DESIGN OF THE IMPROVED EVAPORATIVE COOLING STRUCTURE FOR STORAGE OF TOMATOES IN MOROGORO

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE IN POST-HARVEST TECHNOLOGY AND MANAGEMENT OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA.

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EXTENDED ABSTRACT

In most developing countries, smallholder farmers face several challenges while embarking on their farming for agriculture crop production. The challenges are serious during post-harvesting processes. The phenomenon is evident in sub-Saharan countries, Tanzania inclusive. Tanzania's economy is agriculturally based which contributes 26.7% of its GDP and it employs over 80% of the population. As such any efforts geared to eradicate poverty and improve livelihoods should focus on the agriculture (horticulture subsector) which is characterized by small scale subsistent farming, low productivity, and huge post-harvest losses. These huge losses can be attributed to a lack of appropriate post-harvest processing techniques, low awareness, on the part of good harvesting and packaging practices or techniques and lack of storage facilities. Morogoro smallholder farmers of tomatoes are not spared from this phenomenon. Several storage technologies for curbing tomato post-harvest losses have been introduced to smallholder farmers. Some technologies have shown promising results. However, more investigation of the technology's effectiveness is needed.

This study aimed to design an evaporative cooling structure for the storage of tomatoes. A need assessment survey was conducted to help generate information on tomato handling practices and losses for small scale farmers and retailers in six selected areas in the Morogoro region. Sixty respondents with at least 3 years of farming or retailing tomatoes were purposively selected through the help of the extension officer and market leaders to represent part of the tomatoes' handling chain. The findings obtained showed that farmers were not using any storage facilities for tomatoes while retailers used inferior handling facilities and some did not use any storage facilities, ultimately losing most of their tomatoes. This study found that tomato post-harvest losses (PHLs) were 29.7% at the farmers' level and 18.4% at the small scale retailers' level during handling and marketing.

The majority of the respondents showed a desire to possess evaporative coolers to reduce tomato PHLs. In this context, the improved wind operated passive evaporative cooling (IWOPEC) storage structure for tomatoes was designed and fabricated, and its performance was evaluated against other storage conditions. A randomized complete block design (RCBD) was used. The storage environment conditions considered were ambient (AT), cold room (CR), and IWOPEC structure. The results on the effects of temperature and relative humidity (RH) were significantly different ($p<0.05$) under the studied storage environments. Total soluble solids and percentage weight loss significantly increased ($p<0.05$) for all studied environmental conditions, whereas firmness and titratable acid significantly decreased ($p<0.05$) in response to storage time and environmental conditions. The IWOPEC structure reduced temperature, increased RH and gave peak and daily average cooling efficiency of 84.89% and 61.67%, respectively. The result of the benefit-cost ratio (BCR) was 2.51 shows using the IWOPEC structure for the storage of fresh ripened tomatoes is viable. In areas with high PHLs under AT, using the IWOPEC structure to improve the shelf life of tomatoes is economically feasible. Improvement of the IWOPEC structure by having water boot sump and a water pump to increase the cooling efficiency of the storage atmosphere is recommended.

DECLARATION

I, Leonard Saimon Mwankemwa, do hereby declare to the Senate of the Sokoine University of Agriculture that this dissertation is my original work done within the period of registration and that it has been neither submitted nor concurrently submitted in any other institution for a degree award.

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DEDICATION

This work is dedicated to the Almighty God, my parents, my wife, and my family members, who have always been my source of inspiration. Their moral support and insistence enabled me to conduct and complete this study successfully.

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LIST OF ABBREVIATIONS AND SYMBOLS

ANOVA	Analysis of Variance
AT	Ambient temperature storage
CO_2	Carbon dioxide
CR	Cold Room storage
CRBD	Completely Randomized Block Design
ECSs	Evaporative Cooling Structures
IWOPEC	Improved Wind Operated Passive Evaporative Cooler
mm	millimeters
RH	Relative Humidity
rpm	revolution per minute
SPSS	Statistical Package for the Social Sciences
SUA	Sokoine University of Agriculture
TMA	Tanzania Metrological Agency
TSS	Total Soluble Solids
TTA	Total Titratable Acids
TZS	Tanzania shillings
w/w	weight per weight
WPTC	World Processing Tomato Council
%	Percentage
<	Smaller than
>	Greater than
°C	Degree Celsius

CHAPTER ONE

1.0 General Introduction

1.1 Tomato (*Lycopersicon esculentum mill.*)

Tomatoes (L*ycopersicon esculentum mill.*) are one of the most important cultivated and consumed horticultural crops globally. The nutritional and economic importance of this crop has led to its extensive production (Ochida *et al.,* 2019). Tomato fruits are high in phytonutrients such as vitamins (B, folate, C, and E), minerals (potassium), fiber, carotenoids, and polyphenols, as well as antioxidants. In most cases, tomatoes are consumed fresh as well as in many cooked and processed products (Szabo *et al.,* 2018). Tomatoes and tomato based foods provide a wide variety of nutrients and many health related benefits to the human body. The ripened fruits contain high amounts of lycopene, beta-carotene, naringenin, and chlorogenic acid with antioxidant properties which are beneficial in reducing the incidence of some chronic diseases like cancer and many cardiovascular disorders. In most of the areas where it is cultivated and consumed, it constitutes a very essential part of the people's diet (Viuda-Martos *et al.,* 2014). The importance of tomatoes, explained in this section, resulted in an increase in tomato production, as presented in sub section 1.1.1 of this chapter.

1.1.1 Tomato production

The numerous uses of tomatoes can be a contributing factor to their widespread production (Ochida *et al.,* 2019). The most important consideration in the world today is to provide nutritious food to approximately six billion people (Fróna *et al.,* 2019). The World Processing Tomato Council (WPTC); and Ronga *et al.* (2021) reported that the world production estimate for 2020 was 38.402 million metric tonnes, with China as the largest producer, estimated to produce about 5.8 million metric tonnes, which is 15.1% of global production (Incrocci *et al.,* 2020), while Africa contributes 11.98% (4.6 million metric tonnes) of total global tomato production. Within the African continent, tomatoes are one of the most widely grown vegetables due to their versatility, with production cutting across from smallholder to commercial farming communities (Dube *et al.,* 2020). In Tanzania, the annual tomato production is 129,578 metric tonnes, which represents 51% of the total vegetable production (Luzi-Kihupi *et al.,* 2015). Tomatoes are grown in many parts of Tanzania, with smallholder farmers producing a significant amount (Mutayoba and Nguruko, 2018; and Kapeleka *et al.,* 2020).

The increase in tomato production was made possible by the numerous research advances along the entire value chain. Although postharvest issues are a major problem in most developing countries, most scientific researchers have mainly focused on the production part (Duarte *et al.,* 2020). It is reported that less than 5% of resource allocation in agricultural research in developing countries is on postharvest while more than 95% of resource allocation is on production (Arah *et al.,* 2016). The majority of research conducted along the value chain of tomatoes is based on improving tomato varieties to increase yield and resistance to both diseases and drought (Gatahi, 2020). Kitinoja *et al.* (2018) reported that, many developing countries, tomato producers have achieved better harvests in recent years. However, their better harvests have not translated into profit due to high post-harvest losses (PHLs). There are several causes of PHLs; some of these causes are shown in the following subsection of this chapter.

1.1.2 Tomato storage

Because tomatoes contain 95% water and 5% carbohydrates and fibers, they are difficult to store for an extended period of time at ambient tropics temperatures, which are warm all year round, averaging 25 to 28 °C (Miller, 2001). Meanwhile, storage in the value chain is usually required to ensure the availability of tomatoes throughout the season (Arah *et al.*, 2016). Despite the remarkable progress made in increasing tomato production, tomato farmers in most developing countries are still facing many challenges, mainly in post-harvest losses. These losses are due to poor postharvest handling practices and storage, which result in both qualitative and quantitative losses (Liberty *et al.*, 2013; and Arah *et al.*, 2015). Tomato losses are estimated at 40 to 50% annually between the harvesting and consumption stages of the distribution chain and mostly occur during storage (Moges *et al.*, 2019). Tomatoes have a shelf life of about 48 hours under ambient tropical conditions due to their inherent high moisture content. To extend the shelf life of the crop and maintain the quality of harvested tomatoes, proper storage is required to control the temperature and relative humidity of the storage atmosphere (Liberty *et al.*, 2013).

Refrigeration storage is one of the best options for lengthening the shelf life of stored fresh tomatoes. However, due to high initial capital, unreliable electricity supply, high operating costs, and a lack of managerial skills, its application and adaptability to small scale farmers in developing countries is limited (Lal Basediya *et al*., 2013). For better results and to avoid chilling injuries, handlers should maintain refrigerated storage temperatures of about 10 °C to 15 °C and relative humidity levels between 85 and 95% (Arah *et al.*, 2016). This can also be achieved by using less expensive methods of cooling, such as evaporative cooling technology, which seems to be a more appropriate cooling technology for developing countries like Tanzania.

1.2 Problem Statement and Justification of the Study

1.2.1 Problem statement

Temperature and relative humidity are the dominant factors leading to PHLs for fruits and vegetables in developing countries. For fruits and vegetables, the estimated losses range between 5% and 20% in developed countries and 20% to over 50% in developing countries, with remarkable variation between crops and between countries (Kitinoja and Kader, 2015). Small scale farmers in Mlali ward produce different kinds of fruits and vegetables, including tomatoes. Tomatoes from Mlali are supplied to local and other urban markets within the Morogoro region and other regions in the country. Tomato, as a climacteric fruit, is susceptible to chilling and highly perishable produce, and its deterioration is exacerbated by postharvest handling challenges at both the farmer and retailer levels, resulting in postharvest losses. These losses can be interpreted as the loss of inputs, including capital, the farmer’s energy, and other resources like water and fertilizer. Postharvest losses experienced by smallholder farmers and retailers are of major concern to Mlali farmers and retailers in markets within Morogoro Municipality. Most losses are caused by improper handling practices, a lack of knowledge about how to avoid PHLs, inadequate storage facilities, limited resources, climate change, a poor road network, and small scale farmers' inability to afford cost-intensive cooling and storage systems (Mahajan *et al*., 2017; Kasso and Bekele, 2018).

