2013), investing in PHL reduction is a quick way to enhance food security without increasing production. PHL reduction could therefore provide an attractive opportunity to improve food security in Sub-Saharan Africa. A wide range of interventions for PHL reduction are suggested in literature. These interventions vary in scale, planning time required, and associated cost. However, there are instances where the proposed interventions failed because they did not match with the characteristics of a given supply chain (FAO, 2012). More so, adoption of the proposed interventions is low in some cases because of the mismatch between the context situation and the proposed intervention (Karipidis *et al.*, 2009; Ali, 2012; Sheahan & Barrett, 2017). Affognon *et al.* (2015) provided several examples of interventions that did not perform optimally when implemented due to many constraints not considered or accounted for in the design or implementation. As such, other researchers, such as, Kitinoja *et al.* (2011) advocated for simple methods for postharvest handling to be made available in developing countries as high technology solutions might not apply. Since PHL reduction promises to contribute significantly to food insecurity in Sub-Saharan Africa, it is important that the designing of effective interventions for PHL be earnestly considered.

1.1.3 Agricultural context of Zimbabwe

Agriculture is the backbone of the Zimbabwean economy. In the year 2000, the government of Zimbabwe initiated the Fast Track Land Reform Programme (FTLRP), which extensively redistributed land (Goebel, 2005). At Independence in 1980, over 15 million hectares were devoted to large-scale commercial farming and through the FTLRP, about 7.6 million hectares were redistributed (Scoones *et al.*, 2011). Overall, there was a significant shift to many small-scale (subsistence) farmers focusing on mixed farming, often with low levels of capitalisation (Moyo, 2011b). Through the FTLRP, the agrarian structure in Zimbabwe now includes small-scale subsistence farms (82.1%), small-scale commercial farms (0.6%), and large-scale commercial farms (0.4 %), categorised based on differences in land size, forms of land tenure, social status of landholders and capacity to hire labour (Moyo, 2011a). This transformation in landholding resulted in a drastic decrease in agricultural production from the period 2000 to 2010 (Cliffe *et al.*, 2011). However, agricultural production, especially of horticultural produce has been on the increase since year 2012, mainly due to new forms of financing agriculture, which include credit and sub-contracting, new joint ventures and state credit and support schemes (SNV, 2014).

Fruit and vegetables are the major horticultural crops grown in Zimbabwe. This sector is the fastest growing industry with an average growth of 32% over the last decade and has the potential to develop a strong global competitive position, thereby providing substantial social and economic benefits to the country (SNV, 2014). However, there is a considerable amount of PHL in the fresh produce chains. Although detailed information of PHL for specific fresh produce chains is limited, the Horticulture Research Centre (2008) estimates the losses to range from 30% to 40%. There is need to design effective interventions for PHL reduction to complement efforts to reduce food insecurity in Zimbabwe and to realise the country's agricultural potential.

1.2 Problem statement

Several interventions for PHL reduction in fresh produce chains have been put forward in literature, however, the proposed interventions fall short in that they are either from a logistics control perspective, (e.g. supply chain coordination) (Ahumada & Villalobos, 2009; Rong *et al.*, 2009; East, 2011) or from a quality control perspective (e.g. temperature control) (Bollen & Prussia, 2009; Kader, 2010). The interventions seldom consider concurrently improving quality control and logistics control along the supply chain. According to van der Vorst *et al.* (2011), simultaneously optimising product quality and logistics control activities could help minimise product losses in fresh produce chains. There is need for insights into how logistics and quality control activities influence the incidence of PHL in fresh produce chains. Such insights could enable the designing of effective PHL reduction interventions as a basis for development towards sustainable fresh supply chains.

Moreover, most of the proposed interventions for PHL reduction overlook the impact of the surrounding environment (context) wherein the fresh produce chains operate. According to Hodges *et al.* (2010) and Parfitt *et al.* (2010), interventions for a sustainable approach to PHL reduction should be planned within the context of the relevant supply chain. There is a knowledge gap concerning the influence of context factors on the incidence of PHL in fresh produce chains. It is therefore imperative that a research approach be derived that not only considers logistics or quality control activities, but also the context wherein the fresh produce chains operate.

Previous studies on PHL have mostly estimated quantitative losses with little attention to qualitative losses (Underhill & Kumar, 2015; Sibomana *et al.*, 2016; McKenzie *et al.*, 2017). Moreover, few studies discussed both quantitative and qualitative losses (Hodges *et al.*, 2010; Kader, 2013). However, the studies fell short in estimating the monetary value of such losses (economic losses) and understanding how the losses are distributed over the supply chain. These inadequacies point to the need for a PHL assessment approach that considers all the three types of PHL: quantitative, qualitative, and economic losses. Such an approach could give more insights into the causes, occurrence, and magnitude of PHL in fresh produce chains, thereby enabling the designing of effective interventions for PHL reduction.

1.3 Concepts, theories, and tools

Various concepts (i.e. logistics management, quality management, and postharvest management), theories (i.e. systems theory and contingency theory), and tools (i.e. diagnostic tool and hierarchical decision framework) from several disciplines, are used in this thesis to assess PHL and reduction strategies in fresh produce chains. This section briefly describes these concepts, theories and tools.

1.3.1 Postharvest management

Postharvest management is a set of post-production practices that includes: washing, selection, grading, packing, and storage. These practices eliminate undesirable elements and improve product appearance, as well as ensuring that the product complies with consumer's requirements, such as: quality, quantity, and cost (El-Ramady *et al.*, 2015). Therefore, the aim of postharvest management is to ensure minimal postharvest losses in the chain. The term 'postharvest loss' (PHL) refers to measurable quantitative losses and qualitative food loss in the postharvest system (Kader & Rolle, 2004; Hodges *et al.*, 2010). PHL can be categorised into quantitative, qualitative, and economic losses. *Quantitative losses* refers to physical losses, measured as loss in weight or volume, of food as unacceptable for human consumption and readily discarded (Hodges *et al.*, 2010). *Qualitative losses* occur as a result of either altered physical condition, perceived substandard value, deterioration in texture, wilting, flavour, change in colour, and or nutritional value (Kader, 2005). *Economic losses* are losses in potential revenue or income, and could be due to the low quality of produce (Johnson-Kumolu & Ndimele, 2011). This thesis examines the causes and occurrence of all the three types of PHL in fresh produce chains.

1.3.2 Food logistics management

Food logistics management is concerned with how organisations fulfil market demand by getting the right food product, in the right quantity and quality, at the right time, and place, as efficient and sustainable as possible (van der Vorst, 2000). Food logistics is a crucial aspect of fresh produce chains as the high perishability of fresh produce requires complex planning (Soto-Silva *et al.*, 2016). Inefficient logistics management is one of the several contributors to high PHL in fresh produce chains, as any delay in delivering fresh produce to storage facilities or to the customer soon after harvesting can result in accelerated quality deterioration, leading to PHL (East, 2011). Poor demand forecasting, inefficient inventory control (Kaipia *et al.*, 2013), and lack of supply chain coordination (Gustavsson *et al.*, 2011) are typical examples of inadequate logistics control activities contributing to PHL. This thesis investigates which and how logistics control activities can influence the incidence of PHL along the fresh produce chain.

1.3.3 Food quality management

Quality attributes of fresh produce should be monitored along the chain to maintain the quality of the product until it reaches the consumer. Hence, the way in which product quality is controlled and guaranteed in the fresh produce chains is of vital importance for PHL reduction. Food quality management aims at realising product quality that complies or even exceeds customer and consumer requirements. According to Luning and Marcelis (2007), food quality management encompasses five managerial functions: design, control, improvement, assurance, and policy and strategy of quality. This thesis focuses on managing quality of fresh produce through quality control. Quality control is aimed at keeping product properties, production processes, and human processes within acceptable tolerance (Juran & Godfrey, 1998; Luning & Marcelis, 2007). According to Opara and Mazaud (2001), adequate quality control could result in reduced PHL. Insufficient temperature and humidity control (Woolf & Ferguson, 2000; Dew *et al.*, 2016), inadequate packaging (Gustavsson et al., 2011; Kitinoja, 2013), and poor product handling (Buntong *et al.*, 2013; Kereth *et al.*, 2013) are examples of inadequate quality control activities contributing to PHL. This thesis analyses the influence of quality control practices on the incidence of PHL in fresh produce chains. Such understanding could help implement control measures that can minimise product quality deterioration long the fresh produce chain.

1.3.4 Systems approach

The systems approach is a conceptual framework for problem-solving that considers problems in their entirety (Rubenstein-Montano *et al.*, 2001). The systems approach provides a framework, which is flexible to depict the interaction among various stages and the activities in the supply chain and the cause-effect relationships (Florkowski *et al.*, 2009). Managing a system requires an understanding of how the various parts of the system can operate together in the context of its surrounding (Tow *et al.*, 2011). This research therefore analyses the problem of PHL from a systems approach, where the different elements of the postharvest systems are considered. A postharvest system is a purposeful collection of participants, facilities, technologies and processes that deliver harvested products to their consumers with minimum loss, maximum efficiency and maximum return for all involved (Banks, 2014). It encompasses a sequence of activities and operations that include harvesting, processing (sorting and grading) storage and marking (Spurgeon, 1976). The systems approach is suitable for this research as PHL are not caused by one specific factor or occurs at a specific stage in the chain, but are a result of interlinked factors affecting the postharvest system.

1.3.5 Hierarchical approach to decision-making

A widely acknowledged procedure to understand or control a complex system is to decompose it into more manageable subsystems (Schneeweiss, 1998). The hierarchical decision approach offers a systematic and consistent way to decompose complex decision-making systems into a series of smaller and more manageable decisions (Miller, 2002; Tsolakis *et al.*, 2013). The decisions often are not of equal ranking but show a typical hierarchical relationship. Thus, some decisions have more impact, power or information than the other, or simply are made earlier than other decisions (Schneeweiss, 1998). Decisions made at a higher level shape the scope of decisions made at a lower level, whereas decisions made at lower levels of the hierarchy provide feedback to direct and evaluate decisions made at higher levels (Miller, 2002; Riopel *et al.*, 2005). In fresh produce chains, decision making can be decomposed into three hierarchical levels, i.e. operational, tactical, and strategic levels (Ahumada & Villalobos, 2009; Tsolakis *et al.*, 2013). However, insight into how multiple decisions in logistics and quality management with different time spans could affect PHL is yet limited. This thesis applies the hierarchical decision approach to decompose the complex decision-making in fresh produce chains.

1.3.6 Contingency theory

An important aspect of studying systems involves examining the interaction between a system and its environment (context), as the effectiveness of a system depends on the appropriate matching of the internal operations of the system with its environment (Donaldson, 2001). According to Ackoff (1971), the surrounding environment of a system influences problem-solving as it has an influence on the system, but is not part of the system. This line of reasoning originates from the contingency theory, which hypothesizes that the performance of a system is influenced by the context situation wherein it operates (Chenhall *et al.*, 2006; Islam & Hu, 2012). As such, strategies for PHL reduction in fresh produce chains should be tailored to the specific context wherein the chain operates. The influence of context factors on the performance of control systems in food chains is well elaborated in literature (Perona & Miragliotta, 2004; Kirezieva *et al.*, 2015a; Luning *et al.*, 2015). Examples of context factors that influence performance of control systems in fresh produce chains include, product, process, and organisation characteristics (van der Spiegel *et al.*, 2003; Luning *et al.*, 2011b; Vlajic, 2012; Luning *et al.*, 2013). The contingency theory is the backbone of this thesis, as logistics and quality control activities influencing the incidence of PHL are analysed in view of the context in which the chain operates. The assumption is that fresh produce chains operating in a context, which is highly vulnerable to the incidence of PHL require more advanced logistics and quality control activities to keep PHL low.

1.3.7 Diagnostic tool

A diagnostic tool offers guidance on how to assess the current status of a system and provides insights into improvement opportunities for the existing control systems (Luning *et al.*, 2008). Furthermore, a diagnostic tool can help to assess the influence of context factors on the performance of a system (Luning *et al.*, 2011b; Luning *et al.*, 2015). Several diagnostic tools to assess performance of systems in food chains are presented in literature (Luning *et al.*, 2008; Luning *et al.*, 2011b; Kirezieva *et al.*, 2013a; Kirezieva *et al.*, 2013b). The principles of these diagnostic tools encompass a systematic analysis of core activities that can influence the system output (e.g. PHL) and at what level are they executed. A diagnostic tool involves a comprehensive checklist of core activities and different stereotype descriptions for each activity, i.e. assessment grids (Luning *et al.*, 2009). This thesis applies the principles of developing diagnostic tools to analyse and assess causes of PHL in fresh produce chains, specifically in tomato supply chains in Zimbabwe. The concepts, theories, and tools described in this section are used as a basis for the conceptual framework used in this research. Figure 1.1 shows the initial conceptual framework for PHL analysis in fresh produce chains.

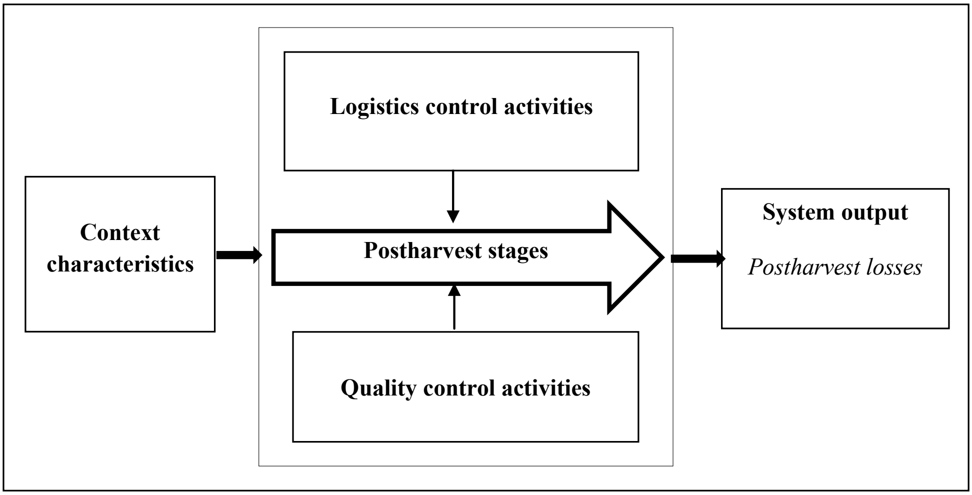

Figure 1.1. A conceptual framework for PHL analysis in fresh produce chains

1.4 Research design

1.4.1 Research objective

This research aims at understanding the influence of logistics control activities, quality control activities, and context factors on the incidence of PHL in fresh produce chains. For this purpose, a diagnostic tool will be developed and used to concurrently analyse the status of logistics and quality control activities, as well as the vulnerability of farmers' context to PHL as basis for development of improvement interventions.

1.4.2 Scope of study

Three case studies are conducted in tomato supply chains in Zimbabwe. Tomato is among the most important vegetable crops grown by farmers in Zimbabwe. Tomato supply chains in Zimbabwe are characterised by three different groups of farmers, small-scale subsistence farmers, small-scale commercial farmers, and large-scale commercial farmers, making it possible to test the developed tool on these diverse categories of tomato farmers.

1.4.3 Research challenges and research questions

Based on the previous sections, four research challenges were identified. This section elaborates how each of these challenges translates into a research question for this thesis. Actors in fresh produce chains need to make appropriate logistics and quality management decisions to minimise quality deterioration and ensure that fresh produce is delivered to customers within acceptable quality and delivery time. However, decision-making in fresh produce chains is complex because the factors affecting the quality of fresh produce are multiple and interdependent. There is need to unravel the complex decision-making process in fresh produce chains. Decision making in fresh produce chains can be decomposed into hierarchical decision levels: strategic, tactical and operational levels(Ahumada & Villalobos, 2009; Ahumada & Villalobos, 2011b; Ahumada & Villalobos, 2011a; Tsolakis *et al.*, 2013). However, information on how multiple decisions in logistics and quality management with different time spans could influence PHL is limited. Therefore, **Chapter 2** presents a study conducted in 2014 to understand which and how decisions in logistics and quality management could influence PHL, in an attempt to address the *first research question*.

RQ1: Which logistics and quality control decisions influence postharvest losses in fresh produce chains and how are the decisions hierarchically organised?

Findings to the first research question resulted in the second research challenge studied in this thesis. To develop effective intervention strategies for PHL reduction, it is important to first identify the core logistics and quality control activities that influence PHL. Furthermore, the context characteristics wherein the fresh produce chains operate need to be identified, as interventions for a sustainable PHL reduction should be planned within the context of the relevant supply chain (Hodges *et al.*, 2010; Parfitt *et al.*, 2010). The study described in **Chapter 3** attempts to answer the *second research question*. Based on the identified core logistics and quality control activities, and context characteristics influencing PHL, a diagnostic tool was developed and used to diagnose the implemented core logistics and quality control activities, the context vulnerability of the fresh produce chain to the incidence of PHL, and the actual PHL in a case study of tomato farmers in Zimbabwe.

RQ2: Which are the core logistics and quality control activities, and the core context characteristics that could influence the incidence of PHL?

To develop effective interventions PHL reduction, it is also important to understand the relations between (i) the implemented logistics control activities and PHL, (ii) the implemented quality control activities and PHL, and (iii) the context vulnerability and PHL. Previous studies on food safety in fresh produce chains (Kirezieva *et al.*, 2013b; Kussaga *et al.*, 2014; Luning *et al.*, 2015; Nanyunja *et al.*, 2015) show that companies operating in a highly vulnerable context with basic systems, experience a higher risk on food safety failure. These studies discussed and demonstrated the relationship between the context characteristics and the effectiveness of quality management systems. In literature, there is limited information on the relations between context vulnerability and PHL, and between the implemented logistics and quality control activities and PHL. This knowledge gap was the basis for *research question 3,* presented in **Chapter 4**.

RQ3: Which logistics control activities, quality control activities, and context characteristics are the determinants of PHL in tomato supply chains in Zimbabwe?

Most studies on PHL focus mainly on quantitative losses and ways to prevent these losses (Buntong *et al.*, 2013; Arah *et al.*, 2015b; Sibomana *et al.*, 2016). More so, interventions forPHL reduction proposed in literature are usually targeted at quantitative losses (Kader, 2005; Kitinoja, 2013; Gogh & Aramyan, 2014). On the other hand, there is limited information concerning the magnitude of qualitative and economic PHL losses (Munhuweyi *et al.*, 2016), yet these can impact farmers as well (Prusky, 2011). Therefore, based on a case study in tomato supply chains for commercial and subsistence tomato farmers in Zimbabwe, this thesis attempted to answer the *fourth research question* in **Chapter 5**.

RQ4: What is the magnitude of qualitative and economic PHL and possible causes associated with logistics and quality control activities in tomato supply chains in Zimbabwe?

1.5 Outline of the thesis

This thesis contains 6 chapters, which include a collection of four papers (Figure 1.2). Each paper focuses on one research question.

Chapter 1 Introduction	Background, problem statement, objectives, and outline of the thesis
Chapter 2 Hierarchical framework for decision making	Hierarchical categorisation of logistics and quality management decisions influencing postharvest losses in fresh produce chains
Chapter 3 Identification of core logistics control, quality control activities, and context	Exploration of logistics and quality control activities in view of context characteristics and postharvest losses in fresh produce chains: A case study for tomatoes supply chain in Zimbabwe
Chapter 4 Case study on quantitative losses	Identification of determinants of postharvest losses in Zimbabwean tomato supply chains as basis for dedicated interventions
Chapter 5 Case study on qualitative and economic losses	Understanding causes of qualitative and economic postharvest losses in tomato supply chains in Sub-Saharan Africa: Case of Zimbabwe
Chapter 6 General discussion	Major findings Integrated findings Managerial implications Methodological considerations for further research Concluding remarks

Figure 1.2 Outline of thesis

Chapter 2

Hierarchical categorisation of logistics and quality management decisions influencing postharvest losses in fresh produce chains

Submitted as: Macheka, L., Spelt, E.J.H., van der Vorst, J.G.A.J., Luning, P.A. Hierarchical categorisation of logistics and quality management decisions influencing postharvest losses in fresh produce chains.

Abstract

High postharvest losses (PHL) are a major obstacle in achieving sustainable fresh produce chains. The problem of PHL is exacerbated by the complexity of fresh produce chains, which complicates decision making in these chains. This paper aimed at understanding the multiple decisions that could unravel the complexity of PHL in fresh produce chains. For this purpose, the hierarchical decision approach was used to identify, analyse, and categorise logistics and quality management decisions that can influence the incidence of PHL. The categorisation of the decisions into strategic, tactical, and operational decision levels was based on well-established distinction of decision levels in management sciences. The developed hierarchical decision framework was then used as a basis to identify, analyse, and hierarchically categorise interventions for PHL reduction proposed in literature. Fifteen logistics management decisions were identified: five strategic, five tactical, and five operational decisions. As for quality management related decisions, four of the decisions are at strategic, eight at tactical, and four at operational level. Results from the analysis and categorisation of proposed interventions in literature revealed that at strategic level, 55% (6/11) of the interventions focus on logistics management, whilst 45% (5/11) on quality management. As for the interventions at tactical level, the results show that 54% (7/13) relate to logistics management and 46% (6/13) to quality management. The situation is different for the interventions at the operational level where 82% (9/11) of the interventions focus on quality management and only 18% (2/11) on logistics management. The framework provides insight in what level proposed measures intervene in the complex system of PHL.

2.1 Introduction

Approximately one third (1.3 billion tonnes) of perishable food crops produced globally for human consumption is lost every year (Gustavsson *et al.*, 2011). The problem of postharvest losses (PHL) is highest in developing countries, where up to 40% of harvested crop is lost before reaching the consumers (Hodges *et al.*, 2010; Gustavsson *et al.*, 2011). PHL are a major obstacle in achieving sustainable fresh produce chains and have repercussions for food security (Hodges *et al.*, 2010). Obviously, interventions for PHL reduction are needed to improve sustainability of fresh produce chains and improve global food security.

The problem of high PHL in fresh produce chains is exacerbated by the complexity of these chains. Fresh produce chains are characterised by highly perishable products that are heterogeneous in nature. More so, once products are harvested, physiological processes such as respiration, transpiration, and ethylene biosynthesis continue to take place leading to quality deterioration (Akkerman *et al.*, 2010; Amorim *et al.*, 2011). As such, chain actors need to make appropriate logistics decisions to ensure fresh produce is delivered to the customer while still of acceptable quality. Moreover, appropriate quality management decisions should be made to minimise quality deterioration along the chain. Therefore, inadequacies in logistics and quality management could contribute to PHL in fresh produce chains. Poor demand forecasting (Van Gogh *et al.*, 2013), inefficient inventory control systems (Kaipia *et al.*, 2011), and lack of supply chain coordination (Gustavsson *et al.*, 2011) are typical examples of inappropriate logistics management contributing to PHL. Insufficient temperature, humidity, and atmospheric conditions control (Kader & Rolle, 2004; HLPE, 2014), inadequate packaging (Gustavsson *et al.*, 2011; Kitinoja, 2013), poor product quality control (Kereth *et al.*, 2013) are examples of inappropriate quality management contributing to PHL.

Decision-making in fresh produce chains is complex because of the multiple and interdependent logistics and quality management decisions that can influence PHL. Hierarchical categorisation of decisions could be a potential approach to unravel the complex decision-making process in fresh produce chains. Such an approach offers a systematic and consistent way to decompose complex decision-making systems into a series of smaller and more manageable decisions (Miller, 2002; Tsolakis *et al.*, 2013). Several hierarchical decision frameworks in fresh produce chains are presented in literature. For example, Ahumada and Villalobos (2009) categorised logistics decisions in agrifood supply chains in to three hierarchical decision levels, which are strategic, tactical and operational levels. Tsolakis *et al* (2013) presented a hierarchical decision-making process for the design and planning of agrifood supply chains. The authors also categorised the decisions into strategic, tactical and operations levels. However, insight into how multiple decisions in logistics and quality management with different time spans could influence PHL is limited. This research aimed at understanding how logistics and quality management decisions can contribute to the incidence of PHL.

2.2 Methodology

2.2.1 Research design

The hierarchical decision approach was used to identify, analyse, and categorise logistics and quality management decisions that can influence the incidence of PHL in fresh produce chains. The developed hierarchical decision framework was then used to categorise interventions for PHL reduction proposed in literature.

2.2.2 Principles hierarchical approach to analyse decision-making

The main principles of hierarchical approach to decision-making are that (Klijn, 1995; Miller, 2002): (i) decisions are arranged based on their inequality or asymmetry in relationships, i.e. the decisions often are not of equal ranking but show a typical hierarchical relationship, (ii) decisions at higher levels show distinct properties not found in decisions at lower levels, (iii) decisions at higher levels constrain the behaviour of decisions at lower levels, i.e. decisions at higher levels give context and boundary conditions (or constraints) for decisions at lower levels, (iv) decisions at higher levels tend to react more slowly than lower levels, i.e. there is an increase in reaction time going upwards through the levels. These principles were used in this study as the basis for the identifying and hierarchically categorising logistics and quality management decisions influencing PHL.

2.2.3 Semi-structured literature search using the hierarchical decision approach

Two semi-structured literature searches were conducted with different purposes: i) to identify quality and logistics management decisions that can affect PHL, and ii) to identify interventions for PHL. The literature search strategy is depicted in Figure 2.1. Scopus, Web of Science and Google Scholar online databases were used to search for quality and logistics management decisions using a predefined set of keywords: “fresh produce”, "quality decisions", "logistics decisions", "food waste", "food losses", and "postharvest losses". In addition, a cross-referencing approach was used to find other relevant papers. The search resulted in 77 documents. Titles, abstracts and keywords of all retrieved documents were reviewed and judged based on the following inclusion criteria: (i) the document is published in a peer-reviewed journal or book, to avoid repetition of the research material itself, such as conference proceedings that are later converted into journal papers (ii) the document, or part of the document, is about postharvest losses, food waste/food losses, logistics management decisions/activities, or quality management decisions/activities, (iii) the document, or part of the document, is about fresh produce chain (fruits and vegetables), (iv) the document was published within the periods year 2000 to year 2014, as this is the period when research on PHL came into the spotlight. The selection led to 44 relevant documents. Finally, full versions of these documents were read and judged again using the inclusion criteria, resulting in a final body of academic literature of 28 documents.

The second literature search was conducted to identify interventions for PHL proposed in literature. Scopus, Thomson Reuters Web of Science and Google Scholar online databases were used to search for academic literature using keywords: "postharvest losses", "intervention strategies", and "postharvest management". Grey and additional literature were collected by searching websites of several NGOs, international organizations (such as World Bank and FAO). The search resulted in an initial body of literature of 53 documents. The summaries and/or full texts of these documents were read and judged based on the inclusion criteria, resulting in a final body of 41 documents of grey. Together with the academic literature, the search resulted in 79 documents on interventions for postharvest losses.

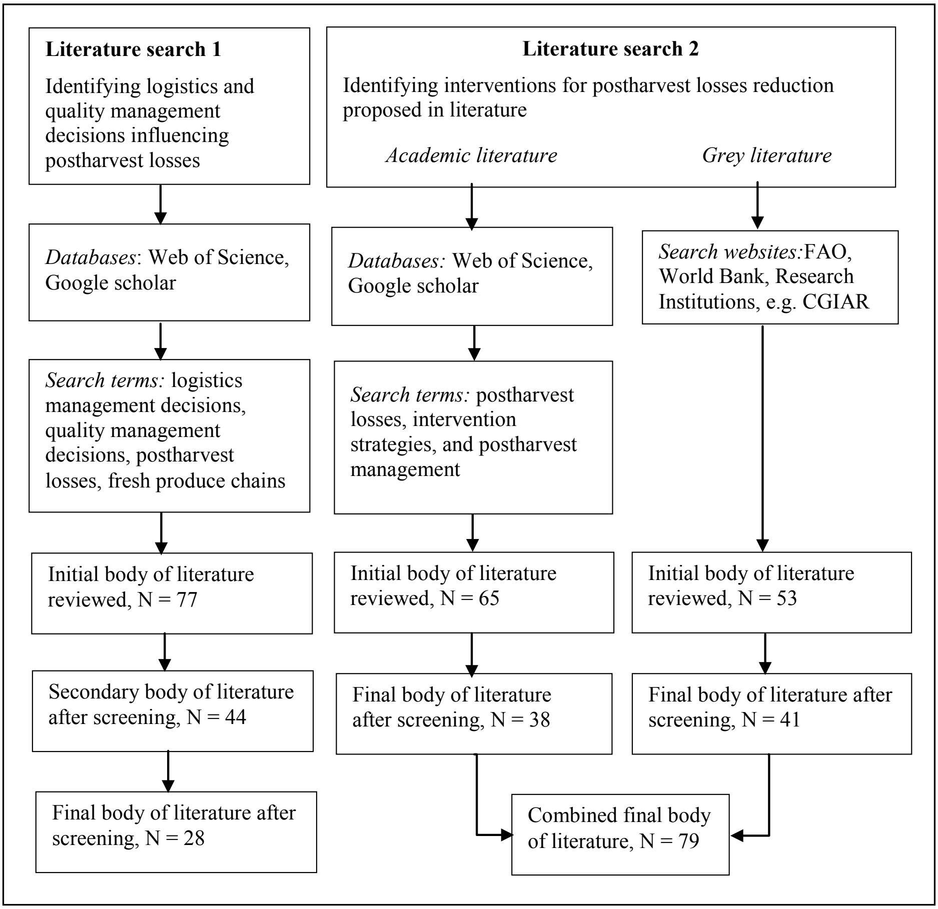

Figure 2.1 Literature search strategy

2.2.4 Criteria to categorise logistics and quality management decisions

The logistics and quality management decisions identified from the literature review were categorised into strategic, tactical and operational decisions using the following criteria: (i) strategic decisions; long-term decision (more than 2 years), have a wide scope and cover multiple functions in the chain, made by top management, require huge capital investment to implement, and their effects are noticeable over several years, (ii) tactical decisions; medium-term (1-2 years), have limited scope and cover a few stages/functions in the chain, and require some capital investment to implement, and (iii) decisions made on daily, weekly or monthly, made by low level employees, time-span, have a narrow scope (specific to a stage in the supply chain) and now or very low capital investment in required to implement the decision.

This categorisation is based on the well-established distinction of decision levels in management science (Fleischmann & Meyr, 2003; Chopra & Meindl, 2007; Rushton *et al.*, 2010; Christopher, 2011).

