DEVELOPMENT OF A WIND AND SOLAR POWERED MOBILE EVAPORATIVE COOLING SYSTEM FOR TEMPORARY STORAGE AND TRANSPORTATION OF FRUIT AND VEGETABLES

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Submitted in partial fulfilment of the requirements for the degree of PhD

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PREFACE

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ABSTRACT

The Limpopo province lies in a semi-arid zone of South Africa and has a sub-tropical climate. Typically of the climate, a lot of fruit like grapes, oranges, lemons, apples, avocados and mangoes and vegetables like potatoes, tomatoes, onions, spinach, carrots and cabbages are grown by both large and small scale farmers. High postharvest losses are experienced by farmers, more so those in small scale production due to physiological deterioration as a result of the environmental factors of temperature and relative humidity. This is because low-cost, adequate cooling technologies are unavailable to the average small scale farmer. The cooling technologies that are available are capital intensive and require grid electricity which is not always available as farms are generally located in remote areas. However there is scope for evaporative cooling which is viewed as simple and cheaper especially if it is coupled with a renewable energy powered source to drive it. This proposal therefore seeks to design, construct and investigate the performance of a mobile cool container to preserve fruit and vegetables. The proposed mobile cool container will be powered by renewable sources of wind and solar energy.

The expected result will be improved understanding of renewable energy powered evaporating cooling, improved knowledge on the psychometrics of evaporating cooling, improved knowledge in the air dynamics/flow inside the cooling container. The results will also provide an understanding of an integrating pre-packaging and proper packaging to be used in tandem with the mobile cool container. As a result of the use of the mobile cool container the shelf life of fruit and vegetables will be increased, thus minimising postharvest losses. This will translate in sustainable fruit and vegetables production that will enable small scale farmers and emerging farmers to enter the export market.
<table>
<thead>
<tr>
<th>ACRONYMS</th>
<th>Description</th>
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<tbody>
<tr>
<td>DAFF</td>
<td>Department of Agriculture Forestry and Fisheries</td>
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<tr>
<td>FAO</td>
<td>Food and Agriculture Organisation</td>
</tr>
<tr>
<td>LSCF</td>
<td>Large Scale Commercial Farmers/Farming</td>
</tr>
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<td>NAMC</td>
<td>National Agricultural Marketing Council</td>
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<tr>
<td>NDP</td>
<td>National Development Plan</td>
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<td>RSA</td>
<td>Republic of South Africa</td>
</tr>
<tr>
<td>SAYB</td>
<td>South African Year Book</td>
</tr>
<tr>
<td>SCF</td>
<td>Small Scale Farmers/Farming</td>
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<td>SSA</td>
<td>Sub Saharan Africa</td>
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1. INTRODUCTION

Agriculture is the mainstay of many Sub-Saharan African (SSA) economies (World Bank, 2007), for instance, about 20% of the Republic of South Africa (RSA) population of over 50 million is either directly or indirectly dependent on agriculture for employment and livelihood. Commercial agriculture in RSA contributes about 3% of gross domestic product and about 7% to formal employment (SAYB, 2011). The crops that are grown in tropical and sub-tropical climates of SSA include field and horticultural crops, fruit and vegetables. The Limpopo and Mpumalanga provinces of South Africa exhibit tropical to sub-tropical conditions and typically a lot of fruit like grapes, oranges, lemons, apples, avocados and mangoes and vegetables like potatoes, tomatoes, onions and cabbages are grown by both large and small scale farmers (Ntombela, 2012).

Attention in the past has been paid to production of cereal crops in SSA for food security and the reduction of postharvest losses affecting these crops as reported by World Bank (2011), at the expense of fresh produce. Prusky (2011) alludes to this and says FAO in 1977 approved the establishment of a Special Action Program for the prevention of food losses with an initial focus on staple food grains and only many years later expanded the programme to include perishable food commodities. Many governments have now incorporated strategies of reducing postharvest losses in fresh produce. The government of South Africa has prioritised agro-processing research with a special focus on reducing postharvest losses experienced by small scale farmers (NDP, 2011; DAFF, 2012).

With the current shift in consumer demand to fruit and vegetables in urban areas, focus in many African countries has moved to the production of fresh produce (Workneh, 2007; Altman et al., 2009). This is more so as small scale farmers (SCF) in African countries obtain higher returns from fresh produce than with other crops (Seorojo et al., 1991). In RSA, fruit and vegetables export prices increased by 42, 3% and 6, 8%, respectively, in 2008 from the previous year (SAYB, 2010). Statistics in RSA indicate that fresh produce like tomatoes; onions and cabbages have the highest quantity of yield (Shabalala and Mosima, 2002). Research on postharvest and biology and technological interventions in the production of fresh produce in Africa are now a research priority (Kitinoja et al., 2011).
In the production of fresh produce in tropical and sub-tropical areas, right up to marketing, the biggest challenge is the maintenance of optimum conditions during storage and transportation to markets (Samira, et al. 2011). Fruit and vegetables have high moisture content which makes them liable to spoilage thereby reducing their shelf life (Workneh, 2007). As living entities, some fresh produce continues to transpire, respire and further ripen after harvest (Ngcobo et al., 2012). This metabolism and senescence according to Workneh (2010) is exacerbated by unfavourable environmental factors. Therefore, product preservation after harvest is paramount so as to reduce postharvest losses which are estimated at a world average of over 30% (Chandra et al., 1999; Kitinoja et al., 2011) and in RSA producers of apples estimate losses as high 30-50% (Wand et al., 2006).

1.1 Introduction to Postharvest Factors and Cooling Technologies

The most important factors affecting the postharvest life and quality of horticultural produce are temperature (Brosnan and Sun, 2001; Ravindra and Goswani, 2008; Pathare et al., 2012) and relative humidity (Thompson et al., 1998; Awole et al., 2011). Produce quality loss after harvest occurs as a result of physiological and biological processes, the rates of which are influenced primarily by product temperature at harvesting and relative humidity surrounding the produce (Kader, 1987; Tadesse, 1991; Pathare et al., 2012). Fresh produce needs low temperature and high relative humidity during storage and transportation (Wills et al., 1989; Workneh and Woldetsadik 2001). As the maintenance of market quality is key to the success of the horticultural industry, it is therefore, not only necessary to cool the product down but to do so as quickly as possible after harvest (Paull, 1999; de Castro et al., 2006). de Castro et al. (2006) and Rudnick and Nowak (1990) propose that when harvesting produce at high temperatures or at an advanced stage of maturity, immediate cooling is necessary to minimise quality losses. The examples of fresh produce that requires immediate cooling after harvest in order to maintain quality include snap beans, leafy vegetables, broccoli and most cut flowers (Brosnan and Sun, 2001).

Outside biological and chemical changes that affect produce, fruit and vegetables also suffer from mechanical damage as they are kept at the farm gate for long periods of time awaiting delivery (Wilson et al., 1999; Kader 2003 & 2010; Singh et al., 2010). The longer fruit and vegetables are kept at the farm gate, after harvest, the more they suffer from deteriorative physiological changes and mechanical damage as a result of miss-handling
during harvesting, grading, transportation and marketing including subjecting produce to abused temperature and relative humidity (Knee and Miller, 2002; Mandal et al., 2010; Rayaguru et al., 2010; Gustavsson et al., 2011). Other factors known to lead to severe mechanical damage are packaging (Kebede, 1991; Haidar and Demissie, 1999) and container technology (Wolde, 1991). These factors, if combined with relatively high temperature, in turn lead to produce physiological and microbiological deterioration of commodities (Johnson et al., 1997; Pinto et al., 2004; Van Zeebroeck et al., 2007).

In general, temperature and relative humidity surrounding produce are the most important factors responsible for the degree of occurrence of deterioration due to physiological and microbiological changes. Thus, appropriate methods of harvesting, handling and air cooling with humidification can be employed (Wills et al., 1998). Farmers can also be trained when and how to harvest fresh produce in order to significantly minimise mechanical damage (Wilson et al., 1999). Once this is done, as per the above-mentioned analysis, the other challenge is the physiological deterioration resulting from inappropriate conditions of temporary storage or transportation systems (Workneh, 2007). Since temperature and relative humidity are key environmental factors in maintaining fruit quality (Jain D, 2007; Nunes et al., 2009; Paul et al., 2010) their regulation, through controlled thermal environmental management (Chopra et al., 2003) during temporary storage and transportation will provide optimal conditions for fresh produce (Zude, 2009).

Non-optimal conditions during temporary storage and transportation systems are associated with the lack of availability of mobile containers that can control temperature and relative humidity (Jain D, 2007). Postharvest losses related to temperature and relative humidity surrounding the produce can be solved by the development of sustainable and appropriate postharvest fruit and vegetables handling technologies (Azene et al., 2011), that will provide a controlled environment for storage of fresh produce immediately after harvest (Chopra et al., 2003). According to Workneh and Woldetsadik (2001), there is a need for appropriate methods for small scale farmers (SCF) or emerging farmers to reduce postharvest losses during storage and transportation, even if it is for short periods of time as the produce can reach better priced markets. Research in controlled environment management will ensure that fresh produce is kept at relatively suitable conditions of temperature and relative humidity (Wills et al., 1989) at all times in the cold chain.
Cooling as a cold chain management technology is used to control the fresh produce environment under required conditions (Ngcobo et al., 2012).

Cooling technologies such as forced air cooling, evaporative cooling, hydro-cooling and vacuum cooling can be utilised to control the temperature of the surrounding air and produce (Thompson et al., 1998). Mechanical refrigeration, and other sophisticated techniques are used in developed countries in order to extend shelf life (Tefera et al., 2007). However, the capital cost involved in development of mechanical refrigeration or controlled atmosphere is a serious constraint for small scale farmers in developing countries (Samira et al., 2011). According to Baloyi (2010), small scale farmers in RSA have failed to access different cooling technologies largely because of their steep price.

These cooling methods, except for evaporative cooling, require high initial capital investment and power sources and therefore, may be unaffordable for SCF or emerging commercial farmers in countries like RSA (Jain D, 2007). Some SCF or emerging commercial farmers are found in rural areas, some of which are not connected to the electricity grid (Kim and Ferreira, 2008). This, therefore, makes it difficult to install and operate mechanical cooling technologies since they are energy intensive (Tefera et al., 2007). This is evidenced by commercial production of fruit and vegetables in RSA which is mainly done by large scale commercial farmers (LSCF) (SAYB, 2011).

LSCF in RSA own an average of 42 ha/farmer (compared to 1.5 ha/farmer for SCF) of irrigated land (Backeberg, 2006) and have the financial capability and necessary power source infrastructure to invest in mechanical cooling systems. Since mechanical cooling is available for large scale production of fresh produce (Tigist et al., 2011), emphasis then should be directed towards sustainable and appropriate cooling methods for SCF (Workneh and Woldetsadik, 2001). This is critical, bearing in mind that countries like the RSA are “water scarce” and 90% of fruit and vegetables are produced under irrigation which is a significant input cost even under flood irrigation (Prusky, 2011; SAYB, 2011). This reason shows that postharvest losses of whatever sort are not affordable. Therefore, it has to be ensured that all fresh produce is preserved after harvest and sold in a marketable state that will fetch prices that will offset the input cost of irrigation (Quick, 1998; Prusky, 2011).
SCF in RSA are small farm-land owners (Machete and Mollel, 2000), plot holders in an irrigation scheme or fully independent irrigation farmers (Du Plessis et al., 2002), owning no more than 1.5 ha of land (Backeberg, 2006; Denison and Manona, 2007). Therefore, farming for SCF occurs on holdings that are small, both in terms of size and output (Makeham and Malcolm, 1986) that does not justify ownership of capital intensive cooling methods. SCF by their nature are known to sell their produce to the local market soon after harvest as they do not have proper storage facilities (Rayaguru et al., 2010). This then forces them to off-load their produce at distressed prices (Verna and Josh, 2000). While there is evidence of growing of fruit and vegetables by SCF in all provinces of RSA (SAYB, 2011), Limpopo and Mpumalanga show the biggest potential in the production of fresh produce (Baloyi, 2010). Mashau et al (2012) claims that Limpopo province produces 31% of the countries sub-tropical fruit. Information on postharvest losses in South Africa is limited though Mashau et al (2012) estimates the losses as above 50 % in Limpopo province due to lack of appropriate technologies. Though cooling methods are expensive it is still necessary to provide appropriate cooling method that will control temperature and relative humidity during storage and transportation as they are the major drivers of produce deterioration after harvest (Workneh, 2010).