Evaporative cooling structures for the storage of perishable crops can be used for the storage of fresh tomatoes. Despite being an appropriate technology for use in developing countries, evaporative cooling structures have been observed to have low cooling efficiency due to existing harsh weather, poor structural design, and operating systems (Ndukwu and Manuwa, 2014; Sibanda and Workneh, 2020b). This situation calls for the need to develop an improved evaporative cooling structure, whose cooling efficiency will be determined and expected to be higher due to structural design considerations. It will be affordable and user-friendly by using wind to operate the structure. Wind as a freely available energy source is underutilized and can be harnessed using simple technology, unlike other renewable energy. Therefore, to address the problem of high PHLs in tomato storage, this study focused on developing an improved wind operated passive evaporative cooling (IWOPEC) structure which will be capable of increasing the shelf life of stored fresh tomatoes while maintaining their quality and eventually reducing the PHL of stored fresh tomatoes.

1.2.2 Justification

To maintain the quality and increase the shelf life of fresh tomatoes, appropriate storage is required to control the temperature and relative humidity of the storage atmosphere (Mahmood *et al.,* 2019). Evaporative cooling structures seem to be a better choice as they remove sensible heat from the produce and are more effective in hot areas (Lal Basediya *et al.,* 2013). In such structures, fresh tomatoes can be stored for an average of five days with minimum changes in weight and firmness (Tasobya, 2019). However, this performance depends on the design of the evaporative cooling structure. Conical, pyramidal, cylindrical, and hexagonal evaporative cooling structures were found to work better compared with a square shape for storage of perishable crops (Mogaji and Fapetu, 2011; Manuwa and Odey, 2012; Deoraj *et al.,* 2015).

Wind operated passive evaporative cooling (WOPEC) structures have shown great potential for further development, but their cooling efficiency (%) is unknown. Research opportunities for structural improvement to have high thermal performance and knowledge of their cooling efficiency (%) are required as a contribution to the science of ECSs. In a comparative study, the square WOPEC was reported to be inferior in temperature reduction to the cylindrical WOPEC structure by 1 °C (Sunmonu *et al.,* 2016). However, the storage capacity for square structures is higher compared with cylindrical structures. Detailed research results of cooling performance on other WOPEC designs, specific to tomatoes, are missing. Therefore, this study is focused on designing a truncated cone (a frustrum) shaped IWOPEC structure for the storage of fresh tomatoes. Increasing cooling performance and storage volume will significantly minimize tomato postharvest losses due to the adoption of this technology. Hence, this leads to increased fresh tomato shelf life and the availability of more readily marketable fresh tomatoes in the market.

1.3 Objectives of the Study

1.3.1 General objective

The general objective of this study was to develop the Improved Wind Operated Passive Evaporative Cooling (IWOPEC) structure for economical storage of fresh tomatoes for small scale tomato farmers and retailers in Morogoro.

1.3.2 Specific objectives

The specific objectives were:

1. To assess the existing tomato storage structures and tomato post-harvest losses in selected areas within the Morogoro region.
2. To develop and evaluate the IWOPEC structure for storage of fresh tomatoes.
3. To evaluate the cost-benefit analysis of the IWOPEC structure for the storage of fresh tomatoes.

1.4 Literature Review

1.4.1 Handling of tomatoes

Handling tomatoes after harvest under normal environmental conditions is challenging, and the use of proper storage technology is inevitable. The application of poor storage technology for tomatoes has resulted in high postharvest losses (PHLs). PHLs have a social and economic impact on both small scale tomato farmers and retailers

(Chattopadhyay, 2018). Different temporary storage facilities have been employed to control temperature and relative humidity (RH), which are the main sources of tomato deterioration. These facilities include cold storage and evaporative cooling structures (ECSs). The application and adaptability of these facilities in tomato storage at a small scale level are still not well adopted due to several factors like awareness, efficiency, storage capacity, unreliable electricity, chilling injury to stored tomatoes, and high purchasing and running costs (Nkolisa *et al.*, 2018; Sibanda and Workneh, 2020a). There are several facilities which, if used, could reduce PHLs; some of these facilities are shown in the following subsection of this chapter.

1.4.2 Cold storage technologies in the preservation of tomatoes

Recently, large-scale promising advanced technologies (high-tech) such as cold storage for maintaining the freshness of fruits and vegetables for a specified period have been invented. The study on the storage of fruits and vegetables in cold rooms by Godana *et al.* (2020) found that for good results, temperatures must be in the range of 0 °C to 15 °C. The study also recommended cold rooms as devices for inhibiting the activity of microorganisms, the incidence of pathogens, enzymatic reactions, and the rate of fruit decay. Kumah *et al.* (2011) found that cold rooms tend to slow the respiratory metabolism of fruits, preventing them from rotting and extending their storage period. Modern chilling machinery uses the rapid freezing method to achieve the preservation, which greatly improves the quality of preservation and storage of fruits and vegetables. However, some of the tropical and sub-tropical fruits and vegetables, including tomatoes, cannot be stored at very low temperatures as they are susceptible to chilling injury (Liberty *et al.*, 2013). Apart from chilling and freezing injuries, the availability of reliable power supply, initial investment, and high operational costs makes cold storage expensive and thus unaffordable for low-income farmers in rural communities (Kitinoja, 2013; Wakholi *et al.,* 2015; Sibanda and Workneh, 2020a). This study seeks to address these challenges.

1.4.3 Evaporative cooling systems and factors affecting storability of perishable agricultural produce

Evaporative cooling systems (ECSs) are also referred to as evaporative refrigerators since they operate by evaporation and are used as refrigerators. Evaporative coolers are fantastic and, when used correctly, can provide much needed cooling for a short period of time. However, ECSs can rarely manage to keep temperatures as low as modern refrigerators. Warmer temperatures and less storage space are part of the trade-offs for their low cost and simplicity (Shahzad *et al.,* 2018; Yahaya and Akande, 2018). Numerous research studies that were conducted in the field of evaporative cooling systems reported them to be effective in mitigating PHLs of perishables at the farmer's level.

Due to their nature, fruits and vegetables are termed perishable produce as they are characterized by high water content and a short shelf life after harvest. Perishable crops like tomatoes are chilled sensitive crops and their shelf life can be increased by lowering respiration rate, decreasing sensitivity to ethylene gas and reducing water loss. Variety, stage of ripening, ambient temperature, and relative humidity are factors which affect the shelf life of fruits and vegetables, ultimately leading to their spoilage (Liberty *et al.,* 2014; Babaremu *et al.,* 2019). To avoid chilling injuries and losses, ripe tomatoes can be stored at temperatures of about 10 ºC to 15 ºC and 85% to 95% relative humidity. Fruits and vegetables stored in poor storage conditions such as high temperatures can deteriorate due to physiological activity, pathological infection, mechanical injuries, and evaporation of water (Benichou *et al.*, 2018). Furthermore, the length of storage is among the factors that affect the quality of fresh agricultural produce. Tomato fruits can be stored in tropical ambient conditions for a short period of less than 7 days if there is enough ventilation to reduce the accumulation of heat from respiration (Abiso *et al.,* 2015). Post-harvest operations through the handling of fruits and vegetables may lead to a decrease in their quantity, quality, and nutritional value (Elik *et al.,* 2019). The common changes that occur during post-harvest include loss of weight, change in firmness, change in total soluble solids, and change in the produce acid level (Parra-Coronado *et al*., 2018; Sinha *et al.,* 2019). Minimizing PHLs of perishable agricultural produce can be achieved through proper control of the above mentioned factors. Therefore, to retain the quality of fresh tomatoes, proper storage of tomatoes is inevitable.

1.4.4 Theory and basic principle of evaporative cooling systems

Generally, an evaporative cooler is made of a porous material that is water-saturated lagging material. The ECSs could be built by using locally available materials and effectively be able to maintain the shelf-life of fruits and vegetables for some days (Lal Basediya *et al.,* 2013). The working principle of ECSs makes use of the free latent energy in the atmosphere through the relationship between air and water, directly or indirectly, with air acting as a water carrier (Baniyounes *et al.*, 2013).

Cooling occurs when hot and dry air is drawn over the materials and the evaporated water into the air, raising its humidity and lowering its temperature. The faster the rate of evaporation, the greater the cooling effect. The efficiency of a cooler depends on the humidity of the surrounding air. Very dry air can absorb a lot of moisture, resulting in a greater cooling effect.

A psychometric chart (Fig. 1.1) is used to determine the amount of cooling if the ambient conditions of the air are known (Riangvilaikul and Kumar, 2010). The most important thing to remember is that the wet-bulb temperature is the minimum temperature that evaporative coolers can achieve no matter how they are constructed. This is irrespective of the use of charcoal or sponges instead of sand or if you use a bag instead of an outer pot. Technically, anything that increases evaporation is good.

