EVALUATION OF A LOW-COST ENERGY-FREE EVAPORATIVE COOLING SYSTEM FOR POSTHARVEST STORAGE OF PERISHABLE HORTICULTURAL PRODUCTS PRODUCED BY SMALLHOLDER FARMERS OF UMSINGA IN KWAZULU-NATAL

By

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Declaration

I, Ntombizandile Nkolisa declare that the research reported in this dissertation is my original work, unless where indicated. The dissertation has not been submitted for any degree at any other institution. All the sources that I have quoted and used in this research have been indicated and acknowledged as complete references.

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Dedication

I dedicate this work to my parents Mrs L.F.A Nkolisa and Mr N.A Nkolisa for their unconditional love, support and encouragement through it all. I love you guys. God Bless you.

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General overview

In this study, a low-cost energy-free evaporative cooling system for postharvest storage of perishable horticultural was investigated. The evaporative cooler is a cost effective, energy free and easy to maintain way of cooling fruit and vegetables. It is basically what smallholder farmers can use as a postharvest storage condition to maintain their fruits and vegetables. However, before the evaporative cooling system was selected, the area of Umsinga where the cooler was installed was studied.

The first chapter is a general introductory chapter, which clearly explains problem statement, has justification, hypothesis and outlines the aims and objectives. The second chapter is a review of literature which gives a broad idea of cooling technologies used to preserve quality and reduce postharvest losses on horticultural products. Consequently, it also gives an overview of the causes of postharvest losses. The third chapter of the study assesses vegetable postharvest loss challenges of smallholder farmers in the rural area of Umsinga in KwaZulu-Natal. The assessment was carried out as survey questionnaires. The fourth chapter of the study was evaluating the evaporative cooling system as an energy-free method for postharvest storage of tomatoes for smallholder farmers. The fifth chapter is evaluating the effect of different storage conditions on biochemical quality of tomatoes. The last chapter of the study is chapter six which has the general discussion, conclusion and recommendations.

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Chapter 1:
GENERAL INTRODUCTION

1.1 Background

Nationally, South Africa has diverse weather and climatic conditions that enable it to produce different types of agricultural products (National Agricultural Marketing Council 2016). KwaZulu-Natal (KZN) is one of the nine provinces of South Africa commonly known for its variable agro-climatic conditions which allow farmers to produce various types of horticultural products, mostly for high nutritional content supply in human diets (Eggie 2008). KZN is regarded as South Africa's best-watered province. It has a larger area suitable for agricultural production compared to other provinces. Despite the fact that KZN covers a small portion of the South African land area, it has a significant percentage of the country's small-scale farmers. Most agricultural activities can be practiced in KZN, due to its reliable rainfall and the fertile soils. The province has a total of 6.5 million hectares of agricultural land, with 82% suitable for livestock production and 18% being the arable land (KZN top business portfolio, 2016). KwaZulu-Natal agricultural sector is dependent on a number of commodities such as field crops (sugar and maize), horticultural crops (sub-tropical fruits- pineapples, and bananas, cashew nuts, potatoes, and vegetables), forestry (SA pine, saligna, black wattle, eucalyptus, and poplar), and livestock (beef, sheep, pigs, and poultry) (Garikia 2014).

Despite the good potential for agricultural practices, KZN smallholder farmers are still faced with challenges related to the uncompetitive production system, lack of technical skills, adequate technology, lack of information and infrastructure, access to finance and market, and limited resources (Kasso and Bekele 2015). Horticultural production is important in addressing some of the socio-economic challenges in historically disadvantaged communities. It can play a vital role in income generation and a vehicle to supply nutritious food. However, producing fresh horticultural products in most smallholder farms comes with a number of challenges, which inhibit these farmers from operating sustainable business enterprises (Department of Agriculture Forestry and Fisheries 2012).

One of the reasons hindering the success of smallholder farmers is post-harvest losses. Fresh produce handling during postharvest is poor mainly because they do not have access and/or cannot afford proper postharvest technologies and adequate postharvest management practices for these perishable products in their value chains (Lebotsa 2004; Prusky 2011). Furthermore, resource-poor smallholder farmers either have no access to electricity or cannot afford the current high costs of electricity. Moreover, smallholder farmers may not be familiar with cheaper and energy efficient alternatives for postharvest technologies (Thamaga-Chitja and Hendriks 2008). DAFF (2012) defined smallholder farmers as the drivers of many economies in Africa. This is because Africa, including South Africa, is still developing, its economies depends entirely on the agricultural sector of the economy. Altman et al. (2009) defined smallholder farmers as those farmers which grow produce in their gardens or farmers who have access to very small pieces of land, sometimes ranging from 2 to 3 hectares. Such farmers are considered the backbones of agriculture and food security (Garikia, 2014). Matshe (2009) stated that smallholder farmers have a potential to contribute significantly to food security if introduced to proper postharvest methods to help them prevent the easy deterioration of produce postharvest. In most cases, the emphasis is put on a production with little effort on how to handle fresh produce during postharvest stages. This leads to an insignificant contribution to food security by the smallholder farmers (Mitcham et al. 1996).

For smallholder farms to become sustainable there is a need to develop and introduce postharvest management programs with the objective to reduce postharvest losses of perishable horticultural products. Research has indicated that smallholder farmers and informal traders in rural areas continue using cultural storage methods that do not preserve fresh produce quality longer and do not extend postharvest shelf life (Lal Basediya et al. 2013). Some of the cultural storage methods used by the farmers include storing the produce in cool dry rooms dependent on natural ventilation, wooden huts, household refrigerators or placing produce on the floor and covering it with plant leaves (Lal Basediya et al. 2013; Liberty et al. 2013). These methods are ineffective compared to the commercial postharvest systems, such as refrigerated cold rooms and the controlled atmosphere storage.

Poor postharvest handling methods for smallholder farmers continue to be the bottleneck and it discourages smallholder farmers from participating in the mainstream agricultural economy.

Therefore, there is a need for the proper adoption of cost-effective and energy efficient postharvest management system for preserving quality, extending shelf life and reducing postharvest losses of perishable horticultural produce. Among several postharvest management systems, evaporative cooling is known to be an economical and efficient technology for reducing temperature, increasing relative humidity and also increasing the shelf life of horticultural produce (Lal Basediya et al. 2013). Evaporative cooling system is structured differently from the known refrigerators or air conditioning technologies (Birch et al. 2015).

The evaporative cooling system can provide cooling without the need for an external energy source, reduce storage temperature, increase relative humidity, maintain the quality of produce, protect food safety, reduce produce losses between harvest and consumption and help keep the freshness of the commodities (Chinenye 2011). Workneh and Woldetsadik (2004) stated that the cooling system works by passing air through a wet pad. Water from the wet pad evaporates and thus removes heat from the air while adding water and providing cooling to the storage chamber (Mogaji and Fapetu 2011). Unlike hydro-cooling, mechanical refrigeration and vacuum cooling, evaporative cooling systems are cheaper, efficiently use electricity, do not use refrigerants, are environmentally friendly and do not require high initial investments.

The area of study for this research will be Umsinga in KwaZulu-Natal province. It's a place known described by Makhabela (2005) with very low farm income because of low productivity, market constraints, lack of resources and other related constraints such as poor postharvest handling methods. Introducing farmers to the low-cost evaporative cooling system will significantly minimize postharvest losses, leading to the availability of more nutritive products, enhances the quality of the produce, increases shelf life and makes the produce readily marketable (Jahun et al. 2016). The project will be worthwhile to the smallholder farmers as adopting these methods would help increase profits. Thus introducing a postharvest technology will help avoid deterioration of horticultural produce, increase their market value and minimize quality and quantity produce losses.

1.2 Problem Statement

Smallholder farmers at Umsinga produce a variety of horticultural crops such as spinach, peppers, tomatoes, beetroot and onions, etc. In most cases, they produce a surplus; which gives them opportunities to send some of their produce to local markets to generate additional income. However, the horticultural produce are inherently perishable, which exposes farmers to significant postharvest losses (PHLs). It, therefore, raises concern when nothing is done to prevent PHLs because not only input seeds or farmers energy are lost, but important resources like water and nutrients are wasted. Postharvest losses experienced by smallholder farmers, of horticultural products are of major concern in the Umsinga area of KZN. The losses are enhanced by improper/inadequate storage facilities, limited knowledge of how to avoid PHLs, limited resources, climate change, poor road network and possible productive cost of cost-intensive cooling systems to most smallholder farmers (DAFF 2012; Kasso and Bekele 2015; Ndubunma and Ulu 2011).

Most PHLs in developing countries are related to temperature and relative humidity and these factors are controlled in storage facilities (Ndukwu and Manuwa 2014). Smallholder farmers of Umsinga are a classic example of farmers producing more than they can consume, but lack proper storage facilities. Postharvest losses in horticultural fresh products have been estimated to be about 30-35% in developing countries (Lal Basediya et al. 2013). In tomato and spinach, Ndubumna and Ulu (2011) stated that about 20-25% losses are experienced due to improper storage methods. A recent report on postharvest studies, stated that in cabbage losses where about 35% and they were experienced because of improper postharvest handling. The report further stated that about 30% of losses could be prevented if cabbage could be stored at room temperature of 4°C, for seven days. At Umsinga, average maximum temperatures could be as high as 30-32 °C during summer months, when most crop production takes place. Therefore, proper storage is a need to help control the high temperatures (Lehlohla 2005). At such high temperatures, the rate of spoilage of horticultural products quality is accelerated and postharvest storage or shelf life of horticultural is low (Kader 2004). This study, therefore, proposes to investigate and compare postharvest storages facility used by the farmers whilst also installing a low-cost evaporative cooling system known to be efficient in keeping the produce at a higher quality level.

1.3 Justification

Previous research conducted on horticultural products under smallholder farmer condition focused more on preharvest practices such as irrigating, fertilizing, disease control, pruning, and other agronomic practices (Ferguson et al. 1999). However, little attention has been given to postharvest storages used by smallholder farmers. Evaporative cooling system is a cost-effective cooling system smallholder farmers can adopt (Deoraj et al. 2015; Liberty et al. 2013). Such method of cooling does not require the use of electricity, as it is a zero energy cooling system (Lal Basediya et al. 2013). Anyanwu (2004) and Dinh (1989) alluded that, constructing the system for smallholder farmers would be cost-effective as it uses a readily available material such as coconut fibre, husks, clay etc. Smallholder farmers are interested in a storage facility which will be cost-effective in maintaining fresh produce quality and quantity as well as increasing shelf life (Ndukwu and Manuwa 2014). The farmers are already using storage facilities which favor the deterioration of the fresh produce in terms of quantity and quality. Due to the use of improper storage conditions during postharvest, a number of fruit and vegetables such as tomato, spinach and lettuce lose nutritional and physical qualities and decreased shelf life (Arah et al. 2015; Gutiérrez-Rodríguez et al. 2010). Therefore, the development and adoption of the low-cost cooling system will open opportunities to the smallholder farmers, this will help them store their fresh produce longer at a higher level of quality and increase farmers and traders profit.

1.4 Hypothesis

The installation of a low-cost evaporative cooling system for postharvest storage of perishable horticultural products will help maintain quality and increase the shelf life of fruit and vegetables during storage.

1.5 Aims and objectives

The overall aim of this study was to develop and evaluate a low cost and energy efficient evaporative cooling system for postharvest treatment, quality preservation and shelf life extension

of horticultural products produced by smallholder farmers at Umsinga in the KwaZulu-Natal province.

The specific objectives of the study were:

1. To conduct a need assessment survey to generate information that can be used as a baseline to establish on which horticultural fresh produce are likely to be affected in quality by improper or inadequate postharvest storage facility.
2. To evaluate the performance of the low cost evaporative cooling system in decreasing temperatures and increasing relative humidity and also in maintaining physiological physical properties of tomatoes.
3. To evaluate the effect of different storage conditions on biochemical quality of tomatoes.

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Chapter 2:
Literature review

Cooling technologies used to preserve quality and reduce postharvest losses in horticultural products - A review

2.1 Introduction

Fruit and vegetables are cultivated worldwide for economic, human and animal processes. In South Africa, fruit and vegetables are considered high-value products because of their importance to humans and animals for nutrients such as minerals, vitamins and dietary fibers (Ntombela 2012). The intake of essential fruits and vegetables is very important to a person's diet because it reduces chronic diseases such as diabetes, cancer and heart diseases (Nicklett and Kadell 2013). Consequently, poor consumption of fruits and vegetables highly contributes to the increase in mortality rate. This is mostly evident in people living in poor rural areas who cannot afford supplements for the provision of essential vitamins and minerals (Kanungsukkasem et al. 2009). One of the main reasons for the poor in rural areas to lack such nutrients is due to the quick deterioration of their produce after harvest which highly contributes to the insufficient consumption of nutrients. For this reason, fruits and vegetables need to be handled with care and appropriately during postharvest, to avoid losses.

Postharvest losses (PHLs) are defined as measurable qualitative and quantitative losses in a certain horticultural products that can occur at any stage between harvest and consumption (Affognon et al. 2015). In developed countries, PHLs are not that severe and are estimated to be around 10-30% (Prusky 2011). This is because farmers in these countries use advanced postharvest handling methods which helps them reduce PHLs (Hodges et al. 2011). However, smallholder farmers experience the most PHLs in their products due to inadequate postharvest handling methods and lack of information on ways to tackle postharvest losses (Department of Agriculture Fishery and Forestry 2012). This does not only discourage the smallholder farmers but also affects their market supply, profit and business reputation. Arah et al. (2015) signified that PHLs are mainly affected by improper postharvest handling methods and storage facilities. This is very common under

smallholder farming conditions. In a report on postharvest losses by Opara (2016), it was indicated that 25% losses experienced in cabbage are due to improper postharvest handling methods used by the farmers. In developing countries, PHLs for a particular fruit or vegetable have been estimated to be about 30-35% due to improper storage methods (Lal Basediya et al. 2013). However, it was shown by Mogaji and Fapetu (2011) that such losses can be reduced through the use of proper cooling technologies. Hence, the main objective of the current study is to review the causes of PHLs, evaluate the techniques and parameters that assist determine the level of PHLs in a produce and to document and highlight the importance of having a cost-effective evaporative cooling system in poor rural communities.

2.2 An overview of the causes of postharvest losses

Postharvest losses (PHLs) of horticultural products are a major challenge to most farmers, especially smallholder farmers with limited access to cooling infrastructure. These farmers grow fruits and vegetables with the objective of yield and profit maximization. However, due to PHLs, these objectives are not achieved. This is mainly due to poor postharvest handling methods and environmental factors associated with PHLs in both fruits and vegetables (Getinet et al. 2008). Postharvest losses occur in a produce as a result of improper implementation of the following techniques; picking method, postharvest treatment, manipulation of temperature, relative humidity, harvesting containers, on-farm storage, packing material and off-farm storage methods (Kasso and Bekele 2016). For instance, harvesting fruit and vegetables with inappropriate harvesting equipment lead to bruises and injuries on the produce. This is pronounced in a produce with moisture content higher than 80%, is fragile and experiences the highest rate of respiration (Sagar and Kumar 2010).

Arah et al. (2015) stated that improper harvesting technique will lead to possible failure and damage of the harvested produce. Moreover, the application of postharvest treatment in excessive amount will favor short shelf life and occurrence of decays and rots of the products (Caleb et al. 2014). Another reason for PHLs is that fruits and vegetables, as living organisms have metabolic processes like respiration which carry on during postharvest even though products have been removed from their source of nourishment. Therefore cooling and storing produce almost

immediately after postharvest treatments helps to maintain respiration and prevent ripening of the harvested fruit or vegetable. This will increase shelf life and help farmers maintain produce quality over longer periods.

2.3 Cold storage technologies for preserving quality and reducing postharvest losses of horticultural products

2.3.1 Critical parameters in cold storage technologies

Temperature and relative humidity control

Cooling technologies for preserving quality of fruits and vegetables are responsible for regulating temperatures to optimum requirements for stored products. Unsuitable temperature and relative humidity are considered the most important environmental factors affecting postharvest shelf life and quality of horticultural products because they contribute significantly to postharvest losses (PHLs) on fresh fruits and vegetables (Brosnan and Sun 2001; Kader 2003). Temperature has a key impact on the texture, composition, size and colour of the selected horticultural products. Furthermore, temperature influences metabolic processes such as respiration and transpiration rate occurring in fruits and vegetables and has a great effect on deterioration rate of horticultural products (Jobling, 2000). Hence, Arah et al. (2015) showed that temperature greatly affects shelf life, quality and deterioration rate of horticultural products. Nunes (2008) mentioned that good temperature management is the most important way of delaying produce deterioration rate, reasoning that, all fruit and vegetables have their own optimum temperature requirements. This is why different horticultural products react differently to different storage conditions.

For example, exposing a firm ripe red tomato (*Solanum lycopersicum L*) fruit to temperatures of 10°C and higher is injurious, as it contributes in the development of bruises, loss in freshness, composition, texture and eating quality (Chau et al. 2009). Similarly, Guillen et al. (2006) stated that under specific temperatures of 12°C, only mature-green stage tomatoes can be stored in order to avoid chilling injury. Horticultural products (cabbage, peppers, cucumber, and plums) exposed to extremely high temperatures of 15-25°C manifest increasing the rate of natural food enzyme reactions and forms colour changes (Zagory and Kader 1988; Birch et al. 2015). However these

high temperatures cause excessive ripening in peaches or tomatoes, sprouting in potatoes and bitter taste in carrots which are directly linked to increased respiration rate, transpiration rate, and ethylene production (Birch et al. 2015; Zagory and Kader 1988). Olympio and Mbu (2003) indicated that all fresh produce exposed to higher temperatures are subjected to damage during storage. This justifies the need for all produce to be placed under optimum temperatures to help increase their shelf life and maintain quality. Favouring good temperature management is the simplest method to inhibit produce deterioration rate and to preserve fruit and vegetable quality (Kader 2003; Nunes 2008).

High temperatures favour the increase of respiration rate, ethylene production, colour changes, watery appearance, wilting, sunburns, ripening disorders and affects metabolic activities of fresh horticultural products such as tomatoes, apples, bananas, peaches, potatoes, lettuce, cucumber, cabbage and spinach (Jobling 2000; Thompson et al. 2001, Workneh and Osthoff 2010). Thompson et al. (2001) further specified that at temperatures ranging between 21-24°C respiration rate is high in tomatoes and this may cause a ripening disorder and colour changes of the product.

Lowering temperatures to optimum suitable levels increases storage life for certain horticultural products (Lal Basediya et al. 2013). According to Getinet et al. (2008), low temperatures decrease physiological, microbiological and biochemical activities in fresh horticultural products. These activities are known to greatly contribute to the deterioration rate of certain harvested fruits and or vegetables. Moreover, low temperatures protect non-appearance quality attributes like nutrition, aroma, and flavour of the produce. Aquino-Bolaños (2000) also maintain that, low temperature reduces water loss, supress ethylene production and relaxes the microbial development. However, different produce require different temperatures during their storage life. For instance, most leafy vegetables require low temperatures between 0-2°C for long periods without significant loss of visual quality. Whilst mature green tomatoes stored below 10°C would undergo chilling injuries. Low temperatures are reported to cause damages such as freezing injury and chilling injury. Freezing injury is known as damage which causes the fruit or vegetable to appear water soaked, whilst chilling injury causes increased susceptibility to rots, loss of water, shrivelling, rusty grey or brown discolouration and reduced weight in most fruits and vegetables (Ding et al. 2002 ; Jobling 2000).

Relative humidity (RH) effects fresh harvested produce, and exposing the fruit or vegetable to their optimal percentage values of relative humidity is always safe for a farmer. This helps to avoid water loss or appearances of rots. This is justified by Arah et al. (2015) who indicated that water loss from harvested horticultural products is mainly caused by the amount of moisture present in the ambient air expressed as relative humidity. If RH is too high, the harvested produce maintains their quality attributes longer. While with low RH the produce easily decays, wilts or shrivels. Furthermore, under high RH, the nutritional quality of the produce is maintained whilst shelf life of the produce is increased. Nevertheless, RH needs to be monitored for different horticultural products. For instance with tomatoes, some produce shrivels at a small percentage of moisture loss, whereas, the perishable nature of strawberries favors 10% increase of decay formation for every drop in water loss (Ayala-Zavala et al. 2008).

It is extremely important to expose fresh produce to their optimal RH requirements in order to control the uniformity of ripening, avoid the formation of decays, rots and water loss, as these increases shelf life and maintains quality. The suitable RH for the majority of fruits is 85-95% and 95-98% for most vegetables, excluding pumpkins and onions which can perform well at RH of 70-75%. High RH in pumpkins promotes rot (Mashela and Morudu 2009) and in onions, high RH leads to decay formation and the layer of the produce being less crisp (Lentz and Van Den Berg 1973). Importantly, the goal of maintaining temperature and RH (Table 1) for fruit and vegetables during storage is to keep the product cool, as this helps avoid moisture loss, chemical and physical changes of the fresh horticultural produce during postharvest (Garikia 2014).

Quality of storage unit

Proper postharvest storage facility for cooling fruit and vegetables are highly important as they help maintain quality and increase the shelf life of the produce. Liberty et al. (2013) reported that the quality and storage life of fruit and vegetables may be seriously compromised within few hours after harvest time unless the produce is cooled instantly. The major problem after harvesting is the changes in the quality parameters of the produce, especially physical characteristics such as colour, texture, as well as freshness. These are directly correlated with the price of the produce, which then affects the sustainability of the farming enterprise. Liberty et al. (2013) further indicated that

in order to extend the shelf life of the produce; the produce should be properly stored and that both the temperature and relative humidity of the storage area should be controlled.

Structure and development of storage units are different and hence perform differently. Some, storage units are designed to have fans which control the air going in and out the system. The air is controlled in such a way that it enters in required amounts by the storage unit (James et al. 2008). Other, storage units have the ability to restrict light, which could affect texture and firmness of the stored produce. Yildiz (1994) stated that storage units which consist of usage of water are designed to have packages where produce can be stored, such that horticultural products which are wetting sensitive can be protected from decays which arise due to wetting. There are functions on some storage units which allow for the temperature to be regulated to optimum levels as the stored product. Lal Basediya (2013) noted that cooling storage units that function through the use of cooling pads, are able to draw energy from its surrounding, producing a considerable cooling effect. This cooling effect causes stored products to be effectively cooled leading to them maintaining good quality for a prolonged period.

Cooling mechanism

Researchers have indicated the existence of cooling technologies that function differently from another. For instance, these cooling systems function differently when it comes to the mass and heat transfer. Hydro-cooling, vacuum cooling and mechanical refrigeration which are some of the cooling technologies are famous for being expensive, requiring high capital and being only suitable for commercial farmers (Cantwell et al. 2009). However, evaporative cooling systems are cheaper, easy to install and maintain, and are considered suitable for smallholder farmers (Kitinoja and Thompson 2010; Jahun et al. 2013; Deoraj et al. 2015). In the hydro-cooling system, heat transfer is by the mean of convection, a process where heat is carried away by the current of moving water (Boyette et al. 1994). Zhang et al. (2014) reported that in vacuum cooling, heat and mass transfer is a complicated process. Zhang et al. (2014) further noted that heat and mass transfer in the vacuum cooling system are governed by thermophysical properties, latent heat of evaporation, convection heat transfer coefficient and vacuum environmental parameters. In refrigeration system, adiabatic absorbers separate heat and mass transfer process, heat transfer occurs in an external conventional single-phase heat exchanger whilst, mass transfer limits the adsorption rate

(Ibarra-Bahena and Romero 2014). Lastly, heat and mass transfer in the evaporative cooling system is mediated through water and air (Deshmukha et al. 2015).

While features of cooling technologies are different, they are considered very important and play specific roles. These cooling methods greatly impact on fruit and vegetable quality and shelf life during postharvest. Using different cooling methods helps in accommodating most produce since most are not suitable for all horticultural products. Storing products using appropriate cooling method helps avoid long exposure of produce to varying environmental temperatures. Further, field heat causes rapid deterioration in some horticultural products and can be easily avoided by cooling products immediately after harvest.

Postharvest handling procedure

Postharvest losses (PHLs) can be avoided by following good postharvest handling procedures. These procedures can be met through proper training of labour and availability of information on the produce in question. This will result in proper postharvest handling which will increase the shelf life, quality and market sale of horticultural products. This enables farmers to gain reasonable profits for their products. For instance, thoroughly washing and drying of fruits and vegetables before storage helps reduce the possibility of occurrence of pathogens that could be carried by the fresh product (El-Ramady et al. 2015). Using modified atmosphere packaging (MAP) helps to minimize water loss on fruits, and carrying tomato's (*Solanum lycopersicum* L.) on containers which do not have sharp edges, prevents bruising and puncturing of the fruit (Arah et al. 2016). Placing large avocados (*Persea Americana)* on lined crates or baskets, with separators, helps to avoid transferring of different field heats by the fruit. It is therefore very important to know the required and recommended postharvest handling materials that help avoid produce from deteriorating. Selection of postharvest handling procedures to be used can be done based on losses experienced in the fruit and vegetables, so that all interventions are done to meet high quality and increased the shelf life of the horticultural products. For developing countries, cost-effective and easy to handle/maintain technologies such as evaporative cooling system should be selected since other methods of cooling are cost intensive. Postharvest losses experienced by farmers in fruits and vegetables due to improper/lack of storages can be reduced if cost effective technologies are adapted.

Microbial attack

The appearance of diseases caused by fungi and bacteria in fruits and vegetables leads to decreased quality and shelf life of the produce, and such produce cannot be sold to the market (Sargent et al. 2000). Brackett (1994) stated that while diseases on fruits and vegetables are not common, poor sanitation during postharvest handling enhances disease formation in horticultural products. When most fruits or vegetables develop a postharvest infection, it would be evident by the presence of spots, skin blemishes, small size, reduction in physical qualities, development of off-flavor and loss of nutrients (Obetta et al. 2011). Diseases can be caused by decays and or pests that would result in postharvest losses in perishable fruits and vegetables (Boyette et al. 1994). Examples of these diseases include blue moulds on apples and grapes, bacterial soft rot on potatoes, gray mould and/ or Alternia rot on tomato and peppers. Black rot is common on sweet potatoes and soft rot on cabbage (Ray and Ravi 2005; Bhat et al. 2010). This estimated that about 19.6% of most fruit and vegetables produced are lost each year due to microbial spoilage (Barth et al. 2009). This spoilage caused by microorganisms, insects and pests can be avoided if products are cooled and stored immediately (Barth et al. 2009). In this way, PHLs could be reduced whilst also, increasing the pathway to food and nutritional security.