2.2.5 Criteria to categorise interventions for PHL reduction proposed in literature

The hierarchical decision framework developed in section 2.2.4 was used to analyse and categorise interventions for PHL reduction proposed in literature. The interventions were categorised into strategic, tactical, and operational levels using the following criteria: scope, time span, and efforts/investments required to successfully implement the intervention.

2.3 Results and discussion

This section presents and discusses the identified and hierarchically categorised logistics and quality management decisions that could affect PHL (Table 2.1 and Table 2.2) and the identified hierarchically organised interventions for PHL reduction, as proposed in literature (Table 2.3).

2.3.1 Identified and categorised logistics management decisions

Fifteen logistics management decisions were identified. Five of the decisions are at the strategic level, five at the tactical, and the other five at the operational level.

Strategic decisions

The identified five logistics decisions at the strategic level are supply chain configuration; designing of communication and information network; selecting type of supplier relationship; positioning of strategic inventory; and selecting mode of transportation. These decisions mainly determine supply chain network design. The decision on s*upply chain configuration* is concerned with the number, type, location, and size of facilities (Schmidt & Wilhelm, 2000; van der Vorst *et al.*, 2007) and can influence the time a product is subject to quality degradation during distribution. The decision on the *design of the communication and information network*, e.g. whether to centralise or decentralise information management in the chain, can affect demand forecasting and subsequently influencing the quantity to produce or process (Kaipia *et al.*, 2013). The decision has repercussions on PHL as it can result in over-production, leading to PHL. The decision on *type of supplier-relationship* can influence PHL as well. For example, long-term relationships through contractual agreements (e.g. contract farming) guaranteeing markets for farmers (Tsolakis *et al.*, 2013). Such contractual agreements can reduce the risk of over-production, thereby minimising PHL (Gustavsson *et al.*, 2011). The decision on *positioning of strategic inventory* in the chain can influence PHL, e.g. positioning inventory near the farmer can eliminate the need for inventory at downstream stages of the chain, minimising the risk of quality deterioration of fresh produce during storage (Kaipia *et al.*, 2013). Lastly, the *mode of transport* should be adapted to the quality decay properties of fresh produce in order to minimise quality decay during distribution (Ahumada and Villalobos, 2011b). Highly perishable fresh produce with a shelf life less than 5 days cannot be transported by ship, which is usually used to transport fresh produce with shelf life of 14 days and above.

Tactical decisions

The five identified logistics decisions at tactical level are decisions on capabilities of information system; production or processing capacity; storage capacity, inventory levels; and capabilities and capacity of mode and type of transport. The decisions prescribe the flow of products along the chain, determine the production and processing capacity, and inventory levels in the chain (Melo *et al.*, 2009; Akkerman *et al.*, 2010). The *capacity and capability of the information system or processing/production facilities, or storage facilities* are important in maintaining quality of fresh produce (Ahumada & Villalobos, 2009). Storage facilities without cooling capabilities cannot maintain the quality of fresh produce for longer storage duration and keeping high *inventory level* or *safety stock* in the chain can create excess stock which can be susceptible to quality decay, leading to PHL (Lee & Wu, 2006). More so, the decision on *production or processing capacity* to invest in, for example, can influence the incidence of PHL. Inadequate processing capacity can limit volumes of harvested produce that can be processed at a certain time, leading to high inventory of unprocessed produce, increasing the chances for quality deterioration before the produce is processed (Gogh & Aramyan, 2014).

Operational decisions

The identified five decisions at the operational level are decisions on processing (harvesting or packing) schedule; inventory issuing policies; size of units/batches; frequency of information exchange, and vehicle scheduling and routing. According to Ahumada and Villalobos (2011a), logistics decisions at the operational level aim at scheduling operations to assure on-time delivery of fresh products to customers. Scheduling *quantity of produce to harvest* can influence the incidence of PHL. Harvesting fresh produce way before its intended delivery date can result in the produce being delivered whilst no longer fresh, increasing the risk of the produce being rejected by customers (Ahumada & Villalobos, 2009). The decision on which *batch to pick first* from storage for distribution can influence PHL as well, e.g. picking fresh produce based on the duration (age) produce has been in storage, and not the actual quality of produce, may result in low storability batches remaining in storage, leading to PHL (East, 2011). It is therefore important to use the appropriate order picking policy to minimise PHL in fresh produce chains. Likewise, an appropriate batch or lot size should be selected as different markets or customer require different batch sizes (Schmidt & Wilhelm, 2000). *Frequency of information exchange* also can have a bearing on PHL. Lack of information on supply and demand can result in oversupply (Kaipia *et al.*, 2013; Jedermann *et al.*, 2014). Lastly, the operational decision on *vehicle scheduling and routing* (delivery routes, exact time of delivery, vehicle to use, and in what sequence customers will get their produce) can affect PHL. Delivering fresh produce using the longest route and at time of day not prescribed by the customer can result in quality deterioration of produce before reaching the customer and rejection by the customer (Akkerman *et al.*, 2010).

Table 2.1 Hierarchy for logistics management decisions and assumed mechanism through which the decisions can influence PHL in fresh produce chains

Decision	Reference	Assumed relation with PHL
Strategic decisions		
Network facilities		
1. Supply chain configuration	Riopel *et al.* (2005), van der Vorst *et al.* (2005), Tsolakis *et al.* (2013), Akkerman *et al.* (2010)	Supply chain configuration (i.e. number, size, and location of facilities) that is designed based on perishability of product handled in the chain and distance to market create better circumstances for daily logistics activities (such as product picking, vehicle scheduling and routing), limiting chances of PHL.
2. Design of the communication and information network	Riopel *et al.* (2005), Kaipia *et al.* (2013)	A centralised information system in which all chain actors have access to, can lead to informed decision-making at tactical and operational levels, limiting chances of PHL.
3. Type of supplier relationship	Riopel *et al.* (2005), Amorim *et al.* (2011), Zhang *et al.* (2009), Tsolakis *et al*. (2013)	Establishing long-term relationships with suppliers who have a reliable supply (history) for quality products can provide better conditions for planning at tactical and operational level, limiting chances of PHL.
Inventory management		
4. Positioning of strategic inventory (customer order decoupling point)	Van Donk (2001), (Olhager, 2012)	Positioning inventory at an appropriate chain location (upstream or downstream) can reduce inventory levels, e.g. safety stock, in subsequent chain stages, reduce number of handling stages, shorten the supply chain and create better conditions for logistics control at operational level, limiting chances of PHL
Transportation management		
5. Mode of transportation	(Riopel *et al.*, 2005), Akkerman *et al.*(2010), Ahumada and Villalobos (2011b), van der Vorst *et al.* (2011)	Availability of appropriate modes of transportation (rail, road, sea, air) that maintain product quality throughout the chain can create better circumstances for planning at tactical and operational level (e.g. vehicle schedule and routing), limiting chances of PHL.
Tactical decisions		
Network facilities		
6. Capabilities of information system	Gunasekaran and Ngai (2004)	Investing in advanced information technology such as EDI or RFID enables exchange of real-time information, which can result in informed and improved decision-making at operational levels (e.g. inventory issuing policy), leading to limited chances of PHL.
Production planning		
7. Production/processing capacity	Ahumada and Villalobos (2011b),	A flexible processing capacity may result in a better match between supply and demand, and more products being transformed into a state that is easier to handle (e.g. packaged produce) at operational level, limiting chances of PHL.

Inventory management		
8. Storage capacity	Melo *et al.* (2009); Manzini *et al.* (2014)	Appropriate storage capacity that allows for products to be stored according to class/product characteristics, e.g. separating climacteric and non-climacteric fruits can limit chances of PHL.
9. Inventory levels/ safety stock	Melo *et al.* (2009), Hong Zhao *et al.* (2010), Pearson *et al.* (2010),	Inventory level or safety stock that is aligned to product demand can reduce the risk of having too high inventory in stock, which might become damaged, spoiled, or obsolete, limiting chances of PHL.
Transportation management		
10. Capabilities and capacity of mode and type of transport	Stank and Goldsby (2000), Riopel *et al.* (2005), Akkerman *et al.* (2010) , Ahumada and Villalobos (2011b)	Mode and type of transport that can maintain cold temperatures (e.g. refrigerated trucks) provides better conditions for operational logistics control activities (e.g. vehicle scheduling and routing) that can maintain initial product quality, liming chances of PHL.
Operational decisions		
Network facilities		
11. Frequency of information exchange	Gunasekaran and Ngai (2004)	Accurate and timely exchange of information (e.g. on product demand and supply or product quality) can reduce uncertainty in the chain. This improves the day-to-day logistical operations such as inventory issuing, limiting chances of PHL.
Production planning		
12. Processing schedule	Ahumada and Villalobos (2011b)	A flexible processing (sorting/ grading and packing) schedule that is aligned to product demand can eliminate high inventory along the chain, limiting chances of PHL.
13. Size of units/batches	East (2011)	Batch sizes that are aligned to available handling methods and equipment can reduce the risk of produce being damaged due to poor handling at operational level, limiting chances of PHL.
Inventory management		
14. Inventory issuing policies (picking of produce for distribution)	East (2011), van der Vorst *et al.* (2011)	Inventory issuing policies that take into account product quality (e.g. FEFO) rather than the time/age of product (e.g. FIFO) can result in produce with low storability removed from storage first, limiting chances of PHL.
Transportation management		
15. Vehicle scheduling and routing	Riopel *et al.* (2005), Akkerman *et al.* (2010), Ahumada and Villalobos (2011a)	A transportation schedule and routing that is based on changes in product quality results in product being delivered to the market at the right time and right quality, limiting chances of PHL.

2.3.2 Identified and categorised quality management decisions

Table 2.2 presents the sixteen identified and hierarchically categorised quality management decisions that can influence the incidence of PHL in fresh produce chains. Four of the decisions are at strategic level, eight at tactical, and four at operational level.

Strategic decisions

The four quality management decisions identified at the strategic level include decisions on level of quality policy on product, technology, equipment, and facilities; level of quality management system; and structure and formalisation level of the organisation. These decisions mainly determine the long term food quality goals, quality management objectives and how to achieve these objectives (Luning & Marcelis, 2009). The decision on *level of quality policy* for products (e.g. brand, product assortment), *advancedness of technological infrastructure and equipment* (e.g. automated equipment) and *quality management system* (e.g. GlobalGap) in fresh produce chains can influence the incidende of PHL. (Nanyunja *et al.*, 2015). For instance, lack of a comprehensive quality policy could result in acceptance of low quality products that do not meet customer specifications, resulting in high rejection, which leads to PHL. Also, the decision on the *structure and formalisation level* of an organisation can affect food safety in fresh produce chains (Kirezieva *et al.*, 2015b; Nanyunja *et al.*, 2015), which ultimately leads to PHL as the safety level of fresh produce is a major cause of PHL in fresh produce chains (Gustavsson *et al.*, 2011).

Tactical decisions

Deciding on product specification and tolerances for incoming material and final product; requirements on sampling design; setting requirements on handling of non-conformance; specifications and tolerances levels for process parameters, equipment and facilities; requirements for maintenance of equipment and facilities; requirements on corrective actions for non-conformance; requirements on technological staff; and assignment of tasks, responsibilities and authority are the quality mangement decisions identified at tactical level. These decisions are mainly concerned with specifying customer demands and translating them into ingredient, product, packaging, process, (monitoring) equipment as well as facility specifications (Luning & Marcelis, 2009). The decision on *product quality specifications and tolerances* for incoming material can infleunce PHL, as product quality specifications that are too stringent and concerned more with shape and size can result in high rejections, contributing to high PHL (Gustavsson *et al.*, 2011). Selection of appropriate *packaging* *material* is important to minimise physical damage, microbial and chemical contamination, and for long-term preservation of produce quality (Kitinoja *et al.*, 2010; Rushton *et al.*, 2010). Use of inappropriate packaging material, such as wooden crates can result in physical injury to the produce, leading to PHL (Gogh & Aramyan, 2014). During quality control, the decision on *sampling design*, which includes sampling location and number of samples, is important in relation to the PHL. A sample that does not represent the quality of the whole batch can result in acceptance of a poor quality products that will be rejcted by the customers (Bollen & Prussia, 2009). Furthermore, inadequacies in *technological expertise and operators' knowledge* (Kitinoja *et al.*, 2011), and unclear *assignment of tasks, responsibilities and authority* (Kirezieva *et al.*, 2013a; Nanyunja *et al.*, 2015) can lead to inadequate description and design of quality control tasks, which can influence the incidence of PHL.

Operational decisions

The identified four decisions at operational level concernconformance checking of product to standards and specifications; conformance checking of process parameters, equipment and facility specifications; conformance checking of people's actions to procedures and policies; checking supplier conformance. These decisions are mainly targeted at hourly, daily, or weekly product quality control and process monitoring. Daily decisions on *corrective action* to take on non-conforming products and out-of-specification process conditions can influence PHL. Inadequate product control during grading can result in spoiled products being mixed with good quality products, increasing chances for the products to be rejected by customers (Bollen & Prussia, 2009). Furthermore, inadequate *monitoring and control* of temperature during storage can affect quality deterioration leading to spoiled products (Shewfelt & Prussia, 2009).

Table 2.2 Hierarchy for quality management decisions and assumed mechanism through which the decisions influence PHL

Decision	**References**	**Assumed mechanism**
Strategic decisions		
Product		
1. Policy on product quality level	Kaipia *et al.* (2013),	A clear policy with concrete goals and allocation of resources to achieve desired product quality level creates conditions for adequate design and operation of quality monitoring systems, hereby limiting chances of PHL.
Process		
2. Quality level of technology, equipment and facilities.	Luning *et al.* (2009)	Advanced facilities and accurate and reliable equipment and (e.g. cold storage facilities or automated temperature control equipment) provide better conditions to keep (initial) quality, limiting chances of PHL
3. Level of quality management system	Luning *et al.* (2009), Jacxsens *et al.* (2011)	An advanced comprehensive quality management system provides better insight into causes of quality decay and how to prevent and control the decay, limiting chances of PHL.
Organisation		
4. Structure and formalisation level of the organisation	Luning and Marcelis (2009), Kirezieva *et al.* (2013b)	A well-coordinated and defined organisational structure for quality management creates rules/circumstances for proper assignment of quality tasks and responsibilities at tactical and operational levels, avoiding inadequate decisions and failures in quality control.
Tactical decisions		
Product		
5. Product specification and tolerances for incoming material and final product	Gustavsson *et al.* (2011)	Product specifications that have flexible defect tolerances and are not strict on product attributes such as shape, reduce amount of products rejected at operational level, limiting chances of PHL.
6. Requirements on sampling design, e.g. sampling location, time of sampling, number of samples	(Luning *et al.*, 2008)	A statistical underpinned and tailored sampling design increases reliability of information on actual product quality, resulting in improved decision-making in product monitoring, limiting chances of PHL.
7. Setting requirements on handling of non-conformance/ waste handling	Kirezieva *et al.* (2013b)	A complete and differentiated description of corrective actions on how to handle rejected produce results in better control activities, limiting chances of PHL.

Process		
8. Setting specifications and tolerances levels for process parameters, equipment and facilities	Luning *et al.* (2008)	Strict specifications and low tolerances on process parameters (e.g. temperature control), equipment and facilities, results in better control of crucial process parameters that are aimed at maintaining the produce quality
9. Requirements for maintenance of equipment and facilities	Manning *et al.* (2006)	Systematic maintenance of measuring equipment will result in stable and predictable accuracy of measurement, which will avoid inadequate quality monitoring decisions, limiting chances of PHL
10. Requirements on corrective actions for non-conformance	Luning and Marcelis (2007)	A comprehensive and differentiated description of corrective actions linking the severity of deviations to the type of corrective actions may result in better grading and packing activities at operational level, limiting chances of PHL.
Organisation		
11. Requirements on technological staff	Kirezieva *et al.* (2015), Kitinoja *et al.* (2011)	Competent staff with adequate expertise on postharvest management is better able to take adequate decisions avoiding failures in execution of monitoring and other quality control tasks, limiting chances of PHL.
12. Assignment of tasks, responsibilities and authority	Gustavsson *et al*. (2011), Kereth *et al*. (2013), Xu (2011)	A robust and detailed assignment of tasks and responsibilities will avoid unpredictable and variable execution of monitoring and other quality control tasks, limiting chances of PHL.
Operational decisions		
Product		
13. Conformance checking of product to standards and specifications and taking corrective actions	Luning *et al.* (2009), Gustavsson *et al*. (2011)	Frequent and accurate checking for conformance of raw and finished products result in improved decision-making and appropriate corrective action, limiting chances of PHL.
Process		
14. Conformance checking of process parameters, equipment and facility specifications and taking corrective actions	Luning *et al.* (2009)	Frequent and accurate checking for conformance of processes, equipment and facilities result in improved decision-making and appropriate corrective action, limiting chances of PHL.
Organisation		
15. Conformance checking of people's actions to procedures and policies and taking corrective actions	Luning *et al.* (2009), Kereth *et al*. (2013)	Frequent and accurate checking for compliance to procedures and the ability to make appropriate corrective actions can limit chances of PHL
16. Checking supplier conformance	Liu *et al.* (2000), Ho *et al.* (2010)	Frequent and accurate checking for compliance of suppliers to quality specifications result in appropriate corrective action leading to reduced rejections, limiting chances of PHL.

Overall, the decision levels presented in Table 2.1 and 2.2 are structured in a way such that decisions at strategic level constraints those at lower levels. For instance, the logistics management decision at strategic level, e.g. decision on supply chain configuration (such as size and location of facilities), put restrictions on tactical decisions (e.g. processing capacity) and the tactical decisions position inventories for use at the operational level. Misalignment of the decisions at the three levels could result in high incidence for PHL. For example, harvesting quantity (operational decision) of produce that is not aligned to the available storage or processing capacity (tactical level) could result in lack of proper storage facilities, leading to quality deterioration.

2.4 Categorisation of proposed interventions for PHL reduction

Table 2.3 shows thirty-five proposed interventions for PHL reduction identified from the literature search. Some of these interventions focus on logistics management (15/35), some on quality management (20/35), and some on both logistics and quality management (2/35). Furthermore, Table 2.3 shows how the interventions were hierarchically categorised into strategic, tactical, and operational levels. As for the fifteen interventions focusing on logistics management, six (40%) are categorised at the strategic, seven (47%) at the tactical, and two (13%) at the operational level. For the twenty interventions focusing on quality management, five (25%) are categorised at the strategic, six (30%) at the tactical, and nine (45%) at the operational level.

Moreover, Table 2.3 reveals that of the eleven interventions (including both logistics and quality management) at strategic level 55% (6/11) focus on logistics management whilst 45% (5/11) on quality management. The interventions focusing on logistics management at this level mainly aim at improving network facilities, e.g. investing into adequate storage facilities, supply chain configuration, and improving road infrastructures. As for those focusing on quality management, they involve development or use of advanced technology (e.g. developing cultivars that have long postharvest-life) and infrastructure (e.g. investing into modified atmosphere storage facilities). As for the interventions at tactical level, 54% (7/13) related to logistics management (6/13) and 46% to quality management. The interventions related to logistics management mainly focused on supply chain (re)design, e.g. shortening the supply chain by reducing multiple handling stages and linking farmers to interact directly with buyers. Those focusing on quality management mainly targeted at quality design in the chain, e.g. implementing quality management systems, or designing intelligent packaging to monitor quality of a product. The situation is different for the interventions at the operational level where 82% (9/11) of the interventions focus on quality management and only 18% (2/11) on logistics management. The interventions related to quality management aim at daily quality control activities, such as grading and sorting of fresh produce. For the interventions related to logistics management, they mainly target order fulfilment through transportation of produce. These interventions require short term planning and little capital investment as compared to strategic and tactical interventions, which require long to medium term planning and huge capital investments (Rushton *et al.*, 2010).

Furthermore, Table 2.3 shows that only 6% (2/35) of all the interventions identified are a combination of logistics management and quality management activities. The combined interventions are often characterised by the use of advanced technologies, e.g. using quality decay models to predict quality changes and using quality-based inventory issuing policy. The concurrent application of logistics and quality control interventions is in-line with the concept of quality-controlled logistics put forward by van der Vorst *et al.,*2011. They discussed the use of real time product quality information in logistics decision-making to improve management of fresh produce chains. More so, 11% (4/35) of the interventions are beyond the scope of farmers of organisations. Examples of such interventions include, establishing legislation and national sanitary and phyto-sanitary standards, investing in public infrastructure such as road and market facilities. Only other stakeholders, such as the government can successfully implement these interventions.

Interventions taken at the strategic level can set the boundaries or direct the interventions at the tactical and operational levels. For instance, the operational intervention to grade every batch of fresh produce into different quality grades is guided by the intervention on implementing GAPs, GMPs, GHPs, which is a tactical level intervention. The scope on interventions at tactical level is in turn guided by interventions at strategic level, such as, establishment of national sanitary and phyto-sanitary standards. Every actor in fresh produce chains, from the farmer to the government has a particular role to play in minimising the incidence of PHL in fresh produce chains.

Table 2.3 Categorisation of proposed interventions for PH reduction into strategic, tactical, and operational levels.

	Interventions	References	Type of intervenion Logistics	Quality
Strategic level				
Network facilities	• Investing into adequate storage facilities	• Hodges *et al.* (2010), Gustavsson *et al.,*(2011)	X	
	• Investing into refrigerated cold storage facilities	• Gustavsson *et al.,*(2011)	X	
	• Investing into modified atmosphere storage facilities	• Kader (2010), FAO (2013)		X
	• Improving road infrastructures (e.g. tarred roads)	• Yahia *et al.* (2004), HLPE (2014)	X[b]	
	• Using refrigerated vehicles to transport fresh produce	• Fonseca and Njie (2009), Macheka *et al.* (2013),	X[a]	X[a]
	• Positioning of inventory near the farmer to reduce amount of inventory in subsequent stages of the chain	• Kaipia *et al.* (2013), van der Vorst and Snels (2014)	X	
	• Establishing suitable market institutions to assist farmers market their produce	• Godfray *et al.* (2010)	X[b]	
Product quality level	• Developing cultivars that have long postharvest-life	• Atanda *et al.* (2011), Affognon *et al.* (2015)		X
Legislation (government)	• Establishing legislation to prevent and reduce food wastage •	• Godfray *et al.* (2010), FAO (2013), HLPE (2014)		X[b]
	• Establishing national sanitary and phyto-sanitary standards to facilitate access to international market	• Gustavsson *et al.* (2011), FAO (2013)		X[b]
Tactical level				
Network facilities	• Reducing multiple handling of produce by eliminating stages in the chain, e.g. packing produce in the field	• Van der Vorst and Snels (2014), Mena *et al.* (2011), Yahia (2009), Kader (2005; 2010)	X	
	• Shortening the food supply chain by assisting small farmers to interact directly with buyers, e.g. excluding middlemen	• Gustavsson *et al.,*(2011)	X	
	• Improving communication along the supply chain to match demand and supply (information exchange)	• HLPE (2014), van der Vorst and Snels (2014), FAO (2013)	X	
	• Developing markets for rejected sub-standard products to avoid throwing away of products	• Kiaya (2014), van der Vorst and Snels (2014)	X	
Production planning	• Increasing capacity and efficiency of processing equipment to reduce waste	• Kader and Rolle (2004),Kitinoja *et al.* (2013)	X	
Inventory management	• Using quality based inventory issuing policy	• Dada and Thiesse (2008)	X[a]	X[a]
Quality systems and design	• Implementing quality management systems	• Bollen and Prussia (2009)		X

	• Using quality decay models to predict quality changes.	• van der Vorst *et al.*(2011), van der Vorst and Snels (2014)		X
	• Implementing good agricultural practices (GAPs), good manufacturing practices (GMPs) and good hygienic practices (GHPs) to ensure quality and safety of food.	• HLPE (2014), Kitinoja *et al.* (2011)		X
	• Using intelligent packaging, this can help to monitor quality of a product (ripeness, freshness)	• Tsolakis et al. (2013)		X
Product design	• Using modified packaging (MAP) to reduce microbial proliferation and to retard fungal growth.	• Kitinoja *et al.* (2011), Kader *et al.* (2012), Affognon *et al.* (2015)		X
Organisation and resources	• Effective training of workers and their supervisors along with delegation of responsibility and authority.	• Kereth *et al.* (2013), van der Vorst and Snels (2014)	X	
Operational level				
Transportation management	• Covering produce during transportation to avoid bad weather conditions affecting the produce	• Kader (2010), FAO (2013), Kiaya (2014)		X
	• Transporting during evening hours to avoid high temperatures	• Kader and Rolle (2004),Yanez *et al.* (2004)	X	
	• Transporting ethylene-sensitive produce separate from ethylene generating produce	• Macheka *et al.* (2013)	X	
Product quality	• Grading and sorting of fresh produce according to quality levels to prevent microbial cross contamination	• Atanda *et al.* (2011), Kader *et al.*(2012), Kiaya (2014)		X
	• Monitoring temperature history	• van der Vorst and Snels (2014)		X
	• Using clean, smooth and ventilated containers for packaging to prevent premature deterioration in product quality	• van der Vorst and Snels (2014)		X
	• Using cushions during packing to protect produce from mechanical damage	• Kader *et al.* (2012), Kitinoja (2013), Macheka *et al.* (2013)		X
	• Using maturity indices to identify proper harvest timing	• HLPE (2014), FAO (2013), Kader (2013)		X
Organisation and resources	• Training of supervisors and operators on fresh produce-handling	• Kitinoja (2013)		X
	• Instructing operators on how to apply good handling practices	• Ali (2012), Kitinoja (2013)		X
	• Teaching of farmers by education and extension services on existing technologies and best practices	• van der Vorst and Snels (2014), Kitinoja (2013), Gustavsson *et al.*(2011)		X

[a] intervention that integrate logistics and quality management activities, [b] interventions that can only be addressed at government level

2.5 Conclusion

This paper aimed at identifying and categorising the multiple logistics and quality control decisions that could affect PHL in order to unravel the complexity the causes of postharvest losses in fresh produce chains. Overall, a total of fifteen logistics management decisions and sixteen quality management decisions were identified from literature that could influence incidence of PHL in fresh produce chains. The analysis and hierarchical categorisation of interventions for PHL reduction, revealed that most of the proposed interventions are related to quality management. The majority of these interventions focus on n the operational level, while most of the logistics management related interventions target at the strategic or tactical level. The hierarchical decision framework illustrates how the multiple decisions in fresh produce chains that could affect PHL can be structured by using the hierarchical categorisation approach. Likewise, the framework supported in eliciting more explicitly, at which level proposed PHL mitigation measures would intervene. Interventions targeted at the strategic level set the boundaries and give direction to decisions and interventions at the tactical and operational level. However, interventions at the strategic level are long-term and costly investments. Depending on the farmers' financial and human resources, short-time and low cost interventions in logistics and quality control at operational level, would be more realistic optins as first steps towards mitigating PHL.

Chapter 3

Exploration of logistics and quality control activities in view of context characteristics and postharvest losses in fresh produce chains: A case study for tomatoes

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Abstract

Postharvest losses in fresh produce chains are a major threat to food security, especially in developing countries. To develop effective intervention strategies for postharvest losses reduction, it is important to first understand the core logistics and quality control activities that could affect postharvest losses in these chains. In this study, a diagnostic tool was developed and used to assess the status of the implemented of core logistics and quality control activities, context characteristics that create vulnerability to PHL, and the actual postharvest losses. Based upon a literature review, the context characteristics to assess the context vulnerability to postharvest losses were divided into product, process, organisation, and supply chain characteristics. The identified core logistics activities are planning on the amount of fresh produce to harvest and process, selecting issuing policies, selecting mode of transportation and type of vehicle, and vehicle scheduling and routing. Maturity determination at harvest, deciding on harvest moment, harvesting, packing, and storage practices, use of grading standards, package material, temperature monitoring during storage and transportation, and equipment maintenance are the core quality control activities identified. The tool was applied to three types of tomato supply chains in Zimbabwe. The major findings are that commercial farmers recorded lower postharvest losses (1%) as compared to subsistence farmers (3%), the context for commercial farmers is less vulnerable to the incidence of postharvest losses as compared to that for subsistence farmers, and logistics and quality control activities for commercial farmers are implemented at a more advanced level. The tool provides a differentiated assessment that allows users to identify improvement opportunities to achieve higher performance for the activities and to reduce context vulnerability.

3.1 Introduction

Postharvest losses (PHL) are a major obstacle in achieving sustainable fresh produce chains and have repercussions for food security, especially in transition countries where approximately up to 40% of the harvested fruit and vegetables end up not being acceptable for human consumption (Hodges *et al.*, 2010; Gustavsson *et al.*, 2011). Major reasons for these high PHL include inadequate logistics and quality control activities. Poor demand forecasting, inefficient inventory control systems (Kaipia *et al.*, 2013), and lack of supply chain coordination (Gustavsson *et al.*, 2011) are typical examples of inadequate logistics control contributing to PHL. Insufficient temperature, humidity, and atmospheric conditions control (Kader & Rolle, 2004), inadequate packaging (Gustavsson *et al.*, 2011; Kitinoja, 2013), and poor product quality control (Kereth *et al.*, 2013) are examples of inadequate quality control activities contributing to PHL.

Several studies have been conducted on improving logistics management (Dada & Thiesse, 2008; Ahumada & Villalobos, 2011a; Amorim *et al.*, 2011; East, 2011; van der Vorst *et al.*, 2011) and quality management (Buntong *et al.*, 2013; Kirezieva *et al.*, 2013a; Sivakumar & Wall, 2013) to minimise PHL in fresh produce chains. However, previous studies (Luning *et al.*, 2011a; Kirezieva *et al.*, 2013b; Kussaga *et al.*, 2014; Nanyunja *et al.*, 2015) discussed and demonstrated that the technical, organisational, and supply chain characteristics of companies operating in (fresh) food chains should be taken into account to understand the effectiveness of quality management systems. These studies showed that companies operating in a high-risk context (typified by uncertainty, ambiguity, and vulnerability to food hazards) with basic systems, i.e. experience-based, not specific, nor formalised, experience a higher risk on food safety failures. Likewise, supply chain actors in fresh produce chains need to implement logistics control and quality control activities (Kirezieva *et al.*, 2013b) that are aligned with the context characteristics in which they operate. To gain understanding on the causes of PHL in developing countries, it is necessary to typify and analyse context characteristics that can influence the incidence of PHL.