In the selection of cooling technologies appropriate for SCF there is a need to be cognisant of their high initial capital cost and high energy demand (Basediya et al., 2011). Studies by Kim and Ferreira (2008) revealed that conventional electric-powered mechanical cooling systems could not be of much use in rural areas and, therefore, advocated for alternative low-cost cooling systems. Low investment and less energy input cooling technologies like evaporative cooling, with a potential energy saving of ~75% compared to mechanical refrigeration (Datta et al., 1987), are therefore encouraged (Jain D, 2007). Should there be need for powering evaporative cooling to increase its efficacy, then cheaper options of either solar or wind energy can be considered. Evaporative cooling is very efficient under hot and dry conditions of arid or semi-arid regions like RSA, where the problem of postharvest losses of fruit and vegetables is attributed to inadequate pre-cooling (Samira et al., 2011). For SCF to be encouraged to venture in horticultural production, cooling technologies should not only be low cost (Workneh and Woldetsadik, 2004; Workneh 2007) but also use appropriate local construction material (Workneh and Woldetsadik, 2001). This then implies that there exists an opportunity to develop and determine the
performance of an evaporative cooling system that uses alternative sources of power like renewable energy. This area of study considering evaporative cooling (Basediya et al., 2011), will find an affordable way (by SCF) of reducing temperature while increasing relative humidity to ensure that optimal conditions are maintained inside the mobile containers during temporary storage and transportation (Wills et al., 1989; Thompson et al., 1998).

Evaporative cooling is a physical phenomenon where evaporation of a liquid, into surrounding air, cools an object or a liquid with which it is in contact (Kitinoja and Thompson, 2010; Workneh, 2010). Evaporation of water produces a considerable cooling effect and the faster the evaporation the greater is the cooling (Basediya et al., 2011). Evaporative cooling is useful for short term storage of fruit and vegetables. It is efficient and economical for temperature reduction and increasing relative humidity (Jha and Chopra, 2006), is a tried and tested method (Odesela and Onyebuchi, 2009), is environmental friendly (Camargo, 2007) and does not require special skills to operate (Basediya et al., 2011). Therefore evaporative cooling could be seen as a means to address postharvest losses in fresh produce suffered by farmers in SSA if cheaper energy sources to power the cooling system, using local available material can be found.

Since evaporative cooling is seen as a cheap and convenient key measure to decrease the deterioration of fresh produce, its integration with alternative sources of energy other than grid electricity would be critical in reducing energy consumption during the cooling process. Possible options are the clean energy sources of wind and solar energy that do not raise concerns about global warming or significant carbon emissions (James and James, 2011). From the literature available there is no evidence of background work in SSA of application of renewable energy as a power source for evaporative cooling. Literature also does not provide information that wind and solar energy have been combined to power forced air evaporative cooling for fresh produce. More so a mobile cool container that can store fresh produce in suitable conditions during prolonged periods of harvesting and transportation from the farms to the market is not currently in existence for use by small scale farmers in RSA. The envisaged mobile cool container should be made from local material, addressing small scale farmers’ needs in SSA which is affordable. The development of the mobile cool container will address the requirements of the Industrial
Policy action Plan – IPAP2 which seeks to support agro-processing and the promotion of sub-tropical fruit for export purposes in South Africa (Ntombela, 2012) amongst other things.

1.2 Concluding Statement for the Introduction

Fruit and vegetables production in RSA are in the sub-tropical regions (SAYB 2011) where the air is dry and warm and fresh produce has high moisture content (James, 1985). The publications SAYB (2010) and SAYB (2011) show that there is a considerable amount of fresh produce in production that is contributing to the RSA’s economy. There is therefore, a need to ensure a significant percentage of this reaches both the domestic and international market in a palatable state. This can only be ensured if optimum storage conditions of temperature and relative humidity are maintained. For this reason, an opportunity may exist for further research towards more even and uniform chilled air delivery within storage containers. Therefore more work needs to be conducted to develop technologies that will maintain optimal storage conditions inside mobile storage containers. Research into appropriate cold chain technologies for SCF is a challenge which requires cooperation from all players in the chain, in particular the container manufacturers to make the technology viable. Mechanical refrigeration already exists but is expensive and has high energy demands and hence the need to develop technologies that have low energy requirements (Thompson and Kasmire, 1981).

It is therefore necessary to develop and test a simple low energy input powered by wind and/or solar energy, appropriate, in-expensive cooling method like evaporative cooling to attain optimum storage conditions for fruit and vegetables. The design specifications of the energy source of evaporative cooling system will introduce a fan and pump as additional components to increase efficacy of the cooling system. Introduction of the fan will require determining the fan size in relation to ventilation rate, temperature range and relative humidity range. The introduction of the water pump will require determining the pump size in relation to water removed per hour, how much water will evaporate due to air removal is still information that still needs to be investigated. Therefore, the objective of this study is to develop an appropriate mobile cool container for SCF for temporary storage and transportation of fruit and vegetables.
2. LITERATURE REVIEW

Horticultural Industry in Africa

With current shifts in consumer demand, there is an exponential demand for fresh fruit and vegetables in Africa (Garcia and Barret, 2004; Workneh, 2007; Ntombela, 2012). In 2009, horticulture contributed R31.7 billion to the South African economy, with prices of vegetables rising by 19.3% from the previous year (SAYB, 2011). The sub-sector is characterized by varying diversity in farm sizes ranging from large-scale producers with substantial investments in irrigation, agricultural inputs, and skilled management to small-scale farmers that are usually under 0.5 ha. Fruits and vegetables contributed US$ 120 million to GDP in Tanzania (TAHA, 2010), while exports in horticulture in Zambia in 2004 were US$36m (Nakaponda, 2006). Mozambique fruits exports to South Africa are worth US$20m annually (Cugala et al., 2009). The gross export earnings in deciduous fruits in 2002 in South Africa were estimated at R8.1 billion (NAMC, 2007).

Experiences in Africa have shown that the production of fruit and vegetables improves farmers’ living conditions i.e. health and income (Bourne, 1977; Workneh, 2007 & 2010). This has seen a number of SADC countries increasing their production of fruit that include mangoes, bananas, citrus, avocado, papaya, pineapple, passion fruit, grapefruit, grape, apple, pear, jack fruit, guava, strawberry and peach. Vegetables include tomatoes, cabbages, onions, sweet pepper, French beans, pea, lentil, leek, chillies, okra, garlic, ginger, carrot, turnip, mushroom, asparagus, cucurbits, lettuce, spinach and other local leafy vegetables (Ngowi et al., 2007). Fruit and vegetables are traded and consumed fresh while others are used in the processing factories, primarily producing fruit juices and fruit juice concentrates.

2.1 Postharvest Losses

Fruit and vegetables require proper postharvest management to maintain quality and reduce losses. The susceptibility of perishable commodities during storage and distribution is the main cause of postharvest losses in the tropical and sub-tropical regions of Africa (Ngcobo et al., 2012). Workneh (2007) and Azene et al. (2011) claim that postharvest losses could discourage farmers from venturing into production and marketing of fresh produce and thus affecting the supply side of consumption of fruit and vegetables in urban
areas. Therefore, reduction of postharvest losses, particularly if it can economically be avoided, would be of great significance to farmers and consumers alike (Johnson and Sangchote, 1994).

Fruit and vegetables are highly perishable (Adeoye et al., 2009) and if not properly handled at their optimum conditions after harvesting or during packaging or transportation, they easily deteriorate and become unacceptable for consumption (Kebede, 1991; Verna and Joshi, 2000). For example, according to Kitinoja et al. (2010) postharvest losses the world over are estimated at an average of 30-40% in fruit and vegetables before they reach the final consumer. The world average postharvest losses general for fresh produce are estimated at 30% (Chandra et al., 1999; Coulomb, 2008). Basediya et al. (2011), reported postharvest losses of fruit and vegetables in India ranging from 30 to 35%. Postharvest losses in African countries, are hard to estimate (Adeoye et al., 2009) though some authorities estimate losses in fruit and vegetables to be 50% (Kader, 2005; FAO, 2008; Kader 2010) or half of what is grown (Lundqvist et al., 2008). Examples of postharvest losses of perishable commodities in African countries are in East Africa, Ethiopia 50% (FAO, 2005), in Central Africa, Rwanda and in West Africa, Ghana losses range from 30% to 80% depending on produce (Kitinoja et al., 2010), and in Southern Africa, Swaziland, losses range 20-50% depending on commodity (Masarirambi et al., 2010) and over 50% in Limpopo province of South Africa (Mashau et al, 2012). Small scale farming exporters of fruit and vegetables in SSA have complained about these huge losses that they experience during short periods of storage before and during transportation (Workneh and Woldetsadik, 2004) and alleviation of these should be a research priority.

2.2 Causes of Postharvest Losses

Postharvest losses occur as a result of many factors that include, environmental (Mandal et al., 2010; Rayaguru et al., 2010; Workneh, 2010), biological and chemical (Baker, 1975) and as well as technical factors (Nakasone and Paull, 1999; Kader, 2010). Fruit and vegetables are also affected by environmental factors (Getinet et al., 2008; Workneh and Osthoff, 2010; Prusky, 2011; Pathare et al., 2012) of temperature, relative humidity and gas composition (Jain, 2007). Most fruit and vegetables have moisture contents higher than 80% (Sagar and Kumar, 2010) and experience high respiration rate (Workneh, 2007; Caleb et al., 2011). Also their texture is fragile and does not withstand impact and harsh
environmental conditions. Technical factors that result in postharvest losses include mechanical/physical damage due to improper handling (Adeoye et al., 2009; Vigneault et al., 2009; Basediya et al., 2011) or lack of skill in the use of appropriate technology designed for keeping optimum conditions of perishable commodities. Physiological and biological processes cause evaporation of water from produce, resulting in chemical and physical changes of fruit and vegetables (Brosnan and Sun, 2001; Pathare et al., 2012).

2.3 Technical Factors
The technical factors that affect produce quality are mainly associated with occurrence of mechanical damage or injury to fruit and vegetables (Williamson, 1963; Prusky, 2011), lack of skilled manpower in technical aspects of how to handle fresh commodities (Beckles, 2012) and long storage time (Wilson et al., 1999). Fresh produce’ response to mechanical stress depends on time (Wang and Chang, 1970) referred to here as “long storage time” and the longer the period the higher the mechanical stress.

2.4 Mechanical Damage
According to Van Zeebroeck et al. (2007), mechanical damage causes a serious challenge to the quality of fresh produce and has a potential to significantly reduce the value of fruit and vegetables. Mechanical damage to fruit and vegetables is usually caused by a number of factors that include:-

- Poor harvesting practices (Kader, 1986),
- Careless handling, such as produce being dropped, thrown or stamped upon during grading, transportation and marketing (Tijskens, 2007),
- Inappropriate packaging or containers with splintered wood, sharp edges, poor nailing that would puncture or injure produce (Miller, 1992) and Over/under packaging of containers (Wilson et al., 1999).

The injury of produce as a result of these factors from harvesting, through transportation to storage is cumulative (Miller, 2003). These factors can lead to tissue softening, pigmentation loss and discoloration of produce (Williamson, 1963; Prusky, 2011). Failure to limit these causes would significantly contribute to postharvest losses (Adeoye et al., 2009). According to Basediya et al. (2011), mechanical injury due to impact when produce is dropped can result in splitting of fruit and internal bruising (not visible
externally). Impact damage is detrimental and its effect is not just limited to visual aspects but also causes a risk of fungal and bacterial contamination which may lead to a shorter shelf life (Tefera et al., 2007; Tijskens, 2007). Similarly, mechanical damage occurs when temperature and relative humidity are not regulated in mobile containers (Workneh, 2007) and there is limited cold air circulation. This usually causes tissue wounds, abrasion and breakage of fruit or vegetables (Tefera et al., 2007; Kader 2010).

There is also injury to fresh produce that is caused by extremes of temperature i.e. both excessively high or low (Vigneault et al., 2009). Different fruit and vegetables have varying tolerance limits to extremes of temperature and this is more so when considering cool storage (Kader, 1986; Prusky, 2011). Table 2.1 shows the effect of chilling injury and symptoms that affect fresh produce when it is stored below their recommended optimum temperatures.

Table 2.1 Observed effects of chilling injury and their symptoms

<table>
<thead>
<tr>
<th>Effect of chilling injury</th>
<th>Symptom</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discoloration</td>
<td>Internal or external or both, usually brown or black</td>
<td>FAO, 1989; Prusky, 2011</td>
</tr>
<tr>
<td>Skin piking</td>
<td>Sunken spots, especially under dry conditions</td>
<td>Salveit and Morris 1990</td>
</tr>
<tr>
<td>Abnormal ripening (fruits)</td>
<td>Ripening is uneven or fails; off-flavours</td>
<td>FAO, 1989; Prusky, 2011</td>
</tr>
<tr>
<td>Increase in decay</td>
<td>Activity of micro-organisms</td>
<td>Salveit and Morris, 1990</td>
</tr>
</tbody>
</table>

Despite the variations in tolerance limits, for all fresh produce there is a temperature below which injury occurs (Macleod et al., 1976) which is referred to as the lowest safe temperature (LST). But it has to be noted that within a single commodity type, the LST may vary between varieties (Table 2.2). Fruit is generally less sensitive when ripe. Table 2.2 shows the minimum safe temperature (°C) and chilling symptoms under extreme temperatures for various commodities.