2.3.2 Types of cooling technologies

Postharvest losses (PHLs) can be effectively reduced if efficient and appropriate cooling methods are used. Mogaji and Fapetu (2011) stated that, PHLs are mostly due to lack of adequate cooling technologies. Several cooling methods are used by different farmers to preserve quality and increase the shelf life of horticultural products. These cooling methods include hydro-cooling, vacuum cooling, mechanical refrigeration and evaporative cooling system. Hydro-cooling, vacuum cooling and mechanical refrigeration are expensive and hard to install, whilst the evaporative cooling system is cost effective and also considered the best method for preserving quality (Cantwell et al. 2009). Cooling methods which play a vital role in produce shelf life and quality are discussed in subsequent sections below.

Vacuum cooling

Vacuum cooling is efficient in removing field heat and preventing the occurrence of postharvest decays or disorders from fresh produce (He et al. 2013). Prusky (2011) reported that the method consists of chambers where fruits and vegetables are stored after harvest. In the chambers is where the vacuum is created. Differences in pressure between the water within the stored product and the surrounding atmosphere will cause water to evaporate, leading to the formation of vapour escaping into the surrounding which should be evacuated continuously to avoid accumulation in the vessel, which could lead in the reduction of the cooling rate of the system (Sun and Wang 200; Sun and Zheng 2006). The method has the advantage of improving products quality, saving energy, requiring a short processing time, enhancing quality and safety and the fast cooling rate of selected fruits and vegetables (Sun and Wang 2000). However, the use of vacuum cooling method is limited to certain vegetables including lettuce (*Lactuca sativa*), spinach (*Spinacia oleracea*), mushroom (*Agaricus bisporus*) and cabbage (*Brassica oleracea* var. capitata) (Lebotsa, 2004). Other produce like tomatoes (*Solanum lycopersicum L*), potatoes (*Solanum tuberosum*), peppers (*Capsicum*), onions (*Allium cepa*) cannot be vacuum cooled as they have a relatively thick waxy cuticle, suffer from serve water loss and shrivel through use of the vacuum method (MacDonald and Sun 2000). Therefore, because of aforementioned reasons vacuum cooling is not a suitable cooling method for commercial and smallholder farmers who mainly produce products which are not suitable for vacuum cooling method.

Mechanical refrigeration

Mechanical refrigeration is considered a simple cooling method where heat is absorbed in one point and dispensed at another point (Ashby 1995). This is achieved through the circulation of refrigerants between the two points of heat. Lal Basediya et al. (2013) mentioned that, cooling in mechanical refrigeration involves the use of a compressor which is powered by an electric motor and a fan. The cooling of horticultural fresh produce using mechanical refrigeration can be a suitable technique for products that do not undergo chilling injury. In mechanical refrigeration cooling system, chilling injury is experienced in a cucumber at 7°C, mango at 5-12°C and red tomato at 10-12°C. Products would develop dark brown colours, appear water soaked and have dull skins (Seyoum and Woldetsadik 2000). Literature has provided information (Table 2) on some horticultural products which are not considered suitable for mechanical refrigeration and their expected shelf life when stored under mechanical refrigeration. However, in some horticultural

products, the cooling temperature can be regulated to specific product's minimum temperatures and can also be maintained at negative during freezing (Tassou et al. 2010). The method is advantageous to suitable produce since, it is able to slow bacterial growth, decrease temperatures, increase relative humidity and maintain produce quality while extending shelf life. Mechanical refrigeration is also considered as another cooling method that demands energy, very hard to install, expensive and requires readily available energy. As a result, this method is not a viable option for resource-poor smallholder farmers in the rural area where infrastructure is very poor. Researchers have indicated that in developed countries the use of mechanical refrigeration is decreasing due to its high maintenance and usage of refrigerant gases which play a role in ozone layer depletion and global warming (Vala et al. 2014). Although the method proves not to be economically and ecologically friendly, Table 2 illustrated positive response on the expected shelf life of some horticultural products stored under mechanical refrigeration compared with room temperatures and this proved suitable horticultural products under mechanical refrigeration to maintain quality longer and increase shelf life, then when placed at room temperatures.

Evaporative cooling system

Description of an evaporative cooling system

Evaporative cooling system (ECS) are economic and energy-efficient cooling method used for reducing temperature and increasing the relative humidity in a storage facility (Deoraj et al. 2015). This method of cooling horticultural products is effective in reducing average ambient high temperatures to optimum average temperatures as those required for produce maintenance during postharvest storage (Table 3). Relative humidity is also increased to high percentages through use of the evaporative cooling system (Table 3). Jahun et al. (2013) defined this cooling system as an adiabatic process where ambient air is cooled as a result of transferring its sensible heat to the evaporated water carried with the air. Compared to other cooling methods, the evaporative cooling system is more beneficial as it is a cost-effective and simplest method that does not require the use of refrigerants and electricity, it's easy to install and can be constructed using readily available material (Lal Basediya et al. 2013; Liberty et al. 2013; Vala et al. 2014).

The ECS involves the cooling of air by forcing dry air through a wetted pad (Workneh and Woldetsadik 2004). Water from the wet pad evaporates and thus removes heat from the air while adding water. Through this method, the temperature is reduced and relative humidity is increased in the cooler (Workneh and Woldetsadik 2001). Therefore, cooling in the selected evaporative cooling system becomes possible and fruit and vegetable quality are maintained. A common drawback associated with this method is that its success is highly dependent on the weather. Hence, Odesola and Onyebuchi (2009) stated that the faster the rate of evaporation, the greater the cooling effect. The method also requires lots of water which is used for wetting the pad at least 2-3 times a day. Evaporative cooling system can be direct or indirect. Abbouda (2012) explained that the direct evaporative cooling system is different from the indirect evaporative cooling system in a way that, water and air as working fluids in the direct cooling system are in direct contact. Whilst in the indirect cooling system a surface plate separates the working fluids.

In the construction of the cooler, cheap and available material such as bricks, wood, mild steel, aluminium sheet, gunny bags, jute papers and plywood can be used (Lal Basediya et al. 2013). Such material needs high maintenance as they can be destroyed easily, which is one of the disadvantages associated with the cooling system. As cooling pad, coconut coir, rice husks, cotton fabric, sawdust, wood, clay date palm fibres etc. can be used. Cooling pads are porous water absorbing material, which is wetted thus causing water evaporation when hot air passes through it. Leaving the pads dry would allow the storage to be ineffective. Therefore, evaporative cooling pads need to be wetted at least 2-3 times daily with water, for effective cooling to happen on the cabinet (Chinenye 2011). Through this process, cooling happens in a cooling chamber. Storage environment becomes conducive to storage of fruit and vegetables. Maintaining this easy method keeps ambient temperatures different from the cabinet temperatures. Storing fruit and vegetables on the evaporative cooler becomes effective, as for temperatures inside the chamber are lowered to almost optimum requirements of the products as illustrated in Table 3 This favours good quality maintenance, increased shelf life and safety of harvested fruit and vegetables. Smallholder farmers, who cannot afford cost intensive cooling methods, can use evaporative cooling system (Liberty et al. 2013).

Methods of evaporative cooling system

Evaporative cooling system (ECS) can be classified as a direct evaporative cooling system or indirect evaporative cooling system. The methods are discussed below.

- Direct Evaporative cooling system

In a direct evaporative cooling system (DECS) air passes through a wetted evaporative cooling pad (Figure 1) causing evaporation which allows for cold air to enter the storage cabinet in a way of providing cooling to the stored products in the cooler (Lal Basediya et al. 2013). Through the process, lowering of temperatures inside the storage cabinet is achieved. The direct evaporative cooling system is considered the simplest type of ECS in which outdoor air is brought into direct contact with water. They basically maintain primary air flow through the wet channel which results in direct cold air transfer inside the cooling cabinet. Ndukwu and Manuwa (2014) referred to the processes occurring in a DECS as adiabatic and further stated that 100% cooling inside the cabinet cannot be achieved because total saturation of the air is not possible. DECS advantages include its ability to reduce energy by 70%, it can be easily constructed and maintained, and because it removes dust particles in the air, it is suitable to be used by smallholder farmers (Mehere et al. 2014).Moreover, due to its easy fabrication and high efficiency in hot and dry areas, the method appears to be the most studied type of evaporative system in most experimental studies (Liberty et al. 2013; Vala et al. 2014; Jia 2014). Since cooling is achieved by adding moisture to the supply air stream, the new dry bulb and wet bulb temperatures are found on the wet bulb gradient. Musa (2009) noted that, in the DECS dry bulb temperature is reduced whilst wet bulb temperature remains the same. Nonetheless, for most DECS, cooling efficiency is usually 90% especially if the constant water supply is maintained to the cooling pads of the storage cabinet.

- Indirect Evaporative cooling system

Indirect evaporative cooling system (IECs) is defined as a process whereby energy is transferred between two or more fluids without actual direct contact between the fluids (Wang et al., 2011). In this method cooling is achieved by means of the heat exchanger in conjunction with evaporative cooling, thus sensibly lowering the air temperatures with no increase in specific humidity. Porumb et al. (2016) recommend IEC as environmentally friendly and having a very low impact on global warming. According to Jia (2014), since there is no moisture added to the supply stream

the dry and wet bulb temperatures are found on the dry bulb gradient in the IECS, leading to both wet and dry bulb temperatures being reduced. Overall this method of the evaporative cooling system is rated around 60-70% effective in terms of cooling rate. IEC is complicated compared to a direct evaporative cooling system, has two air streams (Figure 2) and could be difficult for use by smallholder farmers.

Conditions affecting cooling of an evaporative cooling system

The cooling effect of any selected evaporative cooling system greatly depends on the rate of evaporation which is influenced by environmental temperatures (Liberty et al. 2013). For example, high temperatures are considered most effective in the occurrence of evaporation on cooling pads for better cooling efficiency. The cooling efficiency, therefore, varies in all developed evaporative cooling systems. Prior to using any developed evaporative cooling system, cooling efficiency should be determined. Cooling efficiency can be calculated using equation 1 below (Abbouda 2012; Kenghe et al. 2015; Lotfizadeh and Layeghi 2014; Zakari et al. 2006). From the equation (1) the cooling efficiency percentage of any developed evaporative cooling system can be determined. The dry bulb temperature from the equation can be recorded using any temperature recording instrument such as data loggers. With the wet bulb, temperature, the values can be read from a psychrometric chart (Figure 3) which can also take readings of enthalpy and saturation efficiency.

Conditions inside the cooling system perform a major role in the cooling effectiveness of the storage system. For instance, the location of the fan should be on the opposite side of the cooling pad in order to be able to draw air out of the cooling cabinet. The cooling pad which is an important part of the cooling system should be wetted with water 2-3 times daily for effective cooling (Chinenye 2011). This, water plays a vital role in the evaporation process occurring on the cooling pad as the cooling pad and for proper maintenance it should not keep dry (Kenghe et al. 2015). The location of the cooling pad within the evaporative cooling system is also very important. The pad should be positioned in a direction such that the air enters the cooling pad, mixing with water and cause evaporation in the cooling system. Through this simple method, better cooling inside the storage system is achieved.

$$\eta = \frac{Tdb - Tc}{Tdb - Twb} x\ 100 \quad \text{..... (1)}$$

Where Td is the dry bulb temperature, Tc is the dry bulb temperature of the cooled air in °C, Tw is the wet bulb temperature

Evaporative cooling system impact on quality of fruit and vegetables

Various researchers have investigated the effectiveness of using the evaporative cooling system in maintaining the quality of fruit and vegetables. According to Olusunde et al. (2015) storing mangoes, tomatoes, bananas, and carrots in an evaporative cooling system help reduce weight loss in the product. Ndukwu and Manuwa (2015) showed that in paw-paw, oranges and amaranths the evaporative cooling system helps reduce the rate of ethylene production. While, Deoraj et al. (2015) alluded that, storing tomatoes in an evaporative cooling system is the best method in terms of preserving acidity of the produce as well as total soluble solids of the produce. Melkamu et al. (2009) also regard the use of the evaporative cooling system as being highly effective in maintaining titratable acids, ascorbic acid and the marketability of tomatoes. In the evaporative cooling system, tomatoes can be stored for an average of five days with small changes in colour, weight, rotting and firmness of the produce (Zakari et al. 2006). Chinenye (2011) emphasized that using an evaporative cooling system trait such as visible colour changes, weight loss and mould spotting in tomatoes can only be seen after 19 days. The cooling system caused sweet pepper cultivars to decline in moisture content, weight and change colour slowly (Bayogan et al. 2017). Findings pertaining the use and benefits of an evaporative cooling system have assisted in concluding that the evaporative cooling system is a highly effective and efficient cooling method, which smallholder farmers can afford to install and operate to alleviate postharvest losses in their produce.

Hydro-cooling

Hydro-cooling technology has been shown to reasonably improve the quality and increase the shelf life of harvested products (Toivonen 1997). Ferreira et al. (2006) defined hydro-cooling as a method or technique that involves cooling horticultural products with water to remove heat and

hinder ripening. It requires a water tank, pumps, water discharge chamber and refrigeration unit (Vigneault et al. 2000). Sibanda (2013) specified that water used in the system should at least be at temperatures close to 0°C, containing a mild disinfectant such as chlorine for successful cooling. In the hydro-cooling method, fruits or vegetables are dumped into cold water in the process of cooling the produce. This method is known to cool the produce fifteen times faster than air (Boyette et al. 1994). For various fruits and vegetables, hydro-cooling is effective in reducing respiration, water loss, control wilting or shriveling and provide uniform cooling on the stored products (Table 4) (Kitinoja and Kader 2004). Liang et al. (2013) documented the effectiveness of hydro-cooling on litchi fruit, which was able to suppress decays, delays increase in electrolyte leakage, polyphenol oxidase and peroxidase activity in the pericarp. Yildiz (1994) noted its suitability for root, stem and flower type vegetables and melons and further indicated that hydro-cooling requires water resistant packages where products can be stored before being hydro-cooled. This cooling method is limited to horticultural products that are not water sensitive. Because of its large water requirement, it is only suitable for farmers in developed countries. It would be inefficient for smallholder farmers living in rural areas as they are only dependent on rainwater. Table 4 below shows how quality and shelf life of some horticultural products are improved through the use of hydro-cooling system compared to ambient conditions.

2.3.3 Performance of cooling technologies

Table 5 summaries the advantages and disadvantages of different cooling technologies in terms of suitability, extending shelf life and maintaining the quality of fresh horticultural products.

2.4 Future prospects

Maintaining quality and increasing the shelf life of fruit and vegetables requires the same cooling technologies for smallholder farmers and commercial farmers (Vala et al. 2014). However, the use and approval of cooling technologies vary greatly between the farmers. This is affected by differences in the structure of development for all the farmers. For instance, smallholder farmers are found in areas where resources are considered very poor, there is lack of suitable infrastructure and limited knowledge, whilst commercial farmers are in areas where communication is easy,

information is easily accessible, with better infrastructure and improved technology as a whole (Falah et al. 2015).Nonetheless, all farmers are affected by postharvest losses of their products. Though losses experienced by smallholder farmers are considered too high which justifies the need for adequate cooling technology to minimise their losses (Liberty et al. 2013).

In the near future, produce prices will increase as a result of farmers wanting to generate more profits on the sold produce and also cover profits for produce lost during postharvest. Due to every day changes in climate, farmers will plant for loss if they are not introduced to proper postharvest handling methods. There will be a more significant gaps between gross production and net availability to consumers due to high postharvest losses (Jany et al. 2008). Farmer's resources will be lost, as they will be planting with an objective to harvest maximum yields. However, improper cooling technologies will greatly contribute to postharvest losses. The solution to the problems is to strengthen the development and deployment of simple and cost-effective cooling technologies such as the evaporative cooling systems that uses readily available material. The evaporative cooling system will allow farmers to keep their produce cool whilst controlling environmental temperatures and relative humidity. Proper cooling also favours safety, maintenance of quality and increased the shelf life of horticultural produce. Postharvest losses could be reduced using these cost effective systems thereby, allowing farmers to obtain maximum yields and gain better profits for their products. In addition, the success of evaporative cooling could enable the phase-out of the expensive cooling methods used by commercial farmers by providing possible ways of developing a minimum energy cooling technology accessible to smallholder farmers.

2.5 Conclusions

Postharvest losses of fruit and vegetables occur due to environmental factors and or harvesting methods which can be controlled. Controlling these factors requires sufficient knowledge and skills of the control processes. This makes it easy to know and understand the interventions required after harvesting a certain horticultural product. Most farmers still lack these skills and require training on the methods that can be suitable for their type of produce. It is evident from literature that there is a gap in knowledge of cost effective cooling technologies used for storing

horticultural products. For instance, the cost-effective and cooling methods were indicated to be most accessible to commercial farmers, while small-scale farmers suffer the most losses, during postharvest. Lack of information on how to avoid postharvest losses through the use of cooling technology is the main contributor to produces losses experienced by small-scale farmers during postharvest. This discourages the small-scale farmers and in some instances end up refraining from farming. Providing information on cooling technologies used to preserve quality and reduce PHLs on fruit and vegetables could be useful in assisting these farmers to maintain the total harvested produce. It is also evident from literature that the evaporative cooling system method is the most suitable technique for use by smallholder farmers. This is because most smallholder farmers are located in rural areas or in less developed areas and this method of cooling could be suitable as it requires less maintenance, is cost effective and can be built with the locally available materials. This would be advantageous to the farmers as their produce would be stored and stay in quality longer, and result in the farmers generating more profits from their fruits and vegetables.

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Table 1: Recommended optimum temperature, relative humidity, and approximate storage life of horticultural fresh products

Produce	Temperature (°C)	Relative humidity (%)	Average storage life
Broccoli	0	95	10-14 days
Cauliflower	0	95	2-4 weeks
Cabbage	0	95	3-5 weeks
Carrots	0	95	1-2 months
Lettuce	0	95	2-3 weeks
Potatoes	10	90	4-9 months
Spinach	0	95	10-14 days
Tomatoes, Green	10-15	90	1-3 weeks
Tomatoes, ripe	7- 9	90	4-7 days
Peppers, hot	10	60-65	6 months
Pumpkin	10- 12	70-75	2-3 months
Sweet potatoes	10-15	80-85	4-6 months
Cucumber	7- 9	95	10-14 days

Source: Food and Agriculture Organization manual (2016)

Table 2: Room temperature and mechanical refrigeration expected shelf life for different horticultural produce at stored conditions

Produce	Room Temperature	Mechanical Refrigeration	References
Banana	2-3 days	2 days	McCurdy et al. (2009)
Tomatoes	1 week	4-5 days	Kader and Kitinoja (2003)
Potatoes	NS	1-2 weeks	McCurdy et al. (2009)
Spinach	3-4 days	2-3 days	McCurdy et al. (2009)
Garlic	1 month	1-2 weeks	Ibarra-Bahena and Romero (2014)
Onion	2-4 weeks	1 month	Kader and Kitinoja (2003)
Apples	Until ripe	1 month	Irtwane (2006)
Peaches	NS	2-3 weeks	Jobling (2000)
Broccoli	1-2 days	3-5 days	McCurdy et al. (2009)
Carrot	4-6 days	1 week	Jobling (2010)

**NS, Not specified on literature*

Table 3: Ambient and Evaporative cooling system average temperature and relative humidity variation for the system at loaded condition with different horticultural products

Produce	Ambient air T (°C)	Ambient air RH (%)	Evaporative cooling system T(°C)	Evaporative cooling RH (%)	References
Tomato	32-40	40.3	24-29	92	Chinenye (2011)
Tomato & Carrot	26-32	18-31	16-26	33-88	Mogaji and Fapetu (2011)
Tomato	25-28	47-58	20-23.5	51-93	Jahun et al. (2014)
Hot pepper	28-30	47-57	20.2-26.5	49-95	Jahun et al. (2014)
Sweet potato	31.5	67.5	25	90	Ndukwu and Manuwa (2014)
Mandarin fruit	14.7-31.2	19.4-55.1	11.1-22	89.9-95	Lal Basediya (2013)
Mangoes	23-43	16-79	14.3-19.2	70-82.4	Liberty et al. (2013)

**RH, relative humidity * T, temperature*

Table 4: Ambient and hydro-cooling system effects on quality and shelf life of different horticultural products at loaded/storage conditions

Produce	Hydro-cooled packaged/wrapped	Ambient Conditions/ Non-Hydro-cooled	References
Peppermint	Maintains relative water content, prevents mass loss, prevents leaves from wilting for a longer period	Decreased Sugars, wilts after few days of storage, short shelf life	Barbosa et al. (2016)
Chinese Kale	Improved freshness, chlorophyll content, longer shelf life, best appearance	short shelf life, poor appearance, poor colour, less freshness	Niyomlao et al. (2000)
Broccoli	Good firmness retention, no colour change, increased shelf life	yellowing, short shelf life	Toivonen (1997)
Snap Beans	Reduced development of mechanical damage symptoms (browning)	Shrivels, weight loss, colour changes	Brecht et al. (1990)
Tomato	Remained decay free during 10 days storage, larger weight/no weight loss	Weight loss, colour change	Vigneault et al. (2000)
Strawberry	Better colour, Lost less weight, retained greater firmness	Colour changes, water loss leading to great loss of weight	Ferreira et al. (2006)

Table 5: Advantages and disadvantages of different cooling technologies

Cooling Technology	Advantages	Disadvantages	References
Vacuum Cooling	Saves energy	Expensive cooling method	Turk and Celik (1993)
	Requires short processing time	Limited to produce such as cabbage, lettuce and mushrooms	Zhang and Sun (2006)
	Hygienic method because air only goes to the vacuum chamber	Can cause weight loss on certain products	Wang and Sun (2001)
	Fast cooling rate	Requires manpower	Brosnan and Sun (2001)
	Uniform and rapid cooling can be achieved	Not suitable for smallholder farmers	
	Uniform temperature distribution		
Mechanical Refrigeration	Most efficient	Causes chilling Injury on some produce	Seyoum and Woldetsadik (2000)
	Doesn't require much attention after storing the produce, rather produce can be stored till ready for consumption	Hard to install	James et al. (2008)
	Easy to use	Very expensive	Vala et al. (2014)
	Can be used for years without experiencing problems	Uses refrigerants, not economically friendly	Ashby (1995)
		Suitable for commercial farmers	
		Energy demanding	
		Not suitable for smallholder farmers	
Evaporative Cooling	Easy to install	Needs constant water supply, to wet the pads	Lal Basediya et al. (2013)
	Constructed using readily available material	No cooling is achieved if pads are dry	Tassou et al. (2014)
	Suitable for use by smallholder farmers	Structure needs to be maintained constantly as material can easily get damaged	Vala et al. (2014)
	Uses minimum electricity		Kitinoja and Thompson (2010)
	Can be maintained easily		Liberty et al.(2013)
	Cost-effective		Workneh (2007)
	Environmental friendly, as does not use refrigerants		
Hydro-cooling	Washes and cools produce at the same time	Limited to produce suitable for wetting	Prusky (2011)
	Simple and effective cooling method	Expensive for smallholder farmers	Boyette et al. (1994)
	Water loss on produce is avoided during cooling	Needs certain packaging for wetting	Yildiz (1994)
		Cost-intensive	Kitinoja et al. (2011)

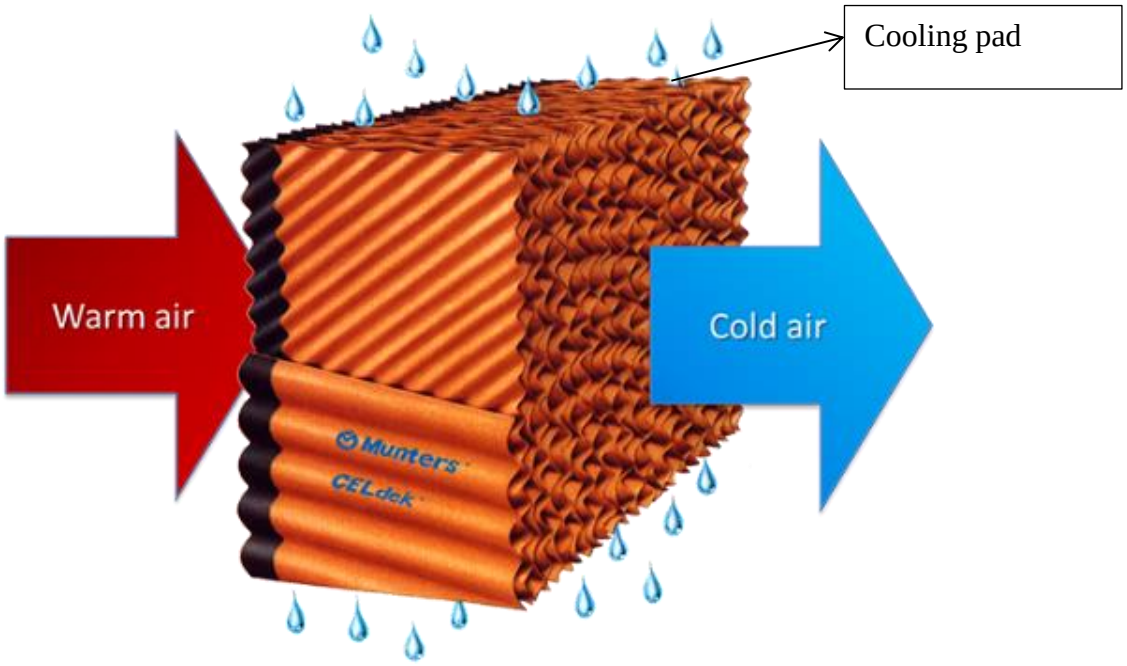

Figure 1: Diagram of a direct evaporative cooling system (Heidarnejad et al. 2010)