The aim of this study is to explore the logistics and quality control activities, as well as the context characteristics that can influence the generation of PHL in fresh produce chains. For this purpose, literature was examined to identify the core logistics and quality control activities influencing the incidence of PHL in fresh produce chains. Subsequently, a diagnostic tool was developed and used to assess the implementation of the core activities in a case of tomato farmers in Zimbabwe. We chose this specific case, because tomato is among the most important vegetable crops grown by farmers in Zimbabwe (eMkambo, 2015). More so, literature (Babalola *et al.*, 2010; Arah *et al.*, 2015b; Sibomana *et al.*, 2016) shows that tomato farmers in Sub-Saharan countries are confronted with significant PHL, ranging between 10 to 40%. Furthermore, tomato supply chains in Zimbabwe are characterised by three different groups of farmers, small-scale subsistence farmers, small-scale commercial farmers, and large-scale commercial farmers, making it possible to test the developed tool on these diverse categories of tomato farmers.

3.2 Materials and Methods

3.2.1 Identifying core logistics and quality control activities

Core logistics and quality control activities that can influence PHL were determined through a literature search. The search was carried out using online databases: Scopus, Thomson Reuters Web of Science, and Google Scholar. Keywords used in the search are “fresh produce”, “quality control”, “logistics control”, “food waste”, “food losses”, and “postharvest losses”. Titles, abstracts, and keywords of all the retrieved documents were reviewed and judged based on the following inclusion criteria: (i) the document is published in a peer-reviewed journal or book, to avoid repetition of the research material itself, such as conference proceedings that are later converted into journal papers, (ii) the document, or part of the document, is about PHL, food waste, food losses, logistics management activities, or quality control activities, (iii) the document, or part of the document, is about fresh produce chain (fruits and vegetables), and (iv) the document was published within the time span of 2000–2014, because in this period there was more research on PHL. The selection led to 37 relevant documents: 19 on logistics control activities, 13 on quality control activities, and five documents contained both logistics and quality control activities.

For both logistics and quality control, an activity was considered core when it has a direct effect on PHL and the effect is underpinned by literature, i.e. supported by more than two scientific studies. The control activities were identified for each postharvest stage in the fresh produce chain, i.e. harvesting, sorting and grading, packing, storage, and transportation. Identified control activities were screened based on the criterion that the effect of the activity on PHL is underpinned by literature, i.e. supported by more than two scientific studies. The screening resulted in six core logistics and 10 core quality control activities.

Context characteristics were identified based on the criteria that the characteristic (i) makes fresh produce vulnerable to PHL if adequate logistics and quality control measures are not implemented, and (ii) cannot be easily changed or cannot be changed at all. The search was carried out using a predefined set of keywords in the following online databases: Scopus, Web of Science, and Google Scholar. Context factors, food waste, food losses, and postharvest losses were the keywords used. The search resulted in 16 context characteristics, which were selected based on the criterion that the influence of the context characteristic on PHL is underpinned by literature, i.e. supported by more than two scientific studies. The identified core logistics and quality control activities resulted in a conceptual framework (Figure 3.1) which was the basis for the diagnostic tool development.

3.3 Diagnostic tool development

3.3.1 The design principles used for diagnostic tool development

The development of the diagnostic tool was based on design principles used in earlier diagnostic tools to assess performance of food management systems (Luning *et al.*, 2008; Luning *et al.*, 2009; Jacxsens *et al.*, 2011b; Luning *et al.*, 2011b; Kirezieva *et al.*, 2013a), i.e. including system context characteristics, focus on core activities, defined system output, and use of judgment grids to enable a differentiated assessment.

The first design principle relates to system activities, such as control activities, which need to be adapted to the context wherein they operate to be effective. It is well elaborated in contingency theory literature (Drazin & Van de Ven, 1985) that the performance of a system or solutions to a set of problems is influenced by external factors. Major context factors included in the current tool are product, process, organisation, and chain characteristics. Product characteristics refer to the inherent properties of initial materials and final products. Production characteristics apply to the conditions during primary production, processing, and handling (Luning *et al.*, 2011a). Organisational characteristics involve administrative conditions, such as requirements on employee competences, assignment of tasks and responsibilities, rules, and procedures, which affect peoples' decision-making behaviour (Luning & Marcelis, 2007). Chain characteristics refer to the conditions during supply, and relationships with other companies and organisations in the chain (Kirezieva *et al.*, 2013b).

The second principle relates to the focus on core activities. For the current tool, core logistics and quality control activities are those activities that can affect PHL. Logistics control activities considered in this tool were restricted to activities aimed at ensuring supply of the right quantity (volume) of fresh produce to the right place at the right time, and against the appropriate cost. Quality control activities were limited to activities aimed at keeping fresh produce within acceptable quality or minimising quality decay, e.g. controlling temperature along the chain.

The third principle is the assessment of the system output, which is in this study the occurrence of PHL. Postharvest losses refer to produce that is unfit for human consumption and removed from the chain (Gustavsson, *et al*., 2011). The last principle refers to the use of grids for a differentiated assessment of the actual situation. To operationalise the conceptual framework into a diagnostic tool, assessment grids were developed for each context factor (i.e. product, process, chain characteristics) and for all core logistics activities and quality control activities. For each core activity, a grid was developed with four typical descriptions of performance levels, i.e. representing a low, basic, moderate, and advanced level.

The criteria used to differentiate the level of logistics control activities are based on the extent to which information on actual available product demand and on product quality are considered in managing the logistics activities (Gunasekaran & Ngai, 2004; van der Vorst *et al.*, 2011). A *low level* of logistics control represents a situation where an activity is not possible or is not applied although it is possible. The *basic level* is characterised by logistics activities that are planned based on incomplete, inaccurate, or outdated historical data on product demand. The *moderate level* is typified by logistics activities that are principally based on information on product availability and demand, but the information is not always available and not accurate (Ahumada & Villalobos, 2009). The *advanced level* is characterised by the use of reliable real-time information on product availability, actual demand, and product quality requirements (van der Vorst *et al.*, 2011).

For quality control activities, the criteria used to differentiate the levels are the use of scientific knowledge, advanced and standardised equipment, procedural methods, and systematic activities in determining the control activities as in the previous studies (Luning *et al.*, 2008; Kirezieva *et al.*, 2013a). The *low level* represents a situation where an activity is not possible or is not applied, although it is possible. The *basic level* is characterised by the use of procedural methods that are based on general knowledge or own experience, the use of basic or even outdated equipment, and ad hoc quality control activities. The *moderate level* is typified by procedural methods that are based on expert knowledge or sector guidelines, use of potentially capable equipment, and common quality control activities. The *advanced level* is typified by the use of procedural methods based on scientific knowledge, the use of advanced equipment, e.g. computerised grading system, which is standardised and internationally acknowledged, and quality control activities that are product specific and statistical underpinned (Luning *et al.*, 2008).

Likewise, for the context characteristics, grids differentiated three stereotype situations (low, moderate, and high) representing products, or process, or organisation, or chain environment characteristics that create vulnerability to PHL; similar to earlier defined context riskiness (Luning *et al.*, 2011b; Kirezieva *et al.*, 2013b).

3.3.2 Development of questionnaire

A structured questionnaire with closed specified answer categories was developed to systematically collect data to assess the implemented logistics control activities (21 questions), quality control activities (30 questions), the context characteristics (23 questions), and the PHL (11 questions) using the grids. The specified answer categories were linked to the grid descriptions to enable the differentiated assessment. The questionnaire consisted of four sections. Section A solicited for general information, such as name, gender, age, and location of the farmers. Section B included the questions to analyse and assess the logistics and quality control activities. Questions in section C solicited information on context characteristics, wherein the respondents operate. Section D included the questions to obtain information on the PHL.

3.4 Tomato supply chain case study

A case study was conducted in tomato supply chains in Zimbabwe to gain insight into the extent to which the core logistics and quality control activities are implemented in view of the context characteristics and the PHL generated.

3.4.1 Selection of tomato farmers

Farmers were considered for the interviews in relation to their involvement in every postharvest stage in the chain, i.e. harvesting, grading and sorting, storage, and transportation. The snowball sampling technique (Biernacki & Waldorf, 1981) was used to select the farmers. Four of the biggest fruit and vegetable retailers and two wholesalers who sell fruits and vegetables in Harare were selected from a list of fresh produce traders in Harare (eMkambo, 2015) and asked to identify farmers supplying them with tomatoes for resale. Four middlemen selected using random numbers from the records of fruit and vegetables traders at Mbare Musika, kept at the Municipality of Harare offices at Mbare Musika, were also asked to identify farmers supplying them with tomatoes for resale. The snowball approach resulted in a final list of 36 farmers who were interviewed.

Table 3.1 shows the type and characteristics of farmers interviewed. The farmers represented the three categories of farmers in Zimbabwe as indicated by Gambiza & Nyama (2000): small-scale subsistence farmers (SS-SF), small-scale commercial farmers (SS-CF), and large-scale commercial farmers (LS-CF).

3.4.2 Interviews

Data were collected through face-to-face interviews using the questionnaire (See section 3.3.2) from April to May 2015, which is the peak season for the harvesting of tomatoes grown in the months December 2014 and January 2015. Each interview took an average of one hour. For each question in sections B and C of the questionnaire, the farmers were asked to choose the performance level which was most representative of their situation in terms of (i) logistics control and quality control activities, and (ii) context vulnerability, respectively.

Table 3.1 Typical characteristics of small-scale subsistence, small-scale commercial, and large-scale commercial farmers interviewed

Type of farmer	Typical characteristics
Small-scale subsistence farmers (*n*=13)	• Land size: less than 1 hectare • Method of irrigation: rely on natural rainfall • Labour: family members • Land ownership: most farmers do not have title deeds to the land • Marketing of produce: supply mostly to open markets and to middlemen
Small-scale commercial farmers (*n*=14)	• Land size: less than 10 hectares • Method of irrigation: most of the farmers rely on irrigation system, while a few on natural rainfall • Labour: mostly hired or contract workers • Land ownership: most farmers have title deeds to the land and some have lease agreements • Marketing of produce: supply directly to both formal and open markets, and rarely to middlemen
Large-scale commercial farmers (*n*=9)	• Land size: above 10 hectares • Method of irrigation: Rely mainly of irrigation system • Labour: mostly hired or contract workers • Land ownership: most farmers have title deeds to the land and some have lease agreements • Marketing of produce: supply directly to formal and rarely to open markets

3.5 Data processing and analysis

3.5.1 Assigning scores to the qualitative grids

For the context situation, descriptions for the low, moderate, and high vulnerability correspond to scores 1, 2, and 3 respectively. The higher the score, the more vulnerable is the particular context characteristic. For the logistics and quality control activity grids, the situational descriptions for low, basic, moderate, and high level correspond to the scores 1, 2, 3, and 4 respectively. The higher the score, the more advanced the logistics and quality control activities implemented. A particular context situation and a logistics or quality performance level was assigned based on the answer(s) to the question(s) and the observed logistics and quality control practices (e.g. how the harvested product is stored). The scores were discussed with the respective farmer; in case the farmer had a different opinion on the assigned score. In a case a farmer did not agree with the assigned score, reasons were explained for the assigned scores in order to reach a consensus.

3.5.2 Frequency and mode analysis of individual scores

Performance scores for logistics and quality control activities, and scores for the vulnerability of the context situation for each farmer were uploaded into IBM SPSS Statistics, version 23 (2015) for Windows. The frequency for individual scores and the mode were calculated and used to construct spider web profiles for each cluster of farmers.

3.5.3 Calculation of postharvest losses

In Section D of the questionnaire, data were gathered to assess quantitative PHL. Quantitative PHL were calculated by subtracting the weight of the tomatoes at each postharvest stage from the weight recorded on the previous stage, and the difference in weight was expressed as a percentage of the initial weight. The total PHL for the chain was then calculated by adding up the percentage PHL of each postharvest stage.

3.5.4 Hierarchical cluster analysis

Initial appreciation of the data set, by calculating the mean, mode values and standard deviations, and making spider webs for each group of farmers, showed that the initial categorisation of the farmers based on the typical characteristics (Table 3.1) did not show clear distinctions in terms of scores for the respectively context vulnerability, logistics and quality control activities, and PHL. Hierarchical cluster analysis was then performed with the furthest neighbour method and squared Euclidean distance, using IBM SPSS Statistics version

23 (2015) for Windows, to analyse how farmers could be clustered based on their similarities in context vulnerability, logistics and quality control activities, and PHL. This approach corresponds to analyses in other studies using similar types of diagnostic tools with multiple indicators and various groups of respondents (Luning *et al.*, 2013; Kirezieva *et al.*, 2015b). The mode values for each indicator and for the PHL were then calculated, and spider webs were made for each cluster of farmers.

3.6 Results and Discussion

3.6.1 Diagnostic tool developed from literature review

Conceptual framework

Figure 3.1 presents the structure of the conceptual framework, which consists of (i) 16 context characteristics, (ii) six core logistics control activities and 11 core quality control activities, and (iii) one indicator for the system output.

The **context characteristics** relate to features of the products, process, organisation, and the supply chain environment. These characteristics cannot be changed in the short-term or not at all, but do influence the incidence of PHL. Therefore, the logistics and control activities should be adapted to the context situation to avoid or minimise PHL. Identified *product characteristics* that influence PHL are product perishability (Aidoo *et al.*, 2014) and features of produce variety (Yahia *et al.*, 2004). Features of the processing, storage (Hodges *et al.*, 2010; Gustavsson *et al.*, 2011), and transport facilities (Hodges *et al.*, 2010; Kitinoja, 2013), and the method of cultivation used are the *process characteristics* identified to create conditions that enhance the incidence of PHL. As for *organisational characteristics*, competences of employees (Kitinoja*et al.*, 2011), the commitment of management (Sibomana *et al.*, 2016), the employee involvement, the workforce composition (Luning *et al.*, 2011b; Aidoo *et al.*, 2014), and the availability of capital resources (Kitinoja, 2013) were identified to create conditions that enhance the generation of PHL. Identified *supply chain characteristics*, are the type of stakeholder requirements (Gustavsson *et al.*, 2011), the stability of produce prices at the market (Parfitt *et al.*, 2010; Gustavsson *et al.*, 2011), the power in supplier relationships (Kirezieva *et al.*, 2013b), and the degree of external support services (Kitinoja *et al.*, 2011).

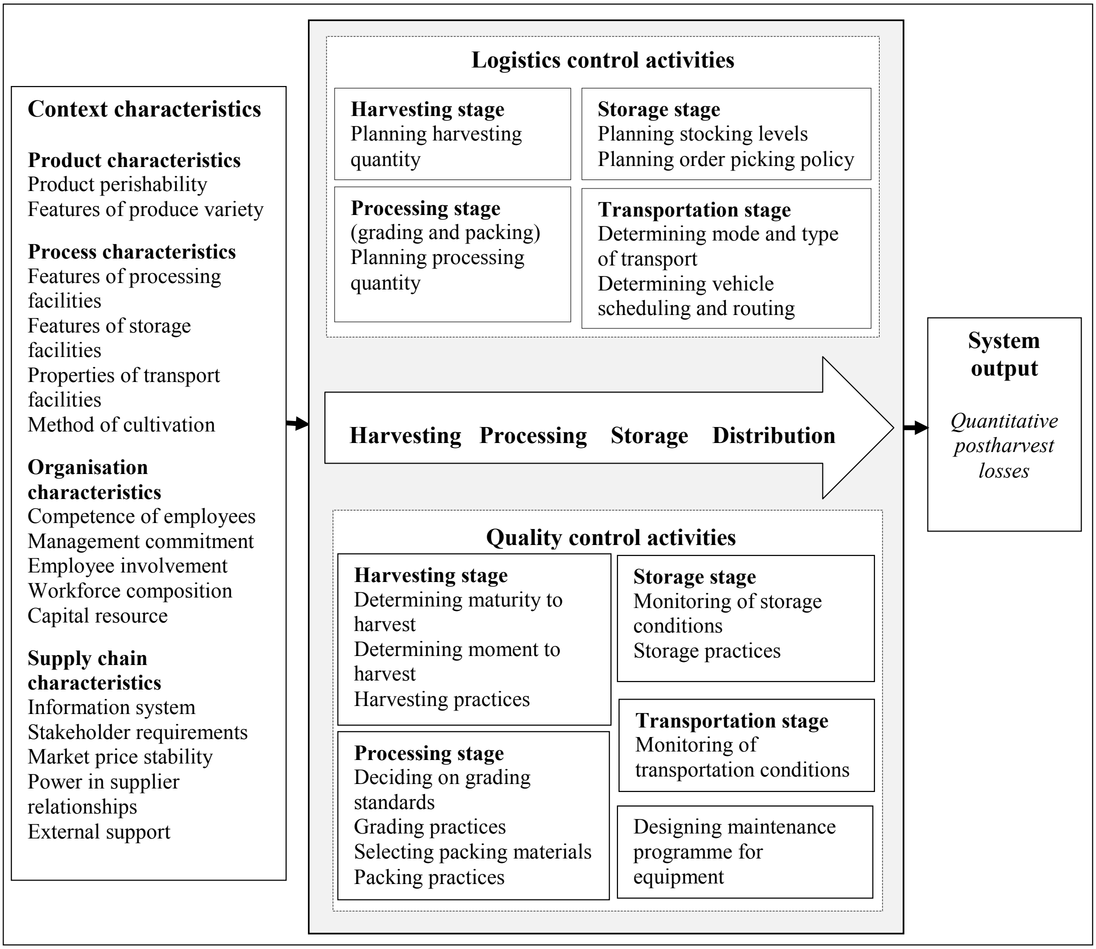

Figure 3.1 Conceptual framework showing the context characteristics, core logistics and quality control activities and postharvest losses

Figure 3.1 also shows the core **logistics activities** that can affect PHL. These activities are: *planning on the amount of fresh produce to harvest and to process* (Ahumada & Villalobos, 2011a; Mena *et al.*, 2011), *selecting issuing policies*, *selecting mode of transportation* and *type of vehicle*, and *vehicle scheduling and routing* (Tsolakis *et al.*, 2013). Additionally, Figure 3.1 shows the core **quality control activities** that can affect PHL. These activities are: *determining the maturity at which to harvest* (Shewfelt, 2009), *deciding on the moment of harvest,* e.g. time of day (Yahia *et al.*, 2004), *harvesting practices*, *packing practices,* e.g. packing configuration (Martinez-Romero *et al.*, 2004), storage practices, e.g. stacking method

(Macheka *et al.*, 2013), *use and type of grading standards* (Gustavsson *et al.*, 2011), *selection of the appropriate packaging material* (Kitinoja, 2013), *monitoring of temperature* during storage and transportation (Hertog *et al.*, 2007), and *maintenance of equipment* (Luning *et al.*, 2008).

Finally, Figure 3.1 presents the **output,** which is the PHL. Quantitative loss was used as the indicator to measure the performance of logistics and quality control activities. Quantitative loss relates to fresh produce that is completely spoiled, becoming inedible and thrown out of the chain, thereby reducing the quantity of produce available to the consumer (Hodges *et al.*, 2010; Johnson-Kumolu & Ndimele, 2011).

3.6.2 Operational diagnostic tool

Table 3.2 shows the grids to assess the vulnerability created by the **context characteristics** that could affect the incidence of PHL. The assumption is that fresh produce chain operating in a highly vulnerable context combined with more basic logistics and quality control activities would generate more PHL. To illustrate for the context characteristic "product perishability", a situation is considered highly vulnerable to the incidence of PHL when fresh produce is highly perishable (shelf life less than 5 days) and has a soft protective outer layer, making it more prone to physical injury and quality decay. A situation is considered less vulnerable when the product has a relatively hard natural protective outer layer, which can protect produce from mechanical injury (Sivakumar *et al.*, 2011).

For the core **logistics control activities,** the grids show the descriptions representing low, moderate, and advanced levels (Table 3.3). To illustrate for "planning quantity to harvest activity", the advanced level is typified by determination of product quantity to harvest that is demand driven and based on real-time information about available product quantity and about the available product demand (Adepoju, 2014; Aidoo *et al.*, 2014). Typical for the moderate level is that the quantity of produce to harvest is determined based on demand forecast, which relies on historical data on demand for the produce. The basic level is typified by harvesting of all ripe produce without considering the available demand and the product is pushed into the market irrespective of the demand (Gustavsson *et al.*, 2011).

Table 3.4 presents the assessment grids for the core quality control activities. Similar to the logistics control grids, the quality control grids show the descriptions representing low, moderate, and advanced levels. To illustrate for the activity "determining maturity to harvest", a situation is considered as advanced when fresh produce of different maturity levels is harvested separately to increase the batch homogeneity (Schouten *et al.*, 2007). The moderate level is typified by fresh produce that is harvested based on consumers' quality requirements, but at times consumers' requirements are ignored, resulting in some batches containing produce of mixed maturity and ripeness. The basic level is characterised by harvesting of all maturity and ripeness stages, resulting in batches of heterogeneous maturity and ripeness.

Table 3.2 Grids to assess the vulnerability to PHL inherent to the context characteristics

Context characteristic	Mechanism	Vulnerability		
		Low level (score 1)	Moderate level (score 2)	High level (score 3)
Product characteristics				
Product perishability	• When produce is highly perishable (shelf life less than 5 days) and has a soft protective outer layer, then produce is more prone to physical injury and quality decay, increasing the chance for the incidence of PHL.	• Produce has a hard-natural protective outer layer which protects produce from mechanical damage. • Physiological processes such as respiration, ripening, and pathological breakdown occur at a slow rate prolonging shelf life (10 to 14 days).	• Produce has a relatively hard-natural protective outer layer and physiological processes occur at a relatively slow rate. • Shelf life of produce is between 5 and 10 days	• Short shelf life (1-5 days) and produce has a soft natural protective outer layer, which is prone to mechanical damage. • Limited shelf-life of between 1-4 days.
Features of produce variety	• When the varieties grown are more prone to pests and diseases, and to natural deformations, then produce quality is likely to be poor, increasing the chance for the incidence of PHL.	• Variety grown is a pure hybrid and specifically breed against certain diseases and adverse environmental conditions. • Only seeds from seed houses are used	• Variety grown is either a pure hybrid or open pollinated variety but is resistant to major diseases. • Only seeds from seed houses are used	• Variety grown is an open pollinated variety (OPV) and the seeds used are from the previous tomato crop. • The variety is prone to frost, diseases, insect damage, and physiological disorders
Characteristics of processing and storage facilities	• When processing and storage facilities are not conditioned to provide optimum humidity and temperature conditions, then the produce is likely be exposed to conditions that favour quality deterioration, increasing the chance for the incidence of PHL. •	• Processing and storage facilities are conditioned and have capabilities to adjust temperature and humidity to the required conditions for preserving produce quality.	• Processing and storage facilities are not conditioned • However, basic conditioning is done e.g. through the opening of windows to improve air circulation.	• Processing and storage facilities are not conditioned • Produce stored in open air

Context characteristic	Mechanism	Vulnerability		
		Low level (score 1)	Moderate level (score 2)	High level (score 3)
Transport facility properties	• When fresh produce is transported in unconditioned environment, e.g. open trucks, then produce is likely to be exposed to conditions that favour quality decay, increasing the chance for the incidence of PHL.	• Mode and type of transport used have capabilities to condition temperature and humidity	• Transportation facilities are not conditioned • However, basic conditioning is done, e.g. covering the produce with tarpaulins to avoid sunlight and rain.	• Transportation facilities are not conditioned • Produce not covered during transportation and exposed to all weather conditions.
Method of cultivation	• When the crop is grown in open fields and dependent on natural rainfall, then chances for the crop to be affected by adverse environmental conditions, e.g. frost and insect- pests, are high, increasing the chance for the incidence of PHL.	• The crop is grown under greenhouse; protecting the crop from adverse environmental conditions, such as extreme heat and direct sunlight • Irrigation system is used to water the crop.	• The crop is grown in open field and reply on irrigation system for watering the plants	• The crop is grown in open field and rely on natural rainfall: exposing the crop to adverse environmental conditions and insect-pests
Organisational characteristics				
Competence level of employees	• When operators do not have the required knowledge, skills or experience in fresh produce handling, then they may inadequately execute the logistics or quality control tasks, increasing the chance for the incidence of PHL.	• Operators have relevant technical knowledge, training, and experience in postharvest management.	• Operators have technical knowledge and training in postharvest management, but lack experience.	• Operators do not have technical knowledge, training and, experience in postharvest management.
Management commitment	• When management's commitment on preventing PHL is limited, e.g. does not invest in postharvest equipment and facilities, and	• The company has a written mission statement on postharvest with clear measurable objectives.	• The company has a written mission statement on quality assurance with clear measurable objectives.	• The company has no written mission statement on quality assurance • Investment into improving

Context characteristic	Mechanism	Vulnerability		
		Low level (score 1)	Moderate level (score 2)	High level (score 3)
	employees' competences, then it can negatively affect operators' commitment to properly execute their duties, increasing the chance for the incidence of PHL.	• The company has a financial budget dedicated to improving postharvest management infrastructure and training of employees on good postharvest management practices.	• The company's investment into training of employees on good postharvest management, but investment into postharvest infrastructure is minimal.	postharvest management. The company's investment into infrastructure and training of employees on good postharvest management practices is minimal.
Employee involvement	• When employees are not involved in the set up or improvement of logistics and quality activities, then they can be less aware or less motivated to perform the tasks properly, increasing the chance for incidence of PHL.	• Employees are explicitly involved in the design and modifications of quality and logistics control activities (e.g. part of the committee that drafts or revise operational procedures).	• Employees are asked to provide suggestions for improvement, but are not involved in the actual design and modifications of quality and logistics control activities	• Employees are only informed about the design and modifications of quality and logistics control activities. • Employees are not asked to provide suggestions for improvement.
Workforce composition	• When the workforce constitutes mainly of contract or temporary employees, then the competence level is more variable, which could lead to inadequate execution of quality or logistic tasks, increasing the chance for the incidence of PHL.	• The workforce is composed of mainly permanent workers and a few contract workers, who are assigned duties that do not require major decision making. • All supervisory roles are assigned to permanent workers.	• The workforce is equally composed of permanent and temporary workers. • However, some temporary workers are assigned supervisory roles that require crucial decision-making (e.g. whether to accept or reject a batch.	• The workforce is composed mainly of contract and temporary works. • These workers are assigned key tasks that require important decisions making.
Capital resource	• When resources, such as finance, are limited, then the potential to invest in new technology, such as intelligent packaging, and in advanced facilities, such as cold rooms, is limited, increasing the	• Capital resources are available • Investment is made on new equipment, facilities and technology (e.g. cold rooms and refrigerated trucks)	• Limited capital resources are available • Investments are made toward modern technology but of lower value, e.g. digital weighing scales.	• Lack of capital resources • No budget dedicated towards reducing PHL

Context characteristic	Mechanism	Vulnerability		
		Low level (score 1)	Moderate level (score 2)	High level (score 3)
	chance for the incidence of PHL.	• There is a budget dedicated towards reducing PHLs	• Limited budget available	
Chain environment				
Information system	• When the information system is not centralised and each actor manages own information system, then access and availability of real-time information on quality, quantity, and demand of produce along the chain is limited, increasing uncertainty on demand, produce quality and quantity, leading to wrong decision-making, and increasing the chance for the incidence of PHL.	• Information system is centralised • The information is easily available to all actors in the chain • Information is accurate, timely, credible, complete, relevant, and frequently updated.	• Information system is centralised • However, there are delays in updating information such that it is not real-time information • Some actors do not have access; therefore, information is not always complete	• Lack of information system in the chain. • Where available, information not easily accessed by other actors in the chain as it does not cover the whole chain.
Stakeholder requirements	• When stakeholders' requirements are too strict, inflexible and more concerned with aesthetic requirements (e.g. shape and size of produce), then rejection of produce will be high, increasing the chance for the incidence of PHL.	• Stakeholder requirements are flexible, e.g. different quality grades are accepted. • Quality specifications do not consider imperfections such as shape and size of produce.	• Stakeholder requirements are flexible to some extent: product of different quality grades is accepted at times. • Imperfections such as shape and size are considered in some cases.	• Stakeholder requirements are strict: only top quality produce is required and specifications are more concerned with aesthetic requirements, such as shape and size of produce.
Market price stability	• When market prices fluctuate so much that prices vary for produce of same quality within same day, then farmers are not able predicable supply and demand	• Market prices are stable such that farmers can easily predict any fluctuation that can occur. • The price is purely determined by demand and	• Market prices are stable to some extent, can be constant up to 3-4 days. • Prices rarely fluctuate within a single day.	• Market prices are not stable and highly fluctuate. • Prices can change twice within a single day. • Produce of the same quality can

Context characteristic	Mechanism	Vulnerability		
		Low level (score 1)	Moderate level (score 2)	High level (score 3)
	trends, which can result in high loss in terms of potential revenue that is lost as a result of very low market prices.	supply forces.		be sold at different prices due to the price fluctuations.
External support services	• When there is limited support (e.g. credit facilities, training on postharvest management), to chain actors, then chances for inadequate postharvest management practices and facilities are high, increasing the chance for the incidence of PHL.	• Chain actors receive commendable support from the government and non-organisational organisations and private sector, e.g. financial support, training, and marketing support.	• Limited support from government and NGOs in the form of limited financial loans and basic training.	• There is no support from the government and NGOs.
Power in supplier relationship	• When farmers have less influence on prices and quality specifications, then retailers are likely to set strict specifications and low prices, leading to high chances for rejection of produce by the retailers and loss in potential revenue by the farmers: increasing the chance for the incidence of PHL.	• Power in the chains is shared and all actors have equal influence in the chain: no one actor is dominant. • Produce prices and quality standards are negotiated between actors in the chain.	• Power is shared in the chain to some extent. • Market prices and quality standards are negotiated to some extent, especially in a period of scarcity.	• Very few actors have the power to influence all activities in the chain. • Farmers have less negotiation power.