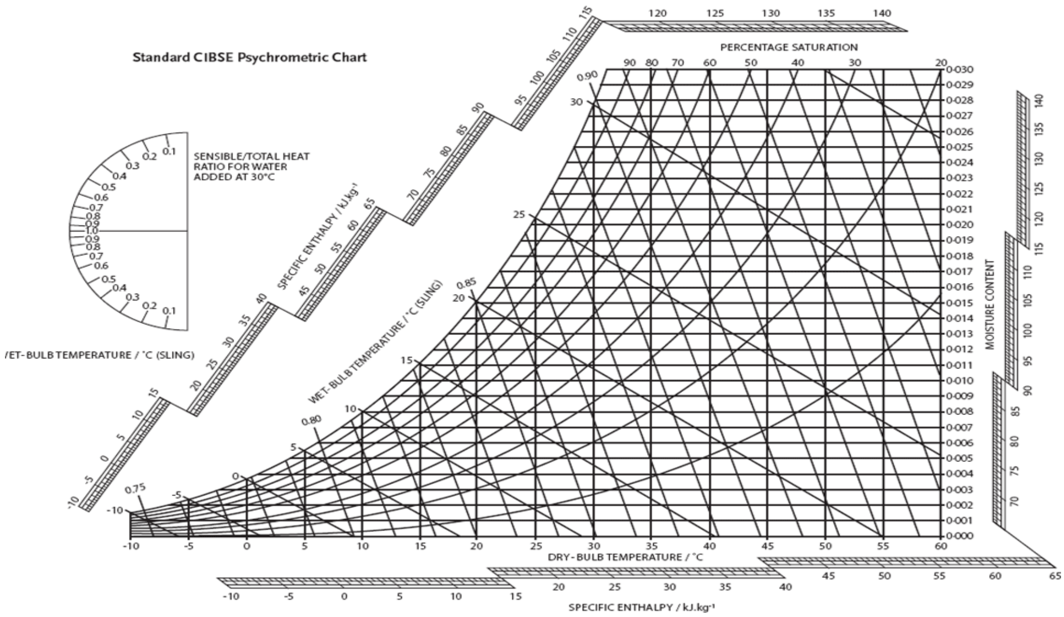

Figure 1.1: Psychrometric chart used to read dry and the wet bulb temperatures

(Source: https://bytlly.com/1i5tyx)

1.4.5 Classification of evaporative coolers

Evaporative cooling structures for the storage of fruits and vegetables are classified into three categories: direct, indirect, and combined evaporative coolers. The direct evaporative coolers are the ones in which the working fluids (water and air) are in direct contact. For the indirect evaporative coolers, there is the existence of a surface (or plate) which separates the working fluids. Lastly, the combined system of direct and indirect evaporative coolers consists of features of both direct and indirect evaporative cooling

(Amer *et al.,* 2015; Bijarniya *et al.,* 2020). Direct evaporative cooling structures can be further classified into active and passive cooling. Active cooling involves the use of electricity to operate a device such as a fan that increases the rate of evaporation. Passive cooling devices use natural phenomena in a thermal zone rate of evaporation (Amer *et al.,* 2015). The current study focuses on the direct class evaporative cooler under the passive category.

1.4.6 Existing evaporative cooling structures

1.4.6.1 Wall in wall evaporative coolers

This type of evaporative cooling technology falls under the direct class evaporative cooler under the passive category and is mostly for summer cooling with high insulation levels, which makes them perform in cold seasons too (Carbonari *et al.,* 2015). It consists of a double-walled rectangular brick construction with the interspace filled with water-saturated lagging material (see appendix 1). The interior surfaces of the cooling chamber wall can be plastered with cement, while the top carries a heat-insulating cover of thick particle board. The walls are built on a short plinth of concrete, and one side of the wall is provided with an access door of sawn wood, and shelves can be provided in the cooler chamber. Fresh produce stored in wall-in-wall evaporative coolers lost less weight but had a higher percentage of rot (Zakari *et al*., 2006; Sunmonu *et al*., 2016).

1.4.6.2 Zero Energy Cooling Chambers (ZECC)

This is an indirect type of evaporative cooler, normally built using local materials, with specially arranged burnt bricks interspaced with porous materials. Perishable produce can be stored in containers in the ZECC (Verploegen *et al.,* 2019). The size of the ZECC structure depends on the amount of produce to be stored. The ZECC can be thought of as a generation of a wall in wall evaporative structures, except that bricks are not joined by mortal and are not plastered (Appendix 1). Generally, under ambient temperatures, tomatoes can have a shelf life of 7 days compared with an extended tomato shelf life of 18 days, equivalent to 75% efficiency in storage. The combination of lower temperatures and higher humidity inside the cooling chamber prevents the decay of tomatoes, consequently increasing their shelf life to 14 days (Lal Basediya *et al.,* 2013). The temperature inside the ZECC can be reduced through the process of an evaporative cooling mechanism and by using a shading curtain to protect the ZECC against direct exposure to solar radiation.

1.4.6.3 Pot in pot refrigerator (clay pot cooler or zeer)

The impact of the pot in pot refrigerator is immediately realized as the shelf life of most produce is extended by 5 to 10 times compared to ambient storage (Chen *et al.,* 2021). Pots of different size are inserted one inside the other separated with water saturated material (Appendix 1). The structure cooling performance depends on the breeze strength, which facilitates evaporation. Also, exposing it to indirect solar radiation aids in evaporation and makes it colder. Instead of using clay pots, it is recommended to use metal pots or cloth bags for better results (Guo, 2016; Joardder and Masud, 2019). Use of pot in pot refrigerator structure was reported to be a good means of storage and extension of shelf life although research verification is needed in this area especially in East African climate, as most of the previous researches were done in West Africa and Middle East (Zheng *et al.*, 2014).

1.4.6.4 Metal-in-wall evaporative cooling

The metal-in-wall evaporative cooling structures are similar to the ZECC, which were developed using bricks (see appendix 1); the cooler chamber is lined with metal, and the interspace material mostly used is sea or riverbed sand. Falayi and Jongbo (2011) constructed the structure with local rammed earth in which storage trials were conducted for tomatoes and vegetable leaves for eight days. Weight loss of the produce and visual observations were carried out to determine the level of deterioration of the produce. Results showed that the cooling chamber attained an average temperature drop of about 7 °C when compared with the 24 °C ambient storage temperature and an average of 74% relative humidity, which was a drop of about 4% that was experienced throughout the study period. The percentage weight loss in the cooler was 4% and 17% for tomatoes and amaranthus, respectively. The author concluded that the structure can successfully store fruits and vegetables for 6 to 8 days without visible deterioration.

1.4.6.5 Metal double walls (Metal in Metal)

A metal in metal evaporative cooling structure differs from a wall in wall evaporative cooling structure in construction materials and cooler size; however, structurally and in shape, they are similar (Appendix 1). The cooling structure was developed using two metal sheets interspaced with porous water lagging materials, with the WOPEC structure as a good example. In the study by Sunmonu *et al.* (2016), in which tomatoes were stored for 16 days, the WOPEC inside the structure registered an average temperature of 6.53ºC lower and 22.86% higher RH compared to ambient values of 33.6ºC and 69.41%, respectively.

1.4.7 Factors affecting evaporative cooling efficiency

Evaporative cooler designs look simple, but several complex scientific principles govern cooling performance and life. The cooling efficiency of evaporative cooling structures depends on various parameters, including pad materials (jute, sisal, sand, soil, charcoal, sponge, etc.) and their water holding capacity; pad thickness; size of perforations of the pad; surface area; water flow rate and wind speed; temperature; and relative humidity of inlet air (Manuwa and Odey, 2012; Ndukwu and Manuwa, 2014; Tasobya, 2019). Most of the factors above were considered during the design and fabrication of the IWOPEC structure during this study.

1.4.8 Future direction of evaporative cooling structures

There have been numerous research studies in the area of evaporative cooling for the storage of perishable crops. Most researchers have put more effort into the development and evaluation of passive and active cooling structures and usually use prototypes consisting of small metal structures (Ndukwu and Manuwa, 2014). Sunmonu *et al*. (2016) focused on the development of wind operated evaporative cooling structures and made a comparative study of cylindrical and square-shaped structures. The study observed a temperature reduction of 6.53 ºC against the ambient temperature of 33.6 ºC and an increase in relative humidity by 22.86% against the ambient relative humidity of 69.41%. The report concluded that the shape of the structure affects cooling performance and storage capacity.

Manuwa and Odey (2012) carried out investigations using local materials used for making cooling pads and shapes for constructing evaporative coolers. Materials investigated included sisal fibres, latex foam, charcoal, and wood shavings. The shapes of cooling systems considered were hexagonal and square cross-sections. Results of tests indicated that the effectiveness of the cooling pads was in the following decreasing order of magnitude: sisal, latex foam, charcoal, and wood shavings. The hexagonal-shaped cooler was found to be more effective in cooling than the square shape. The authors recommended the use of results from this study to assist researchers in their selection of pad materials and structure shape in the study of evaporative cooling systems.

Wanyama (2015) revealed that the slow uptake of the ECSs technology by smallholder farmers was mainly due to ECSs efficiency. Due to this, it was recommended to integrate evaporative cooling technologies into agricultural value chain adoption and adaptation processes. The uptake recommendations by previous researchers revolved around the modification of the existing evaporative cooling structures to increase their performance in storage.

1.4.9 Wind energy utilization in agriculture

Farms have long used wind power to generate electricity for pumping water for ranches and irrigation. Recently, large wind turbines have been installed to provide power to electric companies and consumers (Rehmani *et al.,* 2018). Through technology innovations and economies of scale, the global wind power market has nearly quadrupled in size over the past decade and established itself as one of the most cost-competitive and resilient power sources in the world. Global wind power is estimated at 743 GW, helping to avoid the emission of over 1.1 billion tonnes of CO_2 globally (i.e., 1.48 tonnes of CO_2 avoided per 1W of the installed power plant) (Council, 2021). The available minimum wind power was 0.021W, according to the IWOPEC structure design section of Chapter 3. In that case, with the IWOPEC structure in use, we will avoid a minimum of 31.08 kg of CO_2 globally.

In most cases, the post-harvest stage is a crucial part of the perishable produce handling line that requires facilities that, in most cases, use energy, which is expensive. In this study, the focus was on the direct use of wind energy to power the tomato storage structure to be developed. The cooling efficiency of the intended tomato storage structure depends on many factors, including wind speed. The working mechanism of IWOPEC starts at the wind speed, which actuates the vanes, which transmit rotational energy to the fan inside the storage structure via the shaft. In this study, the working principle explained above was adopted.

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CHAPTER TWO

2.0 Tomato Post-harvest Losses as Influenced by Improper Handling Facilities in Morogoro, Tanzania

2.1 Abstract

Perishables have been a challenge for so long in developing countries. The current status is critical and its control for small scale farmers and retailers has not been adequately addressed. This study aimed to generate information on tomato handling practices and losses for small scale farmers and retailers in six selected areas in the Morogoro region, Tanzania. A need assessment survey was conducted to help gather information on tomato postharvest handling and practices to prepare possible mitigation actions for tomato losses. Sixty respondents with at least 3 years of farming or retailing tomatoes were purposively selected through the help of the extension officer and market leaders to represent part of the tomatoes' handling chain. The SPSS version 16 statistics software was used for data analysis using descriptive statistics. The findings obtained showed that farmers were not using any storage facilities for tomatoes while retailers used inferior handling facilities and some did not use any storage facilities, ultimately losing most of their tomatoes. This study found that tomato post-harvest losses (PHLs) were 29.7% at the farmers' level and 18.4% at the small scale retailers' level during handling and marketing. Besides, 60–80% of the farmers and 30–80% of the retailers were unaware of the existence of evaporative cooling structures (ECSs) to avert tomato PHLs. However, 60–80% of all respondents indicated a desire to have ECSs used to improve their tomato business. This prompted the need to have ECSs introduced to extend the shelf life of tomatoes while maintaining their quality and hence reducing PHLs.