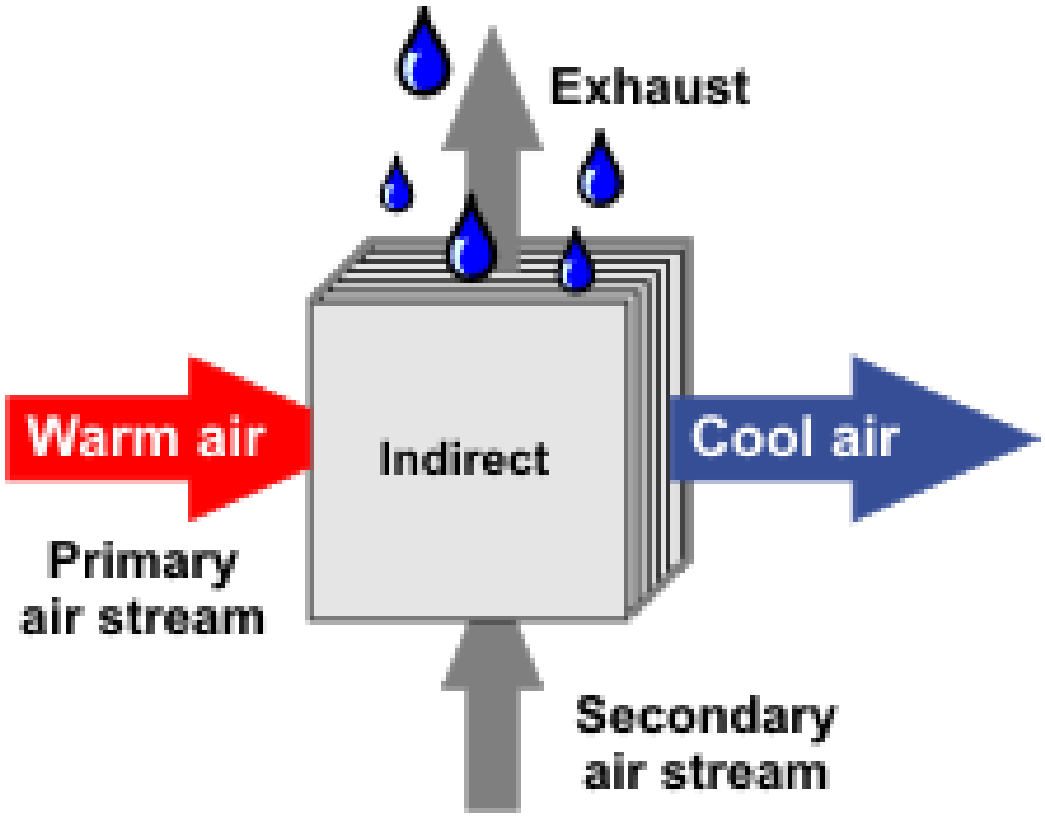

Figure 2: Diagram of an indirect evaporative cooling system (Jia, 2014)

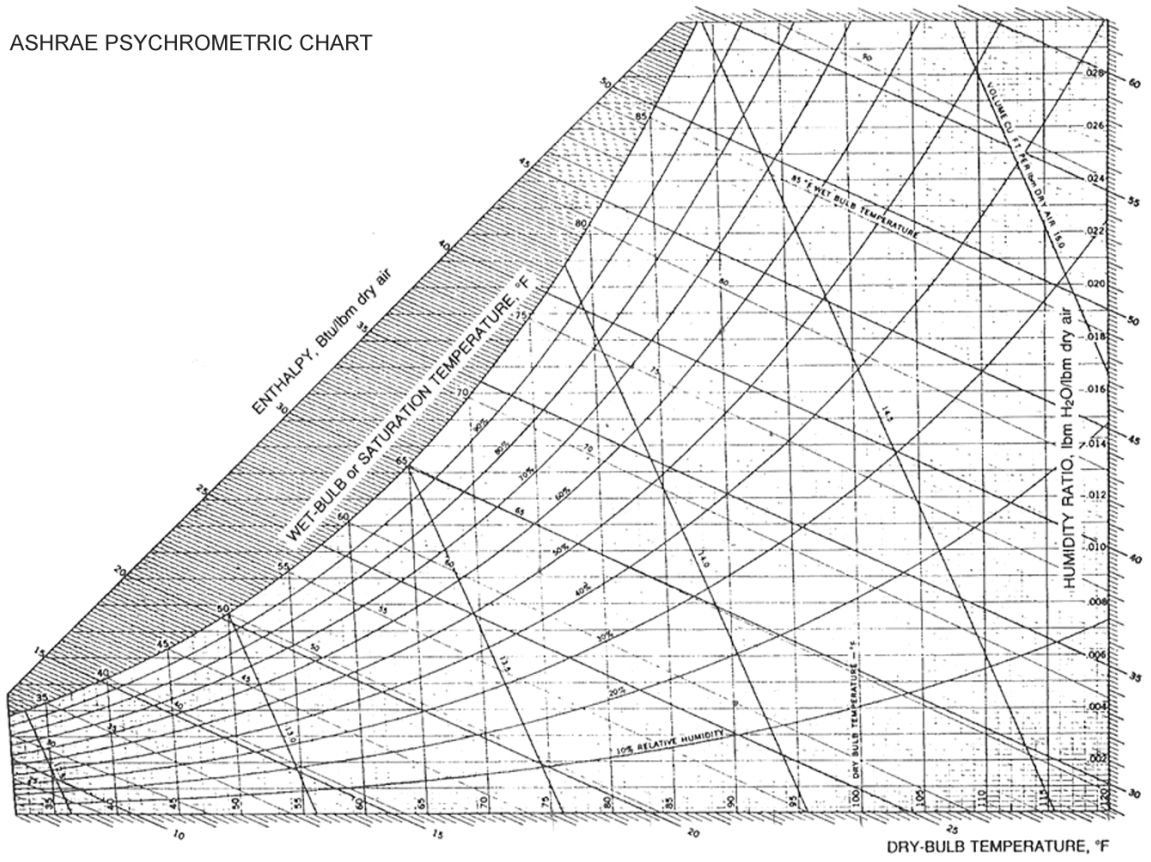

Figure 3: Psychometric chart (Kael, 2008)

Chapter 3:

Assessment of vegetable postharvest loss challenges of smallholder farmers in rural areas of Umsinga in KwaZulu-Natal, South Africa- A survey

Abstract

The aim of this study was to conduct a need assessment survey to help generate information that can be used as a baseline to establish which horticultural fresh produce are likely to be affected in quality by improper or inadequate postharvest storage facilities. The survey assessed postharvest challenges of smallholder farmers of three different areas of Umsinga in KwaZulu-Natal. The areas were Nhlesi, Gudwini and Mkhupula. Primary data used was obtained through the use of questionnaires. Thirty (30) farmers were purposively selected through help of agricultural extension officers of the area. Data was coded and captured in SPSS version 24 using descriptive statistics. Results obtained proved that the smallholder farmers use improper storages to store their vegetables after harvest because they do not have any proper storage facilities and as a result they lose most of their vegetables to waste. Nhlesi was the area which was affected the most in terms of quantity and monetary value lost on the vegetables during postharvest compared to Gudwini and Mkhupula. It also appeared that the farmers had no knowledge of any form of cooling system which could be cost effective. Hence, they all indicated that they do not know what an evaporative cooling system is. However, the farmers indicated that they would like to be introduced to the evaporative cooler and believe it would be very useful in reducing postharvest losses.

Keywords: Assessment, vegetables, postharvest handling methods, postharvest losses

3.1 Introduction

KwaZulu-Natal (KZN) province is famous for its variable agro-climatic conditions which allow farmers to produce various horticultural products for high nutritional content supply in human diets (Eggie 2008). The province has a large area of fertile soil which makes it suitable for production, is the best-watered province compared to other provinces and has reliable rainfall (National Agricultural Marketing Council 2016). KZN is also known for its significant percentage of

smallholder farmers. Smallholder farmers are defined as those farmers which produce in small pieces of land estimated to approximately be, 1 to 2 hectares or in their home gardens (Altman et al. 2009). Smallholder farmers have a potential to contribute significantly to food security especially if introduced to proper postharvest handling methods (Matshe 2009). However, due to improper postharvest handling method currently used by the farmers to handle their fruits and vegetables during postharvest, this leads to an insignificant contribution to food security (Mitcham et al. 1996).

Fruit and vegetables are important horticultural products for preparation of local dishes (Olayemi et al. 2010). Also, fruit and vegetables provide humans with important vitamins and minerals which help prevent certain diseases such as diabetes and cancer. Nonetheless, they are highly perishable and because metabolic processes, such as transpiration and respiration rate occur even after harvest, they need to be handled appropriately during their postharvest life. Department of Agriculture Forestry and Fisheries (2012) stated that smallholder farmers store their products in places where temperatures cannot be regulated, yet the reason why their products deteriorate fast. Whilst Lal Basediya et al. (2013) highlighted some storing methods used by smallholder farmers which are inappropriate and cause the products to deteriorate fast. These methods include storing fruit and vegetables on the floor, under trees, in cool dry rooms dependent on natural ventilation, wooden huts and or placing produce on the floor covering it with plant leaves (Liberty et al. 2013). Smallholder farmers produce various vegetables such as tomatoes, lettuce, peppers, cabbage, spinach etc. which cannot stay in quality longer if stored in conditions which do not have optimum temperatures as required by the specific product. Hence, Lal Basediya et al. (2013) further estimated postharvest losses experienced by smallholder farmer at 30-35%. Ndubumna and Ulu (2011) estimated losses at 20-25% which are caused by improper storage conditions of fruit and vegetables. Postharvest losses have been highlighted as one of the determinants of food problems in most developing countries (Babatola et al. 2010).

Most smallholder farmers produce in surplus which gives the farmers an opportunity to send some of their produce to the market. However, because of the nature of the products being highly perishable and the farmers not storing them in proper storages, farmers cannot send them and this affects their profits. This is a drawback which leads the farmers to lose their products in waste as

they cannot consume all the products at once. Because of these obstacles, smallholder farmers have been left out of the formal research sphere. As a result, there is no statistical data available related to postharvest losses taking place in this farming sector. The current study was therefore conducted to assess a need survey to generate information that can be used as a baseline to establish on which horticultural fresh produce are likely to be affected in quality by improper or inadequate postharvest storage facility.

3.1 Methodology

3.2.1 Characteristics of the study area

The survey study was conducted in three rural smallholder farming communities of Umsinga (28. 5608 S, 30. 4358 E), which is located in the UMzinyathi District in KwaZulu-Natal province, South Africa. The three study sites were Nhlesi (28. 7801 S, 30. 544 E), Gudwini (28. 8566 S, 30. 3361 E) and Mkhupula (28. 8124 S, 30. 5737 E). The study area is presented in Figure 1.

3.2.2 Agricultural potential

The agricultural potential, within Umsinga local municipality, allows for both crop and livestock farming. Umsinga is situated in a dry zone with an average rainfall of 600-700 mm rainfall per annum (Msinga local municipality: local economic development (LED) strategy 2012). Though its rainfalls are not great every year, the area has rivers in which farmers are close to and can use the water from rivers to irrigate. An example of a river in which farmers use for irrigating is Mooi (Mpofana) river (Figure 2). The area is also known for its arable fertile soil which makes it possible for the production of good quality crops. Hence, Makhaphela (2005) indicated that production at Umsinga area is sufficient to provide markets. Msinga local municipality LED Report (2014) alludes that numerous garden clubs cultivate vegetables on 89 hectares of land and these are predominantly located along the available water which is on rivers.

The area of Umsinga has various slopes which restrict farmers from planting their crops. For example, about 40% of the terrain is of even slope but is rocky and therefore not suitable for any

form of crop production, 10% is considered steep and can only be good for trees production and only about 25% is regarded highly suitable for crop production. This however does not affect the good agricultural potential of Umsinga areas because farming in the area contributes 18% of income (Makhaphela 2005).

3.2.3 Crops grown at Umsinga

Smallholder farmers at Umsinga produce different crops in their home gardens or in garden clubs/ groups. There is no variation on produce planted in home gardens and those in garden clubs in terms of quality. The difference observed between these vegetables is in quantity, having more in garden clubs than home gardens. Products produced at Umsinga include tomatoes, potatoes, cabbage, onion, spinach, carrot, butternut, turnip, cauliflower, beetroot, peas, beans and peppers. These are planted both in winter and summer. However, according to Umsinga local municipality (2014) in summer the main important crop produced by the farmers is maize. The examples pictures of some crops grown at Umsinga are represented in Figure 3.

3.2.4 Sampling technique

A purposive sampling technique was used to select the farmers. Latham (2007) defines purposive sampling as a way of selecting a sample based on one's knowledge of the population, its elements and the nature of research aims. Purposive sampling is virtually synonymous with qualitative research that allows for clear identification of the needs of the survey participants (Palys 2008). The sampling method was selected because the selected farmers shared similar characteristics in terms of their production. The farmers were all vegetable farmers, during postharvest the losses they experienced on their produce are almost the same and on the basis that they were all in need of a proper postharvest cooling technology to help minimize losses which they acquire on their products.

3.2.5 Sample size

A total of 30 farmers were purposively selected at Umsinga through the help of agricultural extension workers of the area. From the selected farmers, 10 farmers were from Nhlesi, 10 from Gudwini and the other 10 from Mkhupula. The selected farmers were specifically farmers with at least 7-10 years of farming experience.

3.2.6 Data collection

Data was collected using structured questionnaire which sought for the following information: current postharvest handling of the farmers produce, postharvest issues that are affecting their businesses, ideas they have on how postharvest losses can be reduced and their knowledge about the evaporative cooling system (ECS).

3.2.7 Data analysis

The data was coded and captured in SPSS version 24 using descriptive statistics. These included frequency and percentage and also cross tabs.

3.3 Results and discussion

3.3.1 Characteristics of respondents

Results shown in Table 1 show that the selected farmers in all the areas were all growers of vegetables. Smallholder farmers prefer growing vegetables than fruits because vegetables are easy to grow and maintain, a farmer can easily diverse to another product and farmers make profit fast than when planting fruit trees. Vegetables are also what are used in everyday local dishes (Olayemi et al. 2010).

3.3.2 Postharvest losses experienced by the farmer on vegetables

Postharvest losses experienced by farmers at Umsinga are presented in Figure 4. In terms of quantity, most farmers (67%) lose from 1 to 100 kg of their vegetables during postharvest. Findings

from this study were higher than those of Lal Basediya et al. (2013) who estimated losses experienced by smallholder farmer at 30-35%. They also oppose findings of Ndubumna and Ulu (2011) who reported losses to be around 20-25% in developing areas. This is therefore an indication that the farmers may lose most of what they produce during postharvest handling. Lehlohla (2005) alluded that at Umsinga average maximum temperatures can be as high as 30-35 °C during summer months.

Therefore, the observed postharvest losses could, therefore, be attributed to unfavourable storage conditions, especially higher ambient temperatures, leading to a faster rate of produce ripening and deterioration. According to Kassim (2013), vegetables display larger peaks of respiration rates when exposed to uncontrolled environments. Postharvest losses observed by smallholder farmers at Umsinga can be as high as 600 kg (Figure 4). Therefore this alerts the importance of an intervention in this area through the use of a proper storage facility. This will pave way for better management of quality and reduction of postharvest losses experienced by the farmers. Aulakh and Regmi (2009) explained that food losses do not merely reduce food available for human consumption but also cause negative externalities to society through costs of waste management and loss of scarce resources used in their production.

The losses of 1 -100 kg are mostly affecting farmers at Nhlesi compared to those at Gudwini and Mkhuphula (Figure 5). A total of 10 respondents in Nhlesi said that they experience 1-100 kg losses on their products. From Gudwini and Mkhupula 5 said 1-100 kg whilst the remaining for Gudwini noted that postharvest losses on their vegetables can be as high as 101-200 kg and 201-300 kg and for Mkhupula 101-200 kg, 401-500 kg and 501-600 kg (Figure 5). The study focused more on the losses between 1-100 kg which constitute 67% of farmers responded that their losses are mostly around this quantity range.

According to cross tabulation in Table 2, the majority of the farmers use crates, buckets and their rooms for storing their vegetables. Only a few farmers use also sacks for storing the vegetables. Crates are good as they can be re-used but are also expensive. The other ways of storing vegetables indicated by the farmers are considered to be cheap but need to be replaced almost all the time after use. Storing vegetables inside rooms has challenges because room temperatures are not

always suitable for storage of any vegetable and they are not controlled environments for storage of vegetables. It was also investigated that storing vegetables on crates, sacks and buckets has a number of disadvantages which include passing on each other field heat and diseases, they cause produce to be compressed together and high chances of bruises (Barth et al. 2009). Kareth et al. (2013) stated that the use of sacks as a form of storing vegetables increases the risks of mechanical damages. Thus far, it is hypothesized that the losses experienced on the vegetables as presented in Figure 2 are due to the above-mentioned reasons.

Apart from the fact that farmers store vegetable on improper storage conditions, the respondents highlighted an issue which they indicated they might greatly also be the cause of postharvest losses on vegetables (Table 3). These factors which the farmers emphasized on are easily controllable through use of a proper storage facility. The answers to the cause of postharvest losses occurring on vegetables given by the farmers included over ripening and diseases, heat, lack of air circulation and moisture loss (Table 3). Over-ripening and disease formation on products are mostly experienced by farmers at Mkhupula and Gudwini. At Nhlesi, farmers raised the issue of moisture loss on products, lack of air circulation and also over-ripening. Idah et al. (2007) explained that horticultural products have a high percentage of water and are living even after harvest. This makes them lose quality easily if they are exposed to unfavorable conditions especially to high temperatures. Kader (2005) indicated that leafy vegetables like spinach, cabbage and lettuce have a short shelf life and it becomes shorter if they are not stored under appropriate storage conditions after harvest.

3.3.3 Monetary losses experienced by the farmers

Monetary losses at Umsinga can be as high as R600 (3%) having the highest percentage at around R201-R300 (37%) (Figure 6). Financial losses are the greatest concern to any farmer. Such losses leave questions and regrets to most farmers because in most cases when farmer plants, they expect to gain high returns and more profit. According to Aulakh and Regmi (2009), losing money when producing vegetables frustrates a farmer as in this case it is not only the yield which is lost but also the resources which were used in the production of the vegetables. Furthermore, for farmers who live about 15 km from the local town, it is not easy to refrain from producing vegetables because

going to town to buy vegetables every week is not possible. Vegetables are needed in a human's diet and are important for supplementary with beneficial minerals and vitamins (Kanungsukkasem et al. 2009). This, therefore, proves the need for farmers to continue producing vegetables but to find a solution which would help reduce the monetary losses.

Six out of ten farmers at Nhlesi responded that at least R201-R300 is the amount they lose on their products. From Figure 6 the range of money losses between R201-R300 was the highest (37%) among the areas of Umsinga. At Gudwini, four respondents estimated losses at R101-R200 which was the highest for this area, whilst a few went as far as saying their loses reached R600. At Mkuphula, the losses were highest at R301-R400 by 4 respondents and other farmers estimated less (Figure 7). However, the main focus is at R201-R300 because the highest losses as shown in Figure 6 are in this range and at least two farmers from all the areas responded that they experience losses between this range.

3.3.4 Evaporative cooling system knowledge

As shown in Table 4 from all the areas of Umsinga, 100% of the respondents (farmers) indicated that they were not aware of the evaporative cooling system. However, the interesting part was that the farmers (100%) also indicated that they are interested in trying the technology (Table 4). This proves that the farmers are interested in an intervention which would help them save their vegetables during postharvest. Table 5 supports that the farmers have a positive mind in terms of how useful the ECS will be to them. Twenty-six farmers indicated that the ECS would be very useful to them, two suggested that it would help reduce postharvest losses and one farmer indicated that this technology will encourage them to produce more (Table 5). All the respondents do not know or have never heard of the evaporative cooling system. Twenty-seven farmers explained that they do not know of the cooler because they have never been exposed to it, one respondent even guessed they have no knowledge of the ECS because it requires the use of electricity which they do not have whilst other two respondents agreed to have never heard of the ECS (Table 6).

The use of an evaporative cooler would be advantageous as it would help reduce postharvest losses, it does not need electricity, has the ability to reduce ambient temperatures and increase relative

humidity, is cost-effective, made using readily available material, needs less manpower and easy to maintain (Vala et al. 2014; Udayanga et al. 2015; Jahun et al. 2016).

3.4 Conclusion

The obtained results and observations during the survey were clear, indicating that most farmers at Umsinga grow vegetables. It seemed that the area has a good potential of producing good quality vegetables. The drawback was that farmers lose a number of vegetables after harvest. This is due to improper postharvest handling methods used by the farmers. The farmers are faced with challenges of having inappropriate storage facilities to store their vegetables after harvest. Amongst the investigated areas, Nhlesi farmers accounted the most loses and lost more money compared to Gudwini and Mkhuphula which ranged almost in the same range. The farmers need to be introduced to a proper storage facility which will help them increase shelf life and maintain vegetable quality during postharvest. The farmers were not aware of a cost-effective method of cooling horticultural products, the evaporative cooling system. However, they indicated that having this method would be very useful to them and would help reduce postharvest losses accounted for vegetables.

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Table 1: Details of survey respondents

Participant details	**Frequency**	**Percent**
Grower	30	100
Produce type		
Vegetables	30	100

Table 2: Cross tabulation – current postharvest handling method of fresh vegetables

		Bucket & room	**Crates & room**	**Crates, buckets & room**	**Crates & Buckets**	**Buckets, sacks & crates**	**room**	**Sacks, crates & room**	
Location	Nhlesi	1	1	4	1	1	1	1	**10**
	Gudwini	1	-	2	4	2	-	1	**10**
	Mkhuphula	0	-	3	5	2	-	-	**10**
Total		**2**	**1**	**9**	**10**	**5**	**1**	**2**	**30**

Table 3: Cross tabulation – highlighted causes of postharvest losses

	Nhlesi	**Gudwini**	**Mkhupula**
Over-ripening and hot weather	2	3	-
Heat	2	2	2
Pest and heat	1	-	-
Heat, over-ripening and diseases	1	-	-
Heat and lack of air circulation	2	-	-
Heat and moisture loss	1	-	-
Heat and diseases	1	1	2
Over-ripening, diseases and insects	-	-	-
Over ripening and diseases	-	4	5
Over ripening	-	-	1
Total	**10**	**10**	**10**

Table 4: Cross tabulation – farmers knowledge and interest on having an evaporative cooler

	Aware of ECS	Will you be interested in trying the technology
	NO	**YES**
Nhlesi	10	10
Gudwini	10	10
Mkhuphula	10	10

Table 5: Cross tabulation – response on how useful the evaporative cooling system would be

		Very useful	Reduce postharvest losses	very useful, will reduce losses	very useful, will encourage to produce more	Total
Location	Nhlesi	8	1	1	0	10
	Gudwini	8	0	0	1	10
	Mkhuphula	10	0	0	0	10

Table 6: Cross tabulation - knowledge of the evaporative cooler

	No, it requires electricity	No, never been exposed to it	No, never heard of it
Nhlesi	1	8	1
Gudwini	0	10	0
Mkhuphula	0	9	1

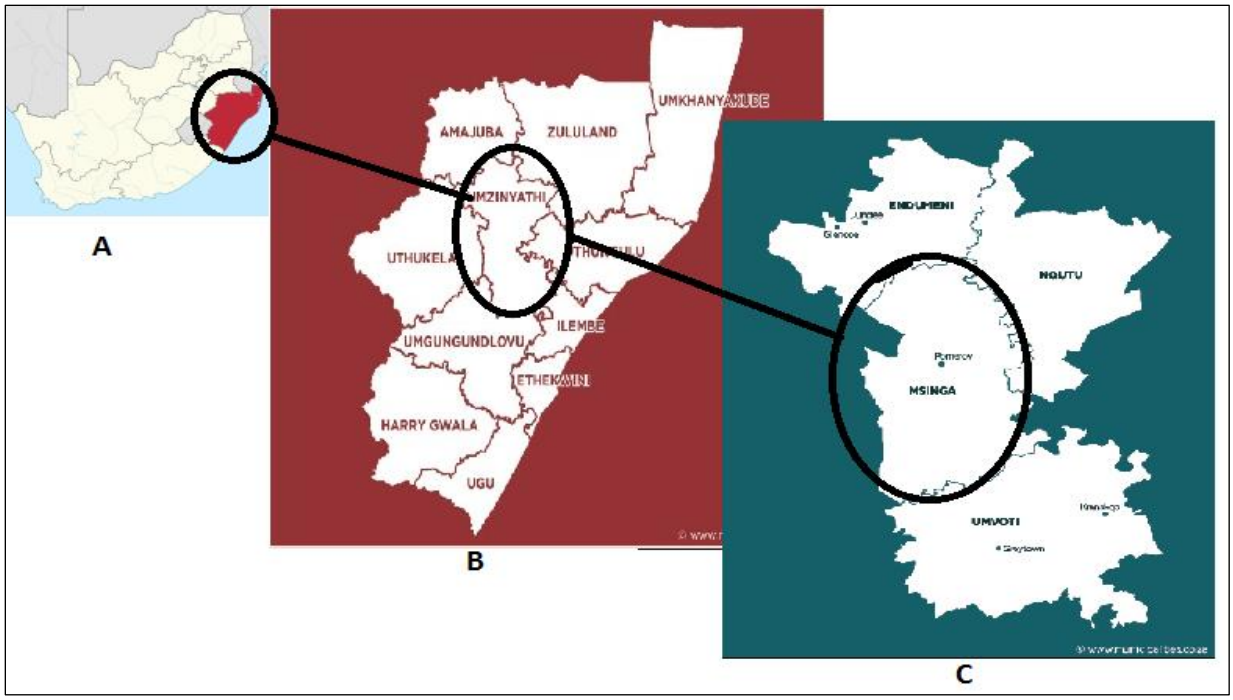

Figure 1: Map of KwaZulu-Natal showing the location of the study area. Msinga Local demographic (2016)

Figure 2: Mooi (Mpofana) river found at Umsinga. Source: Pictures taken by Z Nkolisa (2017)

Figure 3: Some crops produced at Umsinga. Source: Annual Msinga Nutrition fair (2016); Pictures taken by Z Nkolisa (2017)