Solar radiation exposes fresh produce to high temperatures when fruit and vegetables are left for prolonged periods in the sun. As a result the flesh temperature of the produce may reach temperatures as high as 50°C that will cause it to deteriorate rapidly (Macleod et al., 1976). These extreme high temperatures cause high respiration rate and if the produce is in transit without adequate ventilation, it will result in spoilage (Talukder et al., 2003; Tanner and Smale, 2005). Severe water loss is experienced from thin-skinned root crops such as
carrots and turnips and from leafy vegetables when exposed to the tropical sun for long period of time (Wilson et al., 1999). This is one serious challenge faced by farmers in SSA who leave their produce on the roadside or farm gate for prolonged periods before they can be picked by trucks to markets (Kitinoja et al., 2011).

Table 2.2 Susceptibility of fruit and vegetables to chilling injury at low but non-freezing temperatures

<table>
<thead>
<tr>
<th>Commodity</th>
<th>minimum safe temp. °C</th>
<th>Chilling injury symptoms</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avocados</td>
<td>5-13</td>
<td>Grey discoloration of flesh</td>
<td>Campbell et al., 1960; Florissen et al., 1996</td>
</tr>
<tr>
<td>Bananas (green/ripe)</td>
<td>12-14</td>
<td>Dull, grey-brown skin colour</td>
<td>Murata, 1969</td>
</tr>
<tr>
<td>Beans (green)</td>
<td>7</td>
<td>Pitting, russetting</td>
<td>Watada and Morris, 1956</td>
</tr>
<tr>
<td>Cucumbers</td>
<td>7</td>
<td>Pitting water-soaked spots, decay</td>
<td>Lutz and Hardenburg (1966)</td>
</tr>
<tr>
<td>Grapefruit</td>
<td>10</td>
<td>Brown scald, piking, watery breakdown</td>
<td>Lutz and Hardenburg (1966)</td>
</tr>
<tr>
<td>Mangoes</td>
<td>10-13</td>
<td>Grey skin scald, uneven ripening</td>
<td>Lyons, 1973</td>
</tr>
<tr>
<td>Oranges</td>
<td>7</td>
<td>Pitting brown stain, watery breakdown</td>
<td>Eaks, 1960</td>
</tr>
<tr>
<td>Papaya</td>
<td>7</td>
<td>Pitting failure to ripen, off-flavour, decay</td>
<td>FAO, 1989</td>
</tr>
<tr>
<td>Potatoes</td>
<td>4</td>
<td>Internal discoloration, sweetening</td>
<td>Lutz and Hardenburg (1966),</td>
</tr>
<tr>
<td>Pumpkins</td>
<td>10</td>
<td>Decay</td>
<td>FAO, 1989</td>
</tr>
<tr>
<td>Sweet potato</td>
<td>13</td>
<td>Internal discoloration, piking, decay</td>
<td>Lyons, 1973</td>
</tr>
<tr>
<td>Tomatoes: Mature green</td>
<td>13</td>
<td>Water-soaked softening, decay</td>
<td>Salveit 1991</td>
</tr>
</tbody>
</table>

Mechanical damage as a result of the factors that have been identified and discussed previously increases moisture loss (Prusky, 2011) from the produce. The rate of moisture loss may be increased by four fold as a result of a single bad bruise on an apple, and skinned potatoes may lose 300 to 400 percent as much weight as non-skinned potatoes (Wilson et al., 1999). Injuries resulting from mechanical damage such as bruising, surface abrasions and cuts can also accelerate the loss of vitamin C in fruit and vegetables (Lee and Kader, 2000). Therefore, fruit and vegetables targeted for storage should be exempt of any skin abrasions, bruises, spots, rots, decay or any mechanical damage (Quintana and Paull,
To ensure that mechanical damage is isolated or at least minimized appropriate methods of harvesting, handling and air-cooling with humidification should be applied (Wills et al., 1998).

2.4.1 Lack of skilled manpower

The labour should be skilled to know when to harvest the produce, as it is an essential requirement of industrial postharvest handling, for example tomatoes are to be picked at the mature green to breaker stage (Beckles, 2012) to mitigate some of the losses. In determining the best time to harvest produce, the farmers also will need to take into cognisance that harvesting time will vary with, cultivar, how produce will be consumed, distance and time to market (Watkins, 2006; Toivonen, 2007). According to Botondi et al. (2003) produce should be harvested during the coolest part of the day, either very early in the morning or late afternoon. For some fresh produce care should be taken in ensuring that it is not wet from any agents of weather like dew or rain as it will overheat if not well ventilated (FAO, 1989) resulting in decay. Some fruit and vegetables are subject to damage when wet, e.g. oil spotting and rind breakdown in some citrus fruits has been observed.

To develop labour skills harvesters should be trained on how to handle the crop carefully; harvesting dry whenever possible and at proper maturity; handling each produce no more than is necessary while at the same time avoiding over- or under-packing of containers (Kitinoja et al., 2010; Wilson et al., 1999).

2.4.2 Long storage time

Among the factors that contribute to produce deterioration that lead to high postharvest losses is the fact that fruit and vegetables are kept for long periods at the farm gate awaiting transportation to markets resulting in further mechanical damage or physiological deterioration (Kader, 2003). When the duration of stay of produce at the farm gate is prolonged, the resultant mechanical damage due to over handling during and after harvest, causes main cell wall degradation which will allow easy penetration of microbial population into the tissue (Knee and Miller, 2002). This increases chances of decay and growth of micro-organisms (Williamson, 1963). As fresh produce awaits transportation it is often packed and thus, applying a static load on itself. This normally causes deformation to the produce and the degree of deformation depends on the time period the static load is applied (Quintan and Paull, 1993). The longer the period the greater the deformation and
stress effected on the produce (Wang and Chang, 1970). The stress effected on the produce will of course also depend on the ripeness of produce, as it ripens the same static load will inflict more internal flesh damage. To eliminate this challenge will require that the duration between harvest and arrival at the markets be minimized.

2.5 Biological Factors
Fresh produce are living respiring tissues even after they have been detached from the mother plant during harvesting (Brosnan and Sun, 2001) they continue to transpire, respire and further ripen (Kader, 1987; Ngcobo et al., 2012). These metabolism processes cause loss of moisture from produce which is not replaced and this can lead to senescence or total death (Booth, 1974). The physiological deterioration due to respiration, transpiration and biosynthesis is affected by environmental factors of temperature, relative humidity and gas composition, which factors can result in a significant loss of nutritional value and in many cases the whole fruit or vegetable is lost (FAO, 2003; Joas and Lechaudel, 2008).

Chemical and enzymatic changes also occur in fresh produce causing tissue softening, pigmentation loss, off colouring and off-flavour development resulting in postharvest losses (Brosnan and Sun, 2001). In general, physiological, chemical and enzymatic changes are speeded when fresh produce is subjected to ambient temperature during storage and transportation. Despite this knowledge by many small scale farmers in the developing countries fruit and vegetables are transported to local market places without controlling the surrounding temperature and relative humidity (Nunes, 2008).

Maintaining low temperature and high humidity around harvested produce reduces water loss (Thompson et al., 1998), which would, otherwise, result in decreased returns through poor quality (wilting, shrivelling) and loss of saleable weight (Odesola and Onyebuchi, 2009). The effectiveness with which the cold chain is managed to minimise physiological, chemical and enzymatic changes will therefore determine the consumer acceptability for fruit and vegetables (Sullivan et al., 1996). To minimise the rate at which physiological, chemical and enzymatic changes occur, is through the management of environmental factors which are discussed in the next section.
2.6 Environmental Factors

According to Nunes et al. (2009) and Choudhury (2005), temperature and relative humidity are the two most important environmental factors affecting the quality and the storage life of fresh produce. Jain (2007) also includes the gas composition surrounding the produce as an environmental factor that directly affects storage life of fruit and vegetables. Proper storage and transport practices of fruit and vegetables include control of temperature and relative humidity, air circulation and maintenance of space between containers for adequate ventilation (Basediya et al., 2011). The storage life of a product varies with species, variety and pre-harvest conditions particularly quality and maturity (Kader, 1986). In SSA, considerable quantities of fresh produce are lost before it reaches the market due to failure by farmers to regulate temperature and relative humidity during storage and transportation (Emana and Gebremedhim, 2007; Ignacio et al., 2011). Research and information on most fruit and vegetables’ shelf life under SSA conditions is limited (Tefera et al., 2007; Azene et al., 2011). Evidence of literature as discussed in section 2.3.4 shows the use of the relatively cheaper method of evaporative cooling by small scale farmers in SSA to maintain temperature and relative humidity during temporary storage. At the same time produce is left to suffer the abuse of uncontrolled environments during transportation at the back of trucks. Maintenance of fresh produce quality requires correct application of optimum temperatures and relative humidity from harvest to the consumer (Paull, 1999; Zude, 2009) and these factors are hence a serious consideration of this study.

2.6.1 Temperature

Deterioration of fruit and vegetables during storage and transportation is largely influenced by temperature (Mitra and Baldwin, 1997; Getinet et al., 2008; Vigneault et al., 2009; Pathare et al., 2012). According to Lee and Kader (2000), temperature management after harvest is the most important factor to maintain nutrients including vitamins of fruit and vegetables. It is also known that postharvest losses are accelerated at higher temperatures and with longer storage durations (Caleb et al., 2011). In sub-tropical climate like most countries in East and Southern Africa the air temperature is high, which increases the rate of microbial changes, activating enzymatic reactions in produce (Wiley, 1994; Workneh, 2010). Respiration rate, metabolic processes and ethylene biosynthesis of some fruit increase with air/room temperature within a given range (Tanner and Smale, 2005;
Respiration rates can double, triple or even quadruple with every increase in temperature (Zagory and Kader, 1988). High temperatures accelerate physiological deterioration (Mitchell, 1987; Wills et al., 1989) and senescence (Wiley, 1994) as fruit rot organisms spread most rapidly at warm harvest temperatures (Brosnan and Sun, 2001; Sandhya, 2010).

Failure to manage surrounding air temperature can cause produce losses ranging from 25% to 80% especially in tropical and subtropical areas (Coulomb, 2008; Nunes et al., 2009; Kader, 2010; Kitinoja et al., 2010) as is experienced in SSA. The mechanism of containing fruit physiological deterioration through regulated temperature management is the control of the crop's respiration rate (Kader, 1986). Respiration generates heat as sugars, fats, and proteins in the cells of the crop are oxidized (Irtwange, 2006). The loss of these stored food reserves through respiration means decreased food value, loss of flavor, loss of salable weight, and more rapid deterioration. The respiration rate of a product strongly determines its transit and postharvest life (Salveit and Morris, 1990). The higher the storage temperature, the higher the respiration rate will be (Wilson et al., 1999; Sandhya, 2010) hence fresh produce in the tropical and sub-tropical regions of Africa has a limited shelf life (Workneh and Woldetsadik, 2004; Tefera et al., 2007).

The storage of fruit and vegetables at low temperature immediately after harvesting will reduce the rate of decomposition and microbial spoilage (Workneh and Osthoff, 2010). The low temperature helps in retention of quality and freshness of the stored material for a longer period (Chopra et al., 2003). Fresh produce shelf life can double by reducing temperature from 10°C to 5°C (Sun and Zheng, 2006). Generally, the storage temperature of fruit and vegetables is 0°C to 12°C and most tropical and subtropical fruit require high temperatures of 5°C to 12°C or to 13°C according to (FAO, 2003). Otherwise they suffer chilling injury (Irtwange, 2006; Workneh, 2010). Consequently, vegetables have to be classified according to whether they are susceptible to cold temperatures like carrots, potatoes, bananas or not like, tomatoes, peppers, eggplants, cucumbers (FAO, 2003). To achieve these recommended temperatures, produce has to be pre-cooled (Atef, 2009).

The process of pre-cooling is the removal of field heat immediately after harvest to arrest the deterioration and senescence process (Paull, 1990; Kader 2002). Precooling can be achieved through different methods (Nath et al., 2011) that include forced air cooling,
vacuum cooling, hydro-cooling (Rennie et al., 2003) and evaporative cooling (Tigist et al., 2011). Pre-cooling, therefore, helps achieve recommended storage temperatures for fresh produce and thus ensuring maintenance of high level quality that meets customers satisfaction (Brosnan and Sun, 2001; Vigneault et al., 2009). Generally, the optimum storage temperature for fruit and vegetables at the temperature range of 5°C to 12°C is achievable by most cooling technologies including adiabatic evaporative cooling (Workneh, 2010). Adiabatic evaporative cooling is regarded as having the lowest capital investment (Tigist et al., 2011).

According to Basediya et al. (2011), if the surrounding air temperature is reduced to produce storage optimum levels within four hours, the following are achieved; produce respiration rate is decreased; reduction of water loss from produce; suppression of ethylene production, and significant reduction of the development of microbial activity. Table 2.3 gives optimum temperatures °C for the selected fruit and vegetables specific to South Africa, the region and Africa with current or future commercial benefits.