Key words: Tomato, Storage, Farmers, Retailers, tomato varieties, Shelf life

2.2 Introduction

Tomatoes (*Lycopersicon esculentum mill.*) are one of the most widely cultivated and consumed horticultural crops globally. The nutritional and economic importance of this crop has led to its extensive production (Ochida *et al.,* 2019). Tomatoes are an important part of most people's diets in the areas where they are grown and consumed (Arah *et al*., 2015a). The World Processing Tomato Council (WPTC) reported that the global production of tomatoes for the year 2020 was estimated at 39.2 million metric tonnes, with China as the largest producer, estimated to produce about 5.6 million metric tonnes, equivalent to 14.3% (Incrocci *et al.,* 2020), while Africa contributes 11.8% (4.6 million metric tonnes). Within the African continent, tomatoes are one of the most widely grown vegetables due to their versatility, with production cutting across from smallholder to commercial farming communities (Dube *et al.,* 2020). In Tanzania, annual total production is estimated at 129 578 metric tonnes, representing 51% of the total vegetable production (Luzi-Kihupi *et al.,* 2015). Tomatoes are grown in many areas within Tanzania, with significant production by smallholder farmers (Mutayoba and Nguruko, 2018; Kapeleka *et al.,* 2020).

In the tomato value chain, postharvest losses constitute a major problem in most developing countries, but scientific researchers have mainly focused on the production part (Duarte *et al.,* 2020; Cattaneo *et al.,* 2021). It is also reported that less than 5% of resource allocation in agricultural research in developing countries is on postharvest while more than 95% of resource allocation is on production (Arah *et al.,* 2016). Tomato post-harvest losses are estimated at 40 to 50% annually between the harvesting and consumption stages of the distribution chain and mostly occur during storage (Kasso and Bekele, 2018). Tomato postharvest losses are mainly caused by many factors, including the inherently high moisture content that limit its shelf life of about 48 hours under intense ambient tropical conditions (Arah *et al.,* 2016), environmental conditions, and poor post-harvest practices, including storage. Other factors include limited knowledge on how to avoid PHL, weak infrastructure, weak institutional support, limited resources, and the inability to afford cost-effective cooling and storage systems (Mahajan *et al.,* 2017; Kasso and Bekele, 2018). The losses accrued are both qualitative and quantitative, which are the result in poor realization of profit by both farmers and traders (Arah *et al.,* 2015b). The losses can be interpreted as losses of inputs, energy spent by farmers, soil nutrients, and other resources by stakeholders, including farmers and traders.

Currently, the tomato loss status in Morogoro is not documented and its chain control for small scale farmers and retailers has not been adequately addressed. The overall aim of this study was to assess the existing tomato post-harvest handling facilities, including storage structures and awareness of PHLs in Mlali ward and retailers within Morogoro Municipality in the Morogoro region, Tanzania. Information from this study will be useful for introducing mitigation measures for post-harvest losses, including the design of suitable tomato storage structures and the formulation of policies and strategies for the reduction of post-harvest losses.

2.3 Material and Methods

2.3.1 Study area

The study was conducted in Morogoro Municipality, located on the foot slopes of the Uluguru Mountains (6º 49’ 15.67" South in latitude and 37º 39' 40.39" East in longitude with an elevation of around 500 m above mean sea level) in the eastern part of Tanzania and Mlali ward in Mvomero district in the Morogoro region (6° 58' 0" South in latitude and 37° 32' 59" East in longitude). Based on the last national census (NBS, 2012), Morogoro Municipality and Mlali ward (Fig. 2.1) had a population of over 315,866 people and 23 320 people, respectively. This population constituted important stakeholders in tomato farming and the tomato trade. The survey work on retailers was done in three markets (Manzese, Mawenzi and Nanenane) in Morogoro Municipality and three villages in Mlali ward (Mlali, Mkuyuni and Kipera) in the Mvomero district, which represent part of the tomato handling chain.

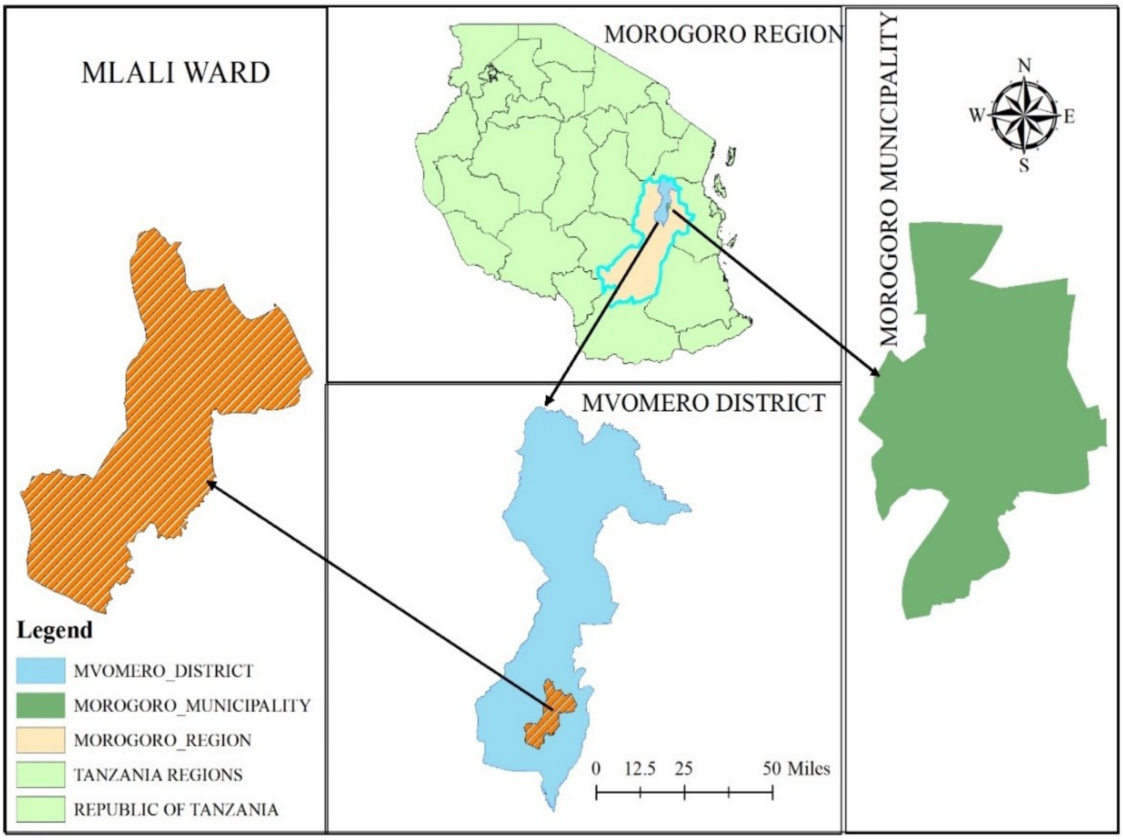

Figure 2.1: Map of Tanzania showing the study site.

2.3.2 Methodology

A purposively sampling technique was used to select the respondents based on one's knowledge of the population, its elements, and the nature of the research aims (Sullo *et al.*, 2020). The other criterion was the experience of at least 3 years of farming or retailing tomatoes. This method was selected because the selected farmers and retailers shared similar characteristics in terms of tomato farming and trading. The post-harvest handling related inquiries were prepared, pre-tested with sample respondents, rechecked for their appropriateness for clear understanding and responding, and administered. A total of 60 respondents were selected with the help of the ward Agricultural Extension Officer. Of the selected respondents, 10 respondents represent one cluster study location (Mlali, Kipera, and Mkuyuni villages; Manzese, Mawenzi, and Nane nane markets).

2.3.3 Data collection

Data was collected from farmers and retailers through administering a structured questionnaire, which comprised open and close-ended questions; a focus group discussion was also held in each study location to validate the data. The aim was to collect information on the varieties grown in Mlali ward, current postharvest handling practices, and the associated losses in Mlali ward and Morogoro municipality. Also, information on awareness of ECS technology was gathered.

2.3.4 Data analysis

The collected data was coded and subjected to statistical Package for Social Sciences (SPSS) version 16 using descriptive analysis. These included means, frequency, and percentages.

2.4 Results and Discussion

2.4.1 Description of the tomato varieties grown in Mlali ward

The tomato varieties grown in Mlali ward and the proportion of farmers involved in their production in the respective villages are presented (Fig. 2). The small scale farmers in all three villages in Mlali ward have shown an overall preference for the Asila F_1 and Imara F_1 varieties. This was attributed to the ability of these varieties to resist diseases, large fruit size, high yields, long shelf life, attractive appearance, and toughness of the fruit mesocarp. These findings are in line with the findings of Panth *et al.* (2020) who stated that variety in crop production determines the product quantity, quality, marketability as well as the ability to tolerate the climate, environmental hazards and diseases. The findings from the current study are also supported by the results of the study conducted by Palilo (2019) who reported that Asila F_1 and Imara F_1 were disease-resistant varieties to tomato bacterial wilt and recommended them to farmers in the Morogoro region. However, there were no explanations provided concerning the cultivation of other tomato varieties, though on a relatively small scale, except for T0-135 grown by 20% of farmers only in Kipera village.