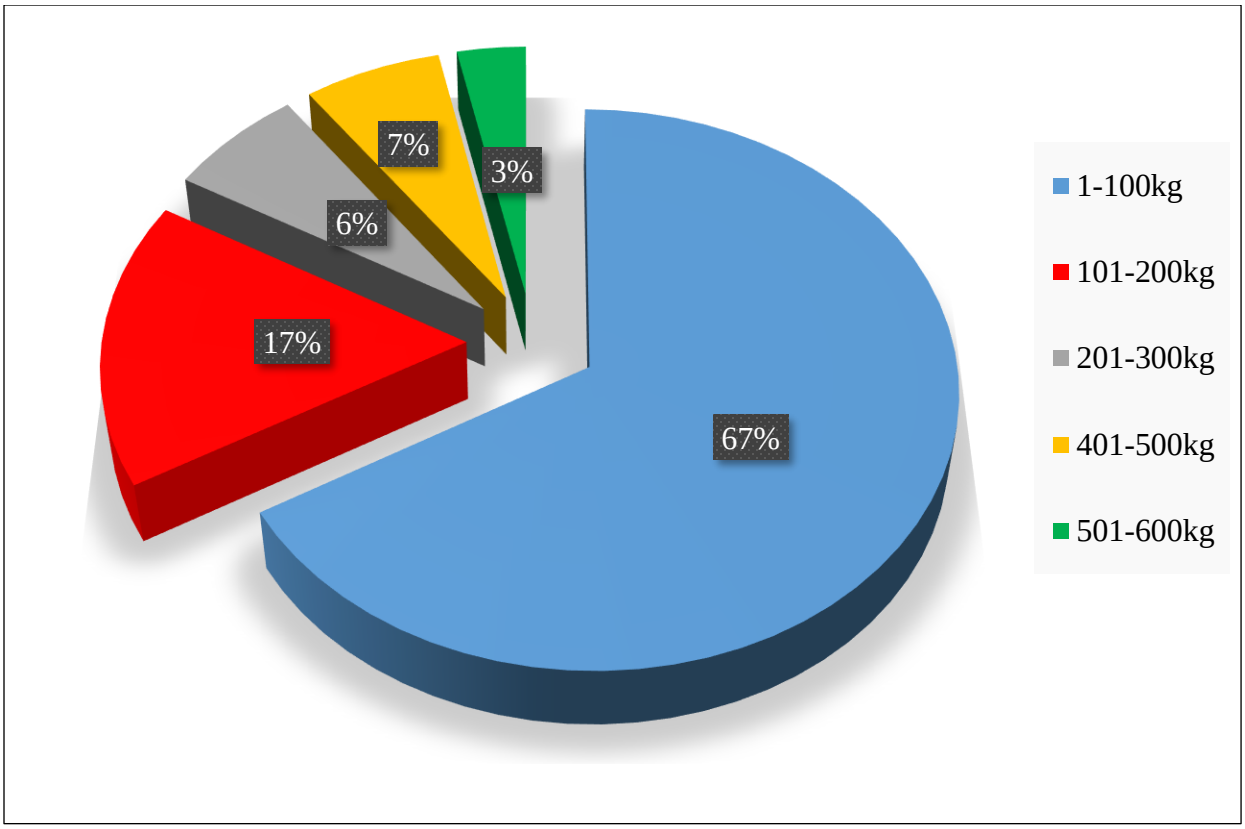

Figure 4: Postharvest losses experienced at Umsinga on vegetables

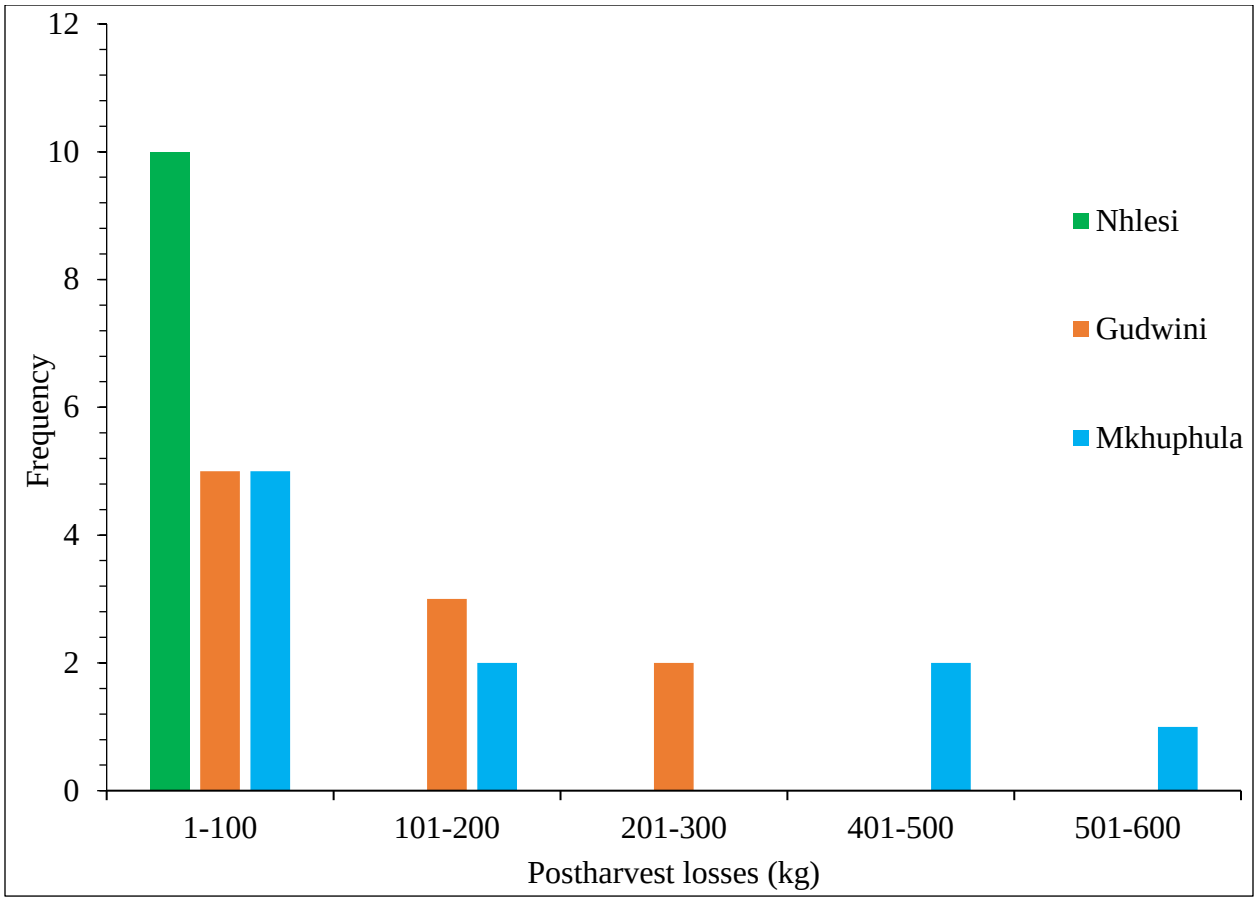

Figure 5: Postharvest losses experienced in different areas of Umsinga on vegetables

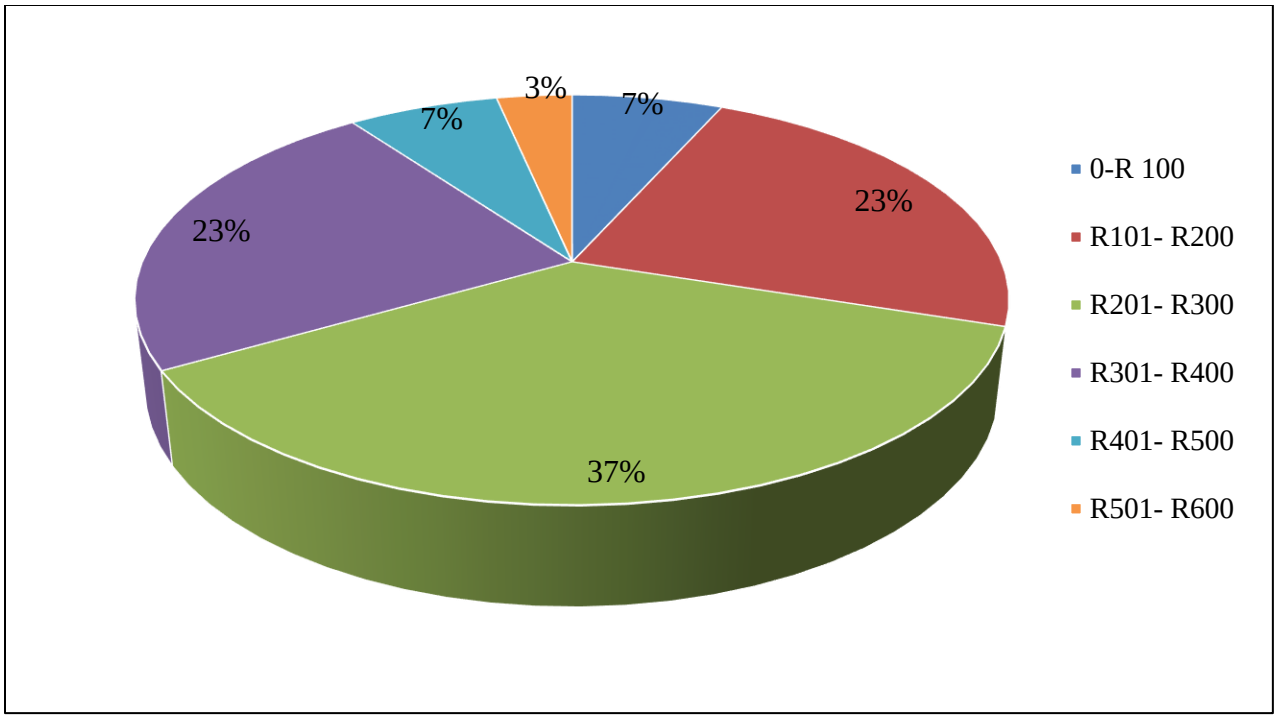

Figure 6: Monetary losses experienced by smallholder farmers of Umsinga during postharvest handling of vegetables

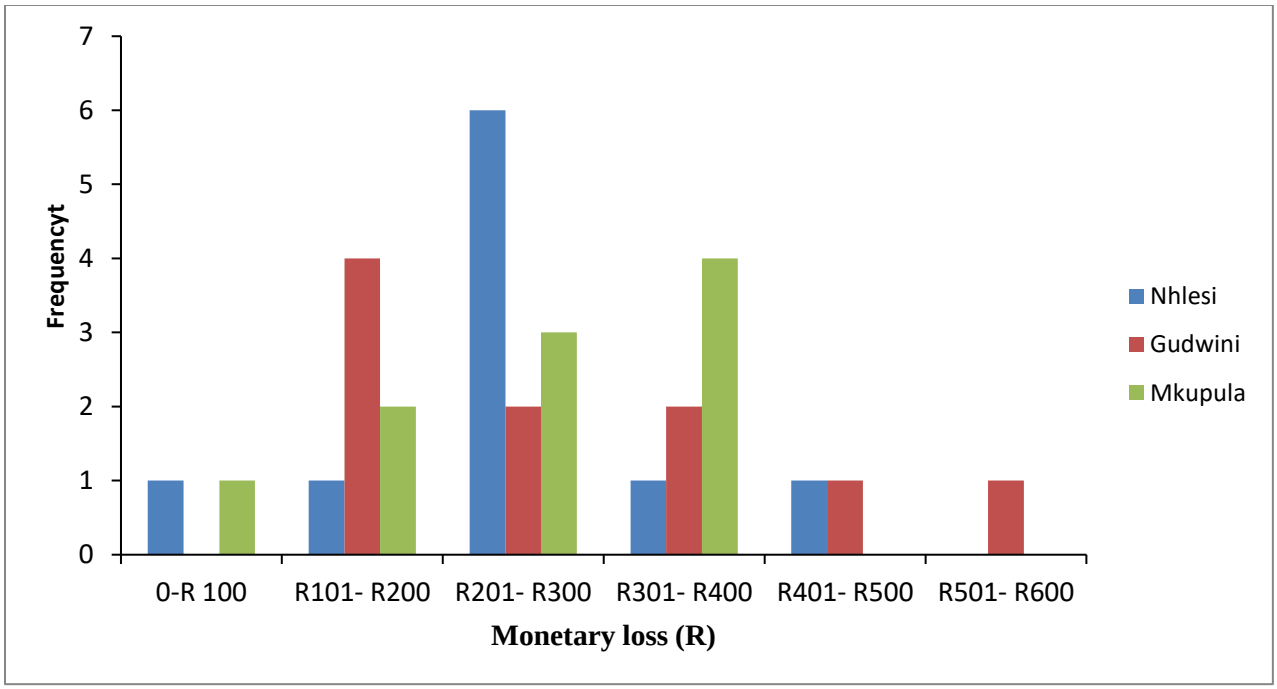

Figure 7: Monetary losses experienced by smallholder farmers in different areas of Umsinga

Chapter 4:

Evaluating evaporative cooling system as an energy-free method for postharvest storage of tomatoes (*Solanum lycopersicum* L.) for smallholder farmers

Abstract

This study evaluated the effectiveness of a low-cost evaporative cooling system and its effect on postharvest storage potential and physicochemical quality properties of tomatoes. The performance of the cooling system was evaluated in terms of temperature drop, increase in relative humidity (RH) and cooling efficiency. Two tomato cultivars ('9065' jam and round) were harvested from smallholder farms in Umsinga, South Africa (28˚45'56.45"S, 30˚33'42.37"E). Tomatoes were assigned to one of the three storage conditions namely; evaporative cooling system (ECS), cold room (CR) and room temperature (RT). Quality parameters evaluated included mass loss, respiration rate, colour, firmness, total soluble solids and titratable acids for both tomato cultivars. ECS reduced temperature to 19.8 °C which was 13% lower than RT (23.0 °C). RH increased from 63.59% in RT to 83.91% in the ECS with an average cooling efficiency of 67.17%. Storage treatments and time had significant ($p < 0.05$) effect on fruit quality. Fruit in the CR retained colour, mass, firmness, respiration rate, TA and TSS of both cultivars longer than the other treatments. However, the ECS was able to preserve the freshness of tomatoes for 20 days and had a slower rate of change in mass, respiration, colour, firmness, TA and TSS compared with those stored at RT. This suggested that the evaluated ECS is capable of maintaining postharvest quality and increasing shelf-life of tomatoes. Therefore, ECS has a potential as a low-cost and energy-free system for preserving quality and reducing postharvest losses under smallholder farming systems.

Keywords: Cooling efficiency, Sustainable cooling, Postharvest losses, Postharvest quality, Ripening

4.1 Introduction

Tomato (*Solanum lycopersicum* L.) is considered as one of the most widely cultivated crops in the world (Ajayi and Oderinde 2013). In human diets, it is famous for provision with beneficial

minerals and vitamins. Also, the tomato is rich in carotenoids, such as lycopene, flavonoids and beta-carotene that assist in fighting various non-communicable diseases such as cardiovascular and some cancer diseases (Nino-Medina et al 2013). These aforementioned reasons have contributed highly to good quality tomato market demand due to high demand in most markets and contribution towards increasing the economy (Falah et al. 2015). Although tomato is an important vegetable crop, it has a perishable nature which is highly affected by improper postharvest handling and storage (Vinha et al. 2013). Nasrin et al. (2008) argued that, due to lack of information on appropriate storage conditions, horticultural products lose their quality and encounter several problems during storage and transportation until they reach markets, where they probably are disposed.

Cooling is the most traditional way of preserving horticultural products and the most common way of keeping quality whilst increasing the shelf life of any harvested produce (Munoz et al. 2017). However, for smallholder farmers, appropriate storage facilities for fruit and vegetables are not taken into consideration and this is due to lack of knowledge and resources (DAFF 2012). Most of the postharvest losses incurred in tomatoes in developing countries are due to lack of storage facilities. Olusunde et al. (2016) estimated that postharvest losses due to improper storages in these countries are as high as 30 - 40%. Mogaji and Fapetu (2011) strengthened findings of Olusunde et al. (2016) estimating 20 - 50% losses due to improper storages in developing countries. This is a drawback to smallholder farmers as it causes the farmer to lose value for their products due to their perishable nature. After harvest, the farmers expose their tomatoes to unfavourable environmental conditions which cause them to deteriorate fast.

During production season, farmers have to harvest and sell or consume within a short period to avoid waste due to improper handling. According to Munoz et al. (2017) during planting season after harvest, since most smallholder farmers have no particular means of storing, their produce still obtain damages which affect the postharvest quality and shelf life. Nonetheless, smallholder farmers cannot refrain from producing fruits and vegetables as these assist them to alleviate food insecurity. The farmers need to consider temperature and relative humidity when handling tomatoes as these are important aspects which affect mostly moisture loss, respiration rate and formation of pathogens on products.

Temperature and relative humidity are important environmental factors known to play a vital role in the postharvest quality of fruit and vegetables (Vala 2014; Chinenye 2011). Such, factors affect processes such as respiration and transpiration on harvested products (Jobling 2000). There is a need for these parameters to be monitored and maintained to its optimum values for any selected produce. Maintenance of such can be achieved through the use of proper storage facilities such as mechanical refrigeration, hydro-cooling and vacuum cooling. However, these storage facilities are expensive for smallholder farmers. The solution for smallholder farmers is cooling by means of evaporation which is through use of an evaporative cooling system. Evaporative cooling system will be cost-effective and easy to use by the farmers. Furthermore, the evaporative cooling system has an efficient and simplest design, constructed using the cheap and readily available material. It is environmentally friendly and does not require much of manpower and can be maintained cheap and easily (Camargo et al. 2005; Abbouda 2012; Liberty et al. 2013). In addition, the evaporative cooler will help maintain quality and increase the shelf life of harvested products and also eliminate common problems associated with poor quality of fruit and vegetables due to improper storage conditions (Chinenye et al. 2013; Vala et al. 2014).

The current study was, therefore, to develop and evaluate the performance of an evaporative cooling system for fruit and vegetable preservation. Specifically, the study aims to (1) determine the effectiveness of the evaporative cooler in terms of decreasing temperature and increasing relative humidity, (2) determine effect of the cooling system on quality and shelf life of stored products and (3) to compare visual quality conditions which govern consumer's acceptability of tomatoes stored inside the ECS with those under room temperature.

4.2 Materials and method

4.2.1 Experimental site

The study was conducted in 2017 at Nhlesi in Umsinga (28°45'56.45"S, 30°33'42.37"E) which is located in the UMzinyathi District in KwaZulu-Natal province, South Africa.

4.2.2 Description of the evaporative cooler and its cooling system

The evaporative cooler was made up of 80 mm thick prefabricated walls of which 20 mm was the white-painted plain carbon steel (mild steel) laminated on the inner and outer wall sides of the 60 mm thick polystyrene insulating foam. The dimensions of the constructed evaporative cooler were: length (L) =3.85 m, breadth (B) = 2.85 m and height (H) = 2.35 m hence, the volume was 25.8 m^3. As shown in Figure 1, the evaporative cooling system consists of a cooling pad, suction fan, a Go Power (GP) solar plate, two small computer fans, water tank and hose pipes as water distribution components. The room is located at the center of the smallholder farmer's field for easy access to all the farmers. The structure of the evaporative cooler was chosen because of its advantages such as fireproof, all-weather material, wind resistant, environmentally friendly and energy conserving (Swierk 2005). Moreover, the white colour of the evaporative cooling system allows the evaporative cooler to reflect light, therefore, minimum heat can be absorbed (Barnard 2011).

The prefabricated room was placed on top of a concrete slab. To extract warm air from the evaporative cooler, a fan was located 1.5 m high on the opposite wall to the cooling pad of the cooling system (Liao et al. 2017). The water tank is of 150 liters big and for it to level with the cooling pad tap, it was placed on top of concrete blocks in order for the water movement from the tank to the cooling pad to be able to flow and reach the cooling pad efficiently. Water flow from water tank to cooling pad was possible through the use of hosepipe. The hosepipe was connected from the water tank to cooling pad. The cooling pad was properly fitted in a metal frame structure to prevent it from weakening fast. After the frame was created around the cooling pad, the area of the visible brown cellulose paper part of the cooling pad is 0.45 m^2 (L = 0.97 m, B = 0.46). On the inside side of the ECS in front of the cooling pad, 2 small computer fans of 60 x 25 mm each were placed. These two computer fans were connected with a white electric wire to a GP solar plate which was placed on the roof of the structure in order to fasten the rate of air flowing inside the cooling system. Currently, no shelves and or drawers are built on the cooling system, instead, plastics were neatly spread on the cement floor and boxes for storing tomatoes placed on top of the plastics. This was done to make sure that even if the floor could be moist, the boxes would not be affected by the wetness. In future though, shelves and drawers to store fruit and vegetables will be built.

The developed evaporative cooling system was evaluated in terms of its effectiveness in decreasing temperature and relative humidity. The process of cooling is highly dependent on the evaporation of water in the cooling pad, hence the cooling pad should always be wetted. Evaporative cooling system structures work on the principle of evaporation (Liberty et al. 2013; Vala et al. 2014). The tank was filled with water collected from the river which is about 100 m below the smallholder farmers farming field twice a day daily. The average flow rate of water into the cooling pad was recorded to be 98 mL per minute.

4.2.3 Design considerations of the developed evaporative cooling system

The following were design considerations:

a) The cooling system was constructed in the center of the smallholder farmers land for easy access to all the farmers.
b) The shape of the evaporative cooling system is rectangular, to provide a large surface area for air movement (Chinenye 2011) and also have enough storage space for all the farmers.
c) The cooling pad of the cooler was located in the direction of air but away from the side where the sun is, to prevent it from drying out easily.
d) The Go Power Solar plate was placed on the roof of the cooling system, facing the direction of the sun.

4.3 Treatments and experimental design

A total of 1000 tomato fruit samples (‘9065’ Jam and 330 Round tomatoes) were harvested from a smallholder farmers field at Umsinga (28. 7801 S, 30. 544 E) and transported in a well-ventilated vehicle to the postharvest research laboratory of the University of KwaZulu-Natal, Pietermaritzburg. From the harvested samples, 500 tomatoes were ‘9065’ jam cultivar and 500 were round. Mature green tomatoes of uniform size and free from blemishes were selected, washed with cold tap water to remove field heat and dirt. After which, from 1000 fruit that were harvested, only 648 were used for the experiment. The 648 tomatoes were divided equally segregated by assigning them to one of three postharvest storage treatments; namely evaporative cooling system,

cold room and room temperature. The sample fruit were neatly packed in 8 display boxes for each treatment whereby 4 boxes contained '9065' jam tomatoes and the other 4 round tomatoes. Each storage condition had a total of 216 tomatoes. The following day, two-thirds of the samples were taken for storage at Umsinga in the evaporative cooling system and under room temperature. Some were left stored in a cold room at 12 °C at the University. The experiment was laid out as a randomized complete block design with 4 replications. The study had 3 treatments (evaporative cooling system, cold room, room temperature). Sampling was done for 20 days on a 5 days interval (0, 5, 10, 15, and 20). A number of samples used was 60 (3 storage facilities x 4 replications x 5 sampling days). The layout of the experiment is presented in Figure 2.

4.4 Data collection

4.4.1 Temperature and relative humidity

For all storage conditions (evaporative cooling system, room temperature and cold room) both temperature and relative humidity were determined. The readings of temperature and relative humidity were taken using a data logger, the HOBO Pro V2 onset. Readings were taken from morning 6:00 am – 18:00 pm at an interval of 2 hours for 20 days.

4.4.2 Cooling efficiency

The cooling efficiency of the evaporative cooling system, which is an important criterion to judge an evaporative cooling system, was calculated as a temperature difference ratio using Eq. 1, previously described by Olusunde et al. (2016).

$$\text{Cooling efficiency} = \frac{Tdb - Tc}{Tdb - Twb} \times 100 \quad (1)$$

Where Tdb, are the dry bulb temperature of ambient conditions; Tc, are the dry bulb temperature of the cooled air and Twb, are the wet bulb temperature

4.4.3 Mass loss

Tomato samples were each weighed using a calibrated weighing scale (Dibbisa et al. 2016) after harvest and at the end of each storage period. For each sample fruit, there was an initial and final mass recorded from the weighing balance and the difference between the two mass considered as the total mass loss during the storage period. As previously described by Koraddi and Davendrappa (2012), Eq. 2 was used to calculate the percentage mass loss of each tomato sample at the end of each storage interval.

$$\text{Mass loss (\%)} = \frac{m1 - m2}{m1} x\ 100 \quad (2)$$

Where m1, was the mass measured immediately after harvest and before storage and m2, was the mass measured after storage according to days spent inside the various cooling system.

4.4.4 Fruit respiration rate

Briefly, each tomato fruit was taken and incubated in a 1 L jar for 15 minutes. Carbon dioxide (CO_2) released by each sample fruit was measured using F-950 Three Gas Analyzer, Felix instrument Inc., USA. Before incubation of each tomato sample, tomatoes were weighed using a weighing balance. Through the use of the Felix instrument CO_2, O_2 and volume were recorded. Respiration rate in terms of CO_2 production of each sample fruit was calculated using Eq. 3, described by Kassim (2013).

$$CO_2 = \frac{Net\ CO2}{1000} X\ Headspace\ x\ \frac{1000}{m}\ x\ \frac{60}{t} \quad (3)$$

Where Net CO_2, was the fruit CO_2 – ambient CO_2 (mL); headspace, was the volume (mL); m, was the sample mass (g) and t, was a time of incubation.

4.4.5 Colour

The colour of each sample tomato were assessed using a method described by Lopez Camelo and Gomez (2004) through use of a Konica Minolta Chromameter CR-300, INC, Japan. Sample fruits were measured in the equatorial region of the tomato. The sample fruits were scanned on three parts and readings recorded from the chromameter. Colour coordinates readings recorded were L*, a* and b*. Hue value was calculated using Eq. 4 as described by Pathare et al. (2013). Before using the chromameter, for standardizing, before taking readings for the different samples, the chromameter was calibrated using a white calibration board.

$$\text{Hue} = \tan^{-1}\left(\frac{b*}{a*}\right) \quad (4)$$

4.4.6 Firmness

Firmness of tomato fruit samples for each sample were measured using a texture analyzer, Instron Universal Testing machine (Model 3345), Buck, United Kingdom. For all firmness tests, tomato samples were positioned on their sides and measurements were taken along the equatorial region of the sample fruit and at the right angle of the first measured point. Average force (N) of penetration on the fruit was taken from the two tested points according to a method explained by (Wu and Abbott 2002).