Table 2.3 Optimum storage temperatures in °C for selected fruit and vegetables

<table>
<thead>
<tr>
<th>Product</th>
<th>Optimum Temp °C</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broccoli</td>
<td>0</td>
<td>Snowdon, 1992; Flores Gutierrez, 2000</td>
</tr>
<tr>
<td>Cabbage</td>
<td>0</td>
<td>Hardenburg et al. 1986; Flores Gutierrez, 2000</td>
</tr>
<tr>
<td>Lettuce</td>
<td>0</td>
<td>Byczynski, 1997; Flores Gutierrez, 2000</td>
</tr>
<tr>
<td>Carrots</td>
<td>0</td>
<td>Flores Gutierrez, 2000; Prusky, 2011</td>
</tr>
<tr>
<td>Tomatoes</td>
<td>12-15</td>
<td>Flores Gutierrez, 2000; Saltveit, 2003,</td>
</tr>
<tr>
<td>Onions, Green Onions</td>
<td>1-2</td>
<td>Byczynski, 1997; Flores Gutierrez, 2000</td>
</tr>
<tr>
<td>Garlic</td>
<td>0°C</td>
<td>Flores Gutierrez, 2000; Prusky, 2011</td>
</tr>
<tr>
<td>Cucumber</td>
<td>10-13</td>
<td>Flores Gutierrez, 2000</td>
</tr>
<tr>
<td>Cauliflower</td>
<td>0</td>
<td>Flores Gutierrez, 2000</td>
</tr>
<tr>
<td>Mushroom</td>
<td>0 – 2</td>
<td>Fadeyibi and Osunde, 2011</td>
</tr>
<tr>
<td>Spinach</td>
<td>0 – 2</td>
<td>Fadeyibi and Osunde, 2011</td>
</tr>
<tr>
<td>Oranges</td>
<td>3 - 7</td>
<td>Wiley, 1997, Fadeyibi &amp; Osunde, 2011; Aharoni, 2004</td>
</tr>
<tr>
<td>Apple</td>
<td>-1 – 5</td>
<td>Wiley, 1997; Aharoni, 2004</td>
</tr>
<tr>
<td>Avocado pear (ripe)</td>
<td>0 – 2</td>
<td>Wiley, 1997, FAO 2003</td>
</tr>
<tr>
<td>Strawberry</td>
<td>0</td>
<td>Wiley, 1997, Fadeyibi and Osunde, 2011</td>
</tr>
<tr>
<td>Papaya</td>
<td>0</td>
<td>Wiley, 1997, FAO 2003</td>
</tr>
<tr>
<td>Guava</td>
<td>5-10</td>
<td>Basediya et al., 2011, Fadeyibi and Osunde, 2011</td>
</tr>
<tr>
<td>Banana (green)</td>
<td>13-14</td>
<td>Hardenburg et al., 1986; Aharoni, 2004</td>
</tr>
</tbody>
</table>
The adoption of sophisticated cooling technologies for the control of temperature to attain optimum recommended temperatures for fresh produce is dependent on the scale of production (Prusky, 2011). This is the reason why large scale farmers have imported these methods while small scale farmers in SSA have been left out because of economies of scale. At the moment there is limited access if any by small scale farmers in SSA to these cooling technologies (Workneh and Woldetsadik, 2004; Ejeta, 2009). This is a real challenge, for South Africa Baloyi (2010) claims that small scale farmers do not have access to on farm cold chain infrastructure. As a result fresh produce is stored and transported at ambient temperature (Paull, 1999). Hence a research priority is to develop a cooling technology that is built on existing knowledge, adaptive, appropriate, suitable and sustainable (Kitinoja et al., 2010) under South African conditions. This will help address the plight of fresh produce growing small scale farmers to ensure they have a facility that they can set to the optimum temperature for each commodity.

2.6.2 Relative humidity

Relative humidity is another important aspect that is considered during handling of fruit and vegetables under a controlled environment (Prusky, 2011). Transpiration rate refers to water loss from produce and is determined by the moisture content of the air, which is usually expressed as relative humidity. When relative humidity is high, produce maintains its saleable weight, appearance, nutritional quality and flavour, while wilting, softening and juiciness are reduced (FAO, 2003; Basediya et al., 2011). In low relative humidity, the air is holding only a small percentage of the total possible quantity of water vapour it can hold. In these conditions the air can take in more moisture causing produce to increase transpiration rate (Getinet et al., 2008). On the other hand, when the relative humidity is high, the rate of water evaporation is low, and therefore cooling is also low (Odesola and Onyebuchi, 2009). High humidity should be used with low temperature storage because humidity and warmth or high temperature in combination favours the growth of fungi and bacteria (Sandhya, 2010). This implies that there is need for regulated storage and transportation conditions of fresh produce.

Hardenburg (1986) concluded that regulated storage or transportation conditions retard the following elements of deterioration in perishable crops:

- Aging due to ripening, softening, and textural and color changes,
• Undesirable metabolic changes and respiratory heat production,
• Moisture loss and the wilting that result,
• Spoilage due to invasion by bacteria, fungi, and yeasts and
• Undesirable growth, such as sprouting of potatoes.

Generally, the recommended storage relative humidity for most horticultural crops is ≥ 90% (Cantwell et al., 2009), lies between 70% and 95% (FAO, 2003) or 80-95% (Prusky, 2011). However, it is known that most produce is stored at relative humidity levels lower than recommended resulting in excessive moisture loss (Kays and Paull, 2004). Effects like wilting, shriveling and dryness can be caused by small moisture losses of 3-6% (Nunes et al., 2009). This will obviously affect marketability of produce or its economic value especially if fruit or vegetables are sold by weight (Robinson et al., 1975). Table 2.4 gives optimum relative humidity as % for selected fruit and vegetables specific to South Africa, SADC and Africa with current or future commercial benefits.

Table 2.4 Optimum storage relative humidity for selected fruit and vegetables

<table>
<thead>
<tr>
<th>Product</th>
<th>Optimum Relative Humidity (%)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broccoli</td>
<td>90-95</td>
<td>Snowdon, 1992; Flores Gutierrez, 2000</td>
</tr>
<tr>
<td>Cabbage</td>
<td>90-95</td>
<td>Hardenburg et al., 1986</td>
</tr>
<tr>
<td>Lettuce</td>
<td>90-95</td>
<td>Flores Gutierrez, 2000</td>
</tr>
<tr>
<td>Carrots</td>
<td>90-95</td>
<td>Flores Gutierrez, 2000; Prusky, 2011</td>
</tr>
<tr>
<td>Tomatoes</td>
<td>≥ 85</td>
<td>FAO 2003; Beckles, 2012</td>
</tr>
<tr>
<td>Potatoes</td>
<td>90</td>
<td>Wilson et al. 1999</td>
</tr>
<tr>
<td>Onions</td>
<td>70-75</td>
<td>Byczynski, 1997; Flores Gutierrez, 2000</td>
</tr>
<tr>
<td>Garlic</td>
<td>70-75</td>
<td>Byczynski, 1997; Flores Gutierrez, 2000</td>
</tr>
<tr>
<td>Cucumber</td>
<td>95</td>
<td>Flores Gutierrez, 2000</td>
</tr>
<tr>
<td>Guava</td>
<td>90</td>
<td>Basediya et al., 2011</td>
</tr>
<tr>
<td>Beets</td>
<td>90-95</td>
<td>Flores Gutierrez, 2000; FAO, 2003</td>
</tr>
<tr>
<td>Green paper</td>
<td>95</td>
<td>Flores Gutierrez, 2000; FAO, 2003</td>
</tr>
<tr>
<td>Celery</td>
<td>90-95</td>
<td>Flores Gutierrez, 2000</td>
</tr>
<tr>
<td>Mango</td>
<td>90-95</td>
<td>Snowdon, 1990</td>
</tr>
<tr>
<td>Banana (green)</td>
<td>90-95</td>
<td>Hardenburg et al., 1986</td>
</tr>
</tbody>
</table>

These optimum relative humidity conditions for temporary storage and transportation are not maintained at small scale farming/emerging commercial farming level because of lack of affordable/low cost appropriate cooling technologies (Baloyi, 2010). Cooling has been identified historically as a cold chain management tool to provide controlled environment for fresh produce (Ngcobo et al., 2012). There is therefore, a need to develop appropriate
cooling facility that is affordable and that compares well with the conventional refrigeration system (Basediya et al., 2011). Among the critical issues to be investigated with this proposed appropriate cooling facility is whether it will increase relative humidity to the required optimum levels. It is also important to undertake a cost benefit analysis of the introduction of such a technology versus conventional refrigeration.

2.7 Research into Cold Chain Technologies

Research into appropriate cold chain technologies for small scale farming in developing countries like South Africa, requires cooperation as well as transport logistics models that include the container manufacturers to make the technology viable (Basediya et al., 2011). According to Prusky (2011), the requirements for maintaining quality and safety of horticultural perishables as they proceed from harvest to consumption are the same in developing and developed countries.

However, according to Ejeta (2009), “The extent to adoption of the necessary postharvest handling procedures and technologies varies widely between and even within countries, depending on the scale of operation, the intended market and the return on investment in each technology.” It is clear, however, that in SSA the problem is not whether or not cooling technologies exist but whether the available technologies are appropriate and affordable by small scale farmers (Azene et al., 2011). For farmers to invest in modern cooling technologies they have to consider economies of scale to determine whether at their level of production they will break even to the extent of obtaining a return on investment (Ejeta, 2009). As a way forward the best solution is to strengthen the development of simple cooling technologies, such as cool containers to better protect produce from deterioration by reduction of temperature and provision of natural means of cooling (Kader, 2005). These technologies should be combined with intermediate-level technologies that will allow low energy cool storage that is mobile so that fresh produce reaches markets at recommended storage conditions (Kader and Rolle 2004; Kader 2005). This will help improve handling fresh produce during temporary storage and transportation.

A lot of cooling technologies have been developed (Thompson and Kasmire, 1981) and discussed that include evaporative cooling, vacuum cooling, hydro-cooling and forced air
cooling (Brennan and Shewfelt, 1989; Gillies and Toivonen, 1995; and Jeong et al., 1996). Small scale farmers in SSA generally have not adopted any storage facilities (Baloyi, 2010; Workneh, 2010) as they require high capital investment (Workneh, 2007; Rayaguru et al., 2010). The cooling technologies that are used by either farmers in developed countries or large scale commercial farmers in SSA are not appropriate for small scale farmers who are not connected to the electricity grid. The appropriate cooling technology should then be, low cost so that small scale farmers can afford; should not use grid electricity, but consider use of alternative sources of energy like solar energy and wind power.

2.8 Available Cooling Technologies in the World

Much of the postharvest losses of fruit and vegetables especially in SSA are due to lack of proper storage facilities (Kitinoja et al., 2011). There are already common methods for preservation of fresh vegetables and fruit immediately after harvest and these are mechanical refrigeration (Jiro, 2002; James et al., 2009), hydro-cooling (Henry et al., 1976; Brosnan and Sun, 2001; Boyette et al., 1994), evaporative cooling (Singh-Negi and Kumar-Roy, 2000), cold room cooling (Perrin and Gaye, 1986; Prusky, 2011), forced air cooling, and vacuum cooling (Wang and Sun, 2001; Zheng and Sun, 2006; Zhang and Sun, 2006). These cooling methods help maintain the quality of fresh produce in the state at which it was harvested in (Hera et al., 2007a).

2.8.1 Mechanical refrigeration

Refrigeration is a low temperature food storage unit operation for the preservation of perishable agricultural produce and it significantly results in reduction of postharvest losses (James et al., 2009). The minimum temperature of the cold chain depends on the minimum safe temperature which is specific to a product and sometimes can also be maintained at negative during freezing (Tassou et al., 2010).

Mechanical refrigeration refers to the process where heat absorption takes place at one point and heat dispersion at the other (Ashby, 1995). This is achieved through circulation of a refrigerant through the system by a compressor (Hera et al., 2007a) picking heat through the evaporator inside the fresh produce space and dissipating it through the condenser on the outside (Ashby, 1995). The compressor can be powered through an electric motor. The refrigeration system is energy intensive as electricity power is consumed throughout the whole cold chain. This in turn leads to high product cost since
unit energy costs make part of the unit cost for production of a given produce (Swain et al., 2009).