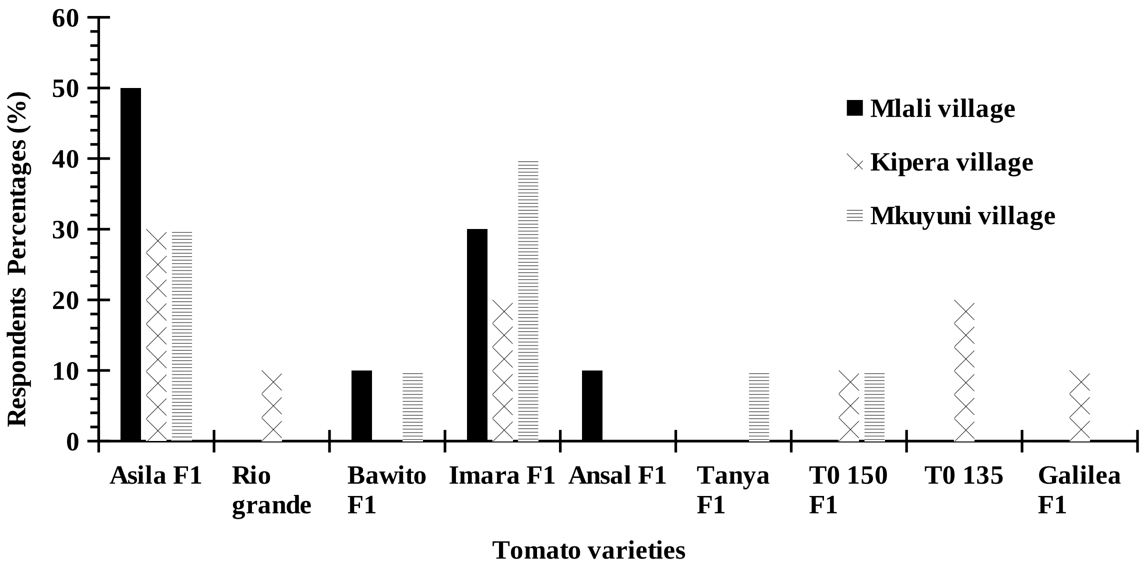

Figure 2.2: Tomato varieties grown by small scale farmers in Mlali ward

2.4.2 Packaging practices techniques in the study areas

Results on tomato postharvest handling techniques in Mlali ward (Table 2.1) have shown that bamboo baskets, wooden crates, plastic crates, plastic buckets, and cardboard boxes are used in the handling and transportation of tomatoes. The majority of the farmers (40-60%) were using bamboo baskets to pack their produce for transportation. This was followed by the use of wooden crates (20–30%), which is increasingly becoming popular.

The use of bamboo baskets was due to the local availability of fabrication materials and low cost. Bamboo baskets were also used to handle tomatoes by the majority of traders (40–50%) as they bought loads distributed to them by other traders in these baskets. Of late, 20% of farmers in Mlali and Mkuyuni villages have used plastic crates (Table 2.1).

Apart from their high initial cost, plastic crates' use is promising as they can be reused several times compared to other packaging means, which are used only once unless they are reworked for suitability of use (Lo-Iacono-Ferreira *et al.*, 2021). Plastic buckets were seldom used except in the municipal trade centres where the use of tables (10-20%) and display stalls (20-30%) was also practiced. Display in open tables is disadvantageous due to the inability to control the environment as well as the fluctuation of weather that may seriously affect the produce respiration rate (Tschirley *et al.*, 2019). The use of full or partially ventilated stalls may give fair results, although the challenge of temperature instability may persist in produce quality that may amplify quantitative losses. The use of wooden crates, plastic buckets, and cardboard boxes has also been reported to increase the perishability rate of tomatoes due to the accumulation of field heat and spread of diseases, compression of the produce due to their weight, and high chances of mechanical damage, including bruises (Nkolisa *et al.*, 2017).

Table 2.1: Percentage postharvest packaging practices of tomatoes in the study areas

Location	Bamboo basket	Cardboard boxes	Wooden crates	Plastic crates	Plastic Bucket	Open tables	Stalls	Total %
Kipera	60	10	20	-	10	-	-	100
Mlali	40	10	30	20	-	-	-	100
Mkuyuni	30	-	50	20	-	-	-	100
Manzese	40	10	-	-	10	10	30	100
Nane nane	40	-	10	-	10	20	20	100
Mawenzi	50	-	-	-	-	20	30	100

2.4.3 Postharvest tomato losses in the study areas

The postharvest losses suffered by small scale tomato growers and retailers in the various study locations are depicted in Fig. 2.3. During the handling and marketing of tomatoes, losses of 18.7%, 21.3%, and 15.4% were reported at Manzese, Mawenzi, and Nane nane retail markets, respectively. Furthermore, at the small scale, farmers' level tomato losses during harvesting and handling were approximately 32.4, 31.0, and 25.3% in Mlali, Kipera, and Mkuyuni villages, respectively (Fig. 2.3). It can be hypothesized that most of the tomato losses experienced in the study areas as presented in Fig. 2.3 and 2.4 were due to the reasons explained in post-harvest handling practices shown in Table 2.1 above. Most of these PHL losses were influenced by many factors including hot weather, lack of air circulation, nature of storage, lack of marketing strategy, attack by microorganisms, poor transportation means, improper harvesting and handling methods and pests (including insects), as shown in Table 2.2. The results from this study are also supported by the study conducted by Nowicki *et al.* (2012).

The observed on-farm PHLs are similar to that reported by Lal Basediya *et al.* (2013) and Kasso and Bekele (2018) who reported tomato losses experienced by smallholder farmers to be 20 to 35%. Nevertheless, these losses are less than 67% at the farmers' level, as reported by Nkolisa *et al.* (2017). The estimated PHLs from the current study is similar to that reported by McKenzie *et al.* (2017) on tomato losses in developing countries, estimated at around 50%. The estimated tomato losses at the retailers' level are in line with results in the study conducted by Kitinoja *et al.* (2018) who reported PHLs of tomatoes at the retailers' level to be in the range of 15 to 20%, which in most cases might be attributed to the high ambient temperature. Hetta and Kamuzora (1999) reported the highest recorded temperature in Morogoro to be 37.2 to 33°C around January, which was close to the time when this study data was collected. Therefore, the findings from the current study highlight the importance of the development and use of improved postharvest handling facilities to reduce the PHLs of the produce and increase their shelf life.

Table 2.2: Cross tabulation – highlighted response on causes of postharvest losses in study areas

Losses causes	**Kipera village**	**Mlali village**	**Mkuyuni village**	**Manzese market**	**Nane nane**	**Mawenzi market**	**Total reaction**
Transportation means and handling methods	1	2	2	2	3	2	12
Nature of storage and lack of ventilation	-	-	-	2	1	1	4
Over ripening and moisture loss	1	2	2	-	1	-	6
Hot weather and Marketing	1	1	1	-	-	1	4
Over ripening, Microorganisms, insects and pests	4	3	4	2	1	2	16
Harvesting method and lack of air circulation		1	1	1		-	3
Hot weather over ripening	3	1		3	4	4	15
Total respondents per area	10	10	10	10	10	10	60

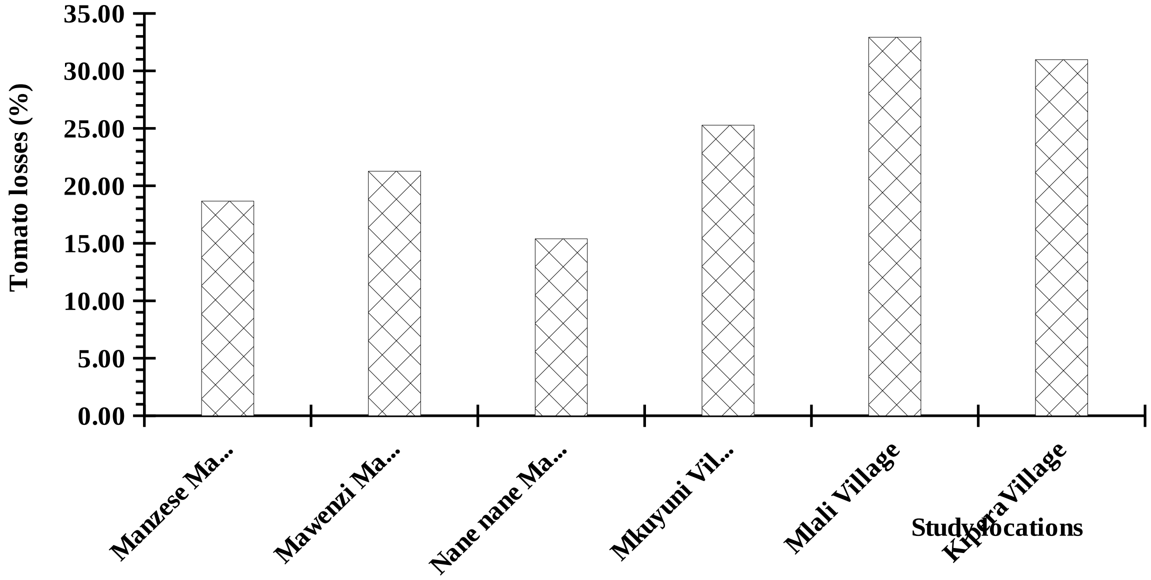

Figure 2.3: Average percentage PHLs on tomatoes experienced by different villages and markets in Morogoro.

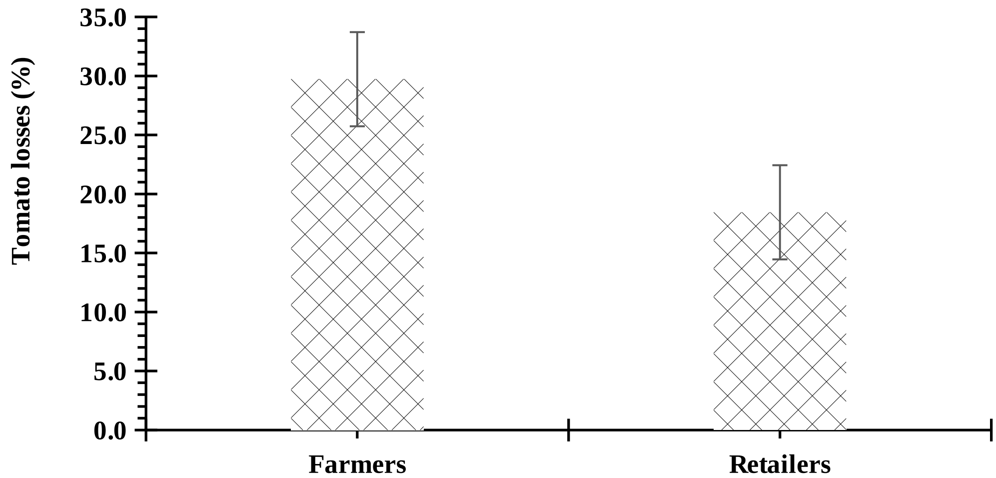

Figure 2.4: Average percentage PHLs on tomatoes experienced by farmers and retailers in Morogoro.