4.4.7 Total soluble solids (TSS)

Total soluble solids of each sample fruit were determined using a digital refractometer, Bellingham and Stanley RFM 340+ refractometer with a measurement performance between 0 - 20 ^{o}Brix. The samples were prepared using a method explained by Tigist et al. (2013), where tomato sample was blended and filtered with a cloth to get clear juice, then using 2-3 clear juice drops to measure TSS**.** The measurements obtained were recorded in ^{o}Brix**.**

4.4.8 Titratable acids (TA)

Total titratable acids were obtained by mixing 10 mL of tomato juice with 50 mL of distilled water then adding 3 drops of phenolphthalein indicator and titrating the mixture with 0.1N NaOH up to a point where the sample changed from a clear colourless to a pink colour. Percentage acid was then calculated using Eq. 5 (Pinheiro et al. 2009).

$$\text{Percentage acid} = \frac{Titre\ (ml\ NaOH)\ x\ acid\ factor\ x\ 100}{10\ (mL\ juice)} \quad (5)$$

4.5 Data analysis

The collected data was statistically analysed by analysis of variance (ANOVA) using GenStat 18th edition (2015) (VSN International) at 5% level of significance. Duncan's multiple range test was used to separate means.

4.6 Results and discussion

4.6.1 Temperature and relative humidity (RH) variation

Results obtained from the data analyzed showed that the different storage conditions had a significant difference **(**$p < 0.05$) on temperature and relative humidity. Temperature differences amongst the three storage conditions (room temperature, cold room and evaporative cooling system) were highly significant **(**$p < 0.05$) throughout the experimental period. Similarly, relative humidity, highly significant differences **(**$p < 0.05$) amongst the different storage conditions existed throughout the experimental period. The temperature and relative humidity for room temperature varied from 19.29 – 22.99 °C and 55.57 – 63.59% during the storage period, respectively. For the evaporative cooling system, temperature and relative humidity varied from 17.24 – 19.84 °C and 79.84 – 83.91% during the storage period, respectively. Cold room, temperature and relative humidity varied from 10.88 – 11.23 °C and 91.42 – 93.49% during the storage period, respectively (Figures 3 and 4).

Findings from this study on the evaporative cooling system were in conformity with that of Mogaji and Fapetu (2011) who indicated that an ECS can maintain the temperature between 16 – 26 ^{o}C during the hottest time of the day when insulation was appreciable and cooling most needed. Findings from this study also support findings of Azene et al. (2014) which indicated that an ECS maintains the range of temperature varying from 17 – 26 °C and relative humidity between 43 - 98%. Furthermore, an ECS has a potential of increasing ambient relative humidity of 50 – 60% to percentages of 76 – 86% (Chinenye 2011). Jahun et al. (2014) reported an increase of relative humidity of 51 – 93%. It was observed that within the period of evaluation of the developed cooling system, temperatures were less at all times compared to room temperature and relative humidity highest in ECS than at room temperature. Such conditions are appropriate for temporal storage of fruit and vegetables and for reducing postharvest losses on these horticultural products which are due to physiological weight loss (Tilahun 2010). Kenghe et al. (2015) had previously reported that for most fruit and vegetables the required storage relative humidity ranges from 80 – 90%, hence the cooler in this study achieved ranges of 79.84 – 83.91%.

Although the ECS was able to decrease temperature and increase relative humidity, the conditions may not be suitable for all and or some fruit and vegetables such as lettuce, red mature tomatoes, cucumber and cabbage which according to FAO (2016) require temperatures of 0 – 12 °C during storage compared to the observed average of 19.84 °C for this evaporative cooler. However, the evaporative cooler is suitable for smallholder farmers who do not own any proper storage facilities because its temperatures and relative humidity are better than the temperature and relative humidity in which the farmers currently store (room temperature) their fruit and vegetables. Furthermore, shelf life and quality of fruit and vegetables such as pumpkin, mature green tomatoes, peas, beans, carrots and turnip, grown by the smallholder farmers, will be increased and better maintained in the evaporative cooler than at room temperatures.

In future studies, the ECS will be improved by installing water pumps which will help pump the circulating water from the main tank (water source) to cooling pad and to another tank which will help transfer water back to the main source. The ECS will also be improved with the addition of solar panels to allow the air extraction fan to work, with a mechanism to regulate relative humidity

and water flow rate as stated by Udayanga (2015). In this case, temperatures can be decreased even more than how they are and relative humidity increased more.

4.6.2 Cooling efficiency

The result for the cooling efficiency of the evaporative cooling system is represented in Table 1. The cooling efficiency ranged from 56.13 - 83.88%. At 6:00 am the cooling efficiency was 56.13%, and was increased to the almost constant level of 65.05, 65.56 and 64.74% at 8:00 am, 10:00 am and 12:00 pm, respectively. Around 14:00 pm, it sharply increased to 83.88% and this could probably be due to constant ambient temperatures of 19.86 °C and constant intensity of the sun during this hour of the day. The results support findings by Helmy et al. (2013) who stated that the highest cooling efficiency is achieved around 14:00 pm when dry bulb temperatures are normally at its peak seasonally. The sharp decrease of the efficiency to 67.83 and 66.97 % at 16:00 pm and 18:00 pm, respectively could be in line with findings of Seweh et al. (2016) who stated that decline in the cooling efficiency of the evaporative cooling system is due to the decrease in the ambient dry bulb temperature as the intensity of the sun decreases during this period. This was true for this study, as at 16:00 pm ambient temperatures decreased to 18.2 °C and at 18:00 pm increased to 22.21 °C, but were still less than the temperatures observed at 14:00 pm when cooling efficiency was the highest.

In this study, the average cooling efficiency was 67.17%, which was comparable with those of Woldemarian and Abera (2014) who reported a cooling efficiency of 67.6%. However, the obtained average contradicts the findings of Zakari et al. (2006) who obtained an average cooling efficiency of 83%, Seweh et al. (2016) who attained an average of 87.17%, and by Chinenye et al. (2013) who obtained an average cooling efficiency of 77 - 98%. This is due to the fact that the cooling system for this study was not fully functional and that different structures of the evaporative coolers were developed and used by different researchers.

The associate accessories for this study which may have caused difference can be itemized and explained as follows: the inside suction fan for drawing air out of the cooling system was not working (the cooler was working on natural ventilation), there was no automatic regeneration of

water from the main source to the cooling pad and to the small tank back to the main source and there was an observed difference in water flow rate per minute of water coming out of the cooling pad. It was also observed from literature that the developed evaporative cooling systems by other researchers had solar panels, water pumps and working suction fan. Though the cooling efficiency is less from findings by most researchers as mentioned above, it is still considered as a fair percentage for the developed evaporative cooler in this study. For future studies, the plan is to fix all that is needed to make the cooler fully functional and this will definitely increase cooling efficiency of the cooling system. Improvements required to increase the cooling efficiency of this study include; installing solar panels and water pumps to help with automatic and regeneration of water flow in the system and to connect the suction fan when solar panels are installed in order for the fan to work.

4.6.3 Mass loss

The data on the mass loss as influenced by storage conditions and time, are presented in Figures 5 and 6. Different storage conditions were observed to have significant differences ($p < 0.05$) on mass loss of both tomato cultivars. It was observed that the mass loss on both tomato cultivars was highest in tomatoes stored under room temperature (11.4%), followed by the evaporative cooling system (10.1%) and the lowest recorded in the cold room (5%). It was hypothesized that differences in mass loss amongst the tomatoes were caused by differences in temperature and relative humidity inside the different storage conditions. Temperature affects respiration and transpiration rate occurring on tomatoes. Liu (2014) suggested that mass loss of fruit and vegetables, during postharvest, is due to respiration and transpiration rate. Relative humidity causes water loss on harvested tomatoes and this causes a decrease in the mass of stored produce (Arah et al. 2015). Such losses lead to wilting and shriveling, which reduce the market value and consumer's acceptability (Znidarcic and Pozrl 2006).

The mass losses of both the tomato cultivars kept in the evaporative cooling system were lower compared to those stored at room temperature (Figure 5 and Figure 6). The results corroborated the findings of Mogaji and Fapetu (2011) who stated that tomatoes kept in the evaporative cooling system maintain mass, losing around 3 - 5 kg within two weeks of storage. Moreover, the study

supports findings of Godana et al. (2015), who observed maximum weight loss on tomatoes stored at room temperature. However, on day 20 of this study, mass loss in 9065 jam tomato, stored in the evaporative cooling system was more than that observed in samples kept at room temperature by 0.49%. This may be due to the fact that there was no automatic flow of water from the water source to the cooling pad and regeneration of the water back to the main source. It, however, explains that it is possible that the water source was refilled later and the water had finished leading to know cooling happening inside the evaporative cooling system. Kenghe et al. (2015) alluded that water plays a vital role in the evaporation process occurring in the cooling pad of an evaporative cooling system. Evaporation causes cooling inside the evaporative cooling system, hence no cooling is expected to occur when the cooling pad of the evaporative cooler is dry. Nonetheless, as seen in Figure 5 and Figure 6, mass loss progressively increased with an increase in storage time from day 5 to day 15, irrespective of the type of storage conditions. However, at the end of the experiment in respect to both tomato cultivars stored in the different storage conditions, tomatoes stored inside the ECS were still marketable at the end of the experiment but tomatoes stored at RT were not all marketable. Differences in mass loss amongst the two investigated cultivars in this study could be caused by differences in the structure of the tomatoes, genetic composition, and also different stages of maturation (Boyette et al. 1994).

4.6.4 Fruit respiration rate

Different storage conditions and the storage period had a significant ($p < 0.05$) effect on the respiration rate of both tomato cultivars (Figures 7 and 8). It was observed that tomatoes stored at room temperature respired more than those stored under the evaporative cooling system and in a cold room. Samples stored under ECS were second highest and CR the lowest. Respiration rate varied from 0.013 - 0.055 $mL.kg^{-1}.hr^{-1}$, 0.021 - 0.095 $mL.kg^{-1}.hr^{-1}$ and 0.014 - 0.082 $mL.kg^{-1}.hr^{-1}$ for round tomatoes stored under CR, RT and ECS, respectively. On 9065 jam tomatoes, respiration rate varied from 0.015 - 0.064 $mL.kg^{-1}.hr^{-1}$, 0.015 - 0.108 $mL.kg^{-1}.hr^{-1}$ and 0.015 - 0.096 $mL.kg^{-1}.hr^{-1}$ for tomatoes stored under CR, RT and ECS, respectively. At RT and ECS, both tomato cultivars had a significant difference ($p < 0.05$) at day 20 but no significant differences ($p < 0.05$) existed on day 0, day 5, day 10 and day 15 for 9065 jam tomatoes. For round tomatoes, the

difference was also observed in day 5. Samples stored at CR showed a fair stable increase in respiration rate for both cultivars.

The highest respiration rate for samples at RT may be due to higher temperatures in this storage condition compared to the other storage conditions. High temperatures accelerate the metabolism of fruit and vegetables and this increases respiration rate occurring on selected produce (Barbosa et al. 2011). In this study, there were no significant differences ($p < 0.05$) on both cultivars stored at RT and under ECS from day 0 – day 15 of the experimental period. However, tomatoes stored at RT respired more, meaning ECS was able to decrease respiration rate of the stored fruit samples. Therefore, the developed cooling system is able to increase shelf life and maintain the quality of the products. As explained by Liu (2014) the basic principle of fruit storage, safety and preservation is to reduce the respiration rate which is highly influenced by exposure of the tomato samples to unfavorable storage conditions during postharvest. The evaporative cooling system was able to decrease respiration rate of tomatoes in the experiment. Finding from this study corresponded with those of Kassim (2013) who explained that, produce stored in uncontrolled environments display larger peaks of respiration rate. Conditions in the ECS showed the potential to decrease respiration rate for stored products as well as improve the shelf life of tomatoes. Furthermore, conditions that are affected by respiration in harvested tomatoes will be reduced, paving the way for better quality.

4.6.5 Colour

Colour is one of the most important perception parameters of the quality of fruit and vegetables (Ahmed et al. 2012). At maturity, colour is used to determine maturity stages, marketability and to influence consumer's decisions. Therefore colour affects tomato appearance (Brandt et al. 2006). In this study, it was observed that colour components (L*, a* and b*) of the investigated tomato samples changed significantly ($p < 0.05$) at all the investigated storage conditions up to the end of the experiment.

The two tomato cultivars (9065 jam and round), stored under RT, CR and ECS had a decreasing trend for L* which characterizes lightness of the sample fruit, during postharvest storage (Table

2). According to Lopez Camelo and Gomez (2004), decreasing L* on tomatoes explains that the tomatoes remained greener in colour. For round tomatoes, L* ranged between 66.39 - 69.19, 54.72 - 73.41 and 53.50 - 73.18 on CR, RT and ECS, respectively. For 9065 jam tomatoes, L* ranged between 62.75 and 69.34, 48.11 and 70.26 and 70.81 in CR, RT and ECS, respectively. Storage and storage length had no significant difference ($p < 0.05$) on L* of both cultivars. A reduction of skin lightness was observed for all treatments which indicate ripening of tomatoes. However, the reduction in L* was more pronounced in tomato for both cultivars which were stored under RT, followed by samples stored in an ECS and lastly CR. The decrease in L* may be due to high temperatures. These findings supported by Kassim (2013) who alluded that at low temperatures, L* decreased slowly compared to high temperatures. Furthermore, this study confirmed these findings for samples stored at CR and exposed to low temperatures, and L* decreasing slowly.

Amongst the colour components, a* showed the obvious change as there was an increase in a* component from day 5 to day 20 (Table 2). In samples stored at CR, RT and ECS, there was no significant difference ($p < 0.05$) observed in the type of storage and storage period after 5 days. Storage started having an effect on the stored samples on day 10 for 9065 Jam tomatoes and on day 15 on round tomatoes. The a* colour component ranged from -13.10 to -15.40, -15.90 to 26.36 and -15.48 to 18.30 on 9065 jam tomatoes and from -15.90 to 11.48, -14.30 to 23.01 and -14.30 to 18.30 on round tomatoes stored at CR, RT and ECS, respectively. This increasing behavior was expected because there were higher temperatures on RT, than ECS and CR. Also, this proves that tomato red colour was developing faster on the tomatoes stored at RT. This, however, was observed to be true during the experiment as the results were in agreement with the findings by Pinheiro et al. (2009) who noted that under low temperatures, there is a delay in the formation of red colour in tomatoes, but at high temperatures, red colour quickly forms. Colour development is sensitive to temperature, having better plastid conversion when the temperature is above 12 °C and below 30 °C (Lopez Camelo and Gomez 2004). This was also observed to be true in this study, considering colour changes of samples at CR and RT. The results from this study also support findings of Takahashi et al. (2013) who explained that fruit colour component change with storage varies depending on the maturity stage of tomatoes. However, it is good that a* component was less in ECS than RT because it proves that, ECS can help delay ripening of stored tomatoes during storage.

There was a significant differences ($p < 0.05$) found between storage and storage period for both cultivars. However, for both cultivars stored on each of the treatments, for b* component there was no specific trend which represented an increase and or decrease occurring on the samples stored in the different storage conditions. Samples of different storage conditions on b* component ranged between 29.21 and 39.72, 29.48 and 39.72 and 29.52 and 39.02 on 9065 Jam tomatoes stored on CR, RT and ECS, respectively. For round tomatoes, b* component ranged between 28.34 and 34.60, 30.91 and 44.59 and 30.98 and 41.75 for CR, RT and ECS, respectively. According to Spokowski (2010), the higher the b* component for tomatoes, the yellow the tomatoes are. For this study, highest b* value was on tomato samples stored in RT, so it is concluded that tomatoes in this storage condition were more yellow compared to CR and ECS.

At CR, from day 0 to day 20, hue ranged between 66.35 and 67.41 for 9065 jam tomatoes and between 65.02 and 67.95 for round tomatoes. This proved that there were no significant differences ($p < 0.05$) on Hue value as affected by storage period (Figure 9 and Figure 10) for both tomato cultivars. A significant difference ($p < 0.05$) was observed in the storage conditions. For RT, hue ranged between, 48.05 and 71.62 for 9065 jam tomatoes and between, 56.12 and 80.35 for round tomatoes. Highest hue for 9065 jam tomatoes on RT was observed on day 5 (71.62) and lowest on day 20 (54.15). For round tomatoes on RT, the highest was observed on day 10 (80.35) and lowest on day 20 (56.12). Furthermore, for round tomatoes under RT, significance difference ($p < 0.05$) was observed in hue throughout the storage time, proving that storage had an effect on the hue of tomatoes. Under ECS, for 9065 jam tomatoes, there was no significant difference ($p < 0.05$) on the storage period of the tomatoes (day 0 - day 15). Significant difference ($p < 0.05$) existed on day 20. On round tomatoes at ECS, there was no significant difference on day 5, 10 and 20 significant difference ($p < 0.05$) existed on day 15 and 20. In this study for both cultivars, storage had a significant effect on the hue of the tomatoes.

According to the present study, tomato hue values were higher and decreasing faster on RT for both cultivars compared to ECS and CR (Figures 10 and 11). In reference to Spokowski (2010) hue values represent 360° circle where 0° is red (+ a*), 90° is yellow and (+ b*), 180° is green (- a*), 270° is blue (- b*) and 360° is red (+ a*). In this study, the hue values for jam tomatoes cultivar

were between 48.05 - 71.62 and for round tomatoes were between 53.25 - 80.35, suggesting that the overall colour of the tomatoes was in the range of red (+ a*) -yellow (+ b*). As shown in Figure 9 and Figure 10, the decrease was seen mostly on RT and ECS, this proves that samples stored in these storage conditions were maturing and becoming redder than samples stored at CR. Findings from this study approve findings by Ahmed et al. (2012) that, hue decreases as tomatoes mature during storage. Samples stored at CR showed no significant differences ($p < 0.05$) on storage period, hence are considered to mature slower than the others at RT and ECS. Also, during sampling from day 5 - day 20, it was easy to identify which tomato samples were stored under CR as no much difference was observed among this produce. Hence the reason for hue ranging from the same value for samples stored at this storage.

4.6.6 Firmness

Firmness of tomato cultivars stored in the different storage facilities is represented in table 3. In fresh tomatoes (9065 Jam and round) which did not undergo storage (day 0), there was no significant difference ($p < 0.05$) amongst the firmness of both cultivars. After 5 days, firmness in round tomatoes, stored at different storage conditions were 18.9, 23.64 and 23.98 Newton (N) for room temperature (RT), cold room (CR) and evaporative cooling system (ECS), respectively. There was no significant difference on the firmness of tomatoes stored under CR compared with RT and CR compared with ECS, however, there was a highly significant difference ($p < 0.05$) on tomatoes stored at RT compared with ECS. For 9065 jam tomatoes, after 5 days firmness of tomatoes was 27.64, 25.23 and 23.99 N on CR, RT and ECS, respectively. Amongst the storage conditions, no significant difference ($p < 0.05$) was seen on 9065jam tomato firmness after 5 days. After 10 days, firmness observed on round tomatoes showed no significant difference amongst different storage conditions, with values of 19.75, 16.92 and 16.60 N for CR, RT and ECS, respectively. With jam tomatoes, after 10 days, firmness observed were 25.11, 18.12 and 23.96 N on CR, RT and ECS, respectively. There was a highly significant difference ($p < 0.05$) on the firmness of jam tomatoes stored under RT compared with CR and EC and no significant difference ($p < 0.05$) was seen on the firmness of tomatoes stored on CR and ECS (Table 3).

For round tomatoes, a highly significant difference ($p < 0.05$) after 5 days was seen in firmness stored under CR compared with those at RT and ECS. However, there was no significant difference ($p < 0.05$) on those stored at RT and ECS. Firmness were 19.56, 12.03 and 13.54 on CR, RT and ECS, respectively. With jam tomatoes, there was a significant difference ($p < 0.05$) in firmness for all tomatoes stored under different conditions. Firmness was 26.26, 14.49 and 18.63 on samples stored in CR, RT and ECS, respectively. Lastly, after 20 days, firmness for round tomatoes were 19.85, 10.31 and 10.16 for CR, RT and ECS, respectively. A highly significant difference ($p < 0.05$) was seen only on tomatoes stored in CR, there was no significant difference ($p < 0.05$) on those at RT and ECS. With jam tomatoes, firmness was 23.50, 12.04 and 12.67 on CR, RT and ECS, respectively (Table 3). Also, the highly significant difference ($p < 0.05$) was seen on those stored under CR, there was no significant difference ($p < 0.05$) on those stored under RT and ECS. Findings from these study proved that there was a decreasing trend in firmness for both tomato cultivars. It was also observed that firmness decreased more at RT and was hypothesized that decrease was affected by high temperatures.

Findings in this study agreed with those of Brashlyanova et al. (2014) who reported that firmness is related to storage temperatures and cultivar type. Hence, differences in firmness existed in this study for the two cultivars. Findings by Cantwell et al. (2009) also supported findings from this study, where it was stated that temperature affected firmness in grape tomatoes. Furthermore, Abrar et al. (2016) reported that decreasing storage temperature slows the metabolic activity of the stored product down including firmness. Supporting findings from different research concerning firmness help this study to conclude that firmness is indeed affected by temperature which affects the ripening rate of any stored produce. However, it was pleasing that ECS was able to maintain the firmness of tomatoes compared to RT and this helps conclude that the develop evaporative cooling system can help increase shelf life and maintain the quality of tomatoes. Hence, is suitable for farmers who currently have no appropriate storage condition.

4.6.7 Total soluble solids

Total soluble solids (TSS) results in Table 3 for tomato samples stored at different storage conditions were significantly different ($p < 0.05$). Round tomato cultivar showed significant variation ($p < 0.05$) in the change of TSS as affected by the number of days of storage during the experiment. Whilst, with 9065 jam tomatoes showed no significant differences ($p < 0.05$) in TSS for the number of days fruits were sampled under different storage conditions. However, for both cultivars, TSS increased significantly during storage at the investigated storage conditions.

Initially, TSS values were 3.89 and 4.04 ^{o}Brix for 9065 jam tomatoes before storage. For round tomatoes, TSS values were 3.988, 4.036 and 4.053 ^{o}Brix before storage. After 5, 10, 15 and 20 days, for both cultivars, TSS kept increasing until the end of storage period (Table 3). TSS was observed to be higher on tomato samples stored at RT because temperatures were higher in this storage condition compared with temperatures in a CR and under an ECS, hence tomatoes ripened faster under these conditions. Baloch and Bibi (2012) explained that increase in TSS is the outcome of conversion of carbohydrates into simple sugars through a complex mechanism during storage. Vinha et al. (2013) stated that TSS increase observed during storage may be associated with the transformation of pectin substances, starch, hemicellulose or other polysaccharides into soluble sugars. Increase in TSS in this study may be due to ripening of the tomato samples and having the ones stored at RT ripening faster because they were exposed to an environment which had the highest temperatures. ECS was able to delay ripening of tomatoes compared to RT. Furthermore, ECS is hypothesized to have an ability to increase the shelf life of stored products compared to room temperatures. According to Tigist et al. (2013) TSS content on tomatoes is cultivar dependent and is frequently correlated with greater tomato yield. However, this explains the differences in TSS content observed for 9065 jam tomatoes and round tomatoes in this study.

4.6.8 Total titratable acids

Storage condition and storage period significantly affected ($p < 0.05$) titratable acids of both the tomato cultivars (9065 Jam and round). After harvest (day 0), there was no significant difference ($p < 0.05$) in titratable acids for both the cultivars. On the first sampling day, after 5 days, titratable acids were 8.321, 7.175 and 8.321 for 9065 jam tomatoes stored in CR, RT and ECS, respectively (Table 3). No significant difference ($p < 0.05$) existed between samples stored in CR and ECS but

there was a significant difference ($p < 0.05$) in samples stored at RT. After 10 – 20 days of the experiment, in 9065 jam tomatoes, titratable acids varied between 7.725 – 5.661 in samples stored in CR, 5.324 – 3.111 for those stored under RT and between 6.691 – 3.806 for those stored in an ECS (Table 3). It was observed that 9065 jam tomatoes decreased in titratable acids more when stored under RT, second in ECS and lastly in CR.

Regards to round tomatoes, after 5 days, titratable acids were 10.062, 8.776 and 9.241 for tomatoes stored in CR, RT and ECS, respectively (Table 3). A significant difference ($p < 0.05$) existed between all the storage conditions. After 10- 20 days titratable acids varied between 8.867 – 5.971 for samples stored in CR, between 6.379 – 4.204 for those stored under RT and between 7.408 – 5.01 in tomatoes stored in an ECS (Table 3). It was also observed that for this cultivar, samples stored in RT decreased in titratable acids faster, followed by those stored in an ECS and lastly those in CR.

In this present study, both tomato cultivars (9065 jam and round), samples stored in CR had higher titratable acids than those stored in ECS and in RT. Tomato samples stored in RT had the lowest titratable acids. It was hypothesized that the variations in titratable acids on the tomatoes could be due to higher respiration rate occurring in RT compared to ECS and CR. Higher respiration rate causes tomatoes to ripen faster. These findings support the report by Isack and Monica (2013) who alluded that, acidity is often used as an indication of maturity as acid decreases during ripening of fruit. These results also correspond with findings of Tigit et al. (2013) and Duma et al. (2017) who reported that higher loss of titratable acids during storage time could be related to higher respiration rate as ripening advances where organic acids are used as a substrate in respiration process. Results by Pinheiro et al. (2009) agreed with this theory explaining that decrease of tomatoes titratable acid occurs because citric acid was used as a substrate for respiration. Messina et al. (2012) reported a similar decreasing trend in the changes of titratable acid of tomatoes during ripening and storage. Furthermore, Tilahun et al. (2017) described that titratable acidity in tomatoes decreases with increasing storage as this might be associated with the conversion of organic acids into sugars and their utilization in respiration. Moreover, Tigist et al. (2013) further argued that variations in titratable acids of tomatoes could be affected by differences in fruit weight. In this study different weight of tomatoes were also observed. The evaporative cooling system proved

that it can help reduce ripening rate of tomatoes and increase the shelf life of the tomatoes compared to the cooling method which is culturally used by the farmers.