Energy consumption in the refrigeration of commodities is the largest portion of the total energy consumption during pre-processing, refrigerated storage, transportation, retail, and end-user’s consumption of agro-food products (Johansson and Lundqvist, 2001). Considerable amounts of energy are consumed by refrigeration facilities involved in the cold chain and, therefore, as a result the amount of energy used tend to determine whether the method will be used or not in view of greenhouse gas emissions. The figure often cited is about 50% of total energy consumption in the food industry is from the refrigeration related facilities (Hera et al., 2007b). At a global level, this consumption reaches about 15-17% of the total electrical energy produced (James and James, 2011). In the UK, the food industry is responsible for 12% of the industrial energy consumption and uses over 4500 GWh.yr⁻¹ of electrical energy consumption (approximately 99% of the energy used for refrigeration is electrical), and the annual energy use for frozen prepared foodstuffs is from 218 to 415 GWh.y⁻¹ (Swain, 2006). Therefore, energy consumption in fresh produce refrigeration is costly. The cold chain costs escalate further if refrigerated trucks are used to transport fruit and vegetables (Tassou et al., 2008) because of the cost of fuel. Since refrigeration is a key measure in decreasing the deterioration of fresh produce, research in alternative sources of energy other than electricity would be critical in reducing energy consumption during the cooling process. Possible options are the clean energy sources that have no pressure on global warming or significant carbon emissions (Hayes, 1977; Fan et al., 2007).

Even though at present the South African situation is not clear, it is definitely not excluded from the overall world situation. Therefore, the research on the cold chain with particular reference to renewable energy situation would dramatically decrease postharvest losses and decrease the demand of electricity from fresh produce pre-cooling in South Africa.

2.8.2 Hydro-cooling
Hydro-cooling is the process of removing field heat from freshly harvested fruit and vegetables by bathing them in chilled water (Vigneault et al., 2009; Gomez-Lopez, 2012). According to Prusky (2011), hydro-cooling is dumping produce into cold water or running
cold water over it. Obviously, since produce is at higher temperature immediately after harvest the heat movement takes place from the produce to the water and hence leading to cooling of produces. This process is an efficient way to remove heat, and can serve as a means of cleaning at the same time. In addition, hydro-cooling reduces water loss, as well as the rates of microbiological and biochemical changes in order to prevent spoilage maintain quality and increase shelf life (Dincer, 1997). Hydro-cooling is however only appropriate for fruit and vegetables that tolerate wetting. The examples of produce that can be hydro-cooled include carrots (root vegetables), peaches, asparagus, cherries (Kitinoja and Thompson, 2010), melons and many types of tree fruits (Vigneault et al., 2009).

The water used in hydro-cooling systems should be at a temperature close to 0°C and contain a mild disinfectant such as chlorine or an approved phenol compound (Dincer, 1997). Selected fruit and vegetables for hydro-cooling should be tolerant to mild levels of disinfectant. Furthermore, the produce and packaging must also be water tolerant (Gast and Flores, 1991).

A secondary benefit of this initial cooling step is that it lowers the amount of energy required for refrigeration (Boromichaicgarkul et al., 1992), since it removes the field heat which otherwise accounts for a significant portion of the total energy requirement for cooling. The major limitations with the adaptation of hydro-cooling by small scale farmers will be the relatively high capital cost (Boyette et al., 1994) and the low energy efficiency (Bennett et al., 1965). Also, Hydro-cooling requires containers that are water resistant which otherwise might cause cross decay contamination (Vigneault et al., 2000).

2.8.3 Vacuum cooling
Vacuum cooling is a rapid evaporative cooling method for porous and moist foods to meet the special cooling requirements (Zhang and Sun, 2006). It is achieved by the evaporation of moisture from the surface and within the produce (Sun and Zheng, 2006). The evaporation is encouraged and made more efficient by reducing the pressure to the point where boiling of water takes place at low temperature (Hass and Gur, 1987). The difference between vacuum cooling and conventional refrigeration is that for the vacuum cooling the cooling effect is achieved by blowing cold air or other cold medium over the product (Mellor, 1980). Speed and efficiency are the two features of vacuum cooling,
which are unsurpassed by any conventional cooling method, especially when cooling boxed or palletised products (Sun and Wang, 2001). Vacuum cooling is energy efficient as it removes heat from the produce only (Vigneault et al., 2009). Cooling time, in order of 30 minutes ensures that strict cooling requirements for safety and quality of foods can be met (Malpas, 1972).

Any product which has free water and whose structure will not be damaged by the removal of such water can be vacuum cooled. The speed and effectiveness of vacuum cooling are mainly related to the ratio between its evaporation surface and the mass of produce (Noble, 1985). Fresh produce with high transpiration rates like lettuce, sweet corn, celery and sprouted beans do well with vacuum cleaning (Vigneault, 2006). As good as this method sounds the capital investment in vacuum cooling is a serious challenge and as a result it is only limited to large scale commercial growers (Brosnan and Sun, 2001). For a good return on investment on vacuum cooling there should be a consistent daily throughput of fresh produce throughout the year (Ryall and Pentzer, 1982). Therefore, vacuum cooling, will not be ideally suited for small scale farmers in SSA who have land holdings where fresh produce output will not justify the financial investment.

2.8.4 Evaporative cooling

Low temperature and high relative humidity can also be achieved through use of evaporative cooling (Workneh and Woldetsadik, 2001). Evaporative cooling is used for pre-cooling of fruit and vegetables before transit and storage in cold store (Maini and Anand, 1992). Evaporative cooling of fruit and vegetables and humidification of the surrounding air involves the use of principles of moist air properties or psychometrics (Workneh, 2007). In this system of cooling, temperature drops considerably and humidity increases to the suitable level for short–term on farm storage or transportation of perishables (Jha and Kudas Aleskha, 2006). Evaporative cooling provides cool air by forcing hot dry air over a wetted pad. The water in the pad evaporates, removing heat (sensible heat) from the air while adding moisture. Since, evaporative cooling only removes room sensible heat, it works best in hot and dry climate (prevalent in Southern Africa) where the prevailing weather conditions will result in maximum evaporative cooling (Ahmed et al., 2011). When water evaporates it draws energy from its surroundings which produce a considerable cooling effect (Basediya et al., 2011).
Evaporative cooling requires air that is not too humid and the faster the rate of evaporation the greater the cooling effect. The efficiency of an evaporative cooler depends on the original humidity of the surrounding air (Dadhich et al., 2008) and the efficiency of evaporative surface (Jain D, 2007).

This cooling technology was found by Chakraverty et al. (2003) to be very economical and relatively efficient technique to store products compared to other mechanical refrigerators. Evaporative cooling has been reported for achieving a favourable environment in greenhouses (Jain and Tiwari, 2002) and the storage structures for fruit and vegetables (Helsen and Willmot, 1991; Umbker et al., 1991). The potential energy savings by replacing conventional refrigerated systems by evaporative systems is approximately 75% (Datta et al., 1987). Consequently, in developing countries there is interest in evaporative cooling as a simple low-cost alternative (Anyawu, 2004). Evaporative cooling does not necessarily require any external power source (Zahra and John, 1996). At the same time there is a realisation that use of forced (powered through a fan) air cooling could increase the cooling effect obtained from evaporative cooling. Due to its high efficiency and low capital investment, evaporative cooling is proposed as the most appropriate method for a cooled environment for SCF as compared to other cooling methods (Workneh and Woldetsadik, 2004; Tigist et al., 2011).

There are two forms of ventilating evaporative coolers, passive (natural ventilated) and non-passive (forced air) cooling. Natural ventilation relies on the velocity of the natural wind for air movement through the wetted pads. It does not have a fan (Olanrewaju, 2010). The main components of a natural ventilation evaporation system include the storage chamber, absorbent material and overhead tank (Mohamed, 2008). In a non-passive system a fan and water pump powered by a source of power are used in the cooling system (Olanrewaju, 2010). The main components of the system are housing, cooling pads, frame, fan, water tank, water pump, water distribution tubing and electrical connections (Kinney, 2004).

Table 2.5 shows temperature differences achieved between inside and outside measurements, relative humidity differences achieved between inside and outside
measurements and shelf life extension that occur when two types of evaporative coolers are used.

Table 2.5 Performance of two types of evaporative coolers in relation to temperature gradient, relative humidity gradient and shelf life extension in days.

<table>
<thead>
<tr>
<th>Type of evaporative cooling technology</th>
<th>Temperature difference achievable (b/n inside &amp; outside)</th>
<th>Relative Humidity achievable (b/n in and out)</th>
<th>Shelf life extension, Days</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural ventilation</td>
<td>Temperature depressions of 3-12°C</td>
<td>Increased relative humidity by 26%</td>
<td>Increased shelf life of mangoes by 2 weeks</td>
<td>Workneh, 2010</td>
</tr>
<tr>
<td></td>
<td>Temperature depressions of 3-5°C in storage of vegetables</td>
<td>Increased relative humidity to 85%</td>
<td></td>
<td>Kitinoja and Gorny, 1999.</td>
</tr>
<tr>
<td>Forced ventilation</td>
<td>10.7°C during 32 days of storage of banana and citrus fruits</td>
<td>36.7% for 32 days of the storage of the same.</td>
<td>Two or more weeks</td>
<td>Workneh and Woldetsadik, 2004</td>
</tr>
<tr>
<td></td>
<td>12°C during the 28 days of storage pepper varieties.</td>
<td>36.1% during the 28 days of storage pepper varieties</td>
<td>Two or more weeks depending on variety.</td>
<td>Samira et al., 2011</td>
</tr>
<tr>
<td></td>
<td>12°C during the 28 days of storage of mango fruit.</td>
<td>34.1% during the 28 days of storage of mango</td>
<td>Three weeks</td>
<td>Tefera et al., 2007, Getinet et al., 2008</td>
</tr>
</tbody>
</table>

The major advantage of evaporative cooling is based upon its low energy use which is a critical component for practical applications for choice of cooling technologies in SSA. What then needs to be further considered is availability and cost (Kitinoja and Thompson, 2010). This research study will on this basis, focus on evaporative cooling as its use by small scale farmers forms part of existing knowledge and is suitable for them as they are small in terms of both landholding and fresh produce harvested and handled on any given day. There is still work that needs to be done in terms of design modification, energy source to run the systems as well as control systems of temperature and relative humidity (Chakravety et al., 2003).
2.9 Evaporative Cooling as Defined by Psychometric Properties

Psychometrics deals with moist air properties and use of these properties to solve postharvest unit operations involving moist air such as cooling, drying and humidification (Paull, 1999). The term moist air refers to a mixture of dry air with moisture (Jones and Hawkins, 1962).

Managing moist air property during postharvest handling of perishable produce reduces moisture loss, decay problems and reduces rate of respiration of live tissue during storage (Workneh, 2007). Psychometric properties of moist air include dry and wet bulb temperature, dew point temperature, vapour pressure, relative humidity, humidity ratio and specific enthalpy (Gaffrey, 1978).

Storage air temperature, humidity ratio and relative humidity can be increased through adiabatic evaporative cooling process (Jha and Kudas Aleskha, 2006). The areas of application of the principles of moist air properties in agriculture include greenhouses (Jain and Tiwari, 2002), animal house cooling and evaporative cooling of fruit and vegetables (Helsen and Willmot, 1991; Umbarker et al., 1991). Evaporative cooling is an adiabatic cooling process where the air temperature decreases without change in its total heat content when dry air is allowed to pass over/through wet surfaces (Getinet et al., 2008). During adiabatic cooling of air, its temperature decreases when the air takes some amount of moisture from a wet surface (Gaffrey, 1978). The humidity ratio of the air increases, which means the air vapour pressure, also increases (Thompson, 1985). The heat content of the air remains the same even after passing through a wet evaporative cooling pad, although the air temperature decreases (Jha and Chopra, 2006). The aim of evaporative cooling is therefore to increase the humidity ratio, vapour pressure and relative humidity and to decrease temperature (Eastop and McConkey, 1993). This technology allows ventilation of air that is at low temperature and with high relative humidity during storage near the fresh fruit and vegetables.

2.10 Performance of Cooling Technologies

Table 2.6 compares different cooling technologies in terms of how they affect storage temperature, relative humidity and how each technology will result in prolonged shelf life for fresh produce.
Table 2.6 Comparison of different cooling technologies in terms temperature and relative humidity and extension of shelf life of fresh produce.