2.4.4 Experienced monetary losses on tomatoes in the study areas

Monetary losses experienced due to PHLs and seasonal selling prices in the study locations are presented (Fig. 2.5 and Fig. 2.6). The study findings demonstrated the dry season experienced lower monetary losses compared to the rainy season due to the difference in tomato production and selling prices. At the farmers' levels, the losses averaged in the range of USD 452 to 790 during the dry season and USD 1349 to1790 per household during the rainy season in all three villages (Fig. 2.5). The same trend was shown at the retail level where losses ranged between USD 6 and USD 37 during the dry season and between USD 8 and USD 52 in the rainy season in all the Morogoro municipal markets per retailer (Fig. 2.6). These losses are of greatest concern to retailers and farmers involved in tomato handling as a transaction between retailers and farmers or middlemen is a business with the expectation of financial returns afterwards (Lenné and Ward, 2010). Bisbis *et al.* (2018) reported that during dry seasons temperatures are high while there are numerous favourable tomato production conditions including fewer pests and diseases which contribute to excess production of tomato fruits. Similarly, higher production in dry seasons, improper handling skills, poor knowledge and low awareness of proper storage facilities lead to major produce and monetary losses (Wunderlich and Martinez, 2018).

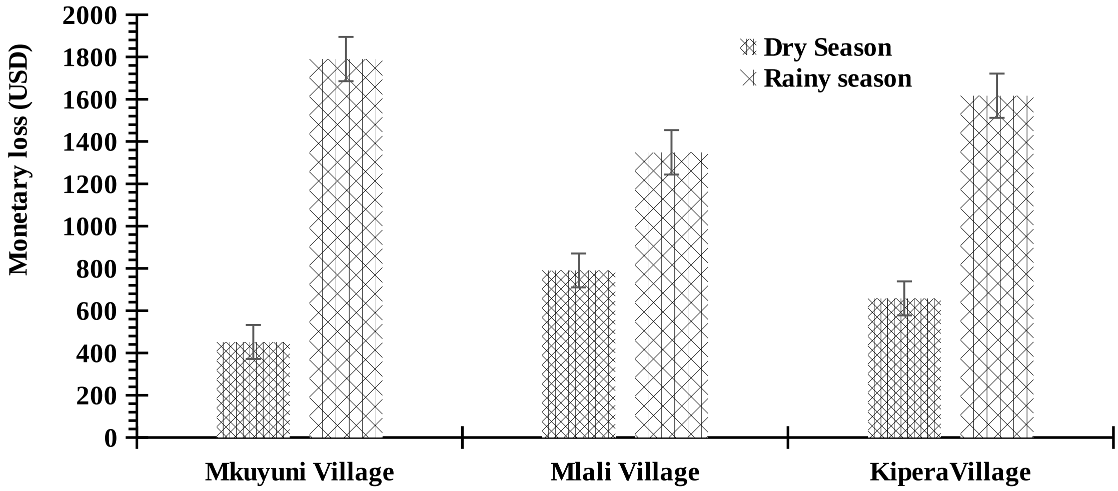

Figure 2.5: Monetary losses experienced by small scale farmer of tomato at Mlali ward

(*United States Dollar (USD) equals to 2,307.00 Tanzanian Shilling: 7 Oct, 2021 11:56 UTC)

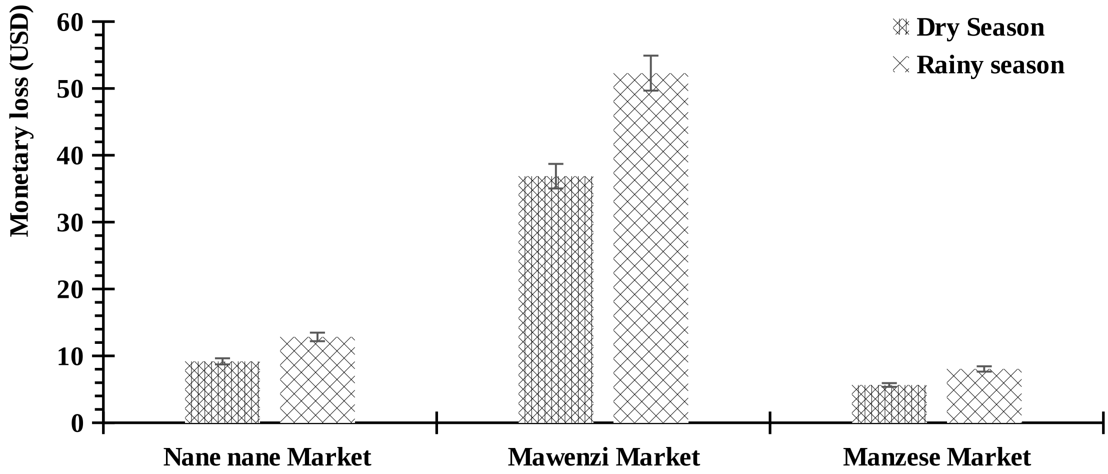

Figure 2.6: Monetary losses experienced by retailers of tomato in Morogoro Municipality Markets.

(* United States Dollar (USD) equals to 2,307.00 Tanzanian Shilling: 7 Oct, 2021 11:56 UTC)

2.4.5 Awareness on evaporative cooling systems and testing

Awareness of the small scale tomato farmers and retailers of ECSs and the interest in using them are presented (Fig. 2.7). Lack of awareness about ECSs was reported by 70%, 80%, and 60% of small scale tomato farmers at Mlali, Kipera and Mkuyuni villages, respectively. The findings are similar to those by Ndukwu and Manuwa (2014) who reported that most of the inhabitants in rural areas have never seen or used any evaporative cooling structures (ECSs) in their lifetime. Lack of awareness of ECSs was reported by 80% of retailers in each of the Mawenzi and Manzese markets and 30% in the Nanenane market. However, 70% of tomato retailers at Nane nane market were aware of ECSs as most of them had seen them at exhibition grounds but had never used or tested them.

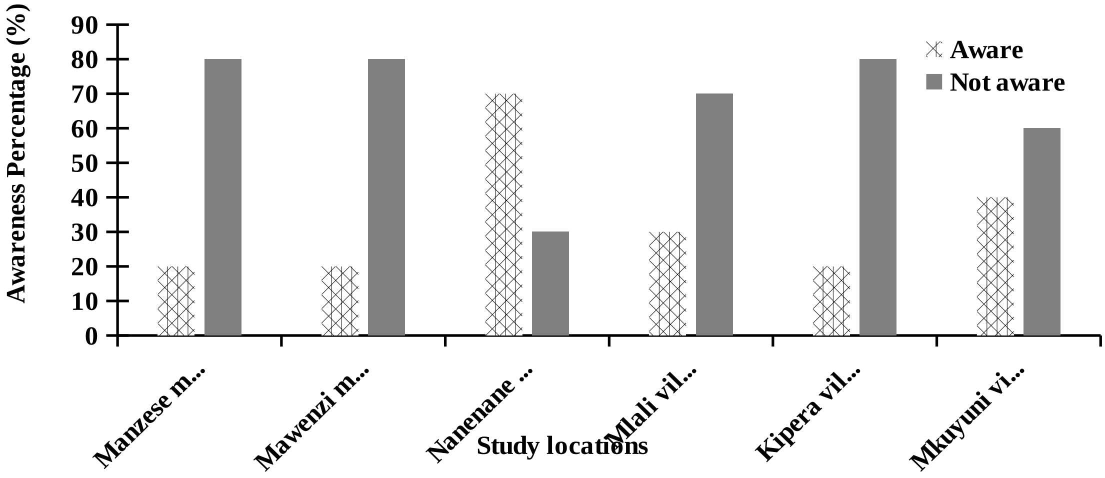

Figure 2.7: Awareness of tomato farmers and retailers on the existence of evaporative cooling structures (ECSs) in Morogoro

The majority of the respondents were interested in testing the ECSs technology as indicated in Fig. 2.8. Eighty percent (80%) of tomato retailers at Manzese market and 70% at Nanenane market were interested. Concerning farmers, 70%, 60%, and 70% in Mkuyuni, Mlali and Kipera villages, respectively were interested. This implies that the respondents were interested in technological intervention which would help them save their tomatoes during postharvest storage and marketing.

The IWOPEC structure as a new technology in the study locations has raised awareness among most farmers and retailers (Fig. 2.7). This indicates that the respondents would wish to adopt an intervention that would help them save their tomatoes during the postharvest phase (Fig. 2.8). Adoption of ECSs would help tomato handlers reduce postharvest losses since it can reduce ambient temperatures and increase relative humidity, it can be made using readily available local materials, needs less manpower and is easy to maintain (Nkolisa *et al.,* 2017).