4.7 Conclusion

On basis of the findings of this study, it can be concluded that the developed low cost evaporative cooling system was able to decrease temperature, increase relative humidity and had a cooling efficiency of 67.17%. The results proved that the suitable method for shelf life extension and better maintenance of firmness, colour, mass loss, respiration, total soluble solids and titratable acids of the tomatoes stored in three different storage conditions was the cold room, followed by the evaporative cooling system and lastly the room temperature. The evaporative cooler was also able to maintain colour, respiration rate, firmness, mass, total soluble solids and titratable acids of the tomatoes for 20 days compared to room temperature. Hence it can be deduced that the evaporative cooler can be used as a storage condition for smallholder farmers. Differences in performance of cultivars in terms of mass loss, firmness, colour, respiration rate, TSS and TA is due to genetic structure, variability in size, maturity stages of the tomatoes and levels of accumulation of carotenoid pigments which contribute to fruit colour changes.

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Table 1: Cooling efficiency hourly percentage of the developed evaporative cooling system for 14 hour period

Time	Ambient air T (°C)	Ambient air RH (%)	Evaporative cooling system T (°C)	Temperature (wet bulb) (°C)	Cooling Efficiency (%)
6:00 am	21.73	56.69	18.57	16.1	56.13
8:00 am	20.09	68.88	17.95	16.8	65.05
10:00 am	18.51	72.62	16.34	15.2	65.56
12:00 pm	19.86	74.19	17.62	16.4	64.74
14:00 pm	23.93	80.57	21.64	21.2	83.88
16:00 pm	18.2	76.34	16.64	15.9	67.83
18:00 pm	22.21	84.08	20.73	20	66.97

T, Temperature; RH, Relative humidity

Table 2: Average changes in colour components of two tomato cultivars stored under different storage conditions

		Colour Components								
		L*			a*			b*		
C	SD	CR	RT	ECS	CR	RT	ECS	CR	RT	ECS
Jam	0	69.34fg	68.59fg	68.05efg	-15.07a	-15.90a	-15.48a	34.62def	32.52cd	31.73abc
	5	66.39def	70.26g	70.81g	-15.40a	-9.68ab	-8.47ab	35.38ef	39.72g	39.02g
	10	64.04d	64.30de	64.74de	-13.10ab	1.32c	-6.18bc	32.01bcd	39.47g	37.13fg
	15	64.69de	57.11c	62.68d	-14.21ab	11.92e	1.12d	31.32abc	32.66cd	32.96cde
	20	62.75d	48.11a	51.95b	-13.40ab	26.56f	18.30e	29.21a	29.48ab	29.54ab
Round	0	68.97c	67.95c	67.54c	-14. 49a	-14.30a	-14.86a	31.47bcde	30.91bc	30.98bcd
	5	69.19c	73.41d	73.18d	-15.90a	-11.64a	-11.52a	34.60cefg	39.34hi	40.48hi
	10	67.37c	73.18d	69.37c	-12.69a	-0.79b	-0.40b	28.34ab	44.59j	41.75ij
	15	66.37c	59.16b	61.04b	-11.48a	18.59cd	14.18c	26.89a	39.58hi	37.26gh
	20	68.78c	54.72a	53.50a	-11.64a	23.01de	24.29e	28.67ab	35.64fg	33.04cdef
P values (9065 Jam tomatoes)		*P < 0.001*			*P < 0.001*			*P < 0.001*		
P values (round tomatoes)		*P < 0.001*			*P < 0.001*			*P < 0.001*		

Means within the same column followed by the same small letter are not significantly different at (p< 0.05) according to Duncan's multiple test range, C, SD, CR, RT and ECS are Cultivar, storage days, cold room, room temperature and evaporative cooling system, respectively

Table 3: Average changes in firmness, total soluble solids (TSS) and total titratable acids (TTA) of two cultivars stored under different storage conditions

Cultivar	Storage condition	Days	Firmness	TSS	TTA
Jam	CR	0	27.14cd	3.895a	9.334h
		5	27.64cd	4.006a	8.321g
		10	25.11cd	4.269b	7.727f
		15	26.26cd	4.538c	6.358d
		20	23.5c	4.715cde	5.661c
	RT	0	29d	4.043a	9.471h
		5	25.23cd	4.249b	7.175e

		10	18.12b	4.698cde	5.324c
		15	14.49ab	4.794de	3.566ab
		20	12.04a	4.836e	3.111a
		0	28.16cd	4.043a	9.487h
		5	23.99c	4.278b	8.321g
	ECS	10	23.96c	4.52c	6.691de
		15	18.63b	4.596cd	5.223c
		20	12.67a	4.584cd	3.806b
		0	24.16g	3.988a	10.551g
		5	21.64efg	4.229b	10.062f
	CR	10	19.75cdef	4.269bc	8.867e
		15	19.56cdef	4.292bc	7.124d
		20	19.85def	4.333bcd	5.971c
		0	21.8efg	4.036a	10.841g
		5	18.7cde	4.238b	8.776e
Round	**RT**	10	16.92cd	4.416cd	6.379c
		15	12.03ab	4.657e	5.199b
		20	10.31a	4.829f	4.204a
		0	22.21fg	4.053a	10.901g
		5	23.98g	4.361bcd	9.241e
	ECS	10	16.6c	4.302bc	7.408d
		15	13.54b	4.399cd	6.131c
		20	10.16a	4.474d	5.010b
P values (9065 jam tomato)			p < 0.001	p < 0.001	p < 0.001
P value (Round tomato)			p < 0.001	p < 0.051	p < 0.001

Means within the same column followed by the same small letter are not significantly different at (p< 0.05) according to Duncan's multiple test range, C, SC, TSS and TTA are Cultivar, Storage condition, total soluble solids and total titratable acids, respectively CR, RT and ECS are cold room, room temperature and evaporative cooling system

Figure 1: Front view of the developed evaporative cooling system storage facility

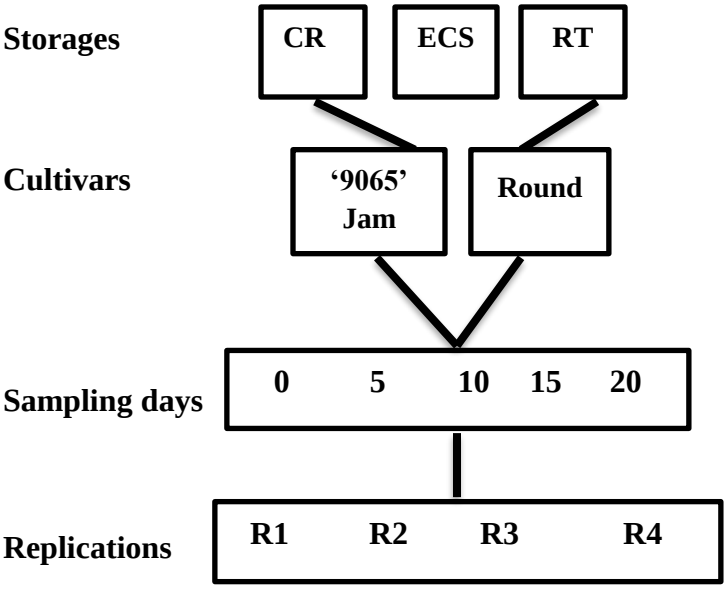

Figure 2: Experiment layout. CR, Cold room; ECS, Evaporative cooling system and RT, Room temperature

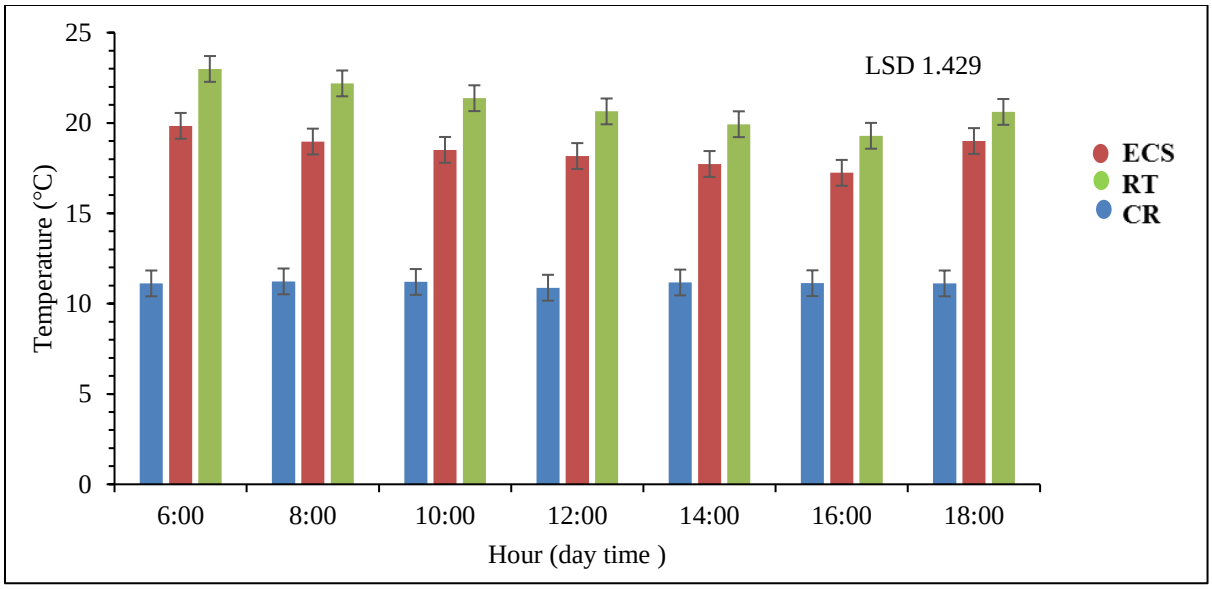

Figure 3: Hourly average temperature for cold room, room temperature and evaporative cooling system (Note: CR, Cold Room; RT, Room Temperature; ECS, Evaporative Cooling System and LSD, Least Significant difference of means at 5% level of significance)

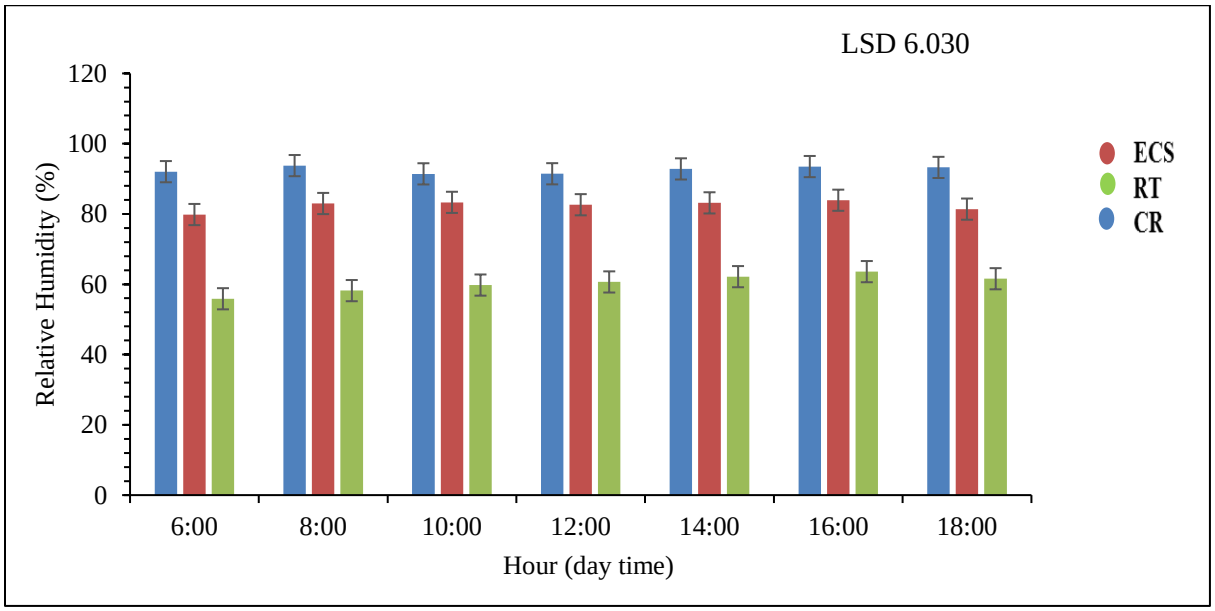

Figure 4: Hourly average relative humidity for cold room, room temperature and evaporative cooling system (Note: CR, Cold Room; RT, Room Temperature; ECS, Evaporative Cooling System and LSD, Least Significant difference of means at 5% level of significance)

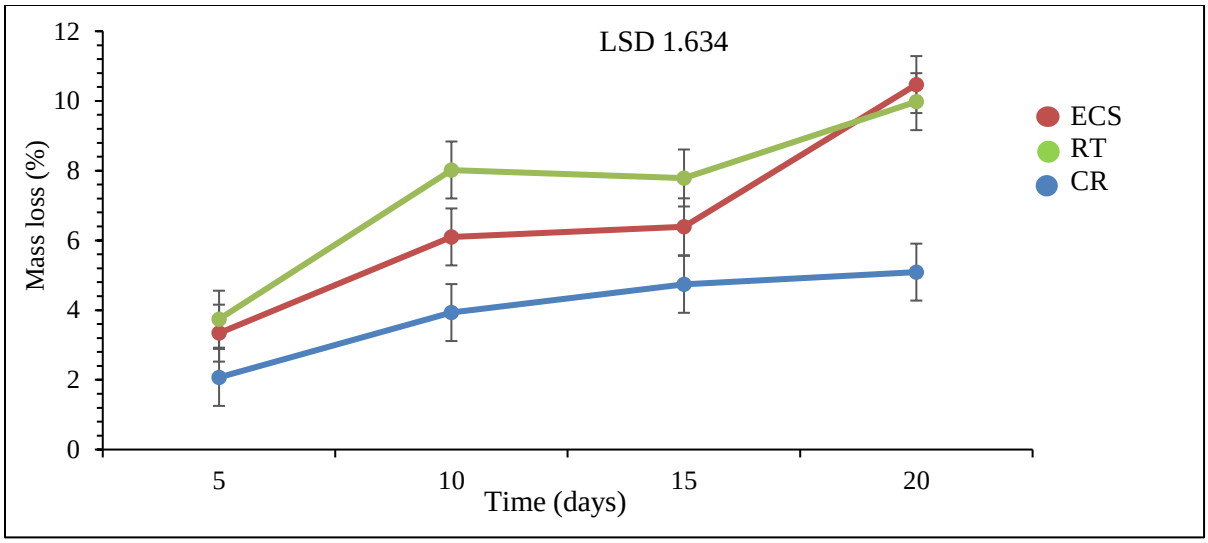

Figure 5: Average percentage weight loss of 9065 Jam tomato sample (Note: CR, Cold Room; RT, Room Temperature; ECS, Evaporative Cooling System and LSD, Least Significant difference of means at 5% level of significance)

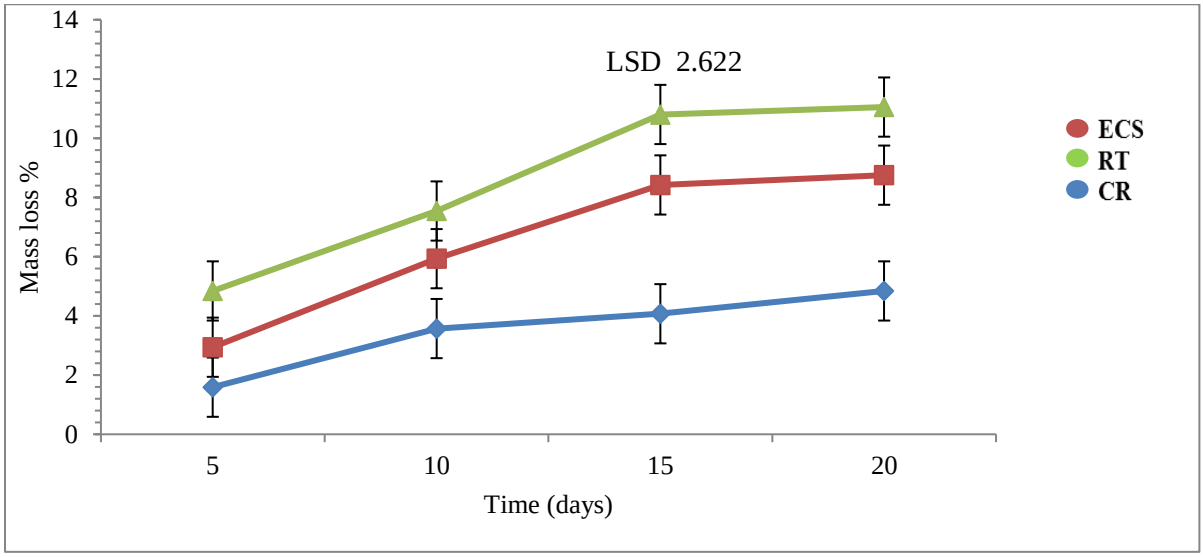

Figure 6: Average percentage weight loss of Round tomato samples (Note: CR, Cold Room; RT, Room Temperature; ECS, Evaporative Cooling System and LSD, Least Significant difference of means at 5% level of significance)

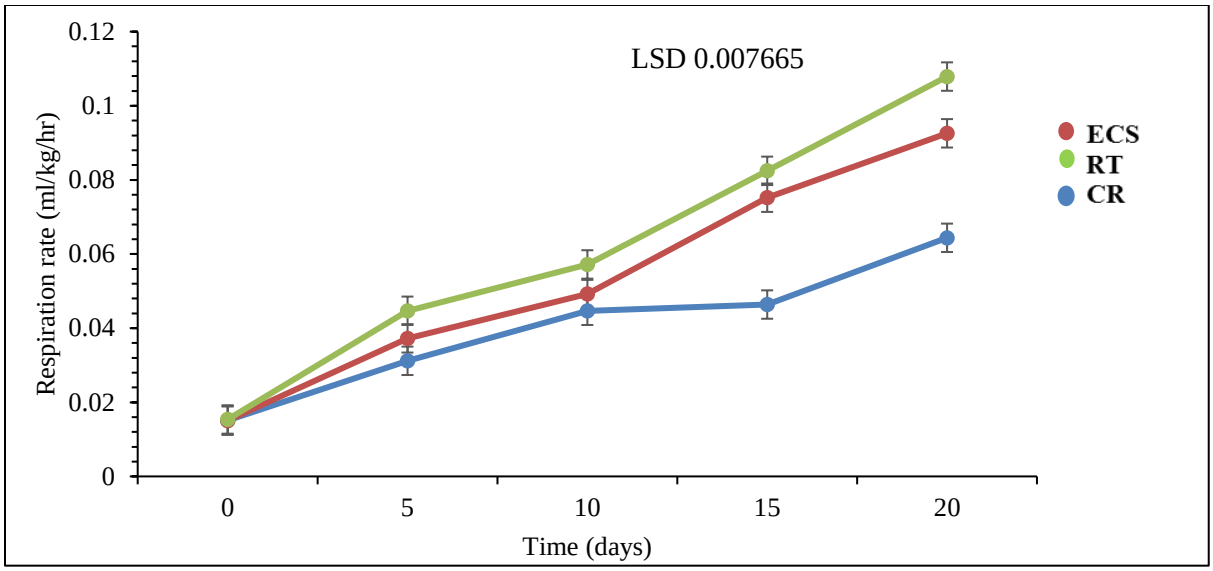

Figure 7: Average respiration rate of 9065 Jam tomato samples (Note: CR, Cold Room; RT, Room Temperature; ECS, Evaporative Cooling System and LSD, Least Significant difference of means at 5% level of significance)

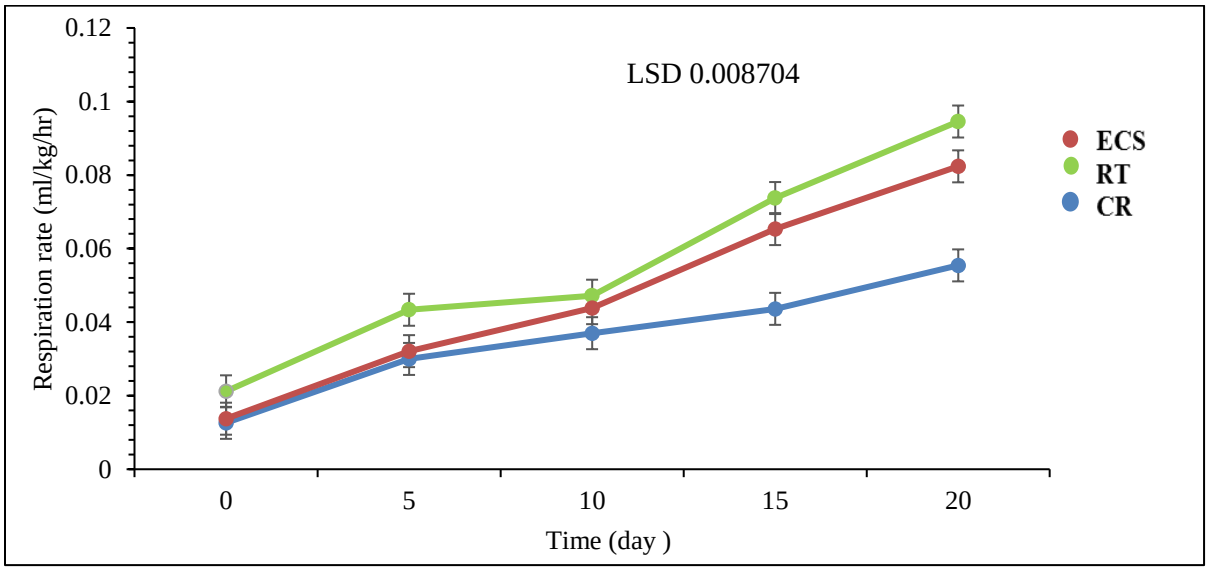

Figure 8: Average respiration rate of Round tomato samples (Note: CR, Cold Room; RT, Room Temperature; ECS, Evaporative Cooling System and LSD, Least Significant difference of means at 5% level of significance)

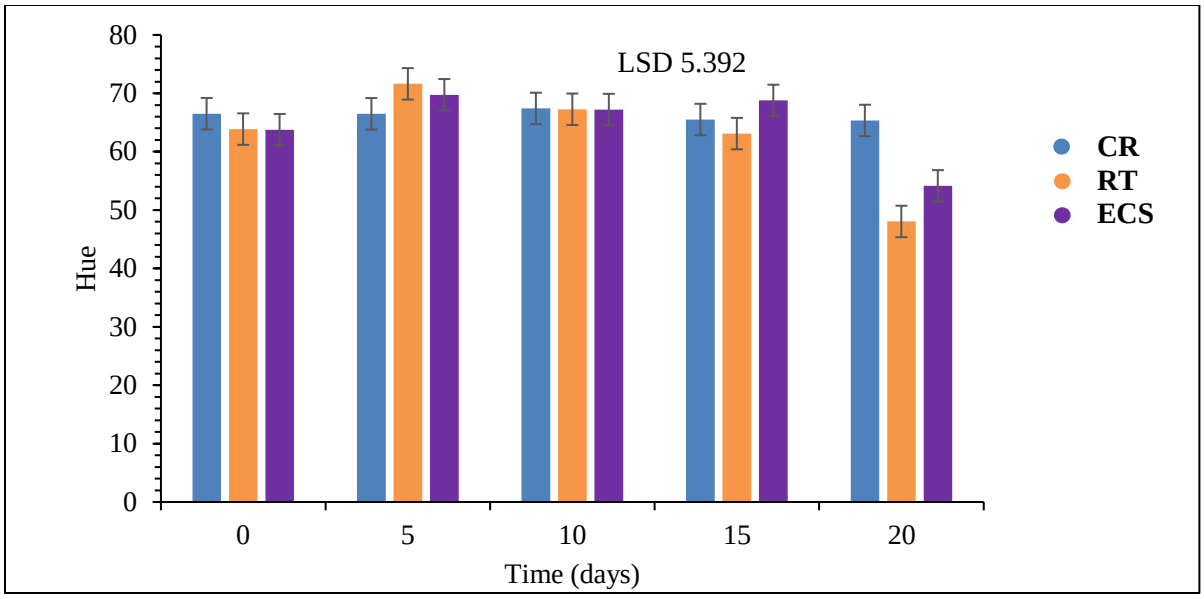

Figure 9: Hue for 9065 Jam tomatoes stored under different storage conditions (Note: CR, Cold Room; RT, Room Temperature; ECS, Evaporative Cooling System and LSD, Least Significant difference of means at 5% level of significance)

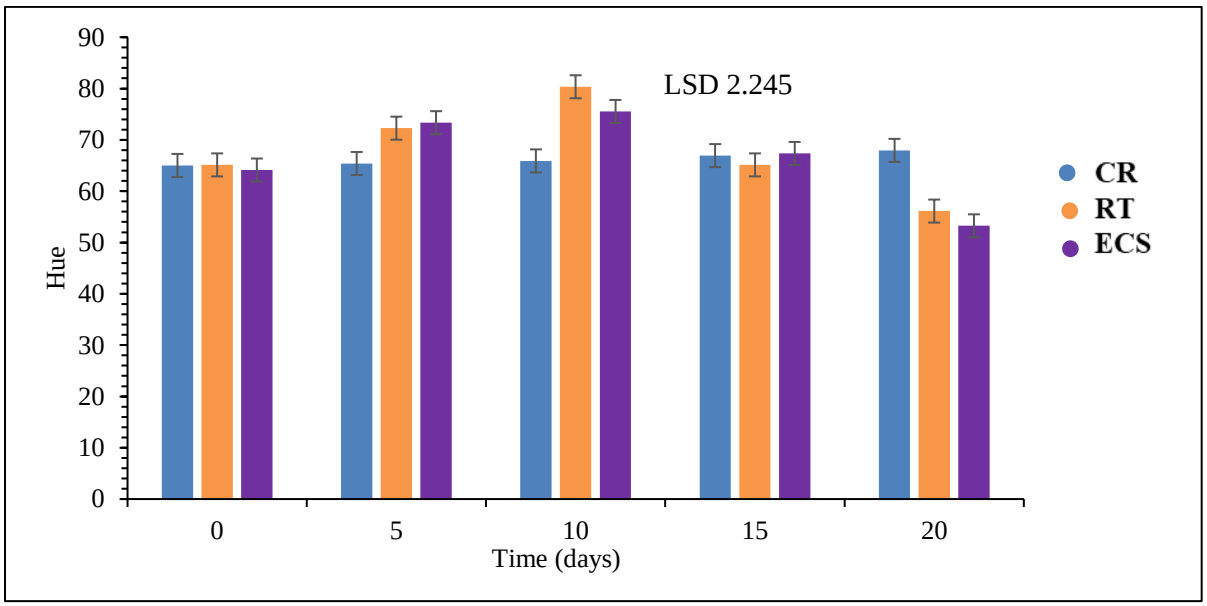

Figure 10: Hue for round tomatoes stored under different storage conditions (Note: CR, Cold Room; RT, Room Temperature; ECS, Evaporative Cooling System and LSD, Least Significant difference of means at 5% level of significance)

Chapter 5:

Evaluating the effect of different storage conditions on quality of tomatoes (*Solanum lycopersicum*)

Abstract

The aim of this study was to investigate the effect of different storage conditions on biochemical quality of two tomato cultivars (9065 jam and round tomatoes). The investigated biochemical properties of the tomato samples were lycopene content, total phenolic content, antioxidants and ascorbic acid. The tomato cultivars were harvested from a smallholder farmer's field at Umsinga and stored for 20 days in one of the three storage conditions namely; cold room (CR), room temperature (RT) and evaporative cooling system (ECS). Samples fruits were laid out as a factorial design with four replications. Sampling was done on a five days interval for 20days. Data were statistically subjected to analysis of variance (ANOVA) GenStat 18th edition and multivariate statistical analyses, principal component analysis. Results obtained proved that the storage conditions and storage period had a significant effect (p <0.05) on the biochemical qualities of the tomato samples. A decreasing trend with storage time was observed for antioxidants and TPC for both the cultivars whilst there was an increasing trend of AA and lycopene content on both the cultivars stored in the different storage conditions. The correlation relationship among cultivars was positive and PCA proved that the cultivars were statistically similar. The best storage conditions for maintaining investigated quality variables of tomatoes was cold room followed by evaporative cooler and storing tomatoes in room temperature was not the best method of cooling the tomatoes.