<table>
<thead>
<tr>
<th>Cooling technology</th>
<th>Performance parameters</th>
<th>References</th>
</tr>
</thead>
</table>
| Evaporative Cooling | (i) Cooling for fruit and vegetables to desired storage can take up to 24 hours after loading  
(ii) Product moisture loss insignificant as a pre-cooling method.  
(iii) Can achieve and maintain temperatures at 10-15°C below ambient. Can achieve relative humidity of 90%.  
(iv) Can increase shelf life from 3 days to 15 days.  
(v) The cost per metric tonne of cooling tropical fruit and vegetables, with a 0.1HP fan, to 13°C averages US$0.14 at an electricity rate of US$0.20/kWh. | Taha et al., 1994; Mordi and Olorunda 2003; Longmore, 1973; Choudhury 2005; Dadligh et al., 2008; Kitinoja and Thompson, 2010; Rayaguru et al., 2010; Basediya et al., 2011 |
| Hydro-cooling | (i) Cooling can be achieved in 10-60 minutes eg. Radishes in less than 10 minutes.  
(ii) Product moisture loss is 0 – 0.5%. Water removes heat about 15 times faster than air at typical flow rates and temperature difference.  
(iii) Can achieve desired temperature gradient depending on refrigeration capacity. For example, 1.4kW refrigeration capacity is required to cool 500kg produce per hour to achieved 11°C depression; 2.8 kW for 24°C and 5.3 kW for 39°C  
(iv) Can increase shelf life to up to 14 days when combined with cold storage  
(v) The cost per metric tonne of cooling various produce to 2°C averages US$16 to US$30 at an electricity rate of US$0.20/kWh  
(vi) Energy use coefficient (sensible heat/electrical energy) is 1.2 | Lambrinos et al., 1997; Thompsson et al., 1998; Brosnan and Sun, 2001; Kitinoja and Thompson, 2010; Chen, 1986 |
| Forced air cooling | (i) Cooling can be achieved in 1 -10 hrs. Increasing air-flow rate from 0.002 to 0.004 m³/s (kg product) can shorten pre-cooling time by 30-40%.  
(ii) Product moisture loss is 0.1 to 2%  
(iii) Can achieve product desired temperature at a rate dependent on the velocity of the cold air flowing through it. For example increasing air velocity from 0.2 to 3.65 m/s can reduce pre-cooling time 2 to 6 fold depending on packaging.  
(iv) Can increase shelf life  
(v) The cost per metric tonne of cooling all produce, with a 1HP fan, to 13°C averages US$7 at an electricity rate of US$0.20/kWh  
(vi) Energy use coefficient (sensible heat/electrical energy) is 0.52 | Lambrinos et al., 1997; Baird et al., 1988; Brosnan and Sun, 2001; Kitinoja and Thompson, 2010; Hass et al., 1976; Chen, 1986 |
| Vacuum cooling | (i) Cooling is rapid cooling in order of 15 -30 minutes. Butterbur stem temperature was lowered from 20°C to 5°C in 25-30 min. Lettuce temperature was lowered from 25°C to 1°C in less than 30 minutes. Sweet corn, celery, sprouted beans, mushrooms can be cooled in 15-30 minutes.  
(ii) Product moisture loss ranges 2 to 4%. For every 5.5°C reduction in temperature there is 1% weight loss.  
(iii) Can achieve desired product storage temperatures of up to 1°C. Temperature achieved depends on the cooling time as the cooling rate depends on the product surface to mass ratio.  
(iv) Increased shelf life of lettuce from 3-5 days at ambient temperature to up to 14 days when combined with cold storage at 1°C Vacuum cooling followed by refrigeration at 0°C gives a shelf life of 40 days compared to 20 days for at 0°C for lettuce marketed by conventional methods.  
(v) The cost  
(vi) Energy use coefficient (sensible heat/electrical energy) is 2.65. Typical energy use for vacuum coolers is 0.22 kWh/carton. | Fordham and Biggs, 1985; Ito et al., 1988; Everington, 1993; Kim et al., 1995; Artes and Martinez, 1996; Brosnan and Sun, 2001; Rennie et al., 2001; Rennie et al., 2003; Vigneault, 2006; Vigneault et al., 2009; Chen, 1986 |
2.11 Problems in Sub-Saharan Africa - Why Advanced Cooling Technologies are not Applied?

Conventional cooling technologies are regarded as energy intensive and also face the challenge related to gas emission that affect the environment (Chindambararam et al., 2011). Advanced cooling methods require a lot of energy e.g. vacuum cooling of one tonne of lettuce requires about 0.56kWh, and 3.7kWh is required for hydro-cooling to reduce temperature by 1ºC (Zhang and Sun, 2006). Hydro-cooling is limited to leafy products and cannot be used for tomatoes, apples and pepper as they have a thick cuticle (Wang and Sun, 2001). The same limitation is found with vacuum cooling which is suitable for fresh produce with a high ratio of surface to volume and has also been found to be unsuitable for oranges, tomatoes and apples (McDonald and Sun, 2000). Tomatoes and oranges are among the major commodities grown by small scale farmers in some SSA countries like South Africa (SAYB, 2011). If a cooling method cannot be used for these commodities then its use becomes very limited.

The construction and operating costs of different cooling technologies vary and some are relatively low and others high depending on the level of farm management (Kitinoja et al., 2010). When the expense of the chosen cooling technique is ignored at selection of technology the farmer ends up justifying the higher selling price of the produce (Boyette et al., 1994). Both vacuum cooling and hydro-cooling are regarded as expensive methods and therefore need to be operated for relatively longer periods in a year to justify an investment on them (Ryall and Pentzer, 1982; Brosnan and Sun, 2001). This is also alluded to by Boyette et al. (1994) who claim that because of the relative high costs of hydro-coolers they need to be economically justified. Brosnan and Sun (2001) concluded that since equipment for vacuum cooling is expensive then this cooling technology is only feasible for large growers or organisations.

Unfortunately small scale farmers in SSA do not have volumes of fresh produce to cater for the use of vacuum and hydro cooling throughout the year (Kitinoja et al., 2010). As a result these two cooling methods are limited to products for which they are much faster and more convenient (Ryall and Pentzer, 1982). Forced air cooling requires a definite stacking pattern (Soule et al., 1966; Parsons et al., 1972; Hass et al., 1976; Arfin and Chau, 1988), hence this technique requires skilled operators so as to achieve the required loading.
pattern to ensure satisfactory cooling rates. Otherwise mechanical refrigeration is known to be the most reliable cooling technology for fresh produce as long as electricity is available (Kim and Ferreira, 2008). Regrettably most small scale farmers in SSA are located in areas where there is no grid electricity (Tefera et al., 2007). Therefore while mechanical refrigeration, vacuum cooling and hydro-cooling could be used in SSA depending on the type of fresh produce and the rate of cooling required, their energy consumption costs and cost of equipment tend to be limiting for small scale farmers.

2.12 Critical Problems Inherent in Modern Cooling Technologies

Different cooling technologies have been defined and discussed in detail in the previous sections. The use of each technology has advantages and disadvantages and most of these technologies have critical inherent problems that give reason as to why they cannot be used by SCF in Africa. Table 2.7 shows advantages and disadvantages of the different cooling technologies.

These cooling methods are available for use by farmers in SSA. There is evidence of use of hydro-cooling, forced air cooling and vacuum cooling by well-resourced and established LSCF in SSA. The use of these methods is found in flower production and large scale production for fresh produce especially for export purposes. Literature has provided evidence of research and use of evaporative coolers by SCF in Africa as shown by publications from authors in different countries (Anyawu (2004) in Nigeria; Ahmed et al. (2011) in Sudan, Samira et al. (2011) in Ethiopia). The results and use of evaporative cooling have demonstrated that coolers can maintain cooling spaces at temperatures below ambient with a depression reaching 12°C (Anyawu, 2004). The best method available for SCF should consider renewable energy sources.

Hydro-cooling, vacuum cooling and forced air cooling systems could still be adapted for small scale farmers in SSA if governments had the necessary capital to set up the equipment and also provide the necessary power source. Fossil fuels could be used to power these cooling methods but these are known to contribute to greenhouse gas emissions (GHGE) which are contributing to climate change (Best et al., 2012). Best et al. (2012) estimates that energy demand for cooling processes and GHGE will increase by 60% by 2030 compared to 2000 levels.
<table>
<thead>
<tr>
<th>Cooling technology</th>
<th>Advantage</th>
<th>Disadvantage</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Evaporative cooling</strong></td>
<td>Inexpensive, energy efficient, environmental benign</td>
<td>Requires a constant water supply to wet the pads</td>
<td>Sandoja <em>et al.</em>, 1987</td>
</tr>
<tr>
<td></td>
<td>Relatively low weight loss for fruit &amp; vegetables under evaporative cooling</td>
<td>No humidification</td>
<td>Bhatnagar <em>et al.</em>, 1990</td>
</tr>
<tr>
<td></td>
<td>Least deterioration in quality parameters of tomatoes.</td>
<td>High dew point condition decreases the cooling capability of the evaporative cooler.</td>
<td>Zahra and John, 1996</td>
</tr>
<tr>
<td></td>
<td>Suitable for rural application as it requires no skill to operate</td>
<td>Pads and interior of cooler are damaged by mineral deposits if the water has high mineral content.</td>
<td>Anyawu, 2004</td>
</tr>
<tr>
<td></td>
<td>Can be made from locally available materials. Evaporative cooling systems are easy to maintain.</td>
<td></td>
<td>Dadhich <em>et al.</em>, 2008</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Basediya <em>et al.</em>, 2011</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Basediya <em>et al.</em>, 2011</td>
</tr>
<tr>
<td><strong>Hydro-cooling</strong></td>
<td>It is a rapid cooling technique compared to others</td>
<td>Is not uniform may leave “hot spots”</td>
<td>Bennett <em>et al.</em>, 1965</td>
</tr>
<tr>
<td></td>
<td>It prevents loss of moisture during cooling</td>
<td>It is only suited for leafy produce for which washing is part of their market preparation</td>
<td>Henry <em>et al.</em>, 1976</td>
</tr>
<tr>
<td></td>
<td>It cools and cleans the produce at the same time. It can also contaminate the product.</td>
<td>Energy efficiency is low</td>
<td>Balls, 1986.</td>
</tr>
<tr>
<td></td>
<td>It is a simple and effective pre-cooling method</td>
<td>The cost is relatively high</td>
<td>Boyette <em>et al.</em>, 1994.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Wills <em>et al.</em>, 1998</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Brosnan and Sun, 2001</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Prusky, 2011</td>
</tr>
<tr>
<td><strong>Forced-air cooling</strong></td>
<td>Cooling faster than conventional cooling but slower than vacuum or hydro-cooling</td>
<td>Has the lowest energy efficiency</td>
<td>Ryall and Pentzer, 1982</td>
</tr>
<tr>
<td></td>
<td>Most common for cooling of flowers</td>
<td>When rapid cooling is required forced air cooling is more costly than other pre-cooling methods</td>
<td>Arfin and Chau, 1988</td>
</tr>
<tr>
<td></td>
<td>Most common cooling method for produce sensitive to exposure to water</td>
<td>The stacking pattern requires skilled operators</td>
<td>Baird <em>et al.</em>, 1988</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Thompson &amp; Chen, 1988</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Rudniki and Nowak, 1990</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Brosman and Sun, 2001</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Kader, 2002</td>
</tr>
<tr>
<td><strong>Vacuum cooling</strong></td>
<td>Rapid cooling achievable by vacuum cooling gives a distinct advantage over other cooling methods. Butterbur stem temperature was lowered from 20°C to 5°C in 25-30 min. Vacuum cooling can achieve uniform cooling if the package is not hermetically sealed to allow free evaporation. Gives the highest energy efficiency</td>
<td>It is a very expensive method and limited therefore to large growers. Vacuum cooling causes weight loss in the produce. For every 5.5°C reduction in temperature there is 1% weight loss. Works best only for produce like lettuce, cabbage, mushroom etc with high surface to volume ratio.</td>
<td>Longmore, 1973</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Ryall and Pentzer, 1982</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Freeman, 1984</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fordham and Biggs, 1985</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Ito <em>et al.</em>, 1988</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Thompson and Chen, 1988</td>
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<td></td>
<td></td>
<td></td>
<td>Turk and Celik, 1993</td>
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</tbody>
</table>

As a result of the high energy demands on existing power sources and global warming threats there is now an initiative for research towards technological alternatives (Hassan
and Mohamad, 2012). Among these is the use of solar energy and other renewable energy sources. Therefore, cooling methods for fresh produce should consider solar energy, for example, in SSA where the solar resource is available throughout the year with values in excess of 2000 KWh.m\(^{-2}\) (Best et al., 2012).

2.13 Sources of Energy for Cooling Technology

Throughout the world 15% of the electrical energy from the grid consumed is used for refrigeration (James and James, 2011) in areas where electricity is available. There is also in existence fossil fuels and fuel substitutes generated from organic matter (Bourne, 2009) which can also be used to power refrigeration equipment. Besides these energy sources there is an option of energy provision from natural energy sources that include among others solar and wind energy (Hayes, 1977). Systems that are based on fossil fuels are being discouraged as they contribute two-thirds of greenhouse gas emissions (Best et al., 2012). Because of the impact the use of fossil fuels has on global warming there is now a technological shift towards the use of clean energy that includes solar, wind energy and other renewable energy sources for refrigeration of fresh produce. Solar energy can be converted to electricity or to heat so as to power a compressor and fan in mechanical refrigeration systems (Fan et al., 2007).