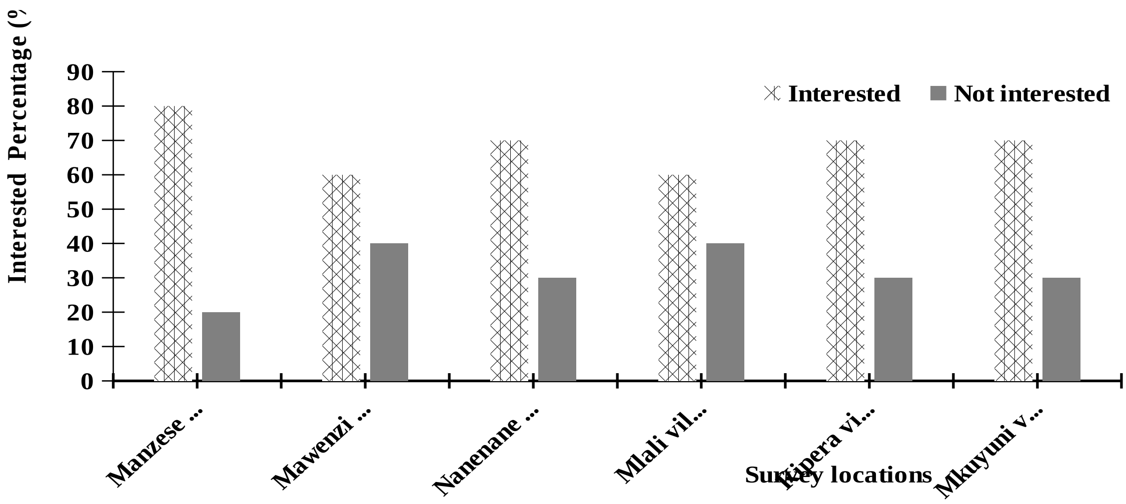

Figure 2.8: Respondent’s interest in using ECSs technology

2.5 Conclusion

The common tomato varieties grown in Mlali ward and the factors contributing to high post-harvest losses of fresh tomatoes were revealed. The common tomato varieties grown in Mlali ward are Asila F1 and Imara F1. Tomato farmers and retailers are challenged by the large number of tomatoes lost due to improper postharvest handling methods used by the chain of actors, including farmers and retailers themselves. Dry season farming experiences more PHLs compared with rainy season farming. Inappropriate storage facilities to store tomatoes after harvest was one of the major value chain challenges faced by farmers and retailers that prompted a need for proper means of storage to be introduced to increase the shelf life of tomatoes and reduce losses. Most tomato retailers and farmers were not aware of evaporative cooling systems which could help them maintain produce shelf life. About 70% of the farmers and retailers were interested in owning the IWOPEC structure because it would be very useful to them and would help reduce tomato postharvest losses. More studies are required to up-scale the IWOPEC for adoption in municipal markets and recommend it to stakeholders, including policymakers.

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CHAPTER THREE

3.0 The Effect of an Improved Evaporative Cooling Structure on Shelf Life of Stored Tomatoes in Morogoro Region, Tanzania.

3.1 Abstract

The losses on perishables have been a challenge in most developing countries. The current status is critical and its control for small scale farmers and retailers has not been adequately addressed. The lack of simple storage facilities in the tomato supply chain contributes to high postharvest losses of tomatoes in Tanzania. This study aimed to design an evaporative cooling structure for the storage of tomatoes. An improved wind operated passive evaporative cooling (IWOPEC) was designed, fabricated and evaluated for its performance. The experimental design was a Randomized Complete Block Design (RCBD). The storage environment conditions considered were ambient (AT), cold room (CR) and IWOPEC structure. Collected data were analysed using GENSTAT software. Under the studied storage environments and times, the results on the effects of temperature and relative humidity (RH) were significantly different ($p<0.05$). Firmness and titratable acid significantly decreased ($p<0.05$) in response to storage time and studied environmental conditions, whereas total soluble solids and percentage weight loss significantly increased ($p<0.05$) for all studied environmental conditions. The IWOPEC structure reduced temperature, increased RH and gave peak and daily average cooling efficiency of 84.89% and 61.67%, respectively. In areas with high PHLs under AT, using the IWOPEC structure to improve the shelf life of tomatoes is economically feasible. Improvement of the IWOPEC structure by having water boot sump and a water pump to increase the cooling efficiency of the storage atmosphere is recommended.

Key words: Tomato, IWOPEC, Evaporative cooling structures (ECSs), Farmers, and Retailers.

3.2 Introduction

Tomato (L*ycopersicon esculentum mill.*) is one of the most important widely cultivated and consumed horticultural crops globally. The nutritional and economic importance of this crop has led to its extensive production (Ochida *et al.*, 2019). The world processing tomato council (WPTC) reported that the world production estimate for 2020 was 39.2 million metric tonnes, with China as the largest producer, estimated to produce about 5.6 million metric tonnes which are 14.3% of global production (Incrocci *et al.*, 2020) while

Africa contributes 11.8% (4.6 million metric tonnes) of total global tomato production. In Tanzania, the annual total production of 129, 578 metric tonnes, represents 51% of the total vegetable production (Luzi-Kihupi *et al.,* 2015). Tomatoes are grown in many areas within Tanzania, with significant production being from smallholder farmers (Mutayoba and Nguruko, 2018; Kapeleka *et al.,* 2020).

Although tomato postharvest issues are a major problem in most the developing countries Tanzania included, most the scientific researchers have mainly focused on the production part (Sibomana *et al.,* 2016; Duarte *et al.,* 2020). The impact made was that tomato producers achieved better harvests in recent years; however, their better harvests have not translated into profit due to high post-harvest losses (PHLs). Tomato has very high moisture content and therefore is very difficult to store at ambient temperatures for a long time. Meanwhile, storage in the value chain is usually required to ensure the availability of tomatoes throughout the season (Arah *et al.,* 2016). Tomato losses are estimated at 40 to 50% annually between the harvesting and consumption stages of the distribution chain and mostly occur during storage (Moges *et al.,* 2019). In most cases, the losses are caused by improper handling practices, limited knowledge on how to avoid PHLs, inadequate storage facilities, limited resources, climate change, poor road network and the inability of the small scale farmers to afford cost-intensive cooling and storage systems (Mahajan *et al.,* 2017; Kasso and Bekele, 2018).

Refrigeration storage is one of the best options for tomato storage techniques used to achieve low storage temperature and controlled relative humidity. However, its application and adaptability to small scale farmers in developing countries are limited due to high initial capital, unreliable electricity supply, high running costs and lack of managerial skills (Lal Basediya *et al.,* 2013). These conditions can be achieved by using less expensive methods of cooling such as evaporative cooling technology which seems to be a more appropriate cooling technology for small scale farmers in developing countries like Tanzania since it is cheap, does not require high managerial skills and does not depend on electricity which is expensive and unreliable. The available evaporative cooling structures for storage of perishable crops despite being the appropriate technology for prolonging the shelf life of fresh tomato storage in developing countries have been observed to have low cooling efficiency due to existing harsh weather, poor structural design and operating system (Ndukwu and Manuwa, 2014; Sibanda and Workneh, 2020). In such structures, fresh tomatoes can be stored for an average of five days with minimum changes in weight, and firmness (Tasobya, 2019). This depends on the design of the evaporative cooling structure and mode of operation. Conical, Pyramidal, cylindrical and hexagonal evaporative cooling structures work better compared with a square shape for perishable crops (Mogaji and Fapetu, 2011; Manuwa and Odey, 2012; Deoraj *et al.*, 2015).

Wind operated passive evaporative cooling (WOPEC) structures have shown great potential for further development, research opportunity for improved efficiency and high thermal performance. Also, cooling performance in cylindrical evaporative cooling structure is higher by more than 1°C compared with square one. However, the storage capacity for square structures is high compared with cylindrical (Sunmonu *et al.*, 2016). Based on the stated limitations above, there was a need to develop an improved evaporative cooling structure, which will be efficient, affordable and user friendly by using wind as a freely available energy source to operate the structure.

Therefore, to address the problem of high PHLs in tomato storage, this study focused on developing an improved wind operated passive evaporative cooling (IWOPEC) structure which will be capable of increasing the shelf life of stored fresh tomatoes while maintaining their quality and eventually reducing PHL in stored fresh tomatoes. Detailed research results on other designs, specific for tomatoes are missing. Therefore, this study is focused on designing a frustum shaped IWOPEC structure for the storage of fresh tomatoes. Adoption of this technology will significantly minimize tomato postharvest losses, leading to the availability of more fresh tomatoes in the market. Furthermore, it will lead to enhanced quality, increased shelf life and making tomatoes readily marketable.

3.3 Material and Methods

3.3.1 Study location and climate

This study experimental and laboratory work were conducted at Sokoine University of Agriculture (SUA) in Morogoro Municipality, located on the foot slopes of the Uluguru Mountains (6^{o} 49’ 15.67” South in latitude and 37^{o} 39’40.39” East in longitude with an elevation of around 500 m above mean sea level) in the eastern part of Tanzania, 196 kilometres West of Dar es Salaam.

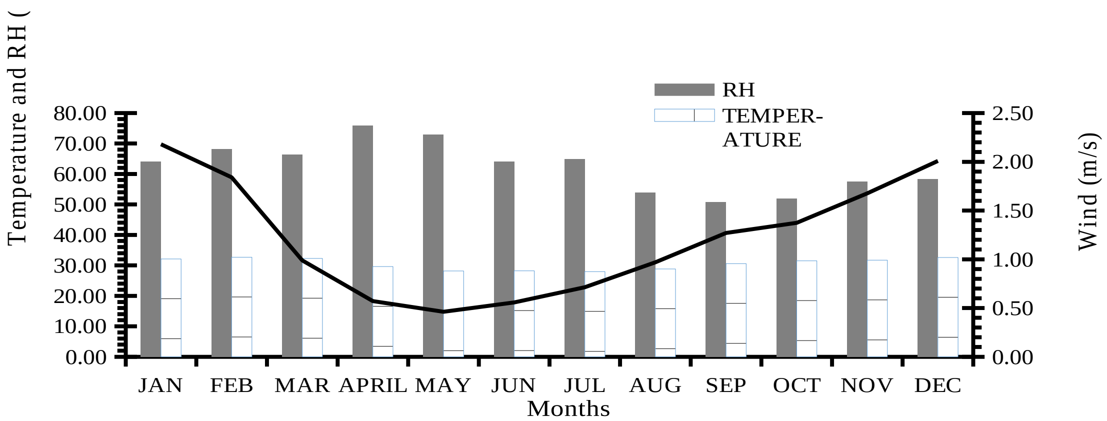


Figure 3.1: Monthly weather data at study location for 5 years (TMA – SUA)

Note: RH is the relative humidity (%); Temperature ºC; and Wind, is the wind speed (m/s).