Table 3.3 Grids to assess logistics control activities in fresh produce chains

Core logistics control activities	Assumption	Level of control		
		Basic (level 2)	Moderate (level 3)	Advanced (level 4)
Harvesting stage				
Planning quantity to harvest	When quantity to harvest is determined based on real time information on available product and the actual demand available, then chances for over-supply is limited, contributing to reduced PHL.	• All ripe produce is harvested without considering available demand. • Produce is pushed into the market irrespective of demand	• Quantity of produce to harvest is mainly determined based on demand forecast. • Relies on historical data on demand for the product	• Quantity of produce to harvest is demand driven. • Decided based on real-time information on actual product available and demanded volumes.
Planning quantity to process	When the quantity of produce to process is demand driven, then low stock levels can be kept, minimising the incidence of PHL.	• Produce is graded and packed without any orders or information on market demand. • Information on market demand is not available	• Amount of produce graded and packed is based on historical data on processing volumes and market demand	• Quantity of produce processed is based on customer orders and real-time information on actual market demand.
Planning stocking levels	When the amount of produce to stock, i.e. safety stock, is decided based on product's quality attributes, such as shelf-life and produce quality, and information on product demand, then incidences of over-stocking, which can result in spoiled or obsolete product, are minimised, limiting the incidence of PHL.	• Considerable stocks of produce are kept, mainly for speculative purposes, such as, better prices. • Product quality attributes, such as remaining shelf-life, are not considered in determining stocking levels.	• Limited inventory is kept. • Stocking levels are determined based on historical information on demand forecast. • Product shelf-life is rarely considered.	• No inventory is kept as produce is harvested and delivered to the market on the same day. • In rare instances when produce is stored, stocking levels are based on real-time information on demand and product quality
Planning order picking	When order picking is based on product quality and time-temperature history information, then incidences of produce deteriorating during storage can be minimised, limiting incidence of PHL.	• Order picking is strictly on first-in-first-out basis (FIFO); without considering the quality status of the produce. • Age of batch is considered.	• Order picking policy is based on historical data (e.g. time-temperature) and also on visible product quality, such as defects.	• Order picking is flexible and based on time-dependent quality information. • Produce with highest chance to deteriorate and with lowest shelf-life is picked first.

Determining the mode and type of transportation	When vehicles used have the required capacity and allow fast transportation of the produce under protective conditions (maintains a cold chain), then the chances for quality deterioration during transportation are reduced, limiting the incidence of PHL.	• The mode and type of transport used does not have the capabilities to maintain a cold chain. • Lack protection to prevent physical injury to produce	• The mode and type of transport used does not have the capabilities to maintain a cold chain. • However, it provides enough protection to prevent physical injury to produce	• Type of transport used has adequate capabilities to maintain a cold chain (e.g. refrigerated trucks are used). • Provides protection against physical injury to produce.
Vehicle scheduling and routing	When distribution of fresh produce is done through the shortest possible route, which also has fewer stops, then produce is delivered to consumers in the shortest possible time whilst still fresh, minimising the incidence of PHL.	• Produce is transported through public transport, which is not reliable and takes longer time to reach the market. • There are many stops and diversions	• Transport used is dedicated to ferry fresh produce only but there are many stops and diversions from the main route to deliver produce other markets off the main route.	• Transport is dedicated to produce meant for the same market and there are no diversions from the main route to deliver produce to other markets.

Low level (level 1), which is not shown in the table, represents a situation where an activity is not possible or not applicable, or is not applied, although it is possible

Table 3.4 Grids to assess quality control activities in fresh produce chains

Core quality control activities	Assumption	Level of control		
		Basic (level 2)	Moderate (level 3)	Advanced (level 4)
Determining maturity to harvest	When maturity at which produce is harvested is based on quality standards, ripeness stage required by consumers, and on product shelf life required by customer, then chances of the produce being rejected by consumers for being over- or-under ripe are low, limiting the generation of PHL.	• All maturity stages, i.e. just ripe, ripe and fully ripe, are harvested and supplied to the market without considering specific customer requirements	• Maturity at which produce is harvested is mainly based on consumer's quality requirements. • At times, produce of mixed maturity stages is harvested and supplied to the market.	• Maturity at which produce is harvested is strictly based on consumer's quality requirements. • Maturity at which produce is harvested is not fixed and varies as per customer order.
Determining moment to harvest	When the moment of harvest is determined based on the cool hours of the day (early morning or late afternoon), then exposure of produce to high temperatures during harvesting is minimised, slowing down the rate of quality decay and senescence processes, limiting the generation of PHL.	• Moment of harvest is fixed; harvesting is either done in the morning, mid-day or late afternoon. • Weather conditions are not usually considered.	• Moment of harvest is not fixed and produce is harvested when the weather conditions are cool and dry. • However, sometimes weather conditions are ignored, especially when there are ready customers.	• Moment of harvest is not fixed and produce only harvested when the weather conditions are favourable.
Harvesting practices	When the most appropriate method of harvesting is used (manual versus mechanical) and pickers are provided with up-to-date harvesting manuals, which are written in a language understood by the pickers, then minimal mechanical injuries to the produce are expected, limiting the generation of PHL.	• Fresh produce is harvested manually only (due to lack of financial resources). • There are no manuals available for use by pickers.	• Fresh produce is harvested manually • However, pickers are provided with manuals on proper harvesting techniques.	• The most appropriate method of harvesting is used and harvesting. • Manuals on proper harvesting techniques are comprehensive, accompanied with visual aids, and easily understandable by pickers, and kept-up-to-date.

Deciding on grading standards	When grading standards clearly define the degree of ripening, colour, size, or the weight, required, and clearly stipulate what to do with out-of-spec fresh produce (e.g. sorting for alternative market), then chances of a homogeneous batch are high, limiting the generation of PHL.	• Specifications are strict, have a low tolerance range, and only high quality produce accepted. • Produce that do not meet the standards is rejected or discarded as waste.	• Produce classified into different grades • Specifications do not clearly stipulate what to do with out-of-spec fresh produce.	• Specifications are flexible and allow for classification of produce into different grades • The standards specify what to do with out-of-spec fresh produce.
Grading practice	When the grading process is automated, equipment with high precision and accuracy is used is used, quality attributes such as total soluble sugars are measured, and grading operators are provided with procedure manuals written in the language understood by employees, then produce is sorted into more homogeneous batches and decision-making by grading personnel is improved, limiting the generation of PHL.	• Grading is done manually and no measurements on quality attributes are done. • Visual assessment is done based on colour, size, and blemishes • There are no procedures for grading available for use by personnel involved in grading	• Grading is done manually. • Visual assessment is done based on colour, size, and defects. • Manuals for grading are available and accompanied by visual aids. • However, the manuals are not usually updated.	• Grading is automated and is based on parameters such as colour, size, weight, shape, and defects. • Manuals are up-to-date, easily understandable, and accompanied with visual aids
Selecting packaging material	When packaging material is selected based on type of produce to be packed, level of protection required, and based on consumer requirements, then chances of physical damage (bruising, compression damage etc.) and rejection of produce due to inappropriate packaging is limited, minimising the generation of PHL.	• Packaging material is not appropriate for both protection against microbial contamination and physical damage. • Same packaging material is used irrespective of market/customer supplied.	• Packaging material is aimed at preventing growth of micro-organism and providing protection against physical damage, but not on maintaining atmospheric conditions.	• Packaging material provides good protection from mechanical injury and adverse environmental conditions. • Furthermore, packaging material used vary depending on customer requirements.
Packing practices	When each packed produce is weighed to control over-filing and under-filling, and operators are provided with up-to-date procedure manuals on proper packing practices, then compression, abrasion or bruising damages are avoided, limiting the generation of PHL.	• Produce is packed until containers are full and no weighing is done. • Incidences of under-and over filling are common.	• Produce is correctly packed to avoid over-and under filling, but not every pack or batch is weighed; only a few samples are weighed. • Procedures are not available for personnel packing to use.	• Produce is correctly packed and each pack is weighed to avoid under and -over filling and ensure correct amount of produce is packed. • Packers are provided with up-to-date manuals.

Storage practices	When fresh produce is stored separately based on product characteristics, e.g. storing climacteric and non-climacteric produce separately, and is stacked on pallets with a space of 1 metre maintained between stacks to allow air circulation, then incidences of cross contamination and quality decay due to ethylene injury or sub-optimal storage conditions are minimised, limiting the generation of PHL.	• Produce of different product characteristics is stored in same room. • Produce clustered together without clear separation and stacked directly on the ground	• Produce of different product is stored in the same storage room • However, produce is stacked on pallets at a reasonable distance apart from each other.	• Produce of different product characteristics such as sensitivity to temperature and ethylene are stored separately in different storage rooms. • Produce is stacked on pallets and a distance of 1 metre is maintained between stacks.
Maintenance of measuring equipment	When the maintenance (e.g. calibration) of measuring equipment, such as thermometers, is scheduled and specific instructions on frequency and tasks are provided, then precision of measuring equipment is maintained, leading to consistent product quality, fewer unexpected quality problems, and limited generation of PHL.	• Maintenance of equipment is reactive, as equipment is only maintained after breaking down.	• Maintenance is ad-hoc and there is no schedule of maintenance activities. • Instructions concerning frequency and maintenance tasks are not documented.	• Maintenance is scheduled and carried out based on data from regular inspections and breakdown analyses. • Specific instructions on frequency of maintenance tasks are well documented.
Monitoring of temperature and humidity *Combined for both storage and transportation*	When monitoring of temperature and humidity conditions is systematic and scheduled, then control of storage conditions will be improved leading to limited incidences for out of control conditions which can cause physiological disorders, limiting the generation of PHL.	• No monitoring is done and no measurement of storage conditions is recorded.	• Measurement is done on an ad hoc basis using basic equipment • Corrective action takes time to be implemented as measurements are done on ad hoc basis.	• Advanced modern technology which is precise, accurate and reliable is used • Corrective action is taken promptly for out-of-specification conditions.

3.7 Case study results

3.7.1 Hierarchical cluster analysis

Figure 3.2 presents the results of the hierarchical cluster analysis performed to group the 36 farmers, according to similarities in context characteristics, performance of logistics and quality control activities, and the generated PHL. Cluster I consists of all large-scale commercial farmers (9) and most (11 out of 14) of the small-scale commercial farmers, while cluster II consists of all small-scale subsistence farmers (13), and a few (3 out of 14) small-scale commercial farmers.

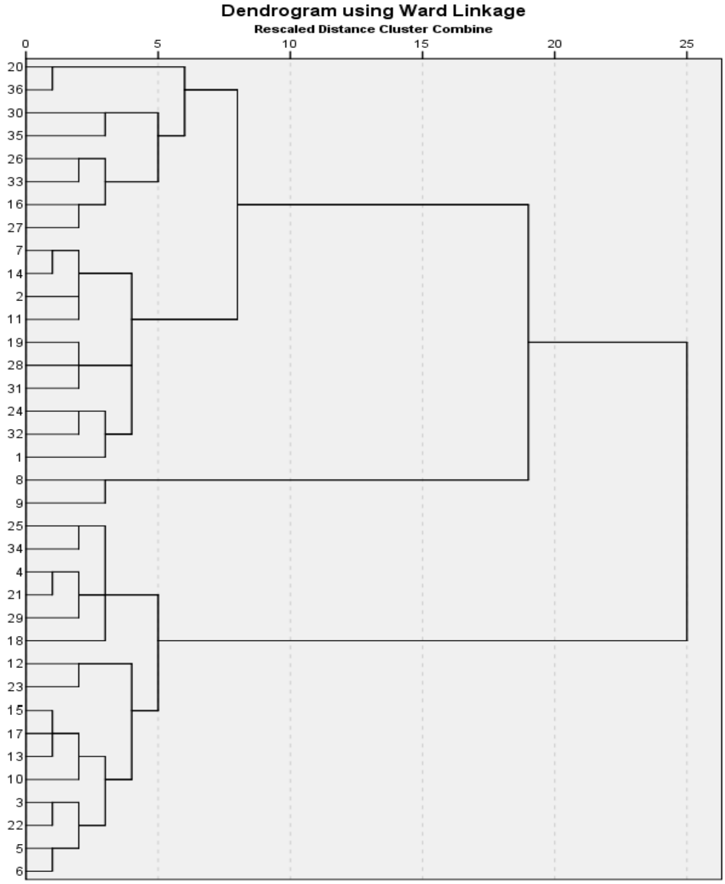

Figure 3.2 Dendogram showing clustering of farmers based on vulnerability of context characteristics to the generation of PHL and performances of logistics and quality control activities.

3.7.2 Profiles of context characteristics, logistics and quality control activities, and postharvest losses

Table 3.5 and 3.6 show the frequency of the individual scores and mode scores for context characteristics and for logistics and quality control activities, respectively. The mode scores were then used to construct the spider webs shown in Figure 3.3. Figure 3.3 illustrates the context vulnerability and the level of the implemented logistics and quality control activities, as well as the amount of PHL at each stage in the chain. The spider webs show that the commercial farmers (cluster I) operate overall in a moderately vulnerable context, as11 of the 16 context characteristics scored *2*. The implemented logistics control activities perform at a basic level, as 4 of the 6 indicators scored *2*. For the quality control activities, the commercial farmers perform at a basic to moderate level: 4 of the indicators scored *2* and 5 indicators scored *3*. On the contrary, the subsistence farmers (cluster II) operate overall in a highly vulnerable context, as 10 of the 16 context characteristics scored *3*. The farmers perform at a basic level for both logistics control activities and quality control activities, as 5 of the 6 logistics indicators scored *2*, and 7 of the 11 quality control indicators also scored *2*.

The graph shows that overall, cluster I farmers generated less PHL, i.e. 1% (86 kg/month) compared to cluster II farmers, who generated 3% (154 kg/month). The recorded amount of PHL for farmers in both clusters is low in comparison with figures reported in literature, which range from 10% to 40% (Aidoo *et al.*, 2014; Addo *et al.*, 2015b; Sibomana *et al.*, 2016). However, we found that in the Zimbabwean situation, there is a market for every tomato quality level, due to sun drying and street food vending, except only for those that are no longer edible (Gadaga, *et al*., 2008). This could be the reason for the low PHL experienced by both farmers.

Multiple studies (Adepoju, 2014; Aidoo *et al.*, 2014; Addo *et al.*, 2015b; Arah *et al.*, 2015b; Sibomana *et al.*, 2016) provide multiple causes for the differences in PHL for commercial farmers and subsistence farmers. The potential explanation given in the literature for this difference can be categorised into those associated with the context, or logistics control, or quality control.

Table 3.5 Frequency of the individual scores and mode scores for context characteristics for Cluster 1 farmers, (commercial farmers) and Cluster II farmers (subsistence farmers), mode score was then used to construct the spider webs

	Indicators	**Cluster 1** (*n=20*) *Frequency*				**Cluster 2** (*n=16*) *Frequency*			
		1[a]	2	3	**Mode**	1	2	3	**Mode**
Product characteristics	Product perishability	4	*13*	3	**2**[b]	0	2	*14*	**3**
	Features of produce variety	4	*10*	6	**2**	0	5	*11*	**3**
Process characteristics	Features of processing facilities	2	*6*	12	**3**	0	5	*11*	**3**
	Features of storage facilities	2	*13*	5	**2**	1	5	*10*	**3**
	Properties of transport facilities	3	4	*13*	**3**	0	6	*10*	**3**
	Method of cultivation	*14*	*5*	1	**1**	2	3	*11*	**3**
Organisational characteristics	Competence of employees	4	*12*	4	**2**	0	7	*9*	**3**
	Management commitment	4	*10*	6	**2**	3	4	*9*	**3**
	Employee involvement	4	6	*10*	**3**	0	1	*15*	**3**
	Workforce composition	3	*12*	5	**2**	2	*8*	6	**2**
	Capital investment	6	*10*	4	**2**	3	*8*	5	**2**
Supply chain environment characteristics	Information system	4	*11*	6	**2**	1	4	*11*	**3**
	Stakeholder requirements	6	*9*	5	**2**	4	*8*	4	**2**
	Market price stability	5	*11*	4	**2**	2	5	*9*	**3**
	Power in supplier relationships	5	*13*	2	**2**	4	3	*9*	**3**
	External support	*14*	4	2	**1**	5	8	3	**2**

[a]*Scores represent; 1 – low vulnerability , 2 – moderate vulnerability, 3 – high vulnerability*
[b] *The mode represent the most frequent score among farmers in the case study*

Table 3.6 Frequency of the individual scores and mode scores for the logistics and quality control activities for Cluster 1 farmers, (commercial farmers) and Cluster II farmers (subsistence farmers).

		Cluster 1 (*n=20*)					**Cluster 2** (*n=16*)				
	Indicators	**1**[a]	**2**	**3**	**4**	**Mode**	**1**	**2**	**3**	**4**	**Mode**
Quality control activities	Maturity to harvest	0	4	*13*	3	**3**[b]	2	*11*	3	0	**2**
	Moment to harvest	0	2	*14*	4	**3**	3	*9*	4	0	**2**
	Harvesting practices	3	*12*	5	0	**2**	4	*10*	2	0	**2**
	Grading standards	1	*13*	4	2	**2**	*11*	5	2	0	**1**
	Grading practices	0	*16*	4	0	**2**	6	*9*	1	0	**2**
	Packaging material	0	4	*14*	2	**3**	2	*9*	5	0	**2**
	Packaging practices	1	4	*13*	2	**3**	3	*9*	4	0	**2**
	Maintanance program	3	*13*	4	0	**2**	*15*	1	0	0	**1**
	Storage practices	2	*12*	3	3	**2**	4	*10*	2	0	**2**
	Monitoring storage conditions	14	3	1	2	**1**	*16*	0	0	0	**1**
	Monitoring transportation conditions	20	0	0	0	**1**	*16*	0	0	0	**1**
Logistics control activities	Harvesting quantity	5	*13*	2	0	**2**	*10*	5	1	0	**1**
	Processing quantity	7	*13*	0	0	**2**	4	*11*	1	0	**2**
	Stocking levels	0	5	*15*	0	**3**	3	*8*	5	0	**2**
	Order picking	0	3	*17*	0	**2**	6	*10*	0	0	**2**
	Mode and type of transport	4	*10*	3	3	**2**	2	*11*	3	0	**2**
	Vehicle scheduling	2	5	*13*	0	**3**	4	*9*	3	0	**2**

[a]*Scores represent; 1 – low level, 2 - basic level, 3 - average level, 4 - advanced level of performance*
[b] *The mode represent the most frequent score among farmers in the case study*

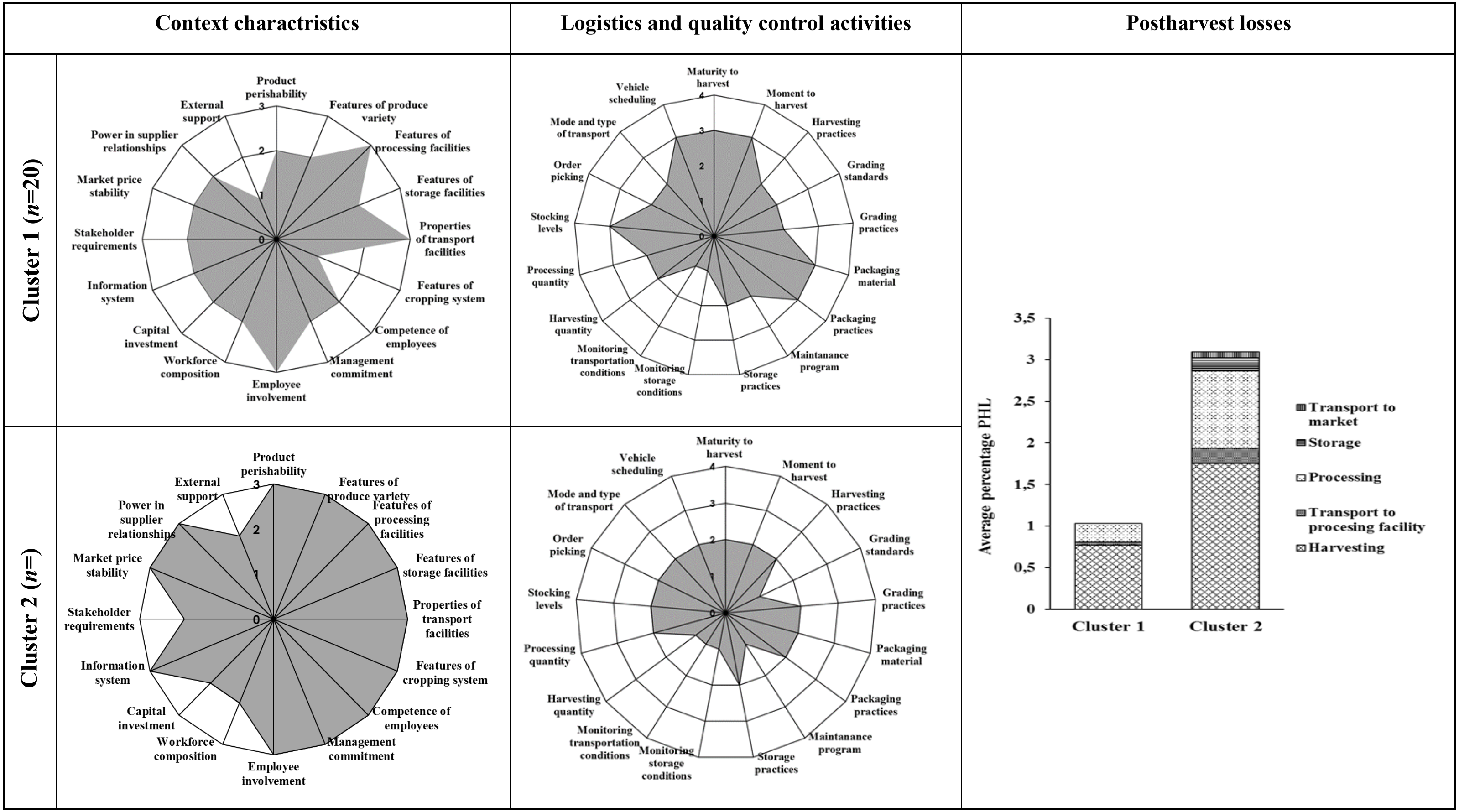

Figure 3.3 Spiderwebs depicting mode scores for logistics and quality control activities and bar graph shows the average postharvest losses (kg/month) for the two clusters of farmers. A highly coloured web diagram for context characteristics is associated with a high vulnerability to PHL if control activities are not implemented. For control activities, a highly coloured web diagram is associated with a more advanced level for the control activities

Typical context related characteristics attributed to the difference in PHL between commercial and subsistence farmers in literature are method of cultivation and varieties grown. Sibomana *et al.* (2016), who studied PHL in tomato supply chains in Sub-Saharan Africa, found that commercial farmers incur less PHL (8-10%) as compared to subsistence farmers who incur PHL of up to 30%. They attributed the low PHL in the tomato supply chain for commercial farmers to the use of greenhouses in growing the tomatoes, the use of disease resistant varieties, and the availability of good postharvest infrastructures, such as storage facilities. We also found that the lower PHL in the chain for commercial farmers (cluster I) as compared to that for subsistence farmers is associated with using greenhouse cultivation and varieties resistant to diseases, and having access to external support from banks and government by the commercial farmers. Tomatoes grown in greenhouses are protected from climatic conditions such as frost and strong winds, and from pests, and diseases (Madakadze & Kwaramba, 2004). Open field cultivation exposes the tomatoes to contamination from the environment (Nanyunja *et al.*, 2016). Furthermore, growing tomatoes from retained seed increases diseases in tomatoes (Korsten, 2006), leading to high PHL (Adepoju, 2014). We also found that most (16/20) commercial farmers had appropriate storage facilities and some (4/16) even had cold storage facilities. The farmers highlighted that access to financial loans from banks enabled them to invest in storage facilities, leading to a lower chance of PHL.

Other studies attributed PHL to various logistics activities. Studies on the causes of high PHL in tomato supply chains in Nigeria (Adepoju, 2014), and Ghana (Aidoo *et al.*, 2014; Addo *et al.*, 2015b) found that the road and transport conditions used by farmers are major causes for PHL. Adepoju (2014) reported that most subsistence farmers in Nigeria transport their produce to the market using either public transport or small and open trucks, exposing fresh produce to high temperature, dust, and mechanical damage. Aidoo *et al.* (2014) and Addo *et al.* (2015) attributed high PHL in the chains for subsistence farmers in Ghana to unrefrigerated trucks, long distance to markets, and bad road conditions. In our study, 13 of 20 commercial farmers used closed trucks to transport fresh produce to the market, while all the subsistence farmers used open trucks, and two subsistence farmers were even using ox-drawn carts, exposing the fresh produce to adverse environmental conditions.

Other studies focused on particular quality control measures as explanations for PHL. Erith, *et al.* (2013) studied causes of high in tomato supply chains in Africa and found that packing of tomatoes in wooden crates increases the chance of mechanical injury to the tomatoes. The impact of packaging on PHL is further discussed in a study on determinants of PHL in tomato supply chains by Arah *et al.* (2015b), who reported poor packaging (wooden crates with sharp edges) as one of the main determinants of PHL in tomato supply chains in Ghana. Kamrath *et al.* (2015) attributes PHL in tomato chains to the use of wooden crates that are poorly constructed and poor packing practices (tomatoes tightly packed and not properly secured). All these studies recommend that tomatoes should be packed in plastic crates to minimise chances for mechanical damage, which was a practice implemented by all commercial farmers in our study.

3.7.3 Usefulness of diagnostic tool

In contrast with previous studies that approach the problem of high PHL either from a logistics or quality control point of view, our diagnosis provides a comprehensive view on logistics and control, context, and the generated PHL from both the perspectives of the farmers and researchers. The diagnostic tool provides a systematic approach and gives a mechanistic view to the problem of PHL, i.e. PHL are not only affected by logistics and quality control activities, but context factors also have an impact. The developed diagnostic tool supported a concurrent analysis of context, logistics, and quality control activities as possible causes of generated PHL. The differentiated assessment can serve as a basis for the identification of interventions to develop towards more advanced logistics and quality control activities, and interventions to reduce the context vulnerability. The interventions differ in time span and costs and can be selected based on the existing resources for the different types of farmers. Subsistence farmers, who typically have low investment capacity, could implement short term and low costs interventions, while commercial farmers, who typically have a higher investment capacity due to access to financial loans, can implement long-term interventions.

3.8 Conclusions and considerations

In this study, we found that commercial farmers generated lower (1%) PHL as compared to subsistence farmers (3%) and the two groups of farmers differed in their context vulnerability and the implemented logistics and control activities. The commercial farmers operate in a less vulnerable context situation, because they use greenhouse cultivation, they use improved and resistant varieties, and they have better access to financial loans from banks. Furthermore, they have more advanced stocking levels and planning and vehicle scheduling, and implemented more advanced quality control activities at harvesting and packaging compared to the subsistence farmers. The subsistence farmers typically operate in a highly vulnerable context as they practice the open field cultivation, which exposes crops to adverse environmental conditions, and they use varieties prone to diseases. The farmers also have basic logistics and quality control activities implemented.

From a methodological perspective, the limited number of farmers interviewed, although representative of the tomato farmer types in Zimbabwe, could be seen as a limitation of our study. It prevented a clear distinction between small-scale commercial farmers and large-scale commercial farmers, and the small-scale subsistence farmers. Another limitation is that for calculating the PHL in this study, only the quantitative losses were considered. Considering other indicators of PHL such as economic loss, which is loss of revenue and/or income due to loss in value for low quality produce, might give a different picture of the PHL. Further research considering qualitative and economic losses, in calculating the PHL might enable a more nuanced view of PHL in fresh produce chains.

Chapter 4

Identification of determinants of postharvest losses in Zimbabwean tomato supply chains as basis for dedicated interventions

Based on: Macheka L, Spelt E, Bakker, E, van der Vorst J. G. A. J, Luning P. A (2018). Identification of determinants of postharvest losses in Zimbabwean tomato supply chains as basis for dedicated interventions. *Food Control 87 (C), pp 135-144*

Abstract

Postharvest losses (PHL) are a major problem in tomato supply chains, especially in tropical climates, as up to 40% of harvested fruits are estimated to decay along the chain. The study aimed at identifying which farmers' context characteristics, logistics and quality control activities relate with the incidence of PHL in tomato supply chains, particularly in Zimbabwe. Commercial and subsistence tomato farmers (n=197) from five major tomato-growing areas were analysed using a diagnostic tool to assess the status of the implemented logistics and quality control activities, the vulnerability of farmers' context, and the actual PHL. Hierarchical cluster analysis resulted in three clusters of farmers grouped based on similarities on context vulnerability and status of the implemented logistics and quality control activities. Spearman's rank correlation analysis and multiple linear regression analyses revealed that more advanced logistics and control activities, and context characteristics with a lower vulnerability to PHL are associated with less postharvest losses. The context characteristics, *features of storage facilities*, *method of cultivation*, and *market price stability* were significant determinants ($p<0.05$) and explained 29% (Adjusted R2 0.287) of the variation in the PHL. The logistics control activity, *determining processing volumes* was identified as a possible determinant ($p<0.05$) and explained 21% (Adjusted $R^2 = 0.205$) of the variation in the observed PHL. The quality control activities, *deciding on maturity to harvest*, *deciding on moment to harvest*, and *storage practices* were the identified determinants ($p<0.05$), which explained 23% (Adjusted $R^2 = 0.230$) of the variability in the observed postharvest losses. A framework of intervention strategies tailored to tomato farmers' development stage is proposed to support them in a step-wise improvement of logistics and quality control practices to reduce PHL and advance towards sustainable fresh produce chains.

4.1 Introduction

Tomato is one of the most popular vegetables worldwide (Beckles, 2012). In Zimbabwe, tomato is an important cash crop grown by both commercial and subsistence farmers (Saunyama & Knapp, 2003) and it is the highest selling vegetable on both formal and informal markets. In the period January 2015 - June 2015, tomato sales at the biggest informal market in Zimbabwe, Mbare Musika, generated a revenue of US$8 335 413.00, contributing 60% of the total revenue generated from the sale of fruits and vegetables in the same period (eMkambo, 2015). However, postharvest losses (PHL) are a major problem in tomato supply chains (Gustavsson *et al.*, 2011). Globally, PHL in tomato supply chains range from 10% to 40% of the harvested tomatoes (Sibomana *et al.*, 2016). Tomatoes are vulnerable to PHL due to their perishable nature (Buntong *et al.*, 2013), and humid conditions in tropical climates increase quality decay once tomatoes are harvested (Schouten *et al.*, 2007; Prusky, 2011).

The root causes of PHL are multidimensional and complex (Sheahan & Barrett, 2017). Multiple studies attributed PHL in tomato supply chains to either logistical challenges, e.g. inappropriate modes of transport (Buntong *et al.*, 2013) or to quality control challenges, e.g. use of wooden crates (Mbuk *et al.*, 2011; Kitinoja, 2013) and inappropriate handling practices (Sibomana *et al.*, 2016). Other studies on determinants of PHL in tomato supply chains mainly considered social economic factors, such as age, income, gender, land size, and type of markets (Babalola *et al.*, 2010; Ayandiji *et al.*, 2011; Aidoo *et al.*, 2014; Arah *et al.*, 2015b).

Besides, multiple studies investigated interventions to mitigate PHL (Hodges *et al.*, 2010; Gustavsson *et al.*, 2011; Buntong *et al.*, 2013). However, proposed interventions usually require high investment, which is not always feasible in emerging countries (Kitinoja *et al.*, 2011; Prusky, 2011). Hodges *et al.* (2010) and Parfitt *et al.* (2010) suggested that interventions should be adapted to the particular context of the supply chain actors. Therefore, insights in how the incidence of PHL in tomato chains relates to context characteristics, logistics, and quality control activities are required.