2.13.1 Wind power/ current

It is estimated that 1% of the solar energy that reaches the earth is transformed into kinetic energy of wind (1.2 \(\times 10^5\)) (Golding, 1976). Wind energy is generally available along coastal regions and can be utilised if the annual energy available is at an average speed of 5ms\(^{-1}\) and is 490 MJ.m\(^{-2}\) of surface perpendicular to the wind flux (FAO, 1992). Wind Power has a versatility of uses worldwide that include battery charging, home power, and water pumping applications (Twidell and Weir, 1986). There is scope also to extend the use of wind power to other areas including agricultural produce processing (FAO, 1979).

There is no literature that shows that wind energy has been harnessed for cooling purposes of fresh produce. As a result there exists a research scope in the utilisation of wind energy to support non-passive evaporative cooling of fresh produce.
2.13.2 Solar energy option

Solar energy is a viable alternative to fossil fuels as it is clean and uses the natural energy from the sun to generate electricity (Hassan and Mohamad, 2012). FAO (2000) recognises the need to introduce energy supply especially, to rural population and this would apply to SCF, for increased productivity and for income generation. According to Best et al. (2012), the use of solar energy for refrigeration purposes in the Agro-industry has a potential in developing countries especially in Africa. This is more so as the solar energy is available throughout the year with values in excess of 2000 kWh.m⁻². According to Abu-Hamdeh and Al-Muhtaseb (2010) there is a potential energy saving of 40-50% when solar driven air conditioning systems are used versus conventional systems.

Feasibility studies of this technology have been carried out in Mexico and the Mediterranean area (Ayadi et al., 2008) and showed that it is possible to obtain temperatures as low as -2°C for air-cooled systems using solar energy as a source. There are mainly two types of solar refrigeration technologies i.e. solar electric and solar thermal (Kim and Ferreira, 2008). In the solar electric system solar energy is converted to electricity by use of photovoltaic cells (PVC) that operate a vapour-compression refrigeration technology, while with solar thermal systems solar energy heats the working fluid in the generator of vapour sorption to generate refrigeration effect (Said et al., 2012). Hence, there have been reasons for focusing on the potential of converting solar energy through PV systems for use in agriculture as a basis for sustainable agricultural production (Ekren et al., 2011).

With the intensification use of PV systems in many remote areas the international prices have fallen sharply from US$10 in the 1980s to US$3 per Wp (Bhadra, 1998). AEPC/DANIDA (1999) has recognised that there are energy requirements for agriculture in rural areas for irrigation purposes and agro-processing which can only be met by alternative sources of energy other than grid electricity. Schramm (1993) concludes that the grid electrification is expensive and yet all energy requirements can be met by other sources of energy including solar energy through use of PV systems. According to Crawford et al. (2009), rural electrification as a programme will not reach all the rural population and therefore, there is a need to find other means to supply isolated localised needs. This is especially so “for remote, dispersed populations with low and scattered
energy demands” (Cecelski, 2000). These needs could then possibly be met by PV systems though it is acknowledged that this system requires technical training and back up and maintenance services (Aguado-Monsonet, 1998). Usage of PV systems has found use in pumping systems for drinking water and these have been established in many countries as they have proven to be technically feasible and economically competitive (FAO, 2000).

There is a lot of research work currently being carried out for absorption based refrigeration and air conditioning systems that use solar energy (Liu and Wang, 2004; Balaras et al., 2007; Helm et al., 2009; Said et al., 2012). Information can be obtained from a review of the literature (Wang et al., 2011; Best et al., 2012).

2.14 Review of Energy in Relation to Cooling Technology

Fan et al. (2007) reviewed the research on solar absorption and adsorption refrigeration technologies. From this review it was concluded that solar power sorption technologies could be used for refrigeration, air-conditioning applications and ice-making. Other solar sorptions are still at research study level and are not fully developed. Other issues that still need to be addressed with sorption refrigeration systems regards enhancing the heat and mass transfer to improve performance (Chidambaram et al., 2011). As a result most of the systems are at the stage of demonstration and prototyping (Fan et al., 2007; Chidambaram et al., 2011). While the prospects of developing an environmentally friendly and low energy demand solar power sorption systems are good, the cost of the refrigeration system will limit its use among small scale farmers (Otanicar et al., 2012; Zhai et al., 2011).

In a survey by FAO in Latin America and Asia, 16% of the respondents claimed to use solar energy through PV for refrigeration purposes and that there was cooling for fruit preservation using PV/Wind hybrid systems in Indonesia. Solar energy use has been combined with evaporative cooling by many researchers (Tiwari and Jain, 2001; Maerefat and Haghighi, 2010; Naticchia et al., 2010; Finocchiaro et al., 2012) for cooling of buildings. Naticchia et al. (2010) exploited both air ventilation and heat exchange by use of, as an absorption matrix, a porous insulating material. Maerefat and Haghighi (2010) integrated a solar system employing a solar chimney with evaporative cooling cavity. This was meant to enhance passive cooling and natural ventilation in a solar house, and the numerical experiments showed that daytime temperatures can be significantly reduced at a
poor solar intensity of 200 W.m$^{-2}$ and high ambient temperature of 40$^\circ$C. Finocchiaro et al. (2012) employed a solar energy assisted desiccant and evaporative cooling system for building air conditioning. In this system solar energy was used to regenerate a desiccant material that dehumidifies moist air by vapour adsorption. The resultant dry and warm air was then cooled in a sensible heat exchange and then in an evaporative cooler.

The use of solar energy for evaporative cooling in all the cases that have been discussed has been limited to buildings. There seems to be success stories of using solar energy to power evaporative cooling technologies and this provides an opportunity or the same principles to be extended to the preservation of fresh produce. The use of solar energy to power a water pump and fan is very limited and literature was not found providing evidence that wind energy has been used for evaporative cooling for fresh produce. Therefore, there exists a scope for a research study to either use solar energy, wind energy or a combination of both as a power source for non-passive evaporative cooling of fruit and vegetables.
3. DISCUSSIONS AND CONCLUSIONS

This chapter discusses and concludes the literature review that is contained in Chapter 2 by initially picking key points and then providing an insight into the area of study.

Fruit and vegetables are mainly grown in the sub-tropical regions of Limpopo and Mpumalanga provinces in RSA. High postharvest loses are experienced by all spectrum of farmers in RSA but the challenge is more pronounced for small scale farmers (SCF) as there is lack of appropriate low-cost post-harvest cooling technologies. The quality deterioration of fruit and vegetables is due to factors such as technical, biological and chemical, and as well as environmental aspects and these lead to undesired colour changes, off-flavour and firmness loss.

The technical factors that affect produce quality are mechanical damage, lack of skilled manpower and long storage time. Mechanical damage though is mainly as a result of inappropriate harvesting techniques and inadequate means of transportation. Once fruits or vegetables are damaged there is a high chance of decay and growth of micro-organisms. Generally, technical factors can be addressed by training of harvesters and ensuring that appropriate transportation containers are used. This then may eliminate the effect of mechanical damage leaving researchers to concentrate on other factors.

Biological process of metabolism such as respiration, transpiration and biosynthesis cause fresh produce deterioration through moisture loss which may lead to senescence. The physiological deterioration due to biological processes is in itself compounded by environmental factors that can result in a significant loss of nutritional value. Harnessing of biological process can be done by the control and management of environmental factors.

Environmental factors of temperature and relative humidity are the two most important factors affecting the quality and the storage life of fresh produce. In sub-tropical climate of Limpopo province the air temperature is warm to high, which increases the rate of microbial changes, activating enzymatic reactions in produce. Respiration rate, metabolic processes and ethylene biosynthesis of some fruit increase with air/room temperature within a given range. Failure to manage surrounding air temperature especially in sub-tropical regions like Limpopo province may result in fresh produce losses of 25% to 50%.
To reduce the rate of decomposition and microbial spoilage of fresh produce the fruit and vegetables have to be stored at low temperature immediately after harvest. Relative humidity is another critical aspect that is considered during handling of fresh produce to ensure it does not deteriorate. When relative humidity is high, produce maintains its saleable weight, appearance, nutritional quality and flavour, while wilting, softening and juiciness are reduced. The control of environmental factors can only be done through appropriate storage facilities where temperature and relative humidity can be controlled.

Postharvest losses of fruit and vegetables for SCF in developing countries like RSA are due to lack of proper storage facilities. While there are a number cooling technologies available in the market such as conventional room cooling, forced-air cooling, hydrocooling, and mechanical refrigeration, these technologies are capital intensive and require electricity as input energy and as such are not affordable by SCF except evaporative cooling. Hence there is need to develop appropriate low cost cooling facilities for SCF.

There is evidence of use of hydro-cooling, forced air cooling and vacuum cooling by well-resourced and established LSCF in SSA including RSA. The use of these methods is found in flower production and large scale production for fresh produce especially for export purposes. There is also evidence of research and use of evaporative coolers by SCF in Africa. The results of use of evaporative cooling have demonstrated that coolers can maintain cooling spaces at temperatures below ambient with a depression reaching 12°C. Table 3.1 considers the major constraints in relation to SCF experienced in the use of each cooling technology.

Table 3.1 shows that cooling technologies require an electrical grid to power them and that the grid is not always close to SCF as some are remotely located. The two most limiting factors for the adoption of hydro-cooling and vacuum cooling by SCF is the initial capital cost and the energy demands. Conventional cooling technologies are regarded as energy intensive. Fossil fuels could be used but these are facing challenges because of greenhouse gas emissions and their use is discouraged. The alternative then is the use of renewable energy sources like solar and wind. Not much research work has been done on use of wind energy as a power source for cooling technologies.
Table 3.1 Major constraints in relation to small scale farming

<table>
<thead>
<tr>
<th>Cooling technology</th>
<th>Major constraints in relation to small scale farming</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro-cooling</td>
<td>Suited mainly for leafy produce and small SCF subsists on these. The challenge is that SCF also grow root and grass crops which would also require cooling. The biggest constraints in the use of hydro-cooling by SCF are the low energy efficiency and the capital cost involved in setting up this technology. SCF in SSA do not have resources to set up and sustain hydro-cooling.</td>
</tr>
<tr>
<td>Forced-air Cooling</td>
<td>As a specialised technology it requires skilled operators who are not always found with SCF. Forced air cooling has low energy efficiency and it is the most expensive cooling method.</td>
</tr>
<tr>
<td>Vacuum Cooling</td>
<td>The cost of cooling break-even point is high and requires higher volumes only sustained by large scale growers with economies of scale of growing high value cash crops like flowers. SCF produce low value produce that does not require high input cost.</td>
</tr>
<tr>
<td>Evaporative cooling</td>
<td>Evaporative cooling has had a big impact in cooling of buildings in Asia. At the same time natural ventilation evaporative cooling is being practised by many SCF. Forced air ventilation has been limited as a power source is required to power the fan. Major limitation is the high dew point that decreases the cooling capability.</td>
</tr>
</tbody>
</table>

This then provides an opportunity in the utilisation of wind energy to support cooling technologies. In the literature that has been reviewed there is evidence of research studies based on sorption refrigeration and air conditioning systems that use solar energy. The major limitation with this system is the high input cost of the refrigeration system which constitutes a large portion of the total cost, which prohibits its use among resource poor small scale farmers.

However, potential has been identified in the use of solar energy to power non-passive evaporative cooling for buildings. These success stories in this regard provide an opportunity for the use of solar energy to power a water pump and fan to drive non-passive evaporative cooling. From the conclusions made above, it is proposed that a study be carried to develop a wind and solar powered evaporative cooling system for temporary storage and transportation of fruit and vegetable.
4. PROJECT PROPOSAL

4.1 Introduction
This chapter presents the project proposal to design and evaluate the performance of a mobile cool container in the sub-tropical region of Limpopo province. The project proposal covers the problem statement, the objectives of the study that will include research aims, hypothesis and specific objectives, methodology of study, work plan and time schedule. The hypothesis and specific objectives will be used to investigate the problem statement. The methodology section will describe the procedures that will be followed to achieve the set objectives. This section will also highlight the equipment that will be used in the study. Finally, the intellectual property considerations, expected outcomes and deliverables as well as the contributions to new knowledge will be presented.

4.2 Problem Statement
The farming community incurs huge post-harvest losses annually in SSA (Kitinoja et al., 2011). As a result it is critical that attention is paid to this fact to ensure both small and large scale farmers are profitable and that there is enough fresh produce for consumers (Ntombela, 2012). It has been observed that tropical and subtropical fruit and vegetables such as tomatoes, carrots and spinach have problems in storage and transportation due to their nature of perishability (Mitra and Baldwin, 1997). Tomatoes are one of the most popular fruit/vegetable (Beckles, 2012). Due to the perishability conditions of fresh produce transport and storage are very critical (Talukder et al, 2003).