3.3.2 Design of the of the IWOPEC structure

The design criteria for the IWOPEC structure were based on locally available materials at the level of tomato farmers and retailers in their respective areas while considering evaporative cooling design principles. The choice of the materials was based on the availability of the materials, suitability of the materials under the specific working conditions, cost of the materials, water holding capacity, strength, hardness, toughness and reaction of the materials for food and water as suggested by Luhar *et al.* (2019). As part of the general requirements, the efficiency of a passive evaporative cooler depends on the rate and amount of evaporation of water from the respective saturated material. This is dependent upon the air velocity, the filling material thickness and the degree of saturation of the filling material which is a function of the water flow rate wetting the filling materials (Tasobya, 2019). The interspace filling and covering materials used in this study (i.e sand and sisal bags) were similar to those used in the studies by Babarinsa (2006); Sunmonu *et al.* (2016) and; Balogun and Ariahu (2020).

3.3.2.1 Structural design considerations

The design and fabrication of the IWOPEC structure considered durability, storage capacity and efficiency of the system. Other factors were surface area for air movement, lightweight for easy relocation, and perforated base and vented top wood cover for easy airflow and insulation. Develop of the IWOPEC structure was a stepwise process from the cooling chamber capacity to its efficiency when loaded with stacked webbed plastic crates carrying tomatoes without failure during its intended lifespan.

3.3.2.2 Structural dimensions

A truncated conical, frustum shaped IWOPEC structure (Fig. 3.2) replicated three times was developed using an aluminium sheet 1 mm thick. The inner and outer frustum was separated by a 7 cm thick sand layer. Average volume (cm^3), the volume of plastic crates and samples number (or size) of tomato fruit to be stored guided the choice of structural dimensions. As shown in Fig. 3.2, the structure has an internal radius of 20 cm (R_1) at the bottom and 10 cm (R_2) at the top, a height (H) of 50 cm and a side length (S) of 51cm. The corresponding outside dimensions were 27 cm radius at the bottom and 17 cm radius at the top, and the same height of 50 cm. The structure was covered by sisal sack material on the outside surface which was constantly wetted with ambient temperature water. The bottom aluminium plate was perforated with 16 holes of 8 mm diameter at different locations scattered throughout the plate to allow cold wet air to enter the cooling chamber. The inner chamber of the structure is covered by a wood piece at the top with an air vent around the bearing.

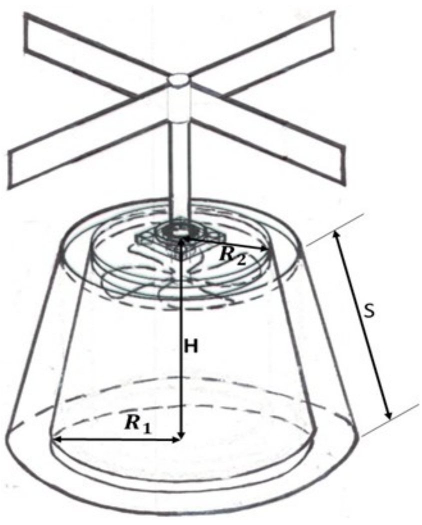


Figure 3.2: Shape of the designed IWOPEC structure

(Note: R_1, is the bottom radius; R_2, is the top radius; S, is the side length and H, is the height).

The side length (S) was calculated by using Equation 1 described by Easa, (1991).

$$S=\sqrt{\left(\left(R_1-R_2\right)^2+H^2\right)}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where: R_1 = the bottom radius, R_2 = the top radius, S = the slope, H = structure height

$S=\sqrt{¿}¿$

3.3.2.3 Cooling chamber volume

To calculate the cooling chamber volume (cm^3) a height of 10 cm was considered as the fan working position in the cooling chamber, meaning the two stacked plastic crates which carry samples of tomato in the chamber can reach up to this height from the bottom (Fig. 3.3). A height of 5 cm separates the chamber bottom and first plastic crate and in between the plastic crates to allow airflow. The dimensions of the plastic crate were 26cm long, 15 cm high and 18cm wide with the two crates occupying 14 040 cm^3 in total the chamber volume. Consideration was also made to the empty spaces between tomatoes, structure and crates (Fig. 3.3).

The designed cooling chamber dimensions with consideration of the fan-led to the calculated volume (V) of 25 643.33 cm^3 using the formula (Equation 2) described by Butuner (2015).

$$Volume=\frac{1}{3}*\pi*H*\left(R_1^2+R_1*R_2+R_2^2\right)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where: R1, is the bottom radius; R2, is the top radius; S, is the slope and H, is the height of stored materials in cooler chamber

$$Volume=\frac{1}{3}*3.14*35*\left(20^2+20*10+10^2\right) \quad = \quad 25\,643.33\ \text{cm}^3$$

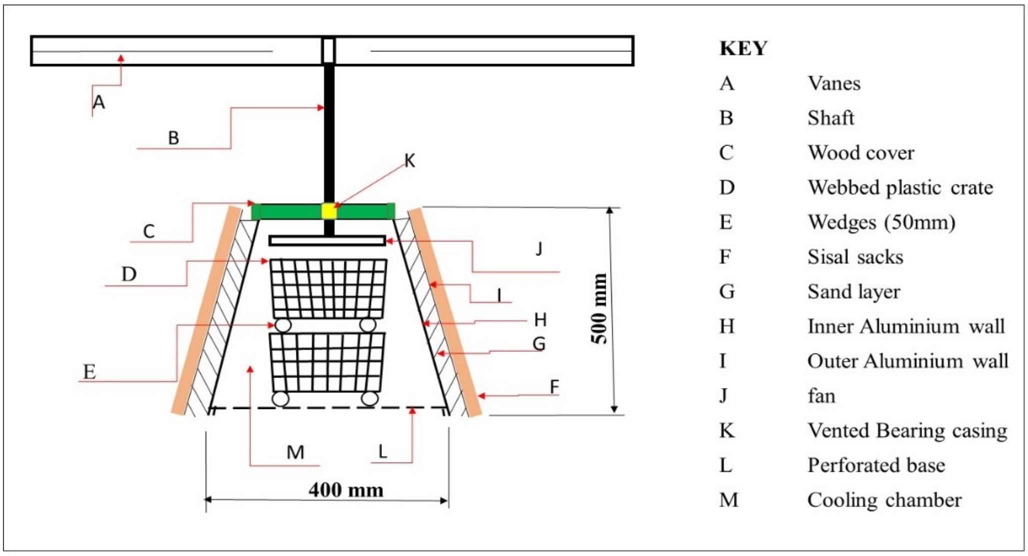


Figure 3.3: Designed IWOPEC structure

The volume of an individual tomato fruit was calculated by using Equation 3 described by Bütüner, (2018).

$$Volume = \frac{4\pi r^3}{3} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3$$

Where: r, is average radius value of selected tomato fruits (which was 2.8cm as measured using Vernier caliper)

$$Volume = \frac{4 * 3.14 * (2.8)^3}{3} = 91.91 = 92\text{cm}^3 \text{ approximately}$$

3.3.2.4 Design of fan blades

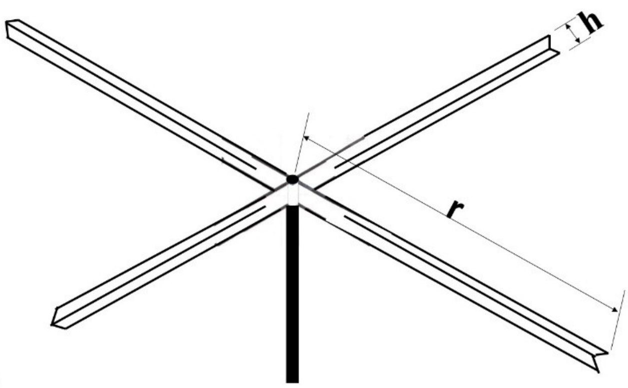
To capture enough wind and for the IWOPEC system to work properly, a four blades vane system was designed and located at the top of the structure with a 1.2 m rotor radius of the blade vane and 2.2 m above the ground level since wind speed increases with elevation. Inside the cooling chamber, a five blades fan constructed from a 1 mm thick aluminium sheet was fixed to the shaft linked to a vane made to rotate with the speed of the wind. Although wind is intermittent, the fan blades were tilted at 15^0 to enhance air radially blowing in the cooling chamber to achieve better efficiency. According to Kimambo *et* *al.* (2019) reported wind speed in Morogoro is estimated to range between 2.24m/s and 3.8 m/s which gives us the confidence to meet enough power for an IWOPEC system. Data collected for 5 years (SUA Meteorological station data, 2015 to 2020) near the experimental area depicted maximum wind speeds ranging from 1.27 to 2.18 m/s from September to January. The average wind speed for 5 years in June averaged 0.56m/s. In one complete vane revolution, the length L advanced was calculated using Equation 4 by Etzkowitz and Leydesdorff, (2000), as:-

$$L = \pi D \theta \qquad \text{…………} 4$$

Where: D is the rotor diameter of the blade vane (2.4 m) see Figure 3.4

θ is the angle of inclination of the fan blade = 90° = $\frac{\pi}{2}$, Since it uses the principle of centrifugal fan to move the air radially

$$L = \frac{3.14 * 2.4 * 3.14}{2} = 11.83\, m$$



Note:

h, is the is the swept height by the blades (14 cm)

r, is the vane rotor radius (1.2m)

Figure 3.4: Details parameters on vanes of IWOPEC structures

3.3.2.5 The amount of air moved in one revolution, Q

The amount of air moved by fan in one revolution was estimated using the relationship by Sunmonu *et al.,* 2016 (Equation 5).

$$Q=\left(\frac{\pi D^2}{4}\right)L \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 5$$

Where: D is the diameter of the vane rotor blade and L is the length (m)

Then, $Q=\left(\frac{\pi * 2.4^2}{4}\right) * 11.83\frac{m3}{s}=$ 53.52 m^3/s

3.3.2.6 The number of vanes revolutions per minute (rpm), n

The number of vanes revolutions per minute was calculated using (Equation 6) described by Valenti *et