In a previous study (Macheka *et al.*, 2017), a diagnostic tool was developed to support a concurrent analysis of the status of logistics and quality control activities, the vulnerability of farmers' context to PHL, and the incidence of PHL. Based on this explorative study in tomato chains, it was hypothesised that farmers operating in a vulnerable context, like open field cultivation, relying on natural rainfall, growing tomatoes from retained seed, combined with basic logistics and quality control activities, such as using public transport and packing of tomatoes in wooden crates, more likely generate higher PHL. However, the determinants of PHL in tomato chains in Zimbabwe could not be confirmed due to the small scale of the study. Therefore, the objective of this study was to gain insight into context characteristics, logistics, and quality control activities that are determinants of PHL in typical Zimbabwean tomato supply chains, which include small-scale subsistence, small-scale commercial, and large-scale commercial farmers. Furthermore, a framework for dedicated interventions to PHL reduction was proposed as basis for further research.

4.2 Materials and methods

4.2.1 Study design

The study was conducted in five major tomato-growing areas in Zimbabwe: Macheke, Murehwa, Mutoko, Domboshava and Harare. These areas are in the same ecological region, natural farming region II, which is characterised by high rainfall (750-1000mm annually), fertile soils, humid, and warm climatic conditions (Gambiza & Nyama, 2006). All the three common categories of farmers in Zimbabwe, i.e. small-scale subsistence farmers (SS-SF), small-scale commercial farmers (SS-CF), and large-scale commercial farmers (LS-CF) (Gambiza & Nyama, 2006; Macheka *et al.*, 2017) were considered. Interviews, structured based on the previously developed tool (Macheka *et al.*, 2017), were conducted to assess the status of logistics and quality control activities and vulnerability of the farmers' context to PHL. Statistical analyses using IBM SPSS software version 23.0 (2015) were performed on the collected data to identify the determinants of PHL.

4.2.2 Selection of farmers

The snowball sampling technique (Biernacki & Waldorf, 1981) was used to select farmers for the interviews since there is no database of tomato farmers in Zimbabwe. Four of the biggest fruit and vegetable retailers and three wholesalers who sell fruits and vegetables in Harare were selected from a list of fresh produce traders in Harare (eMkambo, 2015) and asked to identify farmers supplying them with tomatoes for resale. Six middlemen selected using random numbers from the records of fruit and vegetables traders at Mbare Musika, kept at the Municipality of Harare offices at Mbare Musika, were asked to identify farmers supplying them with tomatoes for resale. The approach resulted in a list of 197 tomato farmers representing the common distribution of farmer types in Zimbabwe i.e. (55%) small-scale subsistence farmers (SS-SF), (25%) small-scale commercial farmers (SS-CF), and (20%) large-scale commercial farmers (LS-CF). The land redistribution, which took place in the year 2000 broadened the base for subsistence farmers and production became concentrated largely in the hands of these farmers (Matondi & Chikulo, 2012), explaining the relatively high percentage of small scale farmers in the study.

4.2.3 Diagnostic tool

Figure 4.1 shows the indicators used to analyse the product, process, organisation, and supply chain characteristics that shape the farmers' context. Moreover, it shows the indicators used to analyse the logistics and quality control activities that can influence the incidence of PHL. The indicator for PHL is quantitative losses (see section 2.2.3).

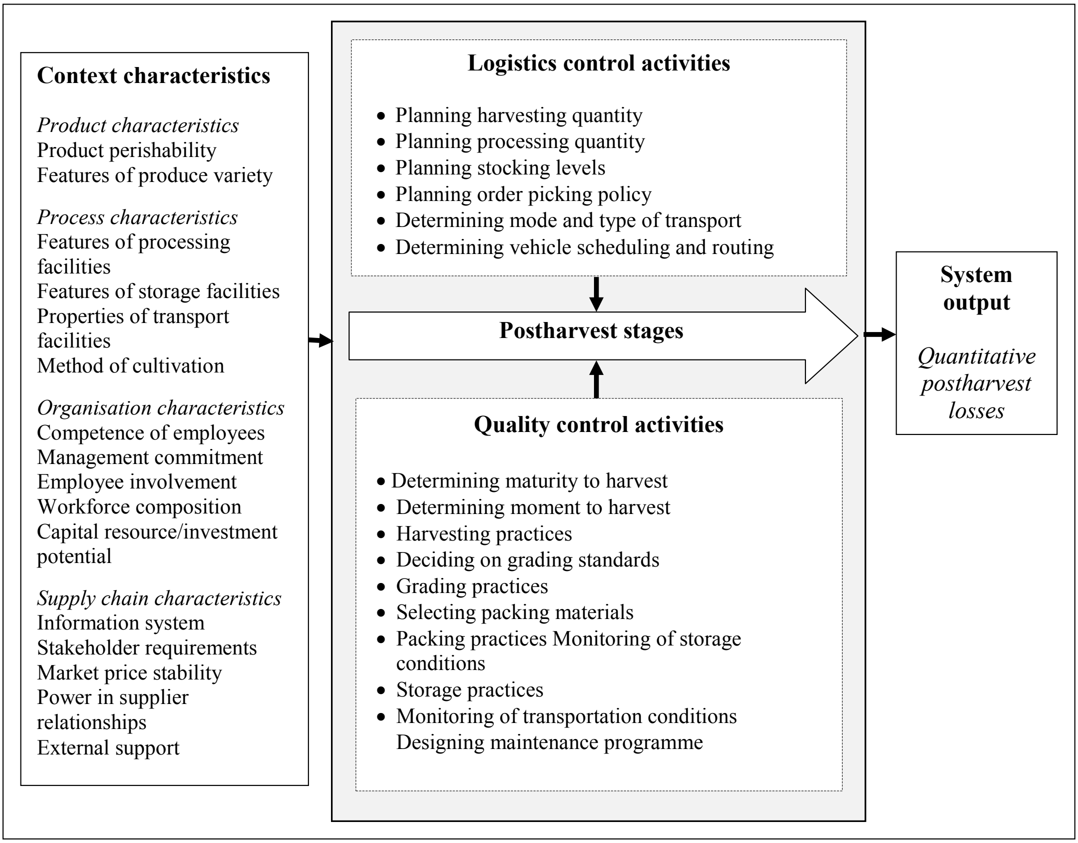

Figure 4.1 Overview of indicators to analyse context characteristics, logistics and quality control activities, and PHL. Adapted from Macheka *et al*., (2017).

For each context indicator, three situational descriptions reflecting a low, moderate, and high vulnerability towards PHL were used. Likewise, four stereotype situations reflecting, respectively, a low, basic, moderate, and advanced status were used to assess the logistics and quality control activities. Table 4.1 shows the overall characteristics used to define these differentiated situational descriptions. The corresponding scores (Table 4.1) are used as data for the statistical analyses. Macheka *et al*., (2017) provides detailed situational descriptions related to this study.

Table 4.1 Overall characteristics that distinguish the low, basic, moderate and advanced status of logistics and quality control activities, and to distinguish low, moderate and high vulnerability in context characteristics.

Logistics and quality control activities

	Low (score 1)	*Basic (score 2)*	*Moderate (score 3)*	*Advanced (score 4)*
Logistics control	Activity is not possible or is not applied.	Activity is planned based on incomplete, inaccurate, or outdated historical data on product demand.	Activity is planned based on information on product availability and demand, but the information is not always available and accurate.	Activity is planned based on reliable real-time information on product availability, actual demand, and product quality requirements.
Quality control	Activity is not possible or is not applied.	Activity is planned based on procedural methods that are based on general knowledge or own experience. Use of basic or outdated equipment, and ad hoc quality control activities.	Activity is planned based on procedural methods that are based on expert knowledge or sector guidelines. Use of potentially capable equipment, and common quality control activities.	Activity is planned based on use of procedural methods based on scientific knowledge and advanced equipment.

Context characteristics

	Low (score 1)	*Moderate (score 2)*	*High (score 3)*
Product characteristics	Produce has a relatively longer shelf life of 10-15 days, physiological processes, such as respiration, occur at a slow rate, and the variety grown is resistant to diseases.	Produce has a shelf life of between 5-10 days, physiological processes occur at a relatively slow rate, and the variety grown is resistant to diseases to some extent.	Produce has a short shelf life between 1-5 days, physiological processes, such as respiration, occur at faster rate, the variety grown is prone to diseases.
Process characteristics	High processing capacity and capabilities to maintain a cold chain and to protect the produce from adverse conditions.	Intermediate processing capacity and capabilities to maintain a cold chain and to protect the produce from adverse conditions.	Low capacity and capabilities to maintain a cold chain and to protect the produce from adverse conditions.
Organisational characteristics	Administrative conditions are supportive for decision-making, e.g. provision of financial resources, training for personnel.	Administrative conditions are supportive of decision-making to some extent.	Constrained administrative conditions that are not supportive for decision-making.
Chain characteristics	Supportive environment for operations, e.g. stable market prices, flexible stakeholder requirements.	Supportive environment to some extent, e.g. less strict stakeholder requirements.	Restrictive environment, e.g. strict stakeholder requirements, volatile market prices.

4.2.4 Data collection

Questionnaire design

A questionnaire with closed specified answer categories was used, as previously described by Macheka *et al*., (2017), to collect data and to assign a farmer's situation to the particular status of the implemented control activities and context vulnerability. The questionnaire comprised of four sections: (i) section A with six questions on logistics control activities, (ii) section B with 11 questions on quality control activities, (iii) section C with 16 questions on context vulnerability, and (iv) section D with four questions on the PHL.

Interviews

Data was collected successfully from 157 tomato farmers, out of the 197 approached farmers, that agreed to participate through a face-to-face structured interview during the peak tomato-growing season from March 2015 to May 2015. Every question and specified answer categories were read out for the farmers, enabling them to pick the most appropriate answer representing their situation. Farmers were asked for their consent to publish data gathered from the interviews. Each interview took approximately 45 minutes to complete the questionnaire. On-site verification was conducted together with the farmers soon after the interview. During the interviews, it was observed that all farmers were able to easily pick the most appropriate answer representing their situation.

Mapping of tomato supply chains

During the interviews, farmers were asked about the different types of markets they supply and the quantity of tomatoes they supply to these different customers and markets. This data was used to map the tomato supply chains.

4.2.5 Data analyses

Estimation of PHL

In this study, PHL refer to tomatoes unfit for human consumption, and exclude produce of lower quality that is still saleable. Quantitative PHL were calculated for each farmer. Farmers were asked to record the number of tomato crates that were unfit for human consumption and removed from the chain at each postharvest stage. The farmers recorded these losses for deliveries to the market made over three different days. Small scale-subsistence farmers and small scale-commercial farmers estimated the PHL in terms of the number of 7 kg wooden crates and large scale-commercial farmers in terms of the number of 40 kg plastic crates. These are the typical crate sizes used for packing and selling tomatoes by the respective farmers. The average PHL in each chain was then calculated using the following formula(Tefera *et al.*, 2007):

$$(\%)\ \text{PHL loss} = \frac{W_0 - W_t}{W_0} \times 100$$

where W_0 is the initial average total number of tomato crates harvested in the three different days and W_t is the average total number of crates removed from the chain.

Statistical analysis

Spearman's rank correlation analysis was used to test for the association between (i) the status of logistics control activities and PHL, (ii) the status of quality control activities and PHL, and (iii) the context vulnerability and PHL. The association was considered significant if the p-value < 0.05. Determinants of PHL were modelled using multiple linear regression analysis, in which the finding was considered statistically significant if the p-value < 0.05. The objective in multiple linear regression was to determine which independent variables, i.e. logistics control activities, or quality control activities, or context characteristics, contributed significantly to explaining the variability in the PHL. Three multiple linear regression analyses were conducted. First, to identify potential determinants for logistics control activities on PHL. The second analysis was to identify possible determinants for quality control activities on PHL. The third analysis was for potential determinants of context characteristics on PHL. The forward selection method was used in all the multiple linear regression analyses (Alexopoulos, 2010).

Hierarchical cluster analysis

A hierarchical cluster analysis was performed to group the farmers based on similarities in context vulnerability to the incidence of PHL, status of logistics and quality control activities, and the PHL generated. For each farmer interviewed, the assigned scores for context vulnerability and the status of logistics and quality control activities were entered into IBM SPSS software version 23.0 (2015). Hierarchical cluster analysis was performed using the Ward's method approach and Euclidean distance (Mooi & Sarstedt, 2011). The differences between the mean scores for the indicators in the three clusters were analysed by using Kruskal-Wallice non-parametric test, with significance of results established at $p<0.05$.

4.3 Results

4.3.1 Map of tomato supply chains in Zimbabwe

Figure 4.2 shows the map of the studied tomato supply chains. Most (65%) of the interviewed small-scale subsistence farmers supplied tomatoes directly to the open market, 27% to middlemen, 8% to formal markets and, 1% to the wholesalers. As for small-scale commercial farmers, 47% of them supplied the informal markets, 30% to middlemen, 15% to wholesalers, 7%, and 1% exported to other countries, such as Mozambique. The bulk (70%) of large-scale commercial farmers supplied the formal markets, and only 15% and 11% of these farmers supplied the middlemen and wholesalers, respectively.

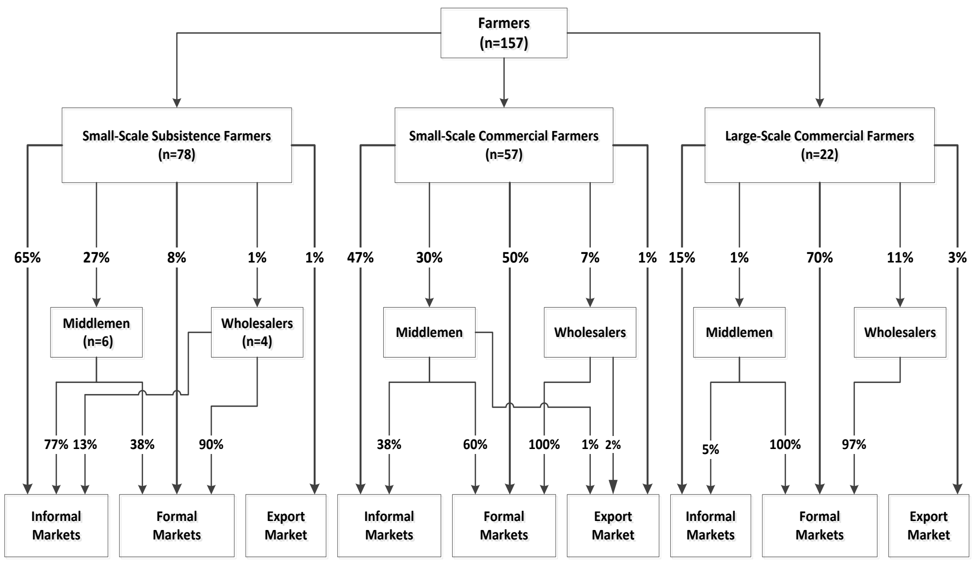

Figure 4.2 Map of the different actors and markets in the tomato supply chains in Zimbabwe (the arrows represent the percentage of actors that supply tomatoes to a certain market type). Formal markets include registered retail shops or wholesales and informal markets include unregistered open or street vending markets.

4.3.2 Relations between PHL and context vulnerability

Table 4.2 shows the statistical associations between PHL and the context vulnerability characteristics. Except for the *competence level of operators*, *employee involvement*, and *workforce composition,* all other context characteristics were statistically significantly associated ($p<0.05$) with the observed PHL. All correlation coefficients were positive, implying that reducing vulnerability of context characteristics could lower the incidence of PHL. The multiple linear regression analysis data (Table 4.2) shows that the context characteristics, *features of storage facilities*, *method of cultivation*, and *market price stability* are determinants of PHL ($p<0.05$). This set of context characteristics explained 21% (Adjusted R^2 0.205) of the variation in the calculated PHL.

Table 4.2 Statistical association between context characteristics and PHL, and possible determinants of PHL

Context characteristics	**Correlation analysis**		**Regression analysis**	
	Correlation Coefficient (R^2)	Significance	Standardised Coefficients Beta (β)	Significance ($p<0.05$)
Product characteristics				
Product perishability	0.51	0.00*	0.03	0.79
Features on produce variety	0.27	0.00*		
Process characteristics				
Features of processing facilities	0.45	0.00*	0.04	0.72
Features of storage facilities	0.51	0.00*	0.28	0.02*
Features of transport facilities	0.27	0.00*	-0.14	0.14
Method of cultivation	0.55	0.00*	0.33	0.01*
Organisational characteristics				
Competence level of operators	0.12	0.38	0.06	0.50
Management commitment	0.24	0.00*	-0.08	0.45
Employee involvement	0.03	0.70	0.04	0.64
Workforce composition	0.04	0.62	-0.03	0.70
Capital resources	0.27	0.00*	-0.09	0.37
Supply chain characteristics				
Information system	0.25	0.00*	0.06	0.52
Stakeholder requirements	0.18	0.02*	0.05	0.51
Market price stability	0.43	0.00*	0.25	0.04*
External support services	0.33	0.00*	0.01	0.89
Power in supplier-relationships	0.27	0.00*	-0.05	0.57

*$p<0.05$, a significant association

Adjusted R^2 for logistics control activities was 0.205

4.3.3 Relations between PHL and status of logistics and quality control activities

Table 4.3 presents the results of the Spearman's rank correlation analysis, which provides insight into possible statistical associations between the calculated PHL and the status of the implemented logistics control and quality control activities in the tomato supply chains studied. The results revealed that all the logistics and quality control activities, except for *packing practice* and *monitoring of storage and transportation conditions* (due to the fact that no monitoring of storage and transportation conditions was done in both chains), were statistically significantly associated ($p<0.05$) with the observed PHL. All correlation coefficients were negative, indicating that implementing the logistics and quality control activities at a higher level could lower the generation of PHL.

Table 4.3 Statistical association between status of logistics and quality control activities and PHL, and the possible determinants of PHL

	Correlation analysis		*Regression analysis*	
	Correlation Coefficient	Significance	Standardised Coefficients Beta (β)	Significance
Harvesting stage				
[a]**Determining quantity to harvest**	-0.23	0.00*	0.02	0.87
Deciding on maturity to harvest	-0.50	0.00*	-0.20	0.05*
Deciding on moment to harvest	-0.21	0.01*	0.16	0.04*
Harvesting practices	-0.17	0.03*	0.10	0.30
Processing stage				
Determining processing volumes	-0.48	0.00*	-0.28	0.00*
Deciding on grading standards	-0.18	0.03*	0.03	0.77
Grading practices	-0.18	0.02*	0.05	0.52
Deciding on packaging material	-0.19	0.02*	-0.12	0.34
Packing practices	-0.08	0.02	0.09	0.43
Storage stage				
Deciding on stocking levels	-0.17	0.04*	-	-
Deciding on order picking policy	-0.24	0.00*	-0.05	0.55
Storage practices	-0.38	0.00*	-0.26	0.00*
Maintenance of equipment	-0.28	0.00*	0.00	0.97
Transportation stage				
Deciding on mode and type of transportation	-0.21	0.01*	-0.05	0.58
Planning vehicle routing	-0.27	0.00*	-0.04	0.67

[a] Activities shown in bold are the logistics control activities, *$p<0.05$, a significant association
Adjusted R^2 for logistics control activities was 0.230, Adjusted R^2 for quality control activities was 0.287

The results of the multiple linear regression analysis (Table 4.3) show that with PHL as the dependent variable and logistics control activities as the independent variables, *determining processing volumes* was a determinant of the observed PHL ($p<0.05$). It explained 23% (Adjusted R^2 = 0.230) of the variation in the generated PHL. *Deciding on maturity to harvest*, *deciding on* *moment to harvest*, and *storage practices* were identified as determinants of PHL ($p<0.05$) and explained 28.7% (Adjusted $R^2 = 0.287$) of the variation in the generated PHL when the multiple linear regression analysis was conducted with quality control activities as independent variables.

4.3.4 Distribution of farmer types over clusters

The hierarchical cluster analysis revealed three clusters of farmers. Cluster I includes mainly small-scale farmers, i.e. 65% (51/78) of the subsistence (SS-SF) and 5% (3/57) of the commercial farmers (SS-CF). Cluster II is a mixture of all farmer types and involves small-scale farmers, 35% (27/78) of the subsistence and 51% (29/57) of the commercial ones, as well as 41% (9/22) large scale commercial farmers (LS-CF). Cluster III consists only of commercial farmers, i.e. 43% (25/57) of the small-scale and 59% (13/22) of the large-scale farmers.

4.3.5 Estimated postharvest losses

Cluster I farmers (mainly subsistence farmers) generated the largest losses (4.9% $\pm$ 2.1), followed by cluster II (1.6% $\pm$ 0.8), and cluster III farmers, which consisted of commercial farmers only (1% $\pm$ 0.9).

4.3.6 Context vulnerability and status of logistics and quality control activities of farmers in the different clusters

Table 4.4 shows a statistically significant difference ($p<0.05$) in context vulnerability to the generation of PHL across all the three clusters for the following characteristics: *features of storage facility*, *properties of transport facilities*, *method of cultivation*, *management commitment*, *capital investment*, *information system*, *stakeholder requirements*, *market price stability*, and *power in supplier relationship*. Commercial farmers (cluster III) revealed a lower vulnerability to the generation of PHL as compared to subsistence farmers (cluster I). For logistics control activities, the results (Table 4.4) revealed a statistically significant difference in the status of the implemented *stocking levels* and *order picking* across all three clusters, with these activities implemented at a higher level for commercial farmers and lower level for subsistence farmers. Table 4.4 also shows that the quality control activity, *storage practices* was implemented at a statistically significant higher level in the chain for commercial farmers as compared to that for subsistence farmers. However, there was no statistically significant difference ($p > 0.05$) in the status of the implemented *harvesting practices* for all three clusters.

Table 4.4 Frequency of the individual scores[a], mean scores[b], and significance difference between the mean scores[abc] for context vulnerability, logistics control activities, and quality control activities for the three clusters of farmers

Indicators	Cluster I (n=54)					Cluster II (n=65)					Cluster III (n=38)				
	1	*2*	*3*	*4*	*Mean*	*1*	*2*	*3*	*4*	*Mean*	*1*	*2*	*3*	*4*	*Mean*
Context characteristics															
Product characteristics															
Product perishability	9^{a}	26	19		2.2^{bc}	3	37	25		2.4^{c}	38				1.0^{ab}
Features of produce variety	11	25	18		2.1^{c}	7	34	24		2.3^{c}	38				1.0^{ab}
Process characteristics															
Features of processing facilities	3	20	31		2.5^{bc}	12	42	11		2.0^{a}	15	21	2		1.8^{a}
Features of storage facilities	1	37	16		2.7^{bc}	7	31	27		2.1^{ac}	23	14	1		1.3^{ab}
Properties of transport facilities	5	21	28		2.4^{bc}	19	36	10		1.9^{ac}	16	22			1.9^{ab}
Method of cultivation		11	43		2.8^{bc}	12	39	14		2.0^{ac}	27	11			1.4^{ab}
Organisational characteristics															
Competence of employees		31	23		2.4^{c}	11	33	21		2.2	13	17	8		1.9^{a}
Management commitment		15	39		2.7^{bc}	9	31	25		2.3^{ac}	22	13	3		1.5^{ab}
Employee involvement		9	45		2.8^{c}	2	17	46		2.7^{c}	8	19	11		2.1^{ab}
Workforce composition		19	35		2.6^{c}	6	21	38		2.5	7	14	17		2.3^{a}
Capital investment	2	29	23		2.4^{bc}	15	29	21		2.1^{ac}	19	16	3		1.6^{ab}
Supply chain characteristics															
Information system		9	45		2.8^{bc}	6	34	25		2.4^{ac}	15	19	4		1.7^{ab}
Stakeholder requirements		17	37		2.7^{bc}	11	33	21		2.2^{ac}	18	20			1.5^{ab}
Market price stability		5	49		2.9^{bc}	4	34	27		2.4^{ac}	27	11			1.3^{ab}
Power in supplier relationships	2	10	42		2.7^{bc}	12	30	23		2.2^{ac}	15	17	6		1.8^{ab}
External support	13	22	19		2.1^{c}	18	27	20		2.0	17	14	7		1.7^{a}
Logistics control activities															
Harvesting quantity	34	16	4		1.4^{c}	21	35	9		1.8^{c}	1	7	11	19	3.3^{ab}
Processing quantity	21	33			2.2	15	29	21		2.1^{c}	4	11	21	2	2.6^{b}
Stocking levels	7	47			1.9^{bc}	8	21	36		2.4^{ac}		5	21	12	3.2^{ab}
Order picking	41	13			1.3^{bc}	27	38			1.6^{ac}		19	15	4	2.7^{ab}
Mode and type of transport	11	37	6		1.9^{c}	21	34	10		2.0^{c}	2	20	16		2.4^{ab}
Vehicle scheduling	6	35	13		2.1^{c}	10	39	16		2.1^{c}	1	13	24		2.6^{ab}
Quality control activities															
Maturity to harvest	47	9	2		1.9^{c}	6	44	15		2.1^{c}		3	10	25	3.2^{ab}
Moment to harvest	3	36	15		2.2	11	36	18		2.1^{c}	4	14	20		2.4^{b}
Harvesting practices	3	41	10		2.1	5	39	21		2.3	5	14	19		2.4
Grading standards	28	18	8		1.6^{c}	17	28	20		2.0^{c}		5	19	14	3.1^{ab}
Grading practices	24	28	2		1.6^{c}	19	37	9		2.5^{c}	3	11	24		2.7^{ab}
Packaging material	6	30	18		2.2^{c}	7	26	32		2.4^{c}	1	5	23	9	3.2^{ab}
Packaging practices	16	30	8		1.9^{c}	12	30	23		2.2		5	21	12	2.0^{a}
Maintanance program	49	5			1.4	57	8			1.3^{c}	11	24	3		1.7^{b}
Storage practices	21	33			1.6^{bc}	17	35	13		1.9^{ac}	4	15	19		2.4^{ab}
Monitoring storage conditions	54				1	65				1	38				1
Monitoring transportation conditions	54				1	65				1	38				1
Calculated postharvest losses		4.9% ± 2.1					1.6% ± 0.8					1% ± 0.9			

[a] In bold represents scores: 1 = low level, 2 = basic level, 3 = average level, 4 = advanced status for implemented logistics and quality control activities; and for context characteristics, 1 = low vulnerability, 2 = moderate vulnerability, 3 = high vulnerability for the generation of PHL
[b] In bold represents the mean score for each indicator per cluster
[a b c] respectively, symbolises significance difference ($P<0.05$) between cluster I farmers, cluster II farmers, and cluster III, based on Kruskal-Wallice non-parametric test. Where no letter is given, then there is no significant difference.

For the context factor *features of storage facilities*, commercial farmers were found to use more modern storage facilities as compared to subsistence farmers (Table 4.4). Most of the commercial farmers (cluster III) (37 out of 38) had warehouses in which they graded and packed the tomatoes and had cold rooms, where they stored the harvested tomatoes before transportation to the market. However, 47 of the 54 subsistence farmers (cluster I) kept the harvested tomatoes stacked under tree shade or under plastics makeshifts before transportation to the market. Studies by Sibomana *et al.* (2016) and Arah *et al.* (2015b) also found that commercial tomato farmers, who typically use modern storage facilities, generate less PHL as compared to subsistence farmers, who typically use traditional storage facilities.

In this study, the context factor *market price stability* and PHL were positively associated, and market price stability was confirmed as determinant of PHL (Table 2). The farmers mentioned that the fluctuations in the market prices considerably contributed to loss in the potential revenue for the farmers, which can be considered as economic PHL (Johnson-Kumolu & Ndimele, 2011). Farmers highlighted that fluctuations in tomato prices are more pronounced on the informal markets than the formal markets due to higher variations in supply and demand. Commercial farmers indicated that they mainly supply formal markets (Figure 4.2 and Table 4.4), such as supermarkets, and agree the prices before supplying. On the contrary, all the subsistence farmers reported that they mainly supply the informal markets, as they cannot meet the strict quality requirements of the formal markets, as previously found in studies on tomato chains in Nigeria (Adeoye *et al.*, 2009) and Ghana (Buntong *et al.*, 2013). So, even though the percentage of quantitative PHL is relatively low, subsistence farmers, especially, are confronted with economic PHL.

The **quality control activities**, *deciding on maturity to harvest, deciding on moment to harvest,* and *storage practices* were identified as determinants of PHL in this study. All subsistence farmers indicated that they harvest tomatoes of all *maturity levels* in anticipation that there will be buyers for each maturity level at the open market, running the risk of PHL in cases where tomatoes of a certain maturity level are not wanted. Commercial farmers, however, indicated that they mainly harvest tomatoes of the maturity level prescribed by the customers. Studies by Tiwari *et al.* (2013) and Toivonen (2007) on tomato supply chains in West Africa also identified the maturity at which tomatoes are harvested as determinant of PHL. According to Moneruzzaman *et al.* (2008), mature and very ripe tomatoes decay in quality at a faster rate in supply chains where cold chain management is not practiced.

In our study, subsistence farmers were observed to *harvest tomatoes* in the mid-afternoon, a few hours before transportation to the market, due to lack of proper storage facilities. The farmers indicated that the hot weather affects the quality of the tomatoes, especially during incidences where transportation to the market is delayed. Commercial farmers were observed to be flexible and harvested at any moment of the day, since the tomatoes are grown in greenhouses. Also Aidoo *et al.* (2014) reported that tomato farmers in West Africa without proper storage facilities and who harvest during hot times of the day incur higher PHL (15-19%) as the tomatoes are exposed to high temperature, which leads to high respiration rates (Arah *et al.*, 2015a). However, in our study, the calculated PHL were much lower (ranging from 1% to 4.9%) compared to other studies (Mbuk *et al.*, 2011; Adepoju, 2014; Arah *et al.*, 2015a; Sibomana *et al.*, 2016; McKenzie *et al.*, 2017) (ranging from 5% to 40%). The reason could be that in the Zimbabwean situation, there is a market for every tomato quality level, due to sun drying and street food vending, except only for those that are no longer edible (Gadaga *et al.*, 2008).