There are a number of cooling technologies for large scale commercial farming of fresh produce while at the same time there are limited choices for small scale farmers (Baloyi, 2010). The available technologies are capital intensive (Rayaguru et al., 2010) and are powered by grid electricity which is relatively expensive and not accessible to all small scale farmers. While the evaporative cooling technologies are less capital intensive (Tigist et al., 2011), its use on a large scale has been limited to cooling of building office space in Asia. In Africa it has only been used for temporary storage (Anyawu, 2004; Workneh, 2007; 2010) and not during transportation. There is currently no mobile evaporative cooling system in use for transportation of fresh produce. To increase the efficacy of evaporative cooling there is a need to provide forced air and this requires renewable energy sources. Since not all small scale farmers have access to grid electricity (Kim and Ferreira,
there is a need to provide an alternative source of energy like solar and wind (James and James, 2011). The use of solar energy to power a water pump and fan is very limited and literature providing evidence that wind energy has been used for evaporative cooling for fresh produce was not found. At the moment there is no appropriate cooling container technology which is cheap, efficient, uses renewable energy, and available for small scale farmers for temporary storage and transportation of fruit and vegetables that can maintain optimum conditions of relative humidity and temperature. Carrying out research focusing on the design, construction and performance evaluation of an appropriate cooling container for perishable fruit and vegetables for distribution in the region could result in solving challenges due to physiological deterioration that small scale fruit and vegetable farmers are facing.

The cooling container system will be expected to regulate the internal temperature of transport containers to keep perishable products at recommended storage temperature ranges. Furthermore, the cooling container will increase the micro-atmosphere relative humidity during the short term storage and distribution of fruit and vegetables. The cooling container should be able to maintain optimum storage conditions during the harvesting and waiting period for fresh produce to be transported and should also be mobile so that fruit and vegetables can be transported in the same container to the market. The technology to be introduced should be sustainable and will consider renewable energy utilization (Hayes, 1977) in the systems to be constructed. Combined wind and solar energy system will be considered to ensure clean energy is utilised for this system. Solar PV will be used to generate energy required for the cooling system (Fan et al, 2007; Hassan and Mohamad, 2012) during temporary storage while wind power will be used to power the system during the transportation.

A wind turbine can be introduced which rotates an electric generator and then electricity can be used to drive a cooling fan or water pump to circulate liquid as a coolant (FAO, 1979; Twidell and Weir, 1986). This can be designed in such a way that while a mobile cooling container is being transported/moved, the wind resistance against direction of motion of the cool chamber can be used to generate electricity to power the cooling fan. There is no evidence found in literature that solar energy has been combined with wind energy to power a forced air ventilation evaporative cooling system. This cooling
technology will encourage small scale and emerging fruit and vegetables farmers to enter the lucrative export market (Baloyi, 2010). The objectives, research aims and hypothesis of this study shall be indicated in the following sections.

4.3 Objectives of Study
The overall objective of this study is to reduce postharvest losses in fruit and vegetables due to environmental factors such as temperature and relative humidity that are usually experienced by small scale farmers in areas that are not linked to the national power grid. This will be achieved by developing an appropriate mobile cool container for small scale farmers for temporary storage and transportation of fruit and vegetables. The mobile container will be powered by clean renewable energy.

4.3.1 Research aims
The primary aim of this study is to design, construct and evaluate the performance of a mobile cool container that uses solar and wind energy sources to operate water pump and fan to circulate air in the storage unit during storage and transportation of fruit and vegetables.

4.3.2 Hypothesis
The following are the hypothesis of the studies:
1. Evaporative cooler can be powered by solar and wind energy sources.
2. The mobile cool container will increase the cooling efficiency, increase relative humidity and decrease temperature towards the recommended storage conditions for selected fruit and vegetables.
3. Modelling the air dynamics inside the mobile cool container will develop a system that maintains uniform distribution and delivery of chilled air throughout the packaging and container.
4. The quality of selected fruit and vegetable, during storage and transportation, in the mobile cool container will be such that they will be suitable and will meet the export requirements.

4.3.3 Specific objectives
To achieve the research aims and investigate the hypothesis, the specific objectives are:
1. To design and construct a solar and wind energy powered mobile cool container for storage and transportation of fruit and vegetables.
2. To evaluate the performance of a mobile cool container, in terms of cooling efficiency, an increase in relative humidity and a decrease in temperature.
3. To determine air flow pattern and resistance to air inside the cooler aimed at developing system that maintains a uniform distribution and delivery of chilled air throughout the packaging and mobile cool container.
4. To assess the quality change of selected economic fruit, root vegetable and leaf vegetable for export.
5. To develop an integrated pre-packaging and proper film packaging technology to be combined with the cooling container technology.

In order to test these objectives the following methodology will be applied.

4.4 Materials and Methods

4.4.1 Research site

The design and construction of the mobile cool container will be done at the workshop of the Agricultural Research Council’s, Institute of Agricultural Engineering (ARC-IAE) in Silverton, Pretoria with a geographical position of 25° 43’ 45.2” S, 028° 16’ 37.1” E, at an altitude of 1337m above sea level. Testing of the mobile cool container will be done on station at ARC-IAE and later field trials at selected sites of Dzindi Irrigation Scheme with GPS S 23° 01’ 35.0”, E 030° 25’ 56.2” 567m above sea level and Tshiombo irrigation scheme with GPS S 22° 48’ 22.1”, E 030° 25’ 58.3” and 648m above sea level in Limpopo province.

4.4.2 Design process

A theoretical design of the mobile cool container considering (i) water circulation system (ii) air circulation (iii) storage/transportation mobile chamber and (iv) relative humidity and temperature control system will be established. The theoretical design will be translated to the actual design that will be used for the construction of the mobile cool container prototype.

4.4.3 Theoretical design

The following factors will be determined:
• The storage capacity of the chamber depending on farmers’ requirement. The cooling load will included to calculate the field heat of fresh produce at harvest and the respiratory heat production will be used in designing for the cooling load.

• The ventilation rate (m³/s) will help to determine and to select the right fan size. The cooling pad size will influence the amount of water circulating per unit time. The amount of water circulating per unit time will help determine the pump size.

4.4.4 Construction of mobile cool container
Based on the theoretical design a mobile cooler will be constructed that will accommodate a maximum of 1 tonne of chosen fresh produce. The design and size will ensure that it fits at the back of a 1 tonne single can truck.

4.4.5 Evaluation of the performance of the mobile cool container
The mobile cool container air temperature and relative humidity will be monitored throughout the storage or transport period. The relative humidity of an air-water vapour mixture will be determined using psychometric charts. Both the dry bulb temperature (T) and the wet bulb temperature (T_w) of the inside of the mobile cool container will be recorded using a data recorder. Temperature will be recorded using psychrometer units attached to thermocouples located in the mobile cool container and outside the mobile cool container to measure ambient temperature. Both temperature and relative humidity will be measured on day 0, 4, 8, 12, 16, 20, 24, 28 and 32. The cooling efficiency will be calculated from the psychometric moist air properties.

4.4.6 Determining air flow patterns inside the mobile cool container
The air flow direction and speed in the effective storage area of the cool container will be monitored. The air dynamics/patterns and pressure loss inside the cool container will be measured according to Ngcobo et al. (2012).

4.4.7 Assessment of quality
Fruit and vegetables will be obtained at farm gate. Tomato will be used as a sample fruit while carrots and spinach will be used as root and leaf vegetables, respectively. The tomatoes will be harvested at green-mature stage while still firm (Casierra-Posada et al., 2008). The spinach will be harvested before yellowing settles in (Saenmuang et al., 2011).
It will be ensured that no possible damage has happened either mechanically or physiologically and all fruit and vegetables with bruises or signs of infection will be discarded. The fruit and vegetables will be weighed in crates to a weight of 10 kg and then placed in the mobile cool container. Laboratory tests will be carried out to determine physical damage or physiological deterioration resulting from the use of the mobile cool container.

4.4.8 Experimental design
Fruit from the randomised blocks will be harvested manually. Only tomatoes, carrots and spinach without observable mechanical injury, defects or blemishes will be selected for the study. A factorial experiment with Factor A, of controlled cooling and ambient temperature, Factor B, of packaging of integrated packaging and ordinary perforated box packaging and Factor C (fruit or vegetable) of tomato, Carrot and spinach. The experimental design will be randomised complete block design in a factorial arrangement with three replications. The tomatoes, carrots or spinach will be temporarily stored or transported either under ambient temperature or in the mobile cool container and will be replicated three times according to fruit or vegetables type. The fruit or vegetables will be harvested from the different geographical areas. Analysis of variance (ANOVA) will be used to test for any significant difference in relative humidity and temperature. According to Little and Hills (1978) where there are variations greater than 40% the data will be angularly transformed by arcsine of the square root of the actual ratios to achieve binomial distribution.

4.5 Work Plan, Time Schedule and Equipment and Resources
Having discussed the methodology, it is paramount that all the research activities be well scheduled in a log frame.

4.5.1 Work plan and Time schedule
The list of required equipment and resources are also included in section. To complete the methodological approaches described in the previous section, the following work plan and related activities are proposed to ultimately achieve the purpose of the study.
### PROPOSED RESEARCH ACTIVITIES AND WORK PLAN

#### PROPOSED RESEARCH ACTIVITIES, WORK PLAN AND DELIVERABLES

<table>
<thead>
<tr>
<th>Task Description</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
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<tbody>
<tr>
<td>Development of Seminar Paper</td>
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<tr>
<td>1.1 Literature review and write-up</td>
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<tr>
<td>1.2 Submission of 1st, 2nd and 3rd draft seminar paper</td>
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<td>1.3 Submission of final draft seminar paper</td>
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<tr>
<td>1.4 Presentation of seminar paper</td>
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<tr>
<td>Literature Review</td>
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<tr>
<td>Design of cooler</td>
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<tr>
<td>3.1 Design considerations</td>
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<tr>
<td>3.2 Theoretical design</td>
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<tr>
<td>3.3 Design drawings</td>
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<tr>
<td>Construction of cool container</td>
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<tr>
<td>4.1 Drawing BOQs</td>
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<tr>
<td>4.2 Acquisition of construction materials</td>
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<tr>
<td>4.3 Construction of mobile container</td>
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<tr>
<td>Laboratory Experiments</td>
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<tr>
<td>5.1 Testing of cool container at IAE</td>
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<tr>
<td>5.2 Field Testing of cool container</td>
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<td>5.3</td>
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<tr>
<td>Data Analysis</td>
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<tr>
<td>Thesis write-up</td>
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<tr>
<td>Deliverables</td>
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<tr>
<td>8.1 Seminar paper and Presentation</td>
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<tr>
<td>8.2 Submission of first draft of thesis</td>
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<tr>
<td>8.3 Submission of final draft of thesis</td>
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</tbody>
</table>
4.5.2 Equipment and resources

Acquisition of capital expenditure and living expenses

The living expenses will be covered by the salary of the student as he is contracted by ARC-IAE.

<table>
<thead>
<tr>
<th>ITEM DESCRIPTION</th>
<th>COST</th>
<th>SOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acquisition of capital items for construction of mobile cool container to include; fan, water pump, pipes, and insulating and electrical material and all the instrumentation.</td>
<td>150,000</td>
<td>ARC-IAE</td>
</tr>
<tr>
<td>Acquisition of fruits and vegetables for testing</td>
<td></td>
<td>ARC-IAE</td>
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<tr>
<td>Accommodation and Subsistence Expenses</td>
<td>50,000</td>
<td>ARC-IAE</td>
</tr>
<tr>
<td>Travel Expenses: ARC-IAE to UKZN</td>
<td>20,000</td>
<td>ARC-IAE</td>
</tr>
<tr>
<td>Stationary and Office Support</td>
<td>15,000</td>
<td>ARC-IAE</td>
</tr>
<tr>
<td>Attending one/two seminars/conferences</td>
<td>R30,000</td>
<td>ARC-IAE</td>
</tr>
<tr>
<td><strong>Total Budget</strong></td>
<td><strong>R265,000</strong></td>
<td></td>
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</table>

4.6 Intellectual Considerations

The official documentation of the University of KwaZulu-Natal related to intellectual property titled: *Intellectual Property and Proprietary Information Agreement (Form IP2)*, was signed and submitted to the School of on the 1st of September 2011.

4.7 Expected Outcomes and Deliverables

The following outcomes and deliverables are envisaged as a final product from this study:

(a) Knowledge contributions:

i. One Doctor of Philosophy in Agricultural Engineering dissertation;

ii. Two/more published articles in accredited journals;

iii. One/more national and international conference attendance/presentation; and

iv. Low cost mobile cool container that is powered by clean energy.
(b) Societal contributions: Society will benefit from the knowledge contributions listed in (a), the envisaged mobile cool container will encourage small scale and emerging fruit and vegetable farmers to enter the export market.

(c) Health and economical contributions: The results from the study will extend the shelf life of fruits and vegetables thus minimising the postharvest losses and this will translate to higher income to the small scale farmers.

(d) Environmental contributions: use of renewable energy to power the mobile cool container will reduce reliance on grid electricity and fossil fuels use and thus a reduction in the greenhouse gas emissions. The extended shelf life of fruit and vegetables will ensure all produce is sold while it is still palatable and this will significantly reduce road side dumping which might cause land pollution.
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