Keywords: Storage conditions, total phenolic content, antioxidants, ascorbic acid, lycopene content, quality

5.1 Introduction

Tomato (*Solanum lycopersicum*) is one of the most scientifically investigated horticultural produce because of its commercial importance (Correia et al. 2015). It is considered the main supplier of

several phytonutrients and providing an important role in human health (Tigist et al. 2013). However, tomatoes are inherently perishable which make them to deteriorate fast during postharvest value chain. As means of counteracting such losses tomatoes are harvested as early mature green, however, mature green tomatoes cannot be stored at temperatures less than 10^{o}C as this causes chilling injuries on the fruit (Castro et al. 2005) and red mature tomatoes cannot be stored for more than 7 days under normal ambient conditions in summer (Znidarcic and Pozrl 2006). According to Rajkumar and Mitali (2009) marketability of tomatoes is lost very quickly due to its quick colour change and spoilage during postharvest. This however makes proper postharvest handling and storage of tomatoes very important in order to ensure good quality maintenance, extension of shelf life and to extend supply to the market.

Postharvest storage conditions include methods such as refrigeration, hydro-cooling, vacuum cooling, room cooling, and evaporative cooling system (Xuan et al. 2012; Vala 2014). The main goal of postharvest cooling treatments is to reduce the rate of respiration and transpiration (Falah et al. 2015). Other importance of cooling includes maintaining quality, decreasing susceptibility to ethylene damage, increasing shelf life and decreasing normal metabolism rate which is associated with consuming sugars, acids, vitamins and other constituents of the tomato fruit (Thompson et al. 2001).

The physical quality of horticultural products such as firmness, colour and size are affected by storage time and exposure to unsuitable postharvest temperatures (Cantwell et al. 2009; Pinheiro et al. 2009; Abiso et al. 2015). However, according to Serea et al. (2014) postharvest storage time and temperatures do not only affect physical and physiological properties of tomatoes but also influence biochemical and nutritional properties of the fruit such as ascorbic acid (AA), total phenolic content (TPC), lycopene content and antioxidant activities. Measuring chemical parameters is considered a way of assessing nutritional quality of horticultural products. Hence, Duma et al. (2017) stated that different qualitative and quantitative changes of chemical composition take place during ripening of tomatoes and mostly influenced by temperatures. Temperature is an important environmental factor which is known to decrease and or increase processes occurring in a produce depending on the temperature a produce is exposed to. Hence, Tolesa and Workneh (2017) suggested that, the correct way of preventing postharvest losses

caused by the use of inappropriate temperatures from affecting tomatoes chemical properties is exposing the produce to its optimum cooling temperature requirements during postharvest. According to Munoz et al. (2017) storing any harvested fruit and vegetable is the best way to avoid easy deterioration, maintaining physicochemical properties and increasing shelf life of the produce. Therefore, the aim of this study was to determine the effect of different storage conditions on TPC, AA, lycopene content and antioxidant activity of two different '9065' jam tomatoes and round tomatoes.

5.2 Materials and methods

5.2.1 Experimental site

The study was conducted at Nhlesi in Umsinga which is located under the UMzinyathi District in KwaZulu-Natal province, South Africa (28°45'56.45"S, 30°33'42.37"E) and at the University of KwaZulu-Natal (UKZN); Pietermaritzburg Agricultural Campus, Pietermaritzburg, KwaZulu-Natal, South Africa (29°37'S 30°84'E).

5.2.2 Treatments and experimental design

A total of 1000 tomato fruit samples ('9065' Jam tomatoes and round tomatoes) were harvested from a smallholder farmers field at Umsinga (28°45'56.45"S, 30°33'42.37"E) and transported in a well-ventilated vehicle to the postharvest research laboratory of the University of KwaZulu-Natal, Pietermaritzburg. From the harvested samples, 500 tomatoes were '9065' jam cultivar and 500 were round. Mature green tomatoes of uniform size and free from blemishes were selected, washed with cold tap water to remove field heat and dirt. After which, from 1000 fruit that were harvested, only 648 were used for the experiment. The 648 tomatoes were divided equally segregated by assigning them to one of three postharvest storage treatments; namely evaporative cooling system, cold room and room temperature. The sample fruits were neatly packed in display boxes for each treatment and laid out as a 2×3×5 factorial design, whereby 2 cultivars were assigned to 3 storage

treatments and sampled at 5 days interval. For each cultivar, the design was a factorial arrangement with four replicates of 27 sample fruits per replicate. The day after harvest, two-thirds of the sample fruit were taken for storage at Umsinga under the evaporative cooling system and room temperature and the remaining fruit were stored in a cold room with the delivery air of 12 °C at UKZN.

5.2.3 Sampling

Fruit sampling was done on a 5-day interval for 20 days. Samples were collected from each storage treatments and taken to the UKZN Postharvest Research Laboratory for analysis until the last day of the experiment.

5.3 Data Collection

5.3.1 Total phenolic content

From each tomato sample, 1 g of fresh weight was extracted with 10 mL of 80% methanol (80:20, v/v) and heated in an oven at 40 °C for 24 hours according to an extraction method previously explained by Singleton et al. (1999) with minor modifications, where a fresh sample was used instead of a dried sample.

Total phenolic contents in tomato fruit was determined by the Folin-Ciocalteau (FC) reagent procedure as determined by Singleton and Rossi (1965). Briefly, a 0.1 mL of the crude extract for each fruit sample was mixed with 0.5 mL FC reagent along with 1.5 mL of 7% sodium carbonate solution. Distilled water was added to make a final solution volume of 10 mL. The mixture was heated in an oven at 40°C for 2 hours, and the absorbance was then recoded at 750 nm using a UV-VIS Spectrophotometer (Varioskan Flash Multimode Reader, Thermo Fisher Scientific, USA). The final results were expressed in mg of Gallic acid equivalent to 100 g of fresh weight of fruit sample.

5.3.2 Antioxidant activities

From each tomato sample, 1 g of fresh weight was extracted with 10 mL of 80% methanol (80:20, v/v) and heated in an oven at 40 °C for 24 hours according to an extraction method previously explained by Singleton et al. (1999) with minor modifications, where a fresh sample was used instead of a dried sample. Scavenging effect of 2, 2-diphenyl-1-picrylhydrazyl (DPPH) radical was determined using a method described by Brand-William et al. (1995) with slight modifications, whereby a fresh sample was used instead of dried sample. Before testing of antioxidant capacity on tomatoes, DPPH solution was freshly prepared by dissolving 0.025 g of DPPH in 100% (v/v) methanol. From the prepared extract, 5µL of an aliquot from each sample fruit was added in a cuvette containing 3 mL of the freshly prepared DPPH. The solution was then thoroughly mixed using a pipette tip and allowed to stand for 15 minutes to react at room temperature. The absorbance was measured at 515 nm wavelength using a UV-1800 Spectrophotometer (Shimadzu Scientific Instruments INC., Columbia, USA) against a blank of methanol without DPPH.

5.3.3 Lycopene content

Lycopene content was determined according to a method previously used by Fish et al. (2002). Briefly, 0.5 g fresh weight (FW) of each fruit sample was weighed using a calibrated weighing balance and placed inside different test tubes. 5 mL of butylated hydroxytoluene (BHT)-acetone solution (0.05% w/v), 5 mL of ethanol and 10 mL of hexane were added to the sample fruits on test tubes. The solvents were at a ratio of 2:1:1 making up a total volume of 20 mL. The test tubes were kept on ice in a cooler box and each test tube covered with aluminum foil for light protection at room temperature.

The solution was then shaken using a shaker (IKA® KS 130 control shaker, IKA® work INC., USA) for 15 minutes. After shaking, 3 mL of distilled water was added to the solution to make a final volume of 23 mL and then the solution further shaken for 5 minutes. The solution was then placed at room temperature for 5 minutes to allow the separation of hexane phases. The absorbance was measured at 503 nm using a UV- 1800 Spectrophotometer (Shimadzu Scientific Instruments INC., Columbia, USA) against a hexane blank because hexane forms the upper layer of the

solvents and the mixed samples are 50% hexane by volume. Lycopene (mg/kg fresh weight) was then calculated using equation 1 described by Sawanaruang (2016).

$$\text{Lycopene content} = \text{Abs}_{(503\ nm)} \times 137.4 \quad (1)$$

Where 137.4, was the lycopene constant coefficient and $\text{Abs}_{(503\ nm)}$*, was the absorbance of each sample fruit read at 503 nm*

5.3.4 Ascorbic acid

Ascorbic acid extraction was done following a method described by Matteo et al. (2010) with slight modifications, where a fresh sample was used instead of a dry sample. Briefly, each of the tomato fresh samples (1 g) were extracted by 20 mL of 3 % (w/v) metaphosphoric acid followed by shaking at 300 rpm for 30 minutes using a shaker (IKA® KS 130 control shaker, IKA® work INC., USA) and then the extract centrifuged at 4000 rpm for 10 minutes in a 4°C centrifuge (Sorvall RC- 5C Plus Superspeed Centrifuge, Ramsey, MN 55303 United States). Ascorbic acid content was determined using a method of 2, 6 dichlorophenolindophenol (DCPIP) as described by Kampfenkel et al. (1995). Briefly, 1 mL of each sample extract was added into 3 mL of 0.2 mM DCPIP and measured immediately after mixing for 15 seconds using a UV spectrophotometer (UV- 1800, Shimadzu Scientific Instruments INC., Columbia, USA) at 515 nm. The ascorbic acid concentration on tomatoes was expressed in µmol g^{-1} fresh weight according to the standard curve $A_{525} = 3.6593 \times$ µmol AsA ($R^2 = 0.9982$).

5.4 Data analysis

The collected data was analyzed using Genstat® version 17. Statistically, significant differences between the treatments were determined by analysis of variance (ANOVA) with a GenStat® 18th Edition (VSN International), under 5% levels of significance. The means were separated using Duncan's multiple range. Data was also subjected to multivariate statistical analyses, principal component analysis (PCA) using Unscrambler® (Version 10.3, Camo Software, AS, Norway).

5.5 Results and discussion

5.5.1 Ascorbic acid

The effect of different storage conditions on ascorbic acid (AA) of '9065' jam tomatoes and round tomatoes is shown in Table 1. Results obtained proved that AA was greatly affected by the different temperatures observed for each storage condition. The range of AA content in this study from day 0 to day 20 was 0.03 to 0.12 mg $100g^{-1}$, 0.03 to 0.17 mg $100g^{-1}$ and 0.03 to 0.017 mg $100g^{-1}$ fresh weight of tomato samples stored inside the cold room (CR), in an evaporative cooling system (ECS) and under room temperature (RT), respectively. The observed increase in AA in tomatoes on the investigated treatments corresponds to findings of Ajayi and Oderinde (2013) who stated that AA in tomatoes increases with increase in storage period and that increase is highly affected by differences in temperatures among storage facilities.

Different storage conditions and storage period had a significant difference ($p < 0.05$) in the AA content of both the tomato cultivars. On day 0 to day 20, there was no significant difference ($p < 0.05$) observed among cultivars (Table 1). This is most evident on samples stored under RT and inside an ECS. However, as storage period increased AA increased in the tomato samples. These observations strengthened findings of Znidarcic et al. (2010) who explained that there is an increase in AA content of mature green tomatoes as storage enhances because tomatoes would still be ripening to reach their red colour.

The interaction effect among cultivar, storage condition and storage period were significantly different ($p < 0.05$). From day 5 to day 20, the higher ascorbic acid was found in sampled tomatoes stored inside RT (Table 1). Hussain et al. (2009) indicated that in room temperature tomatoes develop most of their quality attributes faster and are usually associated with having a short shelf life compared to tomatoes stored under controlled environments. Hence, for this study, the lowest AA content on tomatoes was found on tomatoes stored in the CR which had a constant delivery air of 12°C (Table 1). The obtained results of CR having samples with the lowest AA content support findings of Samira et al. (2013) who explained that constant low temperatures retard aging through reduced respiration rate and other metabolic processes on selected produce. Vinha et al.

(2013) alluded that, high levels of acidity on tomatoes is responsible for the stability of AA content during storage. For this study, the observations of Vihna et al. (2013) could be true for samples stored at CR which remained green throughout the experiment compared with those stored at RT and under an ECS.

According to Yoshida et al. (1984), high temperatures are known to increase enzymatic catalysis and lead to the biochemical breakdown of compounds in fruits and vegetables. This usually makes the selected product lose its quality faster and have a short shelf life. For this study samples stored at RT ripened faster and as a result were fully red at the end of the experiment whilst those in the CR were still mature green. Samples inside the ECS were mixed, some remained mature green and some were red. This therefore clearly indicates that samples that were stored in RT were more affected; they ripened faster and had high AA content followed by sample fruits stored inside the ECS, while samples inside the cold room ripened slower and had the lowest AA.

5.5.2 Lycopene content

Table 2 displays the effect of cultivars and storage conditions in lycopene content of tomato samples during the 20 days of storage period. The lycopene content of '9065' jam tomatoes and round tomatoes which were harvested at mature green and stored for 20 days inside the cold room (CR), in an evaporative cooling system (ECS) and at room temperature (RT) ranged between 2.3 and 52.9 mg $100g^{-1}$ of fresh tomato. The highest lycopene content was found on '9065' jam tomato stored in RT. These findings are in agreement with findings of Vinha et al. (2013) who reported that lycopene content on tomatoes stored at RT are usually high because the temperature is not regulated to optimum requirement levels as the stored produce. Also, the obtained lycopene range values are in correspondence with the finding of Brandt et al. (2006) who reported lycopene values of 1 to 55 mg $100g^{-1}$ of fresh tomato.

In this study, the general trend observed during the storage of tomatoes for lycopene content was an increasing trend (Table 2). These findings are in agreement with findings of Sood et al. (2011) who stated that increase in lycopene content on mature green tomatoes is a result of ripening of tomatoes and the samples changing to their red colour. Lycopene content is responsible for the

development of red colour in tomatoes (Tigist et al. 2011; Nair and Lilwani 2015). From day 0 to day 20 on both the cultivars, there was no significant difference ($p < 0.05$) on the tomato samples stored in a CR. As a result, during sampling, especially at day 15 and day 20 it was easy to identify tomato fruits physically, which were stored inside the CR from those stored in an ECS and at RT. These obtained results support findings of Samira et al. (2013) who explained that low temperatures of 10- 12°C on mature green tomatoes retard aging through reduced respiration rate and other undesirable metabolic changes during postharvest.

Sample fruits in an evaporative cooler showed significantly ($p < 0.05$) lower lycopene content during storage period compared to sample fruits stored in RT (Table 2). It was observed that there was a significant difference ($p < 0.05$) on '9065' jam tomatoes stored at RT with those inside the ECS from day 10 till the last day of the experiment. For round tomatoes, a significant difference ($p < 0.05$) existed among tomato samples stored at RT and ECS on day 15 and day 20. It is hypothesized that the observed highest lycopene content on samples at RT was due to higher temperatures which existed in this storage facility compared to the other storage facilities. These findings corresponded with findings of Tedese et al. (2015) who explained that at high temperatures the rate of ripening process which is associated with increasing of lycopene content in tomatoes increases. The interaction among cultivar, storage condition and storage period on the lycopene content of tomato fruit was significantly different ($p < 0.05$) (Table 4.2). Generally, as storage days increased, lycopene content on all samples stored in the different storage conditions increased. It was observed that CR was the best storage method for decreasing ripening rate of the tomato samples. The evaporative cooler performed better compared to RT temperature which caused the highest ripening rate and fast colour changes on the tomatoes.

5.5.3 Total phenolic content

The interaction effect among tomato cultivar, storage condition and storage period proved that there were significant differences ($p < 0.05$) in total phenolic content (TPC) of the sample fruits (Table 3). Total phenolic content on the sample fruits ranges between 0.31 mg $100g^{-1}$ GAE and 0.19 mg $100g^{-1}$ GAE. A general trend of decrease in phenolic content on the tomato samples was observed as the storage period advanced. The obtained decreasing trend on phenolic content of the

samples corresponded to findings of Duma et al. (2017) who explained that on mature green tomatoes, the decrease in the levels of phenolic content of tomatoes is as a result of the rate of ripening, the binding of phenols to proteins and the changes in chemical structure of the sample fruits.

On the first sampling (day 0), there was no significant difference ($p < 0.05$) between '9065 jam tomatoes and round tomatoes. On the second sampling day (day 5) to the last day of the experiment (day 20) there were changes seen on the tomato samples, differently according to the treatment the sample fruits were exposed to. Samples stored in the cold room (CR) had the highest phenolic content and followed by the samples stored in an evaporative cooling system (ECS). Samples stored at room temperature (RT) decreased faster. However, it was also interesting to note that there was no significant difference ($p < 0.05$) on phenolic content on fruit samples between the cultivars in an ECS and at RT on the last day of the experiment. The observed low values of TPC on samples at CR could be an indication of lower respiration and metabolic rates occurring in this storage condition (Lurie and Klein 1990). This, therefore, means that the highest values of TPC in samples stored at RT are due to high metabolic rates due to high temperatures in this storage condition. It was also hypothesized that RT had the highest temperatures compared to ECS and RT. These findings, correspond with those of Vihna et al (2013) who explained that when tomatoes are stored at temperatures of 25 °C and more, metabolic processes and ripening rate increase, which therefore leads to decrease in levels of soluble phenolic compounds. Moldovan (2016) agreed with findings of Vihna et al. (2013) by stating that, exposing a harvested tomato to high temperatures as it requires will lead to decrease in the levels of phenolic content.

The interaction between cultivars and storage period was significant ($p < 0.05$). The results proved that the overall phenolic content of tomatoes was well maintained inside the CR. The ECS performed better than RT but at the end, there was no significant difference ($p < 0.05$) among tomato samples at RT and ECS for both cultivars.

5.5.4 Antioxidants activities

The changes in the antioxidant activity of tomatoes during storage times are due to ripening process. As storage advances, antioxidant activities in tomato samples decreased (Table 4). The results showed a significant difference ($p < 0.05$) among '9065' jam and round tomatoes in antioxidant activities during 20 days of storage.

Antioxidants capacity are related to all the chemical properties of tomatoes investigated in this study which are lycopene content, phenolic compound and ascorbic acid (Odriozola-Serrano et al. 2008; Vinha et al. 2013). This is explained more following findings of Viet (2015) who explained that tomatoes are considered one of the fruits with high antioxidant activity because it contains compounds with high biological activity such as ascorbic acid, phenolic compound and lycopene content. Viet (2015) further stated that antioxidant capacity reflects the amount of lycopene, ascorbic acid and phenolic compounds. Sample tomatoes stored under RT had the lowest antioxidant capacity in this study. This may be due to that, samples stored in RT were ripening faster than the order samples stored inside the CR and under ECS. Also, it was observed that sample fruits inside RT, had the highest lycopene content, highest ascorbic acid and the lowest phenolic content and since these are related to antioxidant capacity they could have led to the lowest value obtained for both round and '9065' jam tomatoes on samples inside the RT.

Findings from this study correspond with findings of Vunnam et al. (2014) who distinguished that antioxidants capacity found on tomatoes decrease with time under storage conditions during postharvest mostly faster in produce exposed to high temperatures. In this study, this could be the result of lowest antioxidants decrease in sample fruits stored under CR as inside this storage, temperatures were the lowest (12°C). Sample fruits stored inside the ECS and RT were changing as a result of daily weather temperatures. However, samples stored in the ECS decreased better in antioxidant capacities compared to those inside RT. Differences on the rate of decrease between the two tomato cultivars could be explained according to findings of Ali et al. (2017) who explained that changes in antioxidants activities in different produce and cultivars depend on fruit type and generic appearance of the produce.

5.6 The correlation of tomatoes parameters to one another

The correlation between tomato parameters for both the cultivars was positive (Tables 5 and 6) with the highest correlation of TPC to TAO ($R^2 = 0.91$) for both cultivars. The lowest correlation observed being LPC to TAO ($R^2 = 0.37$) for '9065' jam tomato and of LPC to TPC ($R^2 = 0.36$) for round tomatoes. However, between all the parameters a good and positive relationship was observed. Total antioxidant activity was positively related to the lycopene content, ascorbic acid and total phenolic content and this may be due to the reason that, these biochemical parameters (lycopene content, phenolic content and ascorbic acid) are considered the main antioxidants (Abushita et al., 2000).

The observed correlation between TPC to TAO was not surprising because mature green tomatoes decrease in the level of phenolic compounds when they are still ripening and antioxidant activities on mature green tomatoes decrease during postharvest as storage advanced (Duma et al., 2003). The low relationship between TAO and LPC is due to the reason of LPC being highly responsible for the development of red colour in tomatoes and for this study, the tomato samples were first investigated at their mature green stages (Tigist et al., 2011). In regards to LPC to AA, the correlation was significant because the observed findings corresponded with findings of Nair and Lilwani (2015) who explained that AA is more on red tomatoes and lycopene is responsible for the red colour.

The other parameters also showed interesting correlation results, with AA to TPC having a high correlation ($R^2 = 0.66$) and LPC to TPC having a low correlation ($R^2 = 0.36$) for both cultivars. During the experiment an inversely proportional relationship was observed for AA, LPC and TPC i.e. as TPC decreased AA and LPC increased.

5.7 The principal component analysis (PCA) based correlation

To further understand the variability of samples, data was subjected the principal component analysis (PCA). PCA was also done to gain a better insight on how clear biochemical properties can relate with each other and how different cultivars and treatments affected measured variables. For round tomatoes, the first principal component (PC-1) contributed 73% and PC-2 contributed 14% of variation and mapping (Figure 1). According to PCA-1, the lowest value was found on

sample fruits stored at room temperature (RT). Illahy et al. (2009) explained that PCA-1 contributes highly to variation, hence the highest percentage compared to PCA-2. Furthermore, samples at RT had larger negatives followed by samples tomatoes stored in an evaporative cooling system (ECS). Evaluating of the correlation loadings showed that the observed mapping of CR samples was influenced to the right hand quadrant by lycopene and ascorbic acid. Sample fruits stored in a cold room (CR) had larger positives according to PCA-1 and larger negatives to PCA-2. Round samples stored in the CR were positively correlated to each other and negatively correlated to sample fruits at ECS and RT. However, RT still had the most negatives which explains that it had samples tomatoes with low lycopene content, antioxidant activities, ascorbic acid and total phenolic content than those stored in an ECS and in a CR. Findings from this study correspond with finding of Vinhna et al. (2013) who explained that produce stored at room temperature have poor qualities compared to those stored in controlled and proper storage facilities.

Prominently, with '9065'jam tomatoes according to PCA-1, the tomato samples with the lowest value were those stored at RT (Figure 2). High value of total phenolic content, lycopene content, ascorbic acid and antioxidant activities were found on samples in a CR which were positively correlated. Samples in the ECS had larger negatives but better values than those at RT. Like with round tomatoes at figure 1, as presented in Figure 2 '9065' jam tomato samples stored in the CR were negatively related to those at ECS and RT but those at ECS still had better biochemical properties than those at RT.

The PCA score of round and '9065 jam tomato samples were well clustered as shown on Figure 3. Both the tomato cultivars had more positives according to PCA-1, which contributed 100% in variation and mapping. Hence they responded to the system quite uniformly. Therefore this means that the samples were positively correlated and statistically similar. The PCA-2 contributed 0% in variation and mapping so it can be concluded that it had much smaller variance. The tomatoes were all harvested at their mature green stages so it is hypothesized that they were growing in a very similar way. These findings support findings of Ali et al. (2017) ho stated that changes in quality of some vegetables can depend highly on generic appearance, growth stages and cultivar.

From the two cluster formed in Figure 4, the highest value was found on the right side of the score plot on Day 1 and samples at day 1 and 2 were positively related in terms of quality. Changes in biochemical quality of the tomato samples were highly affected by storage time. As storage time increase the quality of the tomatoes decreased. Hence, the low value is at Day 5 according to PCA-1. At Day 2 difference on tomatoes were starting to be evident with larger negatives compared to positives. This therefore caused a negative correlation on sample stored in Day 0 with those stored at Day 3 and Day 4.