In both the formal and informal supply chains (Figure 4.2), the harvested tomatoes were stored briefly before transportation to the market, however, the *storage practices* differed (Table 4.4). Commercial farmers stacked the tomato crates on pallets and to a maximum height of four to five crates. However, subsistence farmers had the crates stacked on the ground and to a maximum height of five to seven crates. The subsistence farmers indicated that they stack the crates high due to limited storage space. Stacking high can also cause compression damage (Martinez-Romero *et al.*, 2004; Macheka *et al.*, 2013). Various studies (Ahmad & Siddiqui, 2015; Peng *et al.*, 2017) reported that stacking crates of fresh produce directly on the ground can block air circulation resulting in creation of hot spots within a batch.

Determining processing volumes is the **logistics control activity** found to be a determinant of PHL in this study. Ahumada and Villalobos (2011b) in a study on logistics control activities also identified processing volumes as determinant of PHL. In our study, the subsistence farmers highlighted that since they supplied the markets only once or twice a week, they harvested and processed all the ripe tomatoes, irrespective of market demand, to maximise on every delivery and minimise on transportation costs, as they use hired transport. Commercial farmers on the other hand, indicated that they only harvest and process the quantity ordered by the supermarkets.

Furthermore, most of the commercial farmers (36 out of 38 cluster III farmers) indicated that they use own transportation (Table 4.4), hence they are able to transport the produce to the market as and when there is an order.

4.4 Proposed interventions for postharvest loss reduction in the studied tomato supply chains

The current study indicated that PHL cannot be attributed to a single cause, but to multiple causes related to context factors, quality control, and logistics control activities. Furthermore, the study showed that the supply chain for commercial farmers is more advanced, characterised by modern storage and transportation facilities, and access to financial resources, as compared to that for subsistence farmers, which is characterised by absence or basic storage and transportation facilities, and lack of financial resources. Therefore, we propose that interventions to reduce the incidence of PHL in the studied tomato chains should be differentiated based on the context in which the farmers operate and the available logistics and quality activities practiced. As Hodges *et al.* (2010) and Van Gogh *et al.* (2013) argued, PHL reduction should be planned within the situation characteristics of the relevant supply chain.

In Figure 4.3, we propose a step-wise framework with intervention strategies for PHL reduction for (tomato) farmers in different development stages: underdeveloped, basic, intermediate, and advanced. The proposed interventions are differentiated based on time span, degree of capital investments, formalisation, and intensity of capacity building required to implement the intervention. The interventions are targeted at improving of logistics control, or quality control activities, or at reducing the vulnerability to PHL inherent to farmers' context characteristics, similar to improvement interventions as described for food safety management systems (Luning *et al.*, 2011a; Kussaga *et al.*, 2015).

Underdeveloped → Basic stage

Logistics control
- Transporting produce during the evening hours to avoid high temperatures
- Covering produce during storage and transportation to avoid bad weather conditions

Quality control
- Buying certified seeds from seed-houses
- Packing produce according to quality levels
- Using clean, smooth, and ventilated containers for packing
- Grading and sorting of fresh produce according to quality levels
- Training farmers on basic produce handling

Basic → Intermediate stage

Logistics control
- Using closed trucks for transportation of produce to markets
- Using quality-based inventory issuing policies, such as High Quality First Out

Quality control
- Using control charts and visual aids that show proper postharvest handling procedures
- Using plastic crates to pack produce
- Monitoring and recording of storage and transportation conditions
- Growing cultivars that have long postharvest-life and resistant to diseases
- Implementing Good Agricultural Practices, Good Manufacturing Practices, and Good Hygienic Practices
- Formal training dedicated to postharvest handling
- Improving communication along the supply chain demand and supply

Context
- Developing new markets for sub-standard produce
- Increasing capacity and efficiency of processing equipment

Intermediate stage → Developed stage

Logistics control
- Investing in a cold chain, e.g. refrigerated cold storage and transportation facilities
- All logistics activities are based on real-time product quality information

Quality control
- Growing cultivars with long postharvest life, resistant to diseases, and have specific quality characteristics
- Dedicated training on postharvest technology
- Investing in intelligent packaging to help monitor product quality
- Investing in automated grading systems
- Investing in modified atmosphere storage facilities
- Implementing quality management systems

Context
- Using greenhouse and irrigation cultivation system
- Investing in supply chin relationships
- Establishing suitable market strategies

Figure 4.3 Proposed step-wise intervention strategies for farmers at different development stages in tomato supply chains

Characteristics of interventions, to move from an underdeveloped (highly vulnerable context, and low or poor practices) towards a basic stage (high vulnerability and basic logistics and quality activities), should be (i) simple, informal, and easy to implement on the short term, (ii) limited (or even no) costs required, and (iii) require basic knowledge improvement of farmers. Basic interventions in logistics and quality control activities, such as harvesting tomatoes in the cool hours of the day, carefully separating tomatoes of different qualities during grading, and proper stacking tomatoes on pallets, are simple measures that also subsistence farmers can implement to reduce PHL (Kitinoja *et al.*, 2011; Kader, 2013). Also basic informal training of farmers by extension workers on proper harvesting techniques and postharvest handling of tomatoes could help to reduce the incidence of PHL (Kitinoja *et al.,* 2011).

Features of interventions to move towards the intermediate stage (moderate vulnerable context and basic to average logistics and quality activities) include: (i) small investments in more advanced tools, equipment, and facilities, (ii) introduction of some formalisation to improve and standardise practices, (iii) basic recording and keeping of information on all operations and comparing against specifications, (iv) formal enhancement of farmers' competences. Examples of interventions in quality control are developing prescribed product and process monitoring and specifications, and introducing written formal procedures that are supported with visual means to improve and standardise quality control practices (Luning *et al.*, 2008). Use of more robust crates (e.g. plastic instead of wooden) to avoid bruising, recording and monitoring of environmental conditions (such as temperature) (Ahmad & Siddiqui, 2015; Arah *et al.*, 2015a) are other examples of interventions in quality control. Interventions in logistics control include transporting produce in covered trucks and use of quality based issuing policies, such as High-Quality-First-Out (HQFO) or Low-Quality-First-Out (LQFO) (Dada & Thiesse, 2008; East, 2011). The interventions require some investments in equipment, facilities and competences, and in setting up a quality and logistics control system.

Interventions to move towards the advanced stage (low vulnerability and more advanced logistics and quality activities) are characterised by: (i) substantial investment in advanced materials, advanced equipment, and advanced facilities, (ii) implementation of elaborated control and logistics systems, and (iii) advancement of farmers' competences through specialised training to deal with the more advanced equipment. These investments could further mitigate vulnerability to PHL inherent to the farmers' context and are long-term investments. Examples of such interventions in quality control are automated grading and packing systems (Bollen & Prussia, 2009), use of intelligent packaging material (Jedermann *et al.*, 2014). Using of refrigerated trucks to transport the produce (Yahia, 2010) and having all logistics activities determined based on real-time product quality information (van der Vorst *et al.*, 2011) are examples of interventions in logistics control. Building an integrated supply chain, investment in supplier relations, and investing in an integral cold chain are interventions to develop towards advanced supply chains (Gustavsson *et al.*, 2011), which could minimise incidence of PHL.

4.5 Conclusions and further research

The present study showed a significant association between the context vulnerability and PHL and the status of implemented logistics and quality control activities and PHL. Overall, commercial farmers generated less PHL as compared to subsistence farmers, confirming the hypothesis that farmers operating in a vulnerable context, combined with basic logistics and quality control activities are more likely to generate higher PHL. The multiple regression analyses revealed different kinds of determinants of PHL, those of a contextual, logistics, and quality control nature, pointing to the need for dedicated interventions for PH reduction. The PHL in this study were based on physical losses and the calculated PHL and was relatively low. However, other types of PHL, such as qualitative losses and economic losses, due to fluctuations in market prices, could have an impact on farmers' income and livelihood as well. Therefore, further research will focus on gaining insights into how market price dynamics affect economic PHL.

Finally, the proposed framework of possible interventions tailored to the particular development stage, could support farmers in implementing step-wise improvements in logistics and quality control practices and reduction in context vulnerability to PHL. Further studies are needed to investigate the effect of the step-wise interventions approach on the reduction of PHL and on advancing tomato supply chains in developing countries towards sustainable fresh produce chains. Furthermore, it might be important to analyse if the status of logistics and quality control activities differ between farmers growing tomatoes only and those with a wide range of other crops as this might have influenced certain decisions made by the farmers.

Chapter 5

Understanding causes of qualitative and economic postharvest losses in tomato supply chains in Sub-Saharan Africa: Case of Zimbabwe

Submitted as: Macheka L, Verkerk R, Luning P. A. Understanding causes of qualitative and economic postharvest losses in tomato supply chains in Sub-Saharan Africa: Case of Zimbabwe.

Abstract

Tomato supply chains in Sub-Saharan Africa still suffer from substantial amount of postharvest losses (PHL). There is need for more information on causes of the PHL. This study aimed at getting insights into the extent of qualitative and economic PHL and possible causes associated with logistics and quality control activities as applied by commercial and subsistence farmers. Overall, weight and firmness decreased (7.1% and 14.5%, respectively), whereas pH and total soluble solids (TSS) increased (12.5% and 6.5%, respectively) in tomatoes from commercial farmers. As for tomatoes from subsistence farmers, the overall weight loss (11.1%) and decrease in firmness (21.6%) were significantly higher ($p<0.05$), as well as the increase in TSS (15.6%) and pH (20.9%). This difference could be attributed to particular logistics (e.g. mode and type of transport) and quality control activities (e.g. planning on grading standard) that were more developed for commercial (moderate level, score 3) than for the subsistence farmers (basic level, score 2). The economic loss (decrease in price of the tomatoes) was significantly higher ($p<0.05$) in the chain for subsistence farmers (33.3%) as compared in the chain for commercial farmers (5.7%). Rapid fluctuations in demand and supply in the informal markets as compared to formal markets, where respectively subsistence and commercial farmers supply, explained these differences. Insights from this study can be used in further studies as basis for more holistic intervention strategies to advance towards sustainable tomato chains in Zimbabwe and in Africa in more general.

5.1 Introduction

Tomato (*Solanum lycopersicum* L.) is among the most widely consumed vegetables in the world (Tigist *et al.*, 2013). It is one of the main suppliers of numerous phytonutrients and provides important nutritional value to the human diet (Van Dijk *et al.*, 2006). In Zimbabwe, tomato is the most important vegetable and is the best-selling crop at both the informal and formal markets (eMkambo, 2015). However, tomato production is constrained by high postharvest losses (PHL) (Arah *et al.*, 2015a). Studies showed that PHL in tomato supply chains in Sub-Saharan Africa range between 4 to 40% of the harvested crop (Adepoju, 2014; Affognon *et al.*, 2015; Sibomana *et al.*, 2016; Macheka *et al.*, 2018). The magnitude of the PHL, however, varies among different types of farmers. Macheka *et al.* (2018) found that Zimbabwean small-scale subsistence farmers incur relatively more PHL than commercial farmers. The authors attributed these differences to shortcomings in logistics (e.g. using inappropriate type of transport) and quality control (e.g. using wooden crates for packaging), and due to vulnerability of farmer's context characteristics to the incidence of PHL.

Previous studies on PHL in tomato supply chains focused mainly on quantitative losses (i.e. the physical loss or a reduction in weight) and ways to prevent these losses (Buntong *et al.*, 2013; Addo *et al.*, 2015a; Arah *et al.*, 2015b; Sibomana *et al.*, 2016). While quantitative losses are well documented (e.g. FAOSTAT), much less is known concerning the magnitude of qualitative and economic losses (Munhuweyi *et al.*, 2016), whereas they can impact farmers as well (Prusky, 2011). Qualitative losses include a decrease in sensorial quality of food (Laínez *et al.*, 2008; Arah *et al.*, 2015b). Economic losses are described as a decline in potential revenue or income, and could be due to the low quality of produce (Johnson-Kumolu & Ndimele, 2011). For example, the ratio of maximum to minimum prices within a single day can exceed 3:1 for tomatoes due to varying quality and sudden changes in supply (Hichaambwa *et al.*, 2015).

To develop advanced tomato supply chains, there is a need for an in-depth understanding of the causes of all the three types of PHL. This study aimed at getting insight into the magnitude of qualitative and economic PHL and possible causes associated with logistics and quality control activities as applied by commercial and subsistence farmers.

5.2 Materials and Methods

5.2.1 Study design

In a quantitative field study, amongst commercial (20) and subsistence tomato farmers (20), the variation in tomato quality parameters (firmness, pH, and total soluble solids), weight, and environmental temperature were monitored from harvesting to the moment of actual sales to gain insight in qualitative losses and possible causes. Figure 5.1 shows the typical tomato supply chains for commercial and subsistence tomato farmers in Zimbabwe. Farmers' logistics and quality control practices were analysed using a previously developed diagnostic tool (Macheka *et al.*, 2017) to investigate possible causes associated with these activities. Changes in market prices and the underlying reasons were analysed for the two types of farmers to gain an understanding of the magnitude of economic PHL.

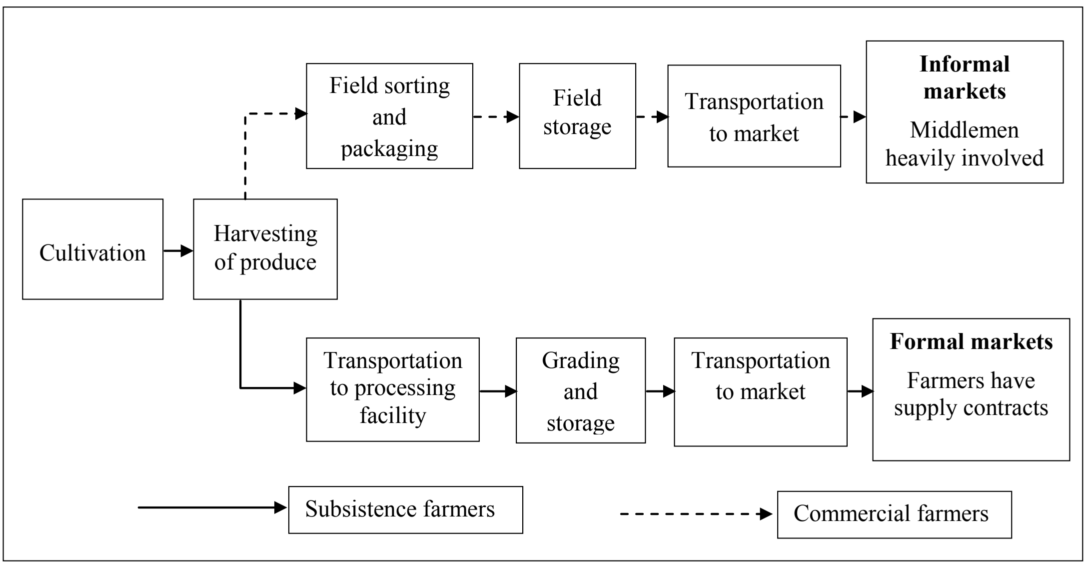

Figure 5.1 Postharvest stages in the tomato supply chains for subsistence and commercial farmers in Zimbabwe

5.2.2 Selection of farmers

Forty tomato farmers, consisting of twenty subsistence farmers and twenty commercial farmers participated in the study. The farmers were selected based on the tomato variety they grow (Tenguru 97 variety, as it can be easily grown under greenhouse and open field conditions) and type of market supplied (formal versus informal). Formal market refers to reliable (i.e. contract arrangement) and lucrative (profitable) markets (Makhura *et al.*, 1998). Informal market refers to a market where there is no involvement of any formal arrangement for a sale of goods between a farmer and a buyer (Makhura *et al.*, 1998), and examples include open air markets. All the forty farmers were selected from a database of 157 tomato farmers gathered and used in a previous study (Macheka *et al.,* 2017). The farmers were from Mutoko, Murehwa, and Macheke farming areas, as these areas are the hub of tomato growing in Zimbabwe (eMkambo, 2015). More so,these areas are almost the same distance to the markets, and they have similar climatic conditions.

5.2.3 Collection of tomatoes and analyses of quality parameters

Two crates, 7 kg each of first grade tomatoes, were purchased from each of the forty farmers during the summer growing season, March-May 2017. The crates were randomly selected from the harvested tomatoes. Figure 5.2 shows the sampling plan followed.

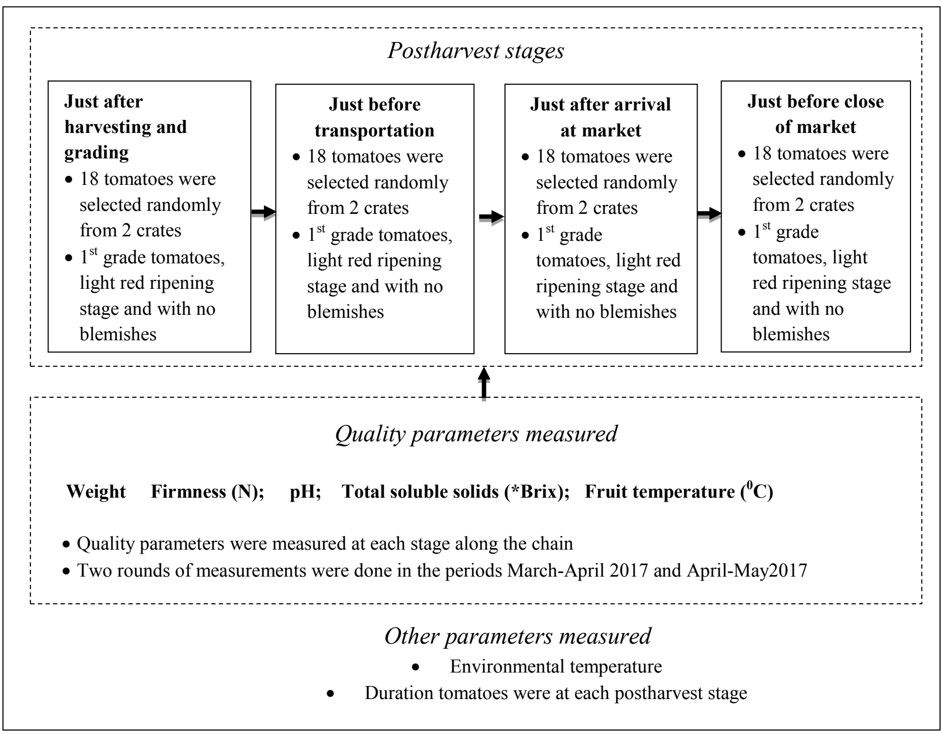

Figure 5.2 Sampling plan to assess quality parameters along the postharvest stages in the tomato supply chain

A total of nine tomatoes of about the same fruit size were sampled from each crate (three from respectively the bottom, middle and the top layer) at the following stages in the chain: (i) after harvesting, (ii) just before transportation, (iii) just after arrival at the market, and (iv) just before close of the market. Overall, 18 tomatoes were sampled at each postharvest stage per farmer and analysed for: weight (g), firmness (N), pH, total soluble solids (°Brix), and temperature (^{0}C). Three measurements were done per fruit. The sampling and analyses were done twice per each farmer. The first sampling and analyses were done during the period March-April 2017 and the second during the period April - May 2017.

Weight loss
Weight of the tomato fruits was measured to get an indication of quantitative losses. After harvest, a total of nine tomatoes per crate were individually marked, weighed, and returned to the respective crates. The marked tomatoes were weighed at each postharvest stage using a precision scale with an accuracy of ± 0.01g (Mettler Toledo scale, Switzerland). The weight loss was calculated relative to the weight shortly after harvesting (t = 0) (Tefera et al., 2007).

$$(\%) \text{ Weight loss} = \frac{W_0 - W_t}{W_0} \times 100$$

where W_0 is the weight of the tomatoes at harvesting stage and W_t is the weight of the same batch at a particular stage in the chain.

Total soluble solids (°Brix)
The total soluble solids (TSS) content was determined using a digital refractometer (Milwaukee, MA871) with a rangeof 0-85 °Brix and resolution of 0.1 °Brix. A sharp stainless-steel vegetable peeler was used to remove a disc (about 3cm in diameter) of the fruit. The fruit was then gently squeezed to allow 1 to 2 drops of fruit juice to drop on the refractometer prism. Between samples the prism of the refractometer was washed with distilled water and the refractometer was standardised against distilled water (0 °Brix TSS).

Firmness
Firmness was calculated as the maximum force necessary to puncture the tomato using a handheld penetrometer (Fruit-tester Model FT327). The fruit was held steady on a firm surface and a 4mm cylindrical, flat-faced probe was pushed into the fruit to a depth of 5mm, corresponding to a mark inscribed on the shaft of the probe (Wu & Abbott, 2002). All the measurements were taken in the outer pericarp, avoiding the areas where the outer pericarp joins the radial arms. The force (N) required to penetrate through the skin to the tomato flesh during penetration was recorded.

Fruit Temperature

A 4-Wire Pt100 probe thermometer (HI955501) was used to assess the temperature of the tomato flesh. The probe of the thermometer was pierced into the tomato to a depth of about 4mm.

Environmental temperature

Atmospheric temperature was monitored using a Fisher Scientific™ Traceable™ Temperature Meter. The duration the tomatoes were at each stage of the chain was also monitored.

5.2.4 Changes in market prices

Changes in market prices weredeterminedby comparing the prevailing market price for that particular day (obtained from eMkambo database, 2017) and the average price a farmer sold the tomatoesat the market. Price changes were monitored deliveries to the market at three different days. For subsistence farmers, the farm gate price, (price of the tomatoes soon after harvesting), the initial price at start of the farmer's market (5 am), and the price at close of the market (10 am) were monitored. For the commercial farmers, prices were monitored at three stages: (i) farm-gate price, (ii) the agreed price with the retailers at delivery to the market, and (iii) the price of the tomatoes at the close of the market.

5.2.5 Assessment of the level of logistics and quality control activities

A previously developed diagnostic tool tested in tomato chains (Macheka *et al*., 2017) was used to assess the level of the implemented logistics and quality control activities. The tool includes indicators to analyse logistics and quality control activities that can impact PHL. Each indicator has a set of questions and closed answers to collect information about farmers' practices for the particular activities. To judge the level of the logistics and quality control activities, for each indicator, four stereotype situational descriptions were defined. They correspond with a low, basic, moderate and advanced level, which link to the scores 1, 2, 3, and 4, respectively.

For logistics control activities, an advanced level is characterised by the use of reliable real-time information on product availability, actual demand, and product quality requirements. The moderate level is typified by logistics activities that are principally based on information about product availability and demand, but the information is not always available and if available, it is not accurate. The basic level is characterised by logistics activities that are planned based on incomplete, inaccurate, or outdated historical data on product demand. The low level represents a situation where an activity is not possible or is not applied although it is possible.

For quality control activities, the advanced level is typified by the use of procedural methods based on scientific knowledge, the use of advanced equipment, which is standardised and internationally acknowledged, and quality control activities that are product specific. The moderate level is typified by procedural methods that are based on expert knowledge or sector guidelines, use of potentially capable equipment, and general quality control activities. The basic level is characterised by the use of procedural methods that are based on general knowledge or own experience, the use of basic or even outdated equipment, and ad hoc quality control activities. The low level represents a situation where an activity is not possible or is not applied, although it is possible (Macheka *et al.*, 2017).

The tool was used to assess six logistics control activities (i.e. determining quantity to harvest, determining processing volumes, deciding on stocking levels, deciding on order picking policy, deciding on mode and type of transportation, and planning vehicle routing) and 11 quality control activities (i.e. deciding on maturity to harvest, deciding on moment to harvest, harvesting practices, deciding on grading standards, grading practices, deciding on packaging material, packing practices, storage practices, maintenance of equipment, and monitoring storage and transportation conditions).

As for the interviews, face-to-face structured interviews using a questionnaire were conducted from March 2017 to May 2017. The researcher asked the question first and then read out the specified answer categories provided on the questionnaire for the farmers to pick the most appropriate answer representing their situation. Each interview took approximately 45 minutes to complete the questionnaire. All farmers were able to easily pick the most appropriate answer representing their situation. The farmers agreed to have the data gathered from the interviews published.

5.2.6 Data analysis

All the statistical analyses were performed using IBM SPSS version 23 (2015). Analysis of variance (ANOVA) was performed to test for the significant difference ($p<0.05$) in the changes of the tomato quality parameters and market prices in the two chains. Data on quality parameters was used to construct histograms to show the frequency distributions at each stage along the tomato chain.

5.3 Results

5.3.1 Changes in quality parameters along the postharvest stages

Table 5.1 shows the overall changes of tomato quality parameters; weight, firmness, total soluble solids and pH.

Table 5.1 Overall changes in tomato fruit quality parameters (average ± standard deviation) along the postharvest stages for commercial farmers (CF) and subsistence farmers (SF).

Postharvest stage	Type of farmer	Weight (g)	Firmness (N)	TSS (^{0}Brix)	pH
After harvest	CF	136.3 ± 11.0	11.0 ± 2.7	4.8 ± 0.5	4.6 ± 0.5
	SF	110.3 ± 20.4	7.4 ± 1.9	4.5 ± 0.4	4.3 ± 0.4
Before transportation	CF	133.3 ± 11.2	10.5 ± 2.4	5.0 ± 0.4	4.6 ± 0.4
	SF	105.7 ± 20.5	6.9 ± 1.8	4.7 ± 0.3	4.4 ± 0.5
After arrival at market	CF	130.3 ± 11.4	9.9 ± 2.2	5.2 ± 0.5	4.7 ± 0.4
	SF	101.9 ± 20.7	6.4 ± 1.7	4.9 ± 0.3	4.6 ± 0.4
Before close of market	CF	126.6 ± 11.4	9.4 ± 2.2	5.4 ± 0.6	4.9 ± 0.5
	SF	98.1 ± 21.5	5.8 ± 1.6	5.2 ± 0.3	5.2 ± 0.3

The mean difference is considered significant at $p<0.05$

Loss of weight in the tomatoes progressively increased along the chain for both commercial and subsistence farmers. However, tomatoes from commercial farmers weighed more and had less variation as compared to those from subsistence farmers (Table 5.1). The average weight of these tomatoes was 136.3g ± 10.9 after harvesting, and decreased to 126.6g ± 11.4 at close of the market, representing a weight loss of 7.1%. For subsistence farmers, the overall weight loss was 11.1% as the weight decreased from 110.3g ± 20.4 after harvesting to 98.1g ± 21.5 at close of the market. Figure 5.3-a1 shows that 61.6% of all the tomatoes from commercial farmers weighted between 125-149g, 32.1% weighed between 100-124g, and 6.3% weighed between 150-174g. On the other hand, for subsistence farmers only 22.2% of all the tomatoes weighted between 125-149g, whereas respectively, 37.5% and 33.5% of the tomatoes were classified in the lower weight ranges 100-124g and 75-99g (Figure 5.3-a2), respectively.

Firmness of the tomatoes decreased by an average of 14.5% and 21.6% in the chain of commercial and subsistence farmers, respectively. The tomatoes from commercial farmers had an average firmness of 11 N ± 2.7 after harvesting, which decreased to 9.4 N ± 2.2 at close of the market (Table

1). For subsistence farmers, initial firmness after harvesting was significantly lower ($p<0.05$), 7.4 N $\pm$ 1.9 and decreased to 5.8 N $\pm$ 1.6 after close of market. Figure 3-b1 shows that for all the tomatoes from commercial farmers, a substantial amount was classified in the higher firmness classes, i.e. between 16-18.9 N (22.2%), 13-15.9 N (30%), and 10-12.9 N (40.3%). Only 7.4% of the tomatoes were in the low firmness range 7-9.9 N, whereas for subsistence farmers (Figure 5.3-b2), the majority of the tomatoes (71.6%) were classified in this firmness range of 7-9.9 N. Much less tomatoes, 22.4%, 4.4%, and 1.3% were in the higher firmness ranges between 10-12.9 N, 13-15.9 N and 16-18.9 N, respectively.

Figure 5.3-c1 and c2 show that the number of tomatoes with a higher 'total soluble solids (TSS)' (^{0}Brix) gradually increased along the chain. In the period just after harvesting and just before close of the market, the percentage increase in TSS content was significantly higher in the tomatoes from subsistence farmers (15.6%) compared to commercial farmers (12.5%). For the commercial farmers, the average TSS content of all the tomatoes after harvesting was 4.8 $\pm$ 0.5 ^{0}Brix, while at close of the market the content increased to 5.4 $\pm$ 0.6 ^{0}Brix. For the subsistence farmers, this was respectively 4.5 $\pm$ 0.4 and 5.2 $\pm$ 0.3 ^{0}Brix. The largest percentage of tomatoes along the supply chain for both commercial (60.8%) and subsistence (56%) farmers were in the 5-5.9 ^{0}Brix range.

Table 5.1 shows a slight increase in fruit pH (decrease in acidity) in both chains. However, there was no significant difference ($p>0.05$) in pH increase between the two chains. pH increased by 6.5% and 20.9% in tomatoes of commercial farmers and subsistence farmers, respectively. The average pH for all tomatoes in the chain for commercial farmers was 4.6 $\pm$ 0.5 after harvesting, and 4.9 $\pm$0.5 at close of the market, and for subsistence farmers this was 4.3 $\pm$ 0.4 and 5.2 $\pm$ 0.3, respectively. The pH for tomatoes from commercial farmers ranged from 4.4-6.9 and that for subsistence farmers had a larger variation, from 3.5-6.9 (Figure 5.3-d1 and d2). Most of the tomatoes, 43.5% and 35.8% from both commercial and subsistence farmers, respectively, were within the same pH range of 5-5.49.

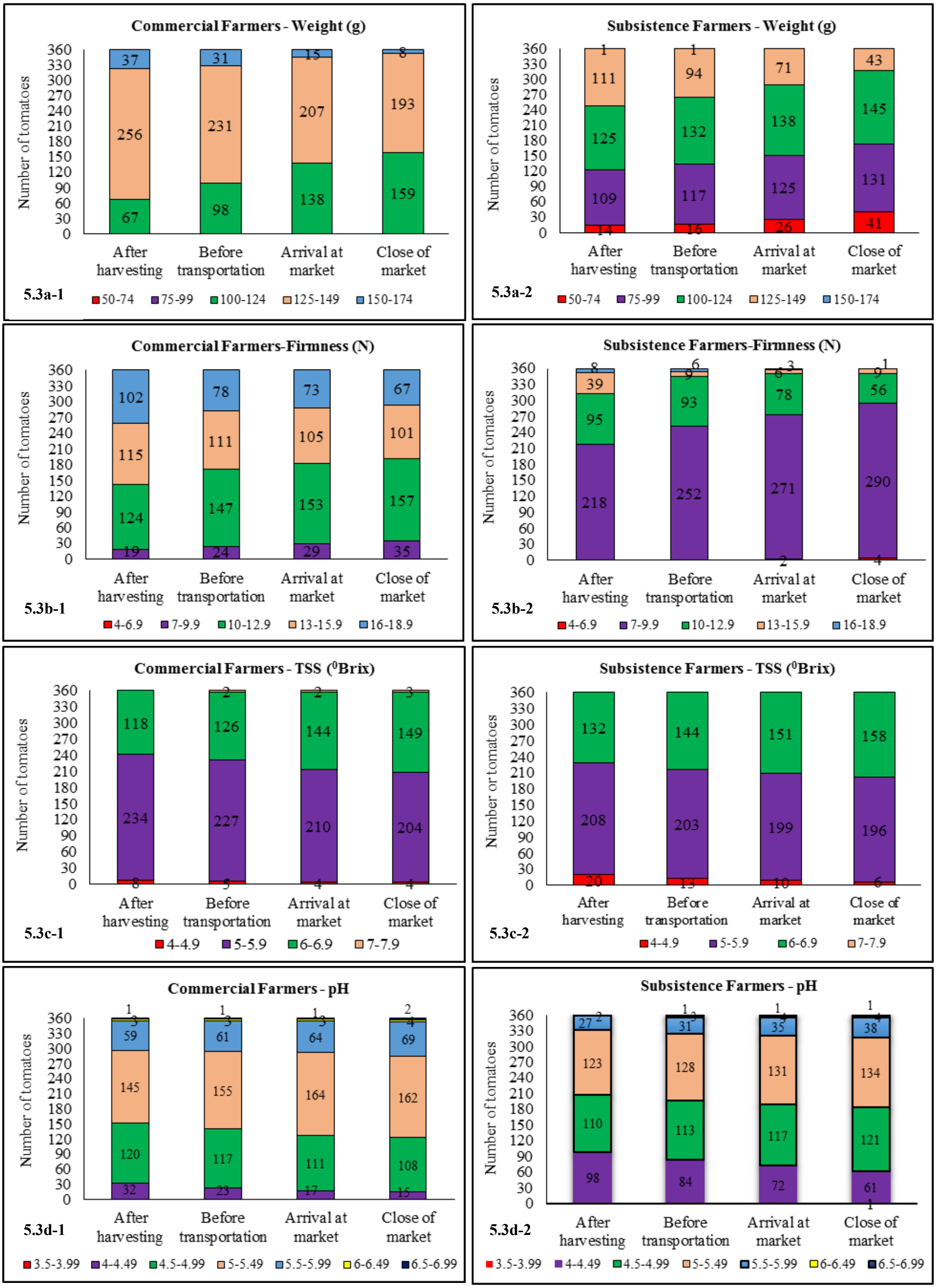

Figure 5.3 Changes in tomato quality parameters along the chain for commercial farmers (1) and subsistence farmers (2): (a) weight, b) firmness, (c) TSS, and (d) pH

Figure 5.4 shows that after harvesting, the fruit temperature of tomatoes from commercial and subsistence farmers ranged between 17-26 ^{0}C and 22-30 ^{0}C, respectively, which is because of the time of harvesting, i.e. between 8 am -10 am for commercial farmers and between 2 pm - 4 pm for subsistence farmers. Furthermore, temperature in the chain for commercial farmers was within the same range (17-25 ^{0}C) throughout all the postharvest stages, whereas substantial temperature fluctuations were observed in the chain for subsistence farmers, 14-25 ^{0}C in the morning and 19-33 ^{0}C from afternoon to midnight. The time-scale for subsistence farmers include an overnight transportation of the tomatoes resulting in a large temperature drop.

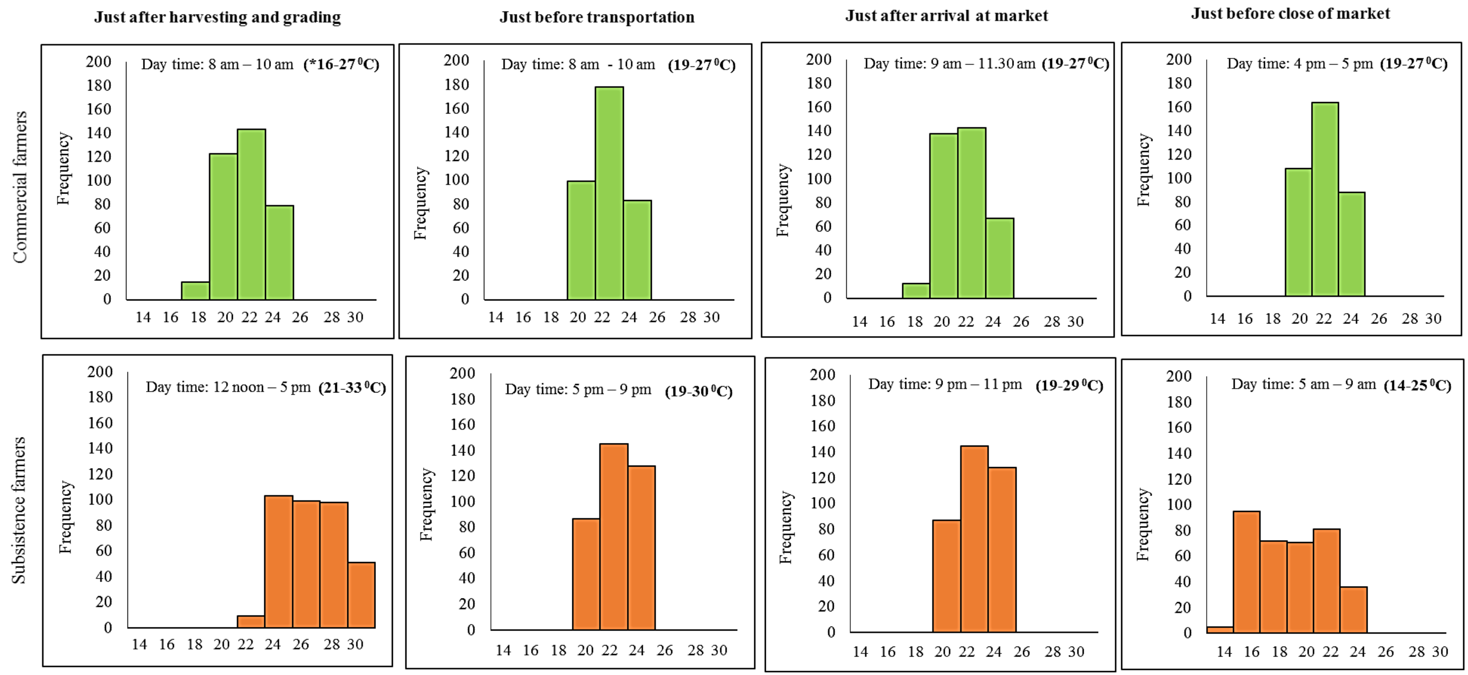

Figure 5.4 Variation in fruit temperature (T ^{0}C) along the tomato supply chains for commercial and subsistence farmers.

*Average environmental temperature (T ^{0}C) at each stage of the chain is shown in bold

5.4 Level of logistics and quality control activities

Table 5.2 shows that 12 of the 17 logistics and quality control activities are implemented at a moderate level (score 3) in the chain for commercial farmers. This level reflects that farmers commonly use procedure-driven methods (like a formal grading protocol), they use capable equipment in their operations, and logistics activities are typically planned based on adequate information on both product availability and demand. The lowest level (score 1) was assigned to the quality control activities *monitoring of transportation* and *storage conditions*, as no monitoring systems were implemented.

The subsistence farmers overall performed the logistics and quality control activities in a simpler way, 12 of the 17 activities scored 2 (i.e. the logistics activities are usually planned based on incomplete and historical data, and quality control activities are basic, not procedure-driven, and use self-made or outdated equipment). Only, the logistics control activity, *planning on stocking levels*, scored 3 (moderate) as all harvested tomatoes are transported to the market the same day and no stock is kept overnight. However, the quality control activities: *planning for grading standards*, *maintenance of equipment*, and *monitoring of storage and transportation conditions,* farmers scored even low (score 1), as these activities were not implemented at all. None of the farmers scored 4 (advanced level), which involves the use of advanced technology, procedures and processes, and all logistics activities are planned based on real-time product quality information. Therefore, there is room for improvement for farmers in both tomato supply chains.

Table 5.2 Level (represented by mode scores) of logistics and quality control activities for commercial and subsistence farmers

	Commercial farmers		Subsistence farmers	
1. Context characteristics				
Market supplied	Formal markets (supermarkets/wholesales)		Informal markets (Mbare Musika, open market)	
Supply contract	Some farmers have a supply contract		None	
Method of cultivation	Greenhouse and irrigated crop		Open field and rain fed	
Cropping material	Hybrid seeds used		Retained seeds are mainly used	
2. Level of logistics and quality control activities				
Activity	**Level of implemented activities**	**Mode score**	**Level of implemented activities**	**Mode score**
Determining on maturity to harvest	• Maturity at which produce is harvested is determined based on consumer's quality requirements. Produce of different maturity stages is harvested and supplied to the market as different batches.	3	• All maturity stages, i.e. just ripe, ripe and fully ripe, are harvested and supplied to the market as mixed batches.	2
Determining on moment to harvest	• Moment of harvest is not fixed as produce is harvested when there is an order.	3	• Moment of harvest is fixed; harvesting is either done in the morning, mid-day or late afternoon. Weather conditions are not usually considered.	2
Harvesting practices	• Fresh produce is harvested manually and pickers are provided with manuals on proper harvesting techniques.	3	• Fresh produce is harvested manually and there are no manuals available for use by pickers.	2
Determining quantity to harvest	• Quantity of produce to harvest is mainly determined based on demand forecast and historical data on demand for the product.	3	• All ripe produce is harvested without considering available demand.	2
Planning on grading standards	• Grading standards are detailed and specify all the quality requirements and the tolerance levels.	3	• Grading standards are not available	1
Grading practices	• Grading is done manually. Visual assessment is done based on colour, size, and defects. Manuals for grading are available and accompanied by visual aids. However, the manuals are not usually updated.	3	• Grading is done manually and no measurements are done on quality attributes. There are no procedures for grading available for use by personnel involved in grading.	2
Planning on packaging material	• The tomatoes are packed in different sizes based on customers' needs and the packaging material is aimed	3	• Tomatoes are packed in wooden crates, which are not appropriate for both protection against microbial	2

	at preventing growth of micro-organism and providing protection against physical damage.		contamination and physical damage. All tomatoes are supplied in 7 kg wooden crates.	
Packing practices	• Produce is correctly packed to avoid over-and under filling, but not every pack or batch is weighed; only a few samples are weighed.	3	• Produce is packed until containers are full and no weighing is done. Incidences of under-and over filling are common.	2
Determining on processing volumes	• Amount of produce graded and packed is based on historical data on processing volumes and market demand.	3	• Produce is graded and packed without any orders or information on market demand. Information on market demand is not available.	2
Storage stage				
Storage practices	• Procedures are not available for packing personnel to use. Produce of different product is stored in the same storage room. However, produce is stacked on pallets at a reasonable distance from each other.	2	• Produce of different product characteristics is stored in same room. Produce clustered together without clear separation and stacked directly on the ground.	2
Planning on stocking levels	• Limited inventory is kept as stocking levels are determined based on historical information on demand forecast.	3	• Limited inventory is kept as in most cases the tomatoes are transported to the market the very day they are harvested.	3
Monitoring storage conditions	• Storage conditions, temperature and humidity, are not recorded.	1	• Storage conditions, temperature and humidity, are not recorded.	1
Planning on order picking policy	• Order picking is strictly on first-in first-out basis (FIFO) without considering the quality status of the produce.	2	• Order picking is strictly on first-in first-out basis (FIFO) without considering the quality status of the produce.	2
Maintenance of equipment	• Maintenance of equipment is reactive, as equipment is only maintained after breaking down.	2	• Maintenance is ad-hoc and there is no schedule of maintenance activities. Instructions concerning frequency and maintenance tasks are not documented.	1
Transportation stage				
Monitoring transportation conditions	• Transportation conditions, temperature and humidity, are not recorded.	1	• Transportation conditions, temperature and humidity, are not recorded.	1
Determining the mode and type of transportation	• The mode and type of transport used do not have the capabilities to maintain a cold chain. However, it provides enough protection to prevent physical injury to produce.	3	• The mode and type of transport used does not have the capabilities to maintain a cold chain and to provide protection against physical injury to produce.	2
Planning vehicle routing	• Transport used is dedicated to ferry fresh produce only but there are many stops and diversions from the main route to deliver produce to other markets off route.	3	• Produce is transported mixed with other different types of farm produce and farmers are also transported on the same lorry. There are many stops and diversions before reaching the market.	2

Activities in italics represent logistics control activities; score 1 = low level; score 2 = basic level; score 3 = moderate level; score 4 = advanced level

5.5 Changes in market prices in supply chains for commercial and subsistence farmers

Figure 5.5 shows changes in prices of tomatoes in the supply chains for commercial and subsistence farmers. Tomato prices for commercial farmers were more stable throughout the three postharvest stages (farm gate, start of market and close of market) as compared to those for tomatoes from subsistence farmers. The farm gate price for tomatoes from commercial farmers was US$3.50 per 7 kg crate and the average selling price at the market was US$3.30, a 5.7% price decrease. As for subsistence farmers, the average farm gate price for their tomatoes was US$3.00 and the selling price at the market was an average of US$2.00, thus 33.3% decrease in price (Figure 5.5).

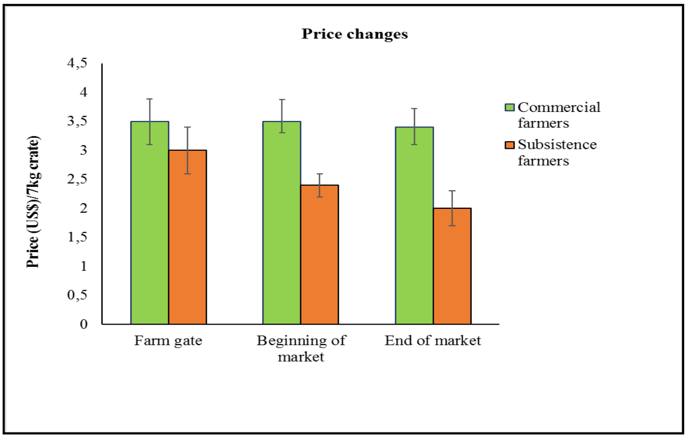

Figure 5.5 Changes in tomato prices along the chain for commercial and subsistence farmers

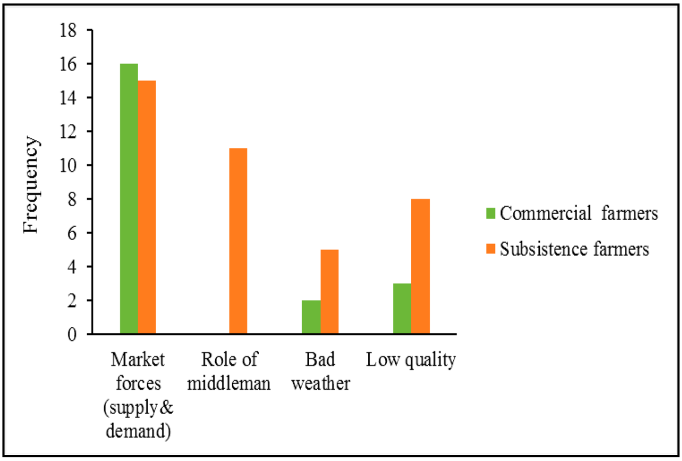

Figure 5.6 Causes of changes in tomato prices along the chain for commercial and subsistence farmers

5.6 Discussion

The study aimed at getting insight into the extent and possible causes of qualitative and economic PHL in the Zimbabwean tomato chain for commercial and subsistence farmers. Firstly, possible causes of observed changes in weight (qualitative losses), firmness, total soluble solids, and pH (qualitative losses), and prices (economic losses) are discussed in view of the environmental temperature conditions. Secondly, we discuss how the logistics and quality activities could explain the recorded PHL. Finally, possible factors affecting price variation in the two chains are discussed.

5.6.1 Possible causes of changes in tomato quality parameters

Weight and firmness in the two tomatoes supply chains decreased significantly ($p<0.05$) along the supply chain (Table 5.1 and Figure 5.3-a and 5.3-b), which could be caused by the relatively high environmental temperatures along both supply chains (Figure 5.4). However, the percentage weight loss and decrease in firmness of tomatoes were significantly higher in the chain for subsistence farmers (11.1% and 21.6%) compared to the chain for commercial farmers (7.1% and 14.5%). These observations are correlated with the larger fruit temperature ranges recorded in the chainfor subsistence farmers (14-30 ^{0}C) as compared to the chain for commercial (17-23 ^{0}C) (Figure 5.4). Previous studies on effects of temperature on quality of tomatoes (Saltveit, 2003; Pinheiro *et al*., 2013) show that the rate of metabolic activities and cell wall degradation increased two to threefold for every 10 ^{0}C increase in temperature above the optimum, 10-15 ^{0}C. Moreover, several studies (Marín-Rodríguez *et al*., 2002; Lana *et al*., 2005; Pinheiro *et al*., 2013) found that temperatures above 25 ^{0}C increase the transpiration rates (CO^2 production) of tomatoes, which cause fruit softening (decrease in firmness) and loss in weight of tomatoes, as observed in our study.

From the moment just after harvesting till just before close of the market, the percentage of TSS of the tomatoes gradually increased. The increase was higher in the chain for subsistence farmers (15.6%) as compared to that for commercial farmers (12.5%). At the same time, a slight increase in pH was observed in both chains (Figure 5.3-d1 and d2, and Table 5.1). The significantly higher increase in TSS for tomatoes from subsistence farmers than for commercial farmers could be attributed to the high loss in weight (11.1% and 7.1%, respectively). Tigist *et al.* (2013) found that excessive moisture loss in tomatoes increase TSS content due to a concentration effect as well as hydrolysis of carbohydrates into soluble sugars. Moreover, Gautier *et al.* (2008) demonstrated that the TSS content increased, at temperatures between 26 and 30 ^{0}C, because the carbohydrate synthesis and evapotranspiration increased. Evapotranspiration is the combination of evaporation and transpiration. The higher and significant increase in TSS content and pH, in the chain for subsistence farmers than for commercial farmers, could be due to the high temperature fluctuations in the chain for subsistence farmers.

5.6.2 Possible influence of logistics and quality control activities and farmers' context on quality losses

The relatively large environmental temperature range observed in the chain for subsistence farmers (14-33 ^{0}C) and to a lesser extent for the commercial farmers (16-27 ^{0}C) along the supply chain, likely affected multiple physiological processes resulting in the observed quality losses as discussed above. However, the initial values of the quality parameters and weight of the tomatoes differed substantially (Figure 5.3). To gain a further understanding of possible underlying causes, the logistics and quality control activities, as well as the farmers' business characteristics were studied (Table 5.2). Overall, the commercial farmers operate these activities at a moderate level (score 3), whereas subsistence farmers operate the activities mainly at a basic (score 2) to low level (score 1). Moreover, the commercial and subsistence farmers differ in their context characteristics; the latter being more vulnerable to PHL. More specifically, subsistence farmers harvested all the maturity stages at once, i.e. just ripe, ripe, and fully ripe, and supply the market as mixed batches and do not supply on demand ('determining quantity to harvest' scored 2). Commercial farmers harvested tomatoes according to a specified maturity level (score 3) and quantity of harvesting is determined based on demand forecasting (score 3) to supply the market with batches of homogeneous maturity.

The more basic practices of subsistence farmers probably contributed to the large variation in initial weight and firmness of their tomatoes as compared to those from commercial farmers (Figure 5.3-a and 5.3-b). Clearly, the variation in weight loss is substantially larger for tomatoes from subsistence farmers; the standard deviation is more than twice higher for tomatoes at all 4 stages. However, this is not the case for firmness, the standard deviation is consistently high (around 26%) for tomatoes in both chains at all stages. The harvesting practice of subsistence farmers (score 2) involves that they pick tomatoes in the late afternoon (21 ^{0}C and 33 ^{0}C), whereas commercial farmers harvest in the early morning (16 ^{0}C - 27 ^{0}C, Figure 5.4), to avoid exposing the tomatoes to high temperatures (score 3). The harvesting time of tomatoes is an important factor in quality loss of tomatoes Awan *et al.* (2012), as tomatoes exposed to low field heat at harvesting have a lower weight loss, TSS, fruit pH, reducing sugars and disease incidence as well as higher juice content, fruit firmness, non-reducing sugars and ascorbic acid as compared to high field heat at harvesting (Rab *et al.*, 2013).

Another reason for the higher initial variation in quality parameters is probably due to differences in quality control as grading practices just after harvesting (commercial farmers scored 3, whereas subsistence farmers scored 1 and 2, Table 5.2). Subsistence farmers usually grade the tomatoes according to ripeness (mainly fruit colour), have no grading protocols, and do not use quality standards, whereas commercial farmers, grade the tomatoes as per customer specifications using strict quality specifications on size, ripeness, maturity, and blemishes. Furthermore, the packing practices differ, score 3 for commercial farmers and score 2 for subsistence farmers. Score 2 implies that farmers use wooden crates, which are often poorly constructed resulting in bruising damage to the tomatoes, affecting initial quality. Score 3 implies packing practices that use plastic and cushioned crates, which protect the tomatoes from bruising damage.

Interestingly, the scores for quality control activities during storage did not differ as both farmers do not control environmental conditions such as temperature. However, the farmers have different storage facilities (farmers' context characteristics, Table 5.2). Unlike in the chain for commercial farmers where the tomatoes are stored in proper storage facilities, though not refrigerated, subsistence farmers commonly store their tomatoes either under the shade of a tree or in a structure made of plastic. Such storage facilities do not protect the tomatoes from bad weather conditions, which have been identified as a major cause of quantitative losses in previous studies (Arah *et al.*, 2015a; Ahmad & Siddiqui, 2016; Emana *et al.*, 2017; McKenzie *et al.*, 2017).

After storage, the main difference between farmer types is observed in the type of transport (Table 5.2). Most (18/20) of the commercial farmers use closed trucks to transport the tomatoes to the market (score 3), whilst all the subsistence farmers use open trucks (score 2, Table 5.2). Although the trucks used by the commercial farmers did not have cooling capabilities and temperature was not monitored (score 1), the tomatoes were protected from extreme weather conditions. This is reflected in the constant fruit temperature range recorded in this supply chain (Figure 5.4). The optimal transportation temperature conditions for tomatoes are between 2 ^{0}C and 5 ^{0}C, and above 23 ^{0}C rapid quality deterioration occurs (Dew *et al.*, 2016; Fahmy & Nakano, 2016). The wide temperature range in the two chains and the lack of monitoring of temperature present an opportunity for improvement in both chains.

Finally, commercial farmers indicated that they only use certified seeds and seedlings from seed-houses (Table 5.2), grow the tomatoes under greenhouses conditions, and use irrigation systems to water the tomatoes, whereas most (17/20) of the subsistence farmers highlighted that they grow the tomatoes in open fields, use seeds retained from the previous crop, and all of them rely on natural rainfall. Certified seeds are usually of good quality and free of diseases as compared to retained seeds, which are commonly contaminated. Previous studies (Clayton *et al.*, 2009; Lammerts van Bueren *et al.*, 2011) showed that vegetables crops, such as tomatoes, grown from certified seeds have better yield and quality characteristics, such as weight and firmness, as compared to those grown from retained seeds. This possibly also explains the large number of tomatoes in higher weight categories (Figure 5.3-a1 and a2). Furthermore, tomatoes grown under greenhouse conditions have been reported to be firmer and weigh more than those grown in the open field due to the protection from adverse weather conditions, such as high temperatures (Kanwar, 2013; Oceania *et al.*, 2015). Likewise, in the current study, we observed firmer and heavier tomatoes in the chain for commercial than for subsistence farmers (Figure 5.3-b1 and b2). Furthermore, studies on the effect of irrigation versus natural rains on the quality of tomatoes showed that irrigated tomatoes are of better quality, i.e. weigh more and are firmer than rain fed tomatoes (Guida *et al.*, 2017; Wang & Xing, 2017). This could explain the large number of tomatoes in the 125g-149g (61.6%) and 13-15.9 N (30%) classes for commercial farmers compared to the chain for subsistence farmers, where the largest number of tomatoes is in the classes 100-124g (37.5%) and 7-9.9 N (71.6%).

5.6.2 Factors affecting price changes

The initial low quality of the tomatoes from subsistence farmers (Table 5.2) could be the reason their tomatoes are already priced lower right at farm gate as compared to those from commercial farmers. The rapid fluctuations in demand and supply in the informal markets as compared to formal markets might explain the higher price decrease in the chain for subsistence farmers (33.3%) as compared in the chain for commercial farmers (5.7%) (Figures 5.6). Commercial farmers indicated that they supply to the markets as per order and prices are agreed beforehand. Therefore, prices inthe chain are usually constant from harvesting stage till close of the market. However, in the informal markets, prices fluctuate significantly, mainly due to lack of information on supply and demand, and lack of supply contracts. This results in oversupply of tomatoes, which leads to lower market prices. Nyaja (2014) and eMkambo (2015) identified lack of vital market information, on supply and demand, as an important reason for commodity oversupply in informal markets in Zimbabwe, leading to reduced margins to the farmers.

In addition, the presence of middlemen in the chain for subsistence farmers could be another factor contributing to the difference in price changes. Subsistence farmers indicated middlemen as a major driver of market price changes in their chain. In Zimbabwe and other Sub-Sahara African countries, middlemen control trading in most of the informal markets and have power in determining the prices (eMkambo, 2015). All commercial farmers interviewed supplied their tomatoes directly to the retailers. Eliminating the middleman has been proposed in some other studies (Cadilhon *et al.*, 2006; Reddy *et al.*, 2010) as an important step in reducing price fluctuations in fresh produce chains, especially in Sub-Saharan Africa where the phenomena of middleman is high. High number of actors in a chain results in more handling stages, which could result inquality deterioration due to poor handling techniques, leading to lower market prices (Gustavsson *et al.*, 2011).

5.7 Conclusion

Overall, commercial farmers had less fluctuations in environmental temperature, lower qualitative and economic losses in their chain as compared to that for subsistence farmers. Moreover, the logistics and quality control activities scored lower in the chain for subsistence farmers than for commercial farmers. The concurrent assessment of quantitative, qualitative and economic postharvest losses quality parameters in view of farmers' logistics and quality control activities, as well as their context characteristics provided a comprehensive insight in underlying causes of PHL. These insights can be used in further studies as basis for more holistic intervention strategies to advance towards sustainable tomato chains in Zimbabwe in particular and in Africa in more general.

Chapter 6

General discussion

6.1 Introduction

Postharvest losses (PHL) are a major challenge in fresh produce chains in Sub-Saharan Africa. Several interventions for PHL reduction are proposed in postharvest literature, but PHL remain a problem. This research aimed at getting insights into which and how logistics and quality control activities, and context characteristics influence PHL in fresh produce chains. A systems approach was used to analyse the problem of PHL, specifically, in a case study of tomato supply chains in Zimbabwe. The following research questions were formulated.

Research questions

RQ1: Which logistics and quality control decisions influence postharvest losses in fresh produce chains and how are the decisions hierarchically organised?

RQ2: Which are the core logistics and quality control activities, and the core context characteristics that can influence the incidence of postharvest losses in Zimbabwe?

RQ3: Which logistics control activities, quality control activities, and context characteristics are the determinants of postharvest losses in tomato supply chains in Zimbabwe?

RQ4: What is the magnitude of qualitative and economic postharvest losses and possible causes associated with logistics and quality control activities in tomato supply chains in Zimbabwe?

This chapter summarises the major findings and discusses how these findings could contribute to the development of effective interventions for PHL reduction. This chapter is organised as follows. First, section 6.2 presents the major findings with respect to the four research questions. Section 6.3 discusses the integrated findings and the contribution to the achievement of the main research objective. Section 6.4 presents the managerial implications of this research. Section 6.5 presents the research limitations and recommendations for future research. Finally, section 6.6 presents concluding remarks.

6.2 Main research findings

6.2.1 Hierarchical categorisation of logistics and quality control decisions influencing postharvest losses in fresh produce chains

The study presented in Chapter 2 aimed at understanding the multiple decisions that could unravel the complexity of PHL in fresh produce chains. For this purpose, the hierarchical decision approach was used to identify, analyse, and categorise logistics and quality management decisions that can influence the incidence of PHL. The developed hierarchical decision framework was then used as a basis to identify, analyse, and hierarchically categorise interventions for PHL reduction proposed in literature. A total of fifteen logistics management decisions were identified: five of the decisions are at the strategic level, five at tactical level, and another five at operational level. As for quality management related decisions, four of the decisions are at strategic level, eight at tactical, and four at operational level. Results from the analysis and categorisation of proposed interventions in literature revealed that at strategic level, 55% (6/11) of the interventions focus on logistics management whilst 45% (5/11) on quality management. As for the interventions at tactical level, the results show that 54% (7/13) are related to logistics management and 46% (6/13) to quality management. The scenario is different for the interventions at the operational level where 82% (9/11) of the interventions focus on quality management and only 18% (2/11) on logistics management. The developed hierarchical framework of decisions provided a systematic way to decompose complex decision-making in fresh produce chains and has potential to support selection of effective interventions for PHL reduction.

6.2.2 Core logistics and quality control activities, and context characteristics influencing the incidence of PHL

The study presented in Chapter 3 aimed at identifying crucial context characteristics,core logistics control, and core quality control activities that can affect the incidence of PHL in fresh produce chains. Postharvest literature was examined to identify the core activities and context characteristics. The identified core context characteristics were categorised into product, process, organisation, and supply chain characteristics. Planning on the amount of fresh produce to harvest and process, selecting issuing policies, selecting mode of transportation and type of vehicle, and vehicle scheduling and routing are the core logistics control activities identified. Maturity determination at harvest, deciding on harvest moment, harvesting, packing, and storage practices, use of grading standards, package material, temperature monitoring during storage and transportation, and equipment maintenance are the core quality control activities identified. A tool to diagnose the status of these core activities, the vulnerability of the postharvest system to the context wherein it operates, and the actual PHL was developed based on the identified core activities and context characteristics. The diagnostic tool was applied to subsistence and commercial tomato farmers in Zimbabwe. The results showed that the context for commercial farmers was less vulnerable to the incidence of PHL as compared to that for subsistence farmers. Moreover, logistics and quality control activities for commercial farmers were at a more advanced level. Furthermore, commercial farmers recorded lower PHL (1%) as compared to subsistence farmers (3%). The diagnostic tool enabled a differentiated assessment of the logistics and quality control activities implemented in the tomato supply chains.