4.7 Conclusion

In this study, for both cultivars, antioxidants and phenolic compounds decreased whilst ascorbic acid and lycopene content increased. As expected, sample tomatoes stored inside the cold room performed best in terms of maintaining biochemical properties of '9065' jam and round tomatoes. The cold room had the lowest temperatures of 12^{o}C which led to the samples stored in the cold room to remain green throughout the experiment. Temperature changes inside the evaporative cooler and in room temperatures caused both the cultivars to reach a red colour at the end of the experiment. Tomatoes stored in the cold room had the lowest lycopene content and ascorbic acid and the highest antioxidants and phenolic content. Whilst evaporative cooler had the lowest lycopene content and AA and highest phenolic compounds and antioxidants compared to room temperature. Sample fruits stored in the evaporative cooling system were better and ripened slower than those stored at room temperature. Therefore it also appeared that the best method of cooling was the cold room, followed by evaporative cooler and lastly storage at room temperature. Correlation proved a positive relationship among the parameters. According to the principal component analysis the tomato cultivars are similar and the biochemical parameters of the sample tomatoes are statistically the same.

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Table 1: The interaction effect of storage condition and cultivars on the ascorbic acid content of tomatoes during 20 days of storage

		Ascorbic acid (mg 100 g^{-1})				
		Storage periods (days)				
Storage condition	**Cultivar**	**0**	**5**	**10**	**15**	**20**
CR	9065 Jam	0.03^{a}	0.08^{c}	0.11^{d}	0.11^{de}	0.12^{ef}
	Round	0.03^{a}	0.07^{b}	0.09^{c}	0.11^{de}	0.12^{de}
RT	9065 Jam	0.03^{a}	0.15^{hij}	0.16^{jklm}	0.16^{klmn}	0.17^{no}
	Round	0.03^{a}	0.15^{hijk}	0.16^{jklm}	0.17^{lmno}	0.17^{o}
ECS	9065 Jam	0.03^{a}	0.13^{fg}	0.14^{gh}	0.15^{hij}	0.17^{mno}
	Round	0.03^{a}	0.14^{ghi}	0.14^{ghij}	0.15^{ijkl}	0.16^{klmn}
P Value (9065 jam tomatoes)= P < 0.001						
P Value (round tomatoes)= P < 0.001						

Means within a column followed by the same letter (s) are not significantly different according to Duncan's multiple range test. CR, cold room; RT, room temperature and ECS, evaporative cooling system

Table 2: The interaction effect of storage condition and cultivars on the lycopene content of tomatoes during 20 days of storage

Lycopene content (mg 100 g^{-1})						
		Storage periods (days)				
Storage condition	**Cultivar**	**0**	**5**	**10**	**15**	**20**
CR	9065 Jam	3.05^{ab}	4.1^{abc}	5.33^{abcde}	7.4^{cdef}	8.79^{efg}
	Round	2.33^{a}	2.87^{ab}	4.01^{abc}	7.13^{cdef}	14.16^{i}
RT	9065 Jam	3.1^{ab}	7.98^{defg}	11.26^{ghi}	31.91^{k}	52.9^{m}
	Round	2.3^{a}	7.45^{cdef}	12.82^{hi}	21.88^{j}	45.31^{l}
ECS	9065 Jam	3.03^{ab}	5.45^{abcde}	6.56^{bcdef}	19.92^{j}	42.98^{l}
	Round	2.25^{a}	4.97^{abcd}	9.7^{fgh}	14.54^{i}	32.46^{k}

P Value (9065 jam tomatoes)= P < 0.001
P Value (round tomatoes)= P < 0.072

Means within a column followed by the same letter (s) are not significantly different according to Duncan's multiple range test. CR, cold room; RT, room temperature and ECS, evaporative cooling system

Table 3: The interaction effect of storage condition and cultivars on the total phenolic content of tomatoes during 20 days of storage

Total phenolic content (mg 100 g^{-1} GAE)						
		Storage periods (days)				
Storage condition	**Cultivar**	**0**	**5**	**10**	**15**	**20**
CR	9065 Jam	0.34^{l}	0.32^{kl}	0.28^{ijk}	0.21^{defg}	0.19^{cde}
	Round	0.33^{l}	0.31^{jkl}	0.23^{efgh}	0.21^{def}	0.17^{bcd}

RT	9065 Jam	0.32^{kl}	0.2^{de}	0.17^{bcd}	0.15^{abc}	0.13^{ab}
	Round	0.31^{jkl}	0.26^{fghi}	0.23^{efgh}	0.19^{de}	0.12^{a}
ECS	9065 Jam	0.33^{kl}	0.27^{hij}	0.21^{de}	0.15^{abc}	0.12^{ab}
	Round	0.34^{l}	0.26^{ghi}	0.17^{bcd}	0.15^{abc}	0.12^{a}
P Value (9065 jam tomatoes)= P < 0.001						
P Value (round tomatoes)= P < 0.001						

Means within a column followed by the same letter (s) are not significantly different according to Duncan's multiple range test. CR, cold room; RT, room temperature and ECS, evaporative cooling system

Table 4: The interaction effect of storage condition and cultivars on the antioxidant activities of tomatoes during 20 days of storage

Antioxidants (mg/100 g)						
		Storage periods (days)				
Storage condition	**Cultivar**	**0**	**5**	**10**	**15**	**20**
CR	9065 Jam	2.92^{p}	2.76^{o}	2.57^{lmn}	2.39^{hij}	2.03^{d}
	Round	2.65^{mno}	2.55^{lm}	2.38^{ghi}	2.27^{efg}	2.03^{d}
ECS	9065 Jam	2.93^{p}	2.69^{o}	2.49^{jkl}	2.29^{fgh}	1.97^{d}
	Round	2.68^{o}	2.51^{kl}	2.29^{fgh}	2.18^{e}	1.84^{c}
RT	9065 Jam	2.90^{P}	2.57^{lmn}	2.35^{fghi}	1.74^{b}	1.08^{a}
	Round	2.68^{no}	2.43^{ijk}	2.56^{ef}	2.06^{d}	1.05^{a}
P Value (9065 jam tomatoes)= P < 0.001						
P Value (round tomatoes)= P < 0.001						

Means within a column followed by the same letter (s) are not significantly different according to Duncan's multiple range test. CR, cold room; RT, room temperature and ECS, evaporative cooling system

Table 5: The correlations of '9065' jam tomatoes parameters to one another

	TAO	**TPC**	**AA**	**LPC**
TAO	1			
TPC	0.9090	1		
AA	0.7436	0.6655	1	
LPC	0.3677	0.3735	0.7313	1

TAO, total antioxidant capacity; TPC, total phenolic content; AA, ascorbic acid; LPC, lycopene content

Table 6: The correlation of round tomato parameters to one another

	TAO	**TPC**	**AA**	**LPC**
TAO	1			
TPC	0.9136	1		
AA	0.7757	0.6627	1	
LPC	0.4122	0.3561	0.7676	1

TAO, total antioxidant capacity; TPC, total phenolic content; AA, ascorbic acid; LPC, lycopene content

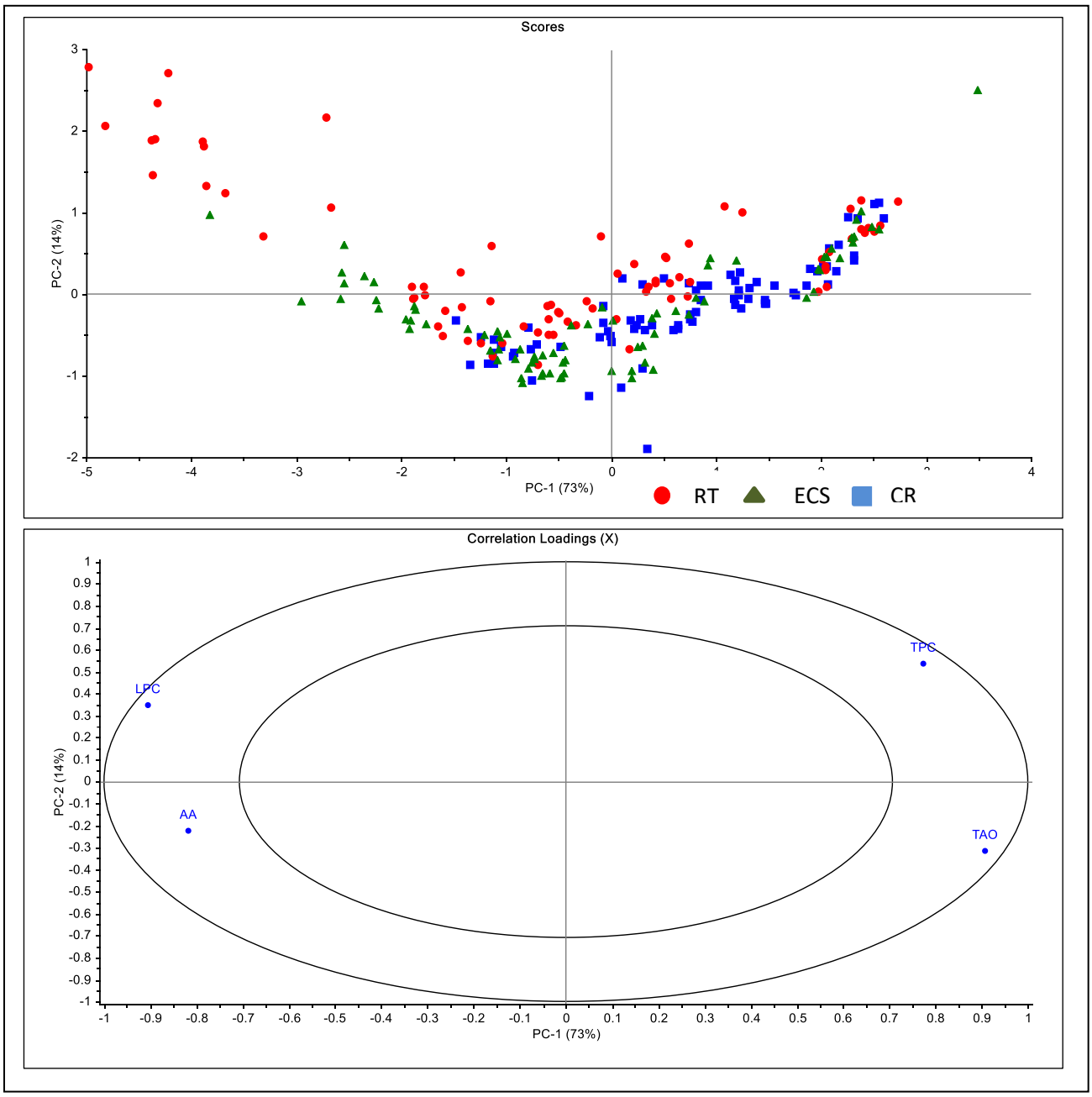

Figure 1: PCA analysis (scores and loadings plot) of biochemical changes occurring in round tomato samples stored in different storage conditions. ECS, Evaporative cooling system; RT, Room temperature and CR, Cold room

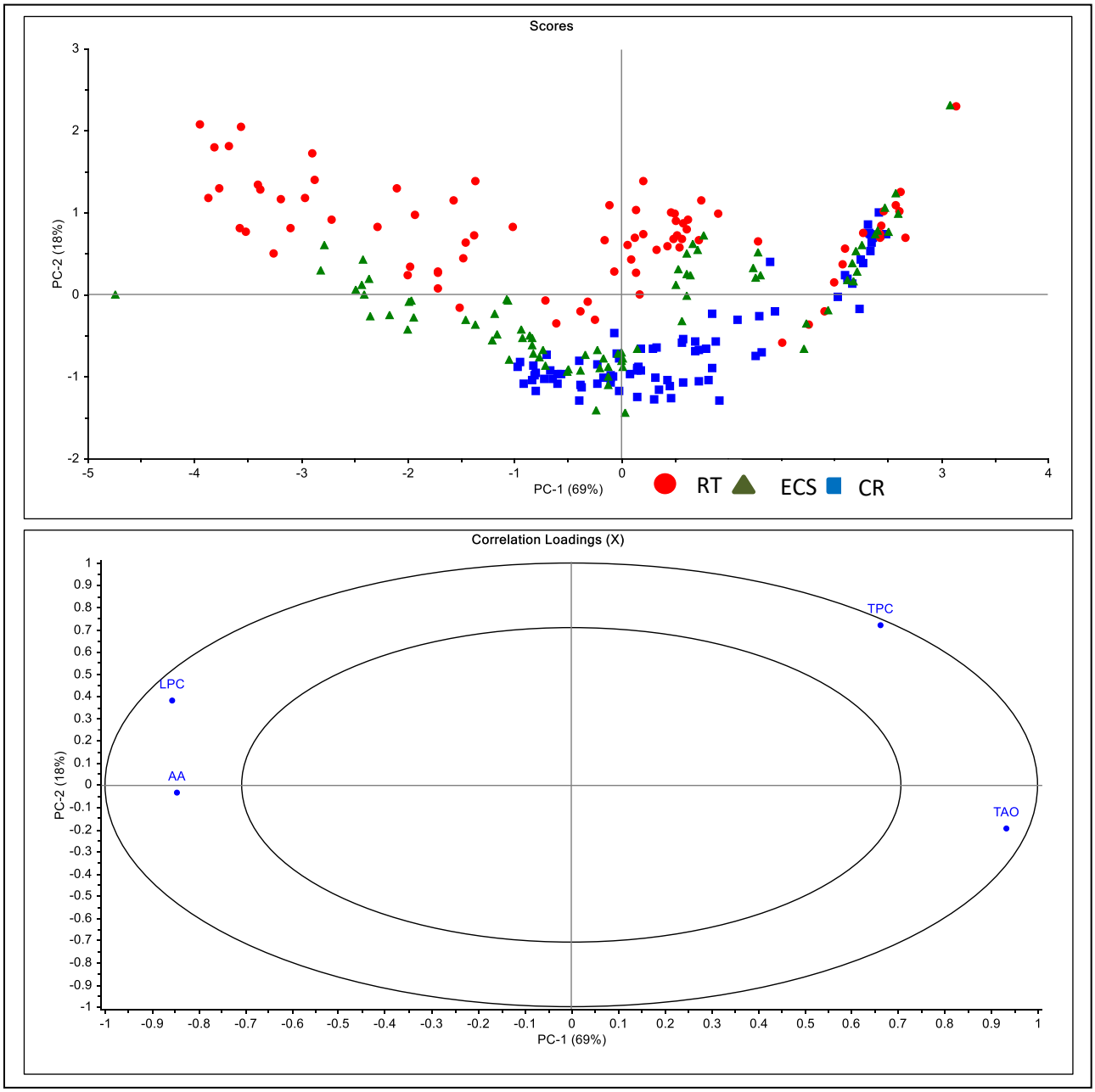

Figure 2: Principal component analysis (scores and loadings plot) of biochemical changes occurring in '9065' jam tomato samples stored in different storage conditions. ECS, Evaporative cooling system; RT, Room temperature; CR, Cold room; AA, ascorbic acid; TPC, total phenolic content; LPC, lycopene content and TAO, total antioxidant activities

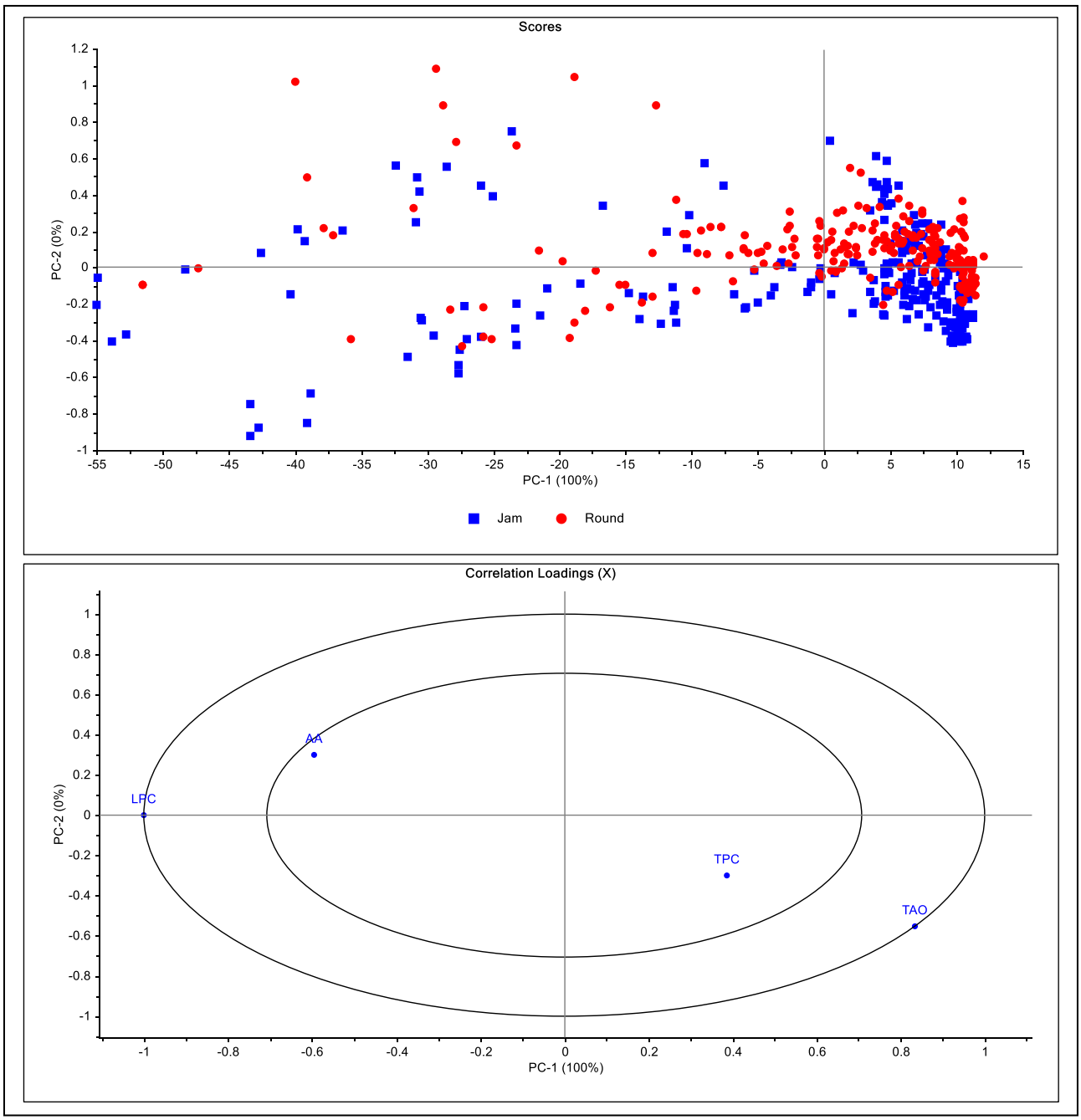

Figure 3: Principle component analysis (scores and loadings plot) of biochemical changes occurring in '9065' jam tomato samples and round tomatoes stored in different storage conditions. ECS, Evaporative cooling system; RT, Room temperature; CR, Cold room; AA, ascorbic acid; TPC, total phenolic content; LPC, lycopene content and TAO, total antioxidant activities

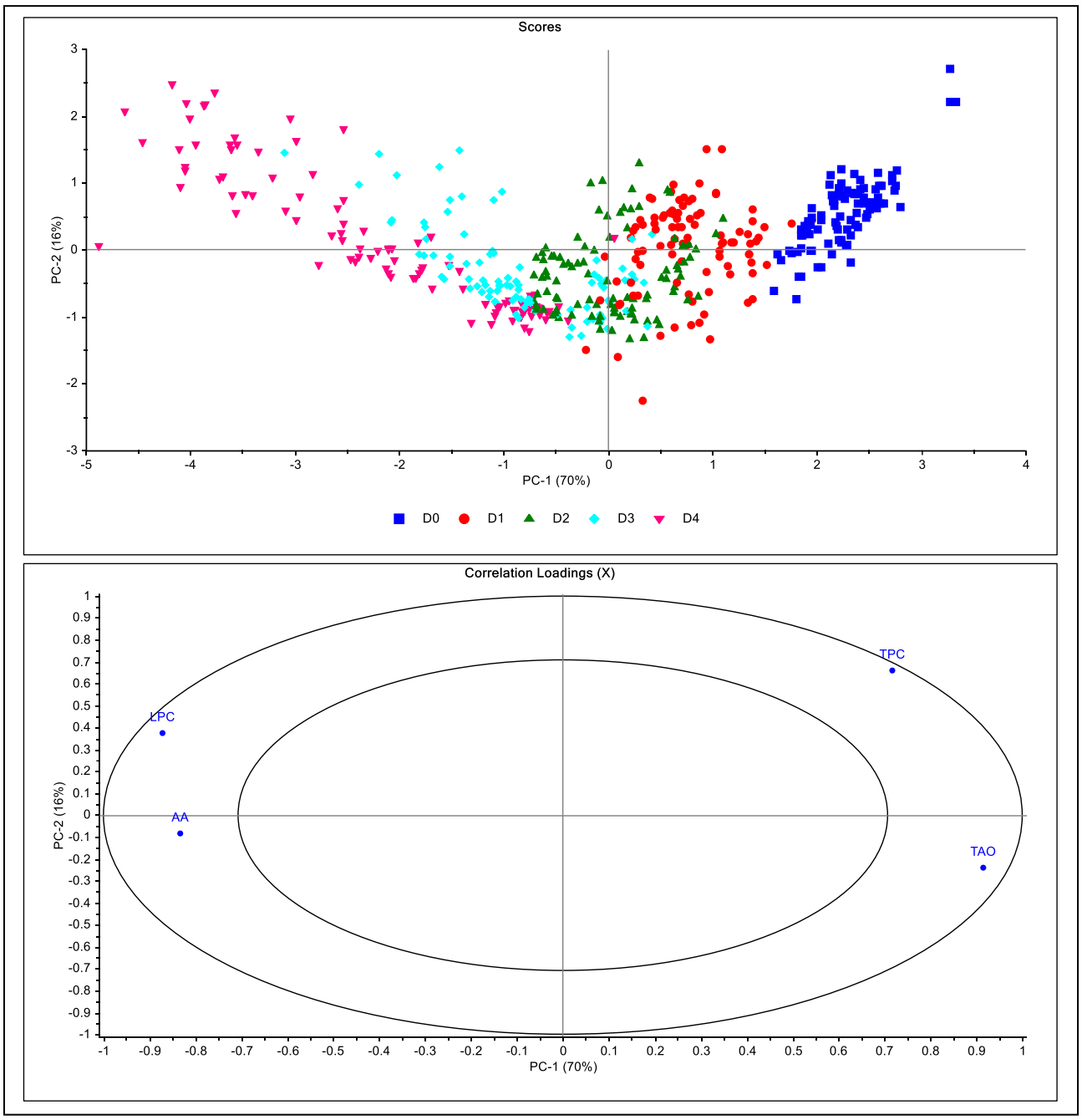

Figure 4: Principle component analysis score plot of biochemical changes occurring in '9065' jam and round tomato on different t storage days samples stored in different storage conditions. ECS, Evaporative cooling system; RT, Room temperature; CR, Cold room; AA, ascorbic acid; TPC, total phenolic content; LPC, lycopene content and TAO, total antioxidant activities

CHAPTER 6

Overall discussion, conclusion and recommendations

6.1 Literature Review

The literature indicated that postharvest losses on horticultural products are caused by a number of factors including improper picking methods used by the farmers when harvesting, postharvest treatment, manipulation of temperature, relative humidity, improper storage facilities and improper packages (Kasso and Bekele 2016). However, most postharvest losses being affected by improper storages used by smallholder farmers (DAFF, 2012). It was also reviewed that there are various postharvest storages farmers can use for their products. These methods include mechanical refrigeration, vacuum cooling, hydro- cooling and evaporative cooling system (Cantwell et al. 2009). Amongst the named storage conditions, the evaporative cooling system is the most accessible to smallholder farmer because of being cost-effective and easily maintained (Abbouda 2012).

6.2 Aim and objectives

A brief highlight on the aim and objectives the study focused on:

The overall aim of this study was to develop and evaluate a low cost evaporative cooling system for postharvest treatment, quality preservation and shelf life extension of horticultural products produced by smallholder farmers at Umsinga in the KwaZulu-Natal province. The specific objectives of the study were:

1. To conduct a need assessment survey to generate information that can be used as a baseline to establish on which horticultural fresh produce are likely to be affected in quality by improper or inadequate postharvest storage facility (Chapter 3).
2. To evaluate the performance of the low cost evaporative cooling system in decreasing temperatures and increasing relative humidity and also in maintaining physiological physical properties of tomatoes (Chapter 4).

3. To evaluate the effect of different storage conditions on biochemical quality of tomatoes (Chapter 5).

6.3 Overview of research findings

- For the first objective, the study observed that farmers at Umsinga lose most of their vegetables to waste. The reason was that the farmers use improper postharvest methods to store their vegetables and because vegetables are highly perishable, they quickly deteriorate. Consequently, this is a drawback to the farmers, hence they indicated that they would be interested in a cost-effective evaporative cooling system. The evaporative cooler will help regulate temperatures, increase relative humidity, maintain postharvest quality of vegetable and increase the shelf life of the vegetables (Vala et al., 2014).

- In the second objective, the evaporative cooling system was able to increase ambient relative humidity and decrease ambient temperatures. Though the evaporative cooler was unable to reduce the temperatures to optimum levels suitable to maintain the quality of tomatoes, it performed better than room temperature which was also one of the storages where the tomato samples were stored. The room is what is culturally used by the farmers to store their produce. Tomato samples ('9065'jam and round) stored inside the evaporative cooler maintained firmness, colour, mass loss, total titratable acid, respiration rate and total soluble solids better than room temperature and had an increased shelf life. The tomato samples were also stored in a cold room which was used as a control and which performed better than the other two methods used to store tomatoes in the study.

- The third objective, proved similar findings as objective 2, that the evaporative cooling system maintained tomato quality better than room temperature and that the cold room was the best for both tomato cultivars. However, objective three focused on the biochemical properties of tomatoes which were lycopene content, antioxidant activities, total phenolic content and ascorbic acid. Moreover, according to the correlation analysis it appeared that both '9065' jam tomatoes and round tomatoes were statistically similar.

6.4 Recommendations

It is recommended that smallholder farmers who do not have any proper storage facilities should be introduced to an evaporative cooling method of cooling in order to help the farmers prevent postharvest losses occurring on their products. In future research, other areas of Umsinga should also be introduced in an evaporative cooling system and the developed evaporative at Umsinga should be reviewed for better performance.

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