6.2.3 Determinants of postharvest losses in tomato supply chains in Zimbabwe

Chapter 4 presented a study aimed at identifying context characteristics, logistics control activities, and quality control activities that are determinants of PHL in tomato supply chains in Zimbabwe. Besides identifying the determinants, the diagnostic tool presented in Chapter 3 was used to assess the status of the implemented logistics and quality control activities, the vulnerability of farmers' context, and the actual PHL. The results revealed that more advanced logistics and quality control activities, and context characteristics with a lower vulnerability to PHL are associated with less PHL. Furthermore, the results revealed that determinants of PHL in the chain studied are multidimensional: some related to the farmers' context (*features of storage facilities, method of cultivation, and market price stability as context characteristics*), others to the logistics (*determining processing volumes*), and quality control activities (*deciding on maturity to harvest, deciding on moment to harvest, and storage practices*). This clearly demonstrates the complexity of the problem of PHL. Furthermore, a framework of possible interventions for PHL reduction tailored to the particular developmental stage of farmers in the supply chain was developed.

6.2.4 Qualitative and economic postharvest losses in Zimbabwean tomato supply chains

Chapter 5 presented a study aimed at getting insight into the extent of qualitative and economic PHL, and the possible causes associated with logistics and quality control activities in tomato supply chains in Zimbabwe. A quantitative field study was conducted in the tomato supply chains for commercial and subsistence tomato farmers. Tomato quality parameters: firmness, pH, total soluble solids (TSS), weight, and environmental temperature were recorded from harvesting to the moment of actual sale. Furthermore, changes in prices of tomatoes along the chain and the underlying reasons were analysed for the two types of farmers. The results showed that weight and firmness for tomatoes from subsistence farmers significantly decreased by 11.1% and 21.6%, respectively, as compared to that for tomatoes from commercial famers (7.1% and 14.5%, respectively). The pH and TSS significantly increased (20.9% and 15.6%, significantly) in the tomatoes from subsistence farmers as compared to those from commercial farmers (12.5% and 6.5%, respectively). These differences apparently related to the observed differences in the status of logistics and quality control activities. Overall, subsistence farmers perform these activities at a basic level, whereas commercial farmers perform most activities at a more advanced level. The economic losses (decrease in price of the tomatoes) were significantly higher in the chain for subsistence farmers (33.3%) as compared to the chain for commercial farmers (5.7%). The difference could be ascribed to fluctuations in demand and supply in the informal markets as compared to formal markets, where subsistence and commercial farmers supply, respectively. This study showed that tomato farmers incur significant qualitative and economic PHL, which is usually not taken into account in PHL studies.

6.3 Integrated findings

This thesis contributes to the current body of postharvest literature and connects the disciplines of logistics management, quality management, and postharvest management. In isolation, each chapter has its own research findings, but together, they contribute towards the overall research objective.

6.3.1 Postharvest losses

This research considered all three types of PHL, i.e. qualitative, quantitative, and economic losses. The case study presented in Chapter 4, revealed relatively low PHL: 1% in the supply chain for commercial farmers and 3% for subsistence farmers. However, only quantitative losses, in the form of physical losses, were considered. Results in Chapter 5, in which quantitative, qualitative and economic losses were considered, provided a deeper understanding. These results revealed a weight loss (quantitative loss) of 11.1% and 21.6% decrease in firmness (qualitative loss) in the chain for subsistence farmers, whereas for commercial farmers the weight loss was 7.1% and the decrease in firmness was 13.8%. Furthermore, the study revealed 33.3% in economic losses (decrease in the price of the tomatoes) in the chain for subsistence farmers and only 5.7% in chain for commercial farmers. This thesis shows that estimating PHL based only on quantitative losses results in an underestimation of the actual PHL. More so, this thesis contributes to postharvest literature by giving insight into likely causes and magnitude of all the three types of PHL in tomato supply chains in Zimbabwe.

6.3.2 Holistic postharvest loss assessment framework

Figure 6.1 depicts the main integrated findings of this research, and shows the links between the different components of the complex system contributing to the incidence of PHL. The holistic framework consists of postharvest stages in fresh produce chain, core logistics and quality control activities that influence the incidence of PHL, crucial context characteristics that create vulnerability to PHL, and multiple types of PHL (quantitative, qualitative, and economic) generated in the chain.

The core logistics and quality control activities influencing PHL at each postharvest stage along the fresh produce chain were identified in Chapter 3. These activities influence the rate at which quality decay occurs in fresh produce, thereby, influencing the incidence of PHL. Together, the activities and the postharvest stages along the chain form the postharvest system, indicated by grey colour in Figure 6.1. Context characteristics that can influence the performance (incidence of PHL) of the postharvest system were also identified to gain an understanding on how they influence PHL. Results presented in Chapters 3 to 5 revealed that logistics and quality control activities implemented at a low level are associated with high PHL, and those implemented at an advanced level are associated with low PHL. Furthermore, the results revealed that tomatoes supply chains operating in a highly vulnerable context are associated with higher PHL as compared to supply chains operating in a low vulnerability context. This thesis therefore provides an understanding on which and how logistics and quality control activities, and context characteristics influence PHL in tomato supply chains in Zimbabwe. In addition, this research revealed that the determinants of PHL in tomato supply chains in Zimbabwe are multidimensional. Some are of a context, some of logistics, and some of quality control nature.

The holistic framework for postharvest loss assessment together with the assessments grids presented in Tables 3.2-3.4 form the diagnostic tool developed in this research. The diagnostic tool was applied in three cases studies in tomato supply chains in Zimbabwe and it enabled for a differentiated assessment that can support users to identify improvement opportunities to achieve higher performance for the activities, thereby minimising PHL. Insights from the assessment can be used in designing effective interventions for PHL reduction, thereby, contributing to improvement towards sustainable fresh produce chains.

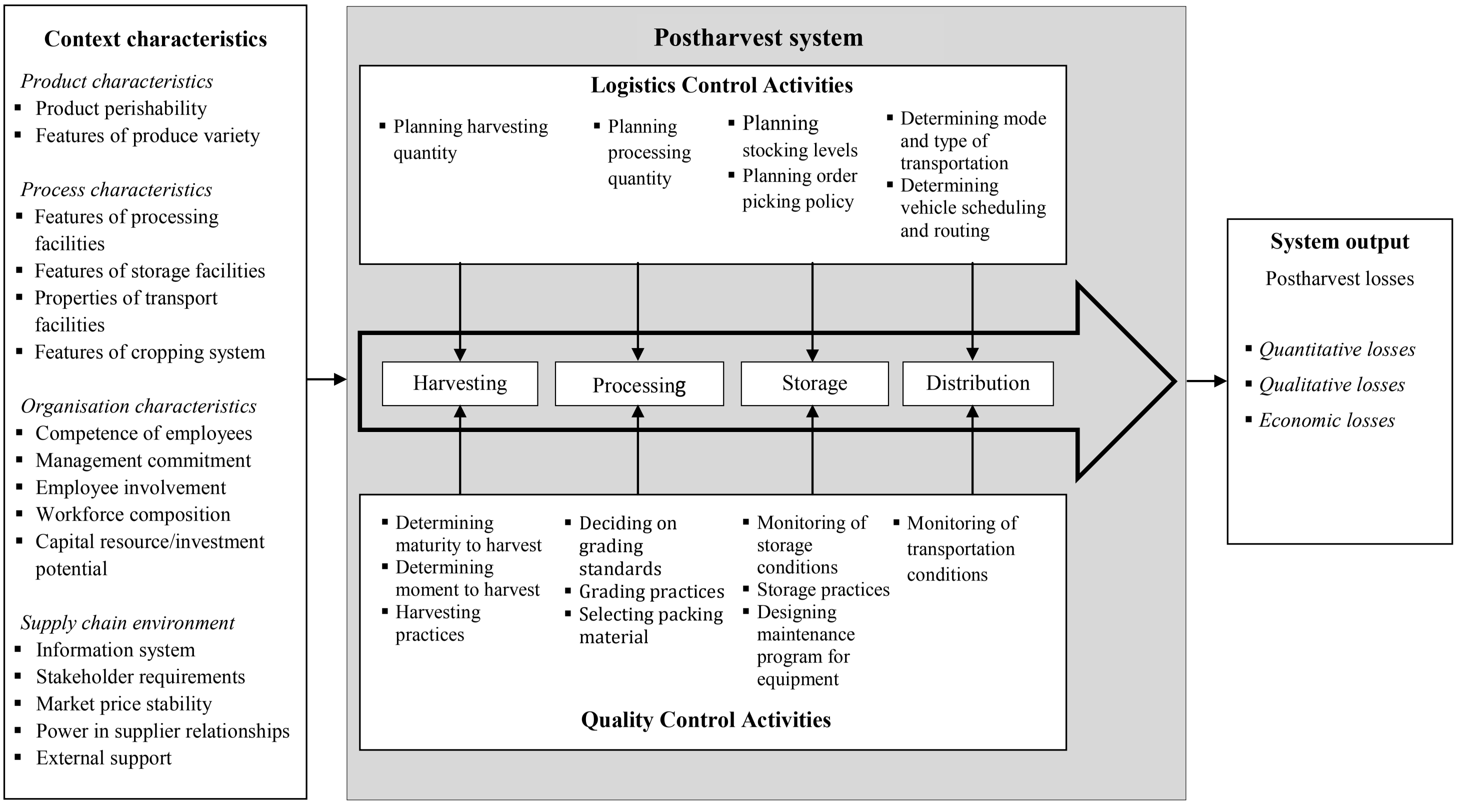

Figure 6.1. Holistic framework for postharvest loss assessment in fresh produce chains

6.3.3 Towards feasible interventions

This thesis presented two frameworks about interventions for PHL reduction in fresh produce chains. Figure 2.3 (Chapter 2) illustrates how interventions for PHL proposed in postharvest literature could be organised into operational, tactical, and strategic levels. Chapter 4 (Figure 4.3) discusses how different interventions for PHL reduction can be targeted at fresh produce chains in different development stages: underdeveloped, basic, intermediate, and advanced. Figure 6.3 is a combined framework of PHL reduction interventions organised both hierarchically and by the development stage of the supply chain.

This thesis has shown that PHL cannot be attributed to a single cause, but to multiple causes related to context factors, quality control activities, and logistics control activities. Therefore, the proposed interventions in Figure 6.3 are targeted at improving logistics control and quality control, and at reducing the vulnerability of the farmers' context characteristics to PHL. Studies in Chapter 3 to 5 revealed that the supply chain for commercial farmers is more advanced, as it is characterised by modern storage and transportation facilities, and farmers have access to financial resources, as compared to the chain for subsistence farmers. The chain for subsistence farmers is characterised by absence of or basic storage and transportation facilities, and farmers that lack access to financial resources. Therefore, this thesis proposes different interventions for different supply chains, depending on their development stage.

Figure 6.4 illustrates how interventions can be differentiated based on the development stage of a given supply chain. It shows that the more advanced interventions target at changing the strategic level, whereas more basic interventions make changes at the operational level. More so, Figure 6.4 shows that the type of interventions become more advanced with the maturing of the supply chains, i.e. more basic interventions are proposed for chains still at the basic stage and more sophisticated interventions for chains at the advanced stage. For supply chains at the underdeveloped to basic stage, interventions at the operational level (e.g. harvesting tomatoes in the cool hours of the day and basic informal training of farmers on proper harvesting techniques) are more appropriate. This is because those chains are characterised by lack of financial resources and with logistics and quality control activities practiced at a low level. Hence, interventions without much efforts in terms of costs and competences are suggested. For supply chains that are in transition from a basic to the intermediate stage, foremost interventions at operational and tactical levels (e.g. use of more robust crates, such as plastic instead of wooden creates, recording and monitoring of environmental conditions) best fit the characteristics of these supply chains. These characteristics include, among others, small investments in more advanced tools. However, a few interventions are targeted at making changes at the strategic level (e.g. improving communication along the supply chain demand and supply). As for supply chains that are in transition from the intermediate stage to the advanced stage, interventions at the strategic level (e.g. investing in automated grading systems and using greenhouse and irrigation cultivation system) best fit the characteristics of these chains. The chains are characterised by use of advanced technologies, substantial investment in advanced materials, and implementation of elaborated control and logistics systems.

Underdeveloped → Basic stage

Logistics control

Operational level
- Transporting produce during the evening hours to avoid high temperatures
- Covering produce during storage and transportation to avoid bad weather conditions

Quality control

Operational level
- Buying certified seeds from seed-houses
- Packing produce according to quality levels
- Using clean, smooth, and ventilated containers for packing
- Grading and sorting of fresh produce according to quality levels
- Training farmers on basic produce handling

Basic → Intermediate stage

Logistics control

Tactical level
- Using closed trucks for transportation of produce to markets
- Using quality-based inventory issuing policies, such as High Quality First Out

Quality control

Operational level
- Using control charts and visual aids that show proper postharvest handling procedures
- Using plastic crates to pack produce
- Monitoring and recording of storage and transportation conditions

Tactical level
- Growing cultivars that have long postharvest-life and resistant to diseases
- Implementing Good Agricultural Practices, Good Manufacturing Practices, and Good Hygienic Practices
- Formal training dedicated to postharvest handling

Strategic level
- Improving communication along the supply chain demand and supply

Context
- Developing new markets for sub-standard produce
- Increasing capacity and efficiency of processing equipment

Intermediate stage → Developed stage

Logistics control

Strategic level
- Investing in a cold chain, e.g., refrigerated cold storage and transportation facilities
- All logistics activities are based on real-time product quality information

Quality control

Tactical level
- Growing cultivars with long postharvest life, resistant to diseases, and have specific quality characteristics
- Dedicated training on postharvest technology
- Investing in intelligent packaging to help monitor product quality

Strategic level
- Investing in automated grading systems
- Investing in modified atmosphere storage facilities
- Implementing quality management systems
- Using greenhouse and irrigation cropping system

Context
- Investing in supply chin relationships
- Establishing suitable market strategies

Figure 6.3. Step-wise approach for implementation of interventions in fresh produce chains at different developmental stages

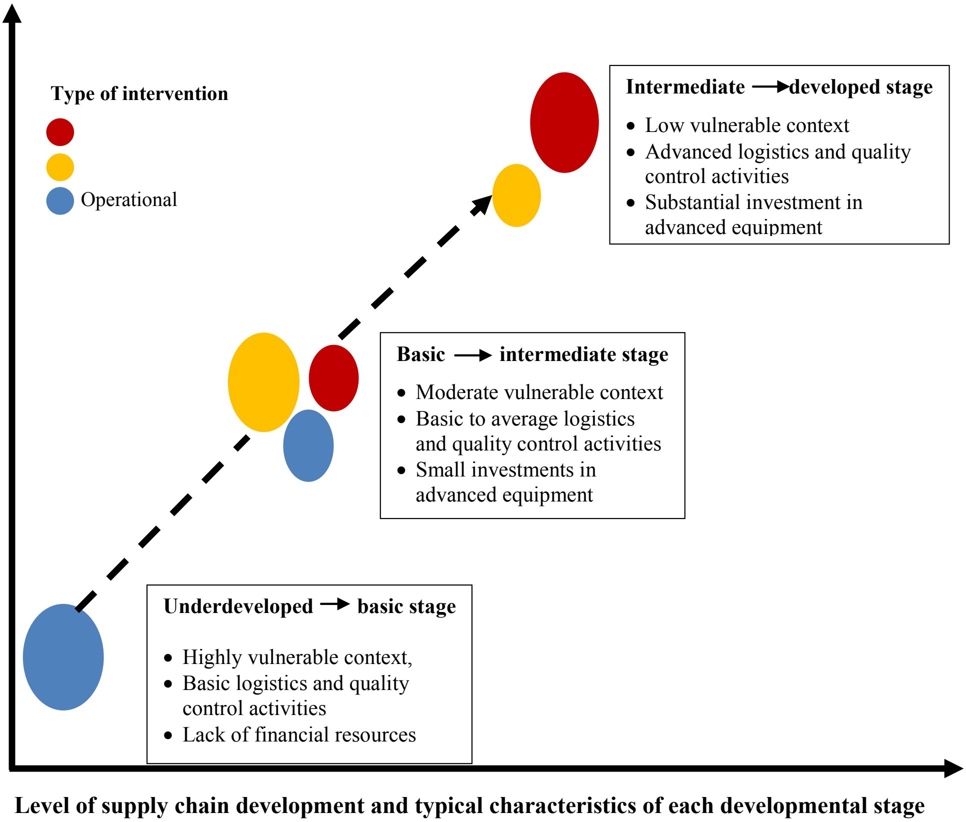

Figure 6.4. Differentiation of interventions for postharvest loss reduction in relation to the developmental stages in fresh produce chains

6.4 Managerial implications

This thesis provides insights and tools that can support policy makers, supply chain actors, and researchers to make informed decisions regarding PHL assessment and reduction strategies. The diagnostic tool developed in this thesis can support supply chain actors to assess logistics and quality control activities practiced in their chains, as well as the vulnerability of their chains to the incidence of PHL. Insights from such an assessment can enable supply chains actors to identify improvement opportunities to achieve higher performance for the activities and to reduce context vulnerability, thereby minimising the incidence of PHL. Considering the complexity of fresh produce chains and the plethora of PHL reduction interventions proposed in literature, the step-wise approach to implementation of PHL reduction interventions proposed in this thesis becomes relevant. According to Kitinoja (2013), PHL reduction strategies are normally adopted if they fit well into an existing value chain and marketing system, more so, if they represent small steps of incremental improvement rather than requiring big changes in practices. Thus, the step-wise approach to implementation of interventions for PHL reduction developed in this research can be a useful tool to the various actors in fresh produce chains.

Practical implications of this research to the Zimbabwean tomato supply chains studied relate to the use of the proposed step-wise approach to implementation of PHL reduction interventions as a guide for the three types of farmers to improve towards achieving sustainable fresh produce chains, in which PHL are limited. For the subsistence farmers, whose chains are typically characterised by absence of, or basic, storage and transportation facilities, lack of financial resources, and little or no postharvest training, interventions at an operational level are most appropriate. These interventions do not require much capital investment and are for a short term. Most of the proposed interventions are targeted at quality control and a few on logistics control. As for supply chains that are in transition from basic to intermediate stage, interventions that are at the tactical level are most appropriate. These interventions include, among others: use of good agricultural practices, good hygienic practices, and use of closed trucks. In the chain for commercial farmers, which are typically characterised by substantial investment in advanced materials, and use of advanced equipment facilities, appropriate interventions are those at the strategic level.

Some of the interventions proposed for these chains are beyond the scope of the company, and can only be successfully implemented with the involvement of other stakeholders, such as the government. These interventions address the context in which the chain operates. For examples, the government should invest in public infrastructure such as roads, or public market facilities interventions government participation. Therefore, the proposed step-wise approach to implementation of PHL reduction interventions gives a differentiated guideline as to interventions that various actors in the fresh produce chain can take, from the government to the farmer, to minimise PHL.

6.5 Limitations and recommendations for further research

The research presented in this thesis gives new insights into which and how logistics and quality control activities, and context characteristics influence PHL in fresh produce. The research is nevertheless subject to some limitations, as also explained in each chapter. This section presents the main limitations of the complete research, as well as opportunities for further research. First of all, the hierarchical framework of logistics and quality control decisions and the step-wise framework of intervention strategies presented in Chapter 2 were solely based on theory without validation in practice. Hence, further research is therefore required to validate these two frameworks. Second, whilst the diagnostic tool presented in Chapter 3 was used and validated in tomato supply chains in Zimbabwe, its applicability in other fresh produce chains cannot be generalised as such, as the tool was not validated in other types of fresh produce chains. It is imperative that the tool is validated in other fresh produce chains and in other countries that present a different context to that of Zimbabwe.

Third, from a methodological perspective, farmers interviewed in the studies presented in Chapter 3-5 were selected through snowball sampling, which is a non-probability sampling technique, raising some concerns regarding the reproducibility of the findings in other contexts. However, the snowball sampling technique was used in this research as there was no readily available database where farmers could be randomly selected and also already classified into the different type of tomato farmers in Zimbabwe. The advantage of using the snowball sampling is that it enabled easy identification of the three groups of tomato farmers in Zimbabwe and the selected farmers were representative of the different types of tomato farmers in Zimbabwe, i.e. small-scale subsistence, small-scale commercial, and large-scale commercial famers. According to Sadler *et al.* (2010), snowball sampling is a more ideal sampling technique when representation from diverse communities is needed.

Finally, in cross sectional studies, it is difficult to make causal inference due to confounding factors. For example, whilst the results in Chapter 4 revealed a positive association between logistics and quality control activities and PHL, and a negative association between context characteristics and PHL, it is difficult to differentiate cause and effect from the associations observed. Confounding occurs when the effect of one variable is mixed together with the effect of another variable leading to results that might not reflect the actual relationship (Skelly *et al.*, 2012). According to Minegishi & Thiel (2000), system dynamics modelling contributes to improving understanding of the complex behaviour of an integrated food industry. Therefore, further research can be directed towards systems dynamic modelling to get more understanding on the interaction of the logistics control activities, quality control activities, and context characteristics, in relation to the incidence of PHL. The PHL reduction interventions proposed in this thesis can be modelled to address the complex issues involved in selecting the most appropriate interventions. Data compiled from the literature review and case studies can also be used as inputs for simulation modelling. Simulation modelling is more suitable for scenario assessment in complex systems (van der Vorst *et al.*, 2009). For this purpose, further research can be directed at combining food quality decay models with logistics models. The resulting model can be a useful tool for deciding on the interventions to implement in a given context with respect to the desired PHL reduction. Examples of previous researches that used simulation modelling in fresh produce chains include studies by van der Vorst *et al.* (2007) and Rijpkema *et al.* (2012).

6.6 Concluding remark

This thesis explores which and how logistics control activities, quality control activities, and context characteristics influence the incidence of PHL in fresh produce chains. The results show the importance of a systems approach in understanding the problem of PHL. More so, the results provides useful insights that can be used to design dedicated and prioritised PHL reduction strategies, which can contribute towards sustainable fresh produce chains. This research was motivated by my personal experience working with subsistence farmers in fresh produce chains in Zimbabwe. I noticed that their expected profits are eroded by high PHL. I hope the new insights provided in this thesis can be used by the various actors in fresh produce chains to improve towards advanced supply chains, in which PHL are minimal.

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Summary

Background and aim

Postharvest losses (PHL) in fresh produce chains are a substantial problem worldwide, and the problem is most prevalent in developing countries. For these countries, PHL are a major obstacle in achieving sustainable food supply chains. The PHL translate to loss of production resources, such as water and crop land used for production, loss in income for the various actors in the supply chain, and the losses are a threat to food security. Once fresh fruit and vegetables are harvested, they start to deteriorate in quality. Therefore, there is a need to transport the harvested produce to storage facilities or the market in the shortest possible time. More so, it is important to slow down the rate at which the physiological processes that lead to quality deterioration occur, in order to deliver fresh and high quality produce to the customers. Despite many intervention strategies having been proposed in the literature, PHL still remain a persistent problem. There is an urgent need to develop PHL reduction strategies tailored to the particular context of farmers in developing countries. The overall objective of this research was to understand the influence of logistics and quality control activities, as well as context factors, on the incidence of PHL in fresh produce chains as a basis for designing dedicated PHL intervention strategies.

Findings

The study presented in Chapter 2 aimed at identifying logistics and quality control decisions that can influence PHL in fresh produce chains. The decisions were identified through a semi-structured literature review. The identified decisions were then analysed and hierarchically categorised into operational, tactical, and strategic levels, based on time span, scope, and investment required to implement the decision. The resultant framework was used as a basis to identify, analyse, and categorise interventions for PHL reduction proposed in literature. The results revealed that proposed interventions at strategic and tactical levels mainly included logistics control decisions whereas interventions at operational level mainly included quality control decisions. The developed hierarchical framework of decisions provides a systematic way to decompose complex decision-making in fresh produce chains and has potential to support selection of effective interventions for PHL reduction.

In Chapter 3, a diagnostic tool was developed to concurrently assess the status of logistics and quality control activities, as well as the context characteristics wherein fresh produce chains

farmers operate. The tool consists of three components: postharvest system (including the core logistics and quality control activities influencing PHL), context characteristics that create vulnerability to PHL, and the output (PHL). The diagnostic tool was applied in a case study of tomato supply chains for small-scale subsistence, small-scale commercial and large-scale commercial farmers in Zimbabwe. The results showed that the context for commercial farmers was less vulnerable to the incidence of PHL as compared to that for subsistence farmers. The status of logistics and quality control activities for commercial farmers were at a more advanced level. Furthermore, commercial farmers recorded lower PHL (1%) as compared to subsistence farmers (3%). The study described in Chapter 3 resulted in a diagnostic tool that supports a differentiated assessment of logistics and quality control activities in view of the context wherein the supply chain actors operate, and can be adopted and applied in other than tomato supply chains as well.

Chapter 4 aimed at identifying the context characteristics, logistics control activities, and quality control activities that are determinants of PHL, in particular, tomato supply chains in Zimbabwe. The results revealed that factors influencing PHL in the tomato supply chains studied are multidimensional. Some of the identified determinants related to logistics control, some to quality control, and some to context characteristics. Furthermore, the results showed that commercial farmers execute logistics and quality control activities at a more advanced level, they operate in a low to moderate vulnerable context. The latter group of farmers performs the activities at a basic to low level, and operates in a highly vulnerable context. The results indicated that reducing context vulnerability and executing logistics and quality control activities at a more advanced level could lower the incidence of PHL. Based on these results, a step-wise framework of PHL reduction interventions that are tailored to the particular developmental stages of fresh produce chains was developed.

Chapter 5 aimed at getting insight into the magnitude of qualitative (firmness, pH, and total soluble solids), quantitative (weight) and economic (potential revenue lost) losses to gain a more comprehensive understanding of PHL. The results showed that all three types of PHL scored relatively high in the chain for subsistence farmers as compared to the chain for commercial farmers. The higher qualitative losses (firmness, pH, and total soluble solids) in the chain for subsistence farmers can be attributed to the logistics and quality control activities performing at a basic level, as compared to the moderate level in the chain for commercial farmers. Furthermore, the higher economic losses in the chain for subsistence farmers could be ascribed to frequent fluctuations in demand and supply in the informal markets as compared to formal markets, where subsistence and commercial farmers supply respectively. The presence of middlemen in the chain for subsistence farmer could be another reason for higher economic PHL in the chain for subsistence farmers as middlemen control trading in most of the informal markets and have power in determining the prices. The comprehensive investigation of the different types of PHL demonstrated that even though quantitative losses were relatively low as compared to other literature findings, the financial consequences of economic PHL for particularly subsistence farmers are substantial.

Conclusions

The research presented in this thesis contributes to the current body of postharvest literature by providing a diagnostic tool that can be used for concurrent and differentiated assessment of logistics and quality control activities in view of the farmers' context characteristics, and the analysis of actual PHL. Insights from such an assessment could enable supply chain actors identify improvement opportunities towards sustainable fresh produce chains. More so, the step-wise framework of interventions for PHL reduction developed in this thesis gives insights into improvement opportunities to achieve higher performance for the activities and to reduce context vulnerability. Furthermore, this thesis shows that all the three types of PHL should be considered when determining the magnitude of PHL in fresh produce chains. Overall, insights provided by this thesis could be used in designing effective interventions for PHL reduction, thereby, contributing to improvement towards sustainable fresh produce chains.

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About the author

Lesley Macheka was born in Makoni, Zimbabwe, on 27 March 1980. In 1999 he completed his high school (Advanced level) education at Bernard Mizeki College, Marondera. Thereafter, Lesley enrolled at the University of Zimbabwe to pursue a BSc Honours degree in Biological Sciences in 2000. He graduated in 2003 and from the 5th of January 2004 to the 30th of September 2004, he was employed as a Research Officer, Plant Pathology section at Plant Protection Research Institute, Zimbabwe. Lesley then joined the Grain Marketing Board (GMB) in October 2004 as a Quality Assurance Officer (Grains and Processed Products). Due to his passion for academia, Lesley left GMB in August 2008 to pursue a MSc degree in Food Quality Management at Wageningen University and Research, the Netherlands, under a NUFFIC fellowship. For his MSc thesis, Lesley researched on using the Quality Controlled Logistics concept to design effective postharvest loss reduction strategies in fresh produce chains. He collected data from banana supply chains in Zimbabwe and cut flower supply chains in Kenya. After completing his MSc studies, Lesley joined Chinhoyi University of Technology in April 2011, as a lecturer in the Department of Food Science and Technology. In August 2012 Lesley was granted another NUFFIC fellowship by the Netherlands Government to pursue a sandwich PhD, whose findings are discussed in this thesis. During the period he was in Zimbabwe for data collection, Lesley continued with his teaching duties at Chinhoyi University of Technology. At undergraduate level, he teaches courses that include: Food Safety and Legislation, Food Quality Management, Sensory Evaluation, and at postgraduate level he teaches Food Safety and Quality Management. He has supervised several BSc and MSc thesis students. His current research includes food safety management and postharvest management in fresh produce chains. Lesley is passionate about photography, a passion he intends to develop into a proffession.

Lesley Macheka
Wageningen School of Social Sciences (WASS)
Completed Training and Supervision Plan

Name of the learning activity	Department/Institute	Year	ECTS*
A) Project related competences			
Writing PhD research proposal	WASS	2012/2013	6
From topic to proposal	WASS	2013	4
Lost harvest & Wasted food	WUR - CDI	2012	4
B) General research related competences			
WASS Introduction course	WASS	2013	1
The Essentials of Scientific Writing and Presenting	WGS	2013	1.2
Food Loss and Food Waste	FAO, Rome	2013	1
'Reducing Postharvest losses in Fresh Supply Chains: A Hierarchical Framework for Food Quality and Food Logistics Decisions'	Postharvest Unlimited ISHS International Conference, Cyprus	2014	1
Techniques for Writing and Presenting a Scientific Paper	WGS	2014	1.2
Scientific Writing	WGS	2014	1.8
Project and Time Management	WGS	2015	1.5
Presenting with Impact	WGS	2016	1
Philosophy and Ethics of Food Science & Technology	WGS	2016	1.5
Writing Grant Proposal	WGS	2016	2
C) Career related competences/personal development			
PhD Excursion organising committee member	VLAG - FQD	2013	1
Teaching and Supervising Thesis students	WGS	2016	0.8
Reviewing Scientific papers	Food Control	2012-2016	1
Supervisions of MSc thesis students	FQD/Chinhoyi University	2013-2016	2
Scientific Artwork with Photoshop	WGS	2016	-
Total			**32**

*One credit according to ECTS is on average equivalent to 28 hours of study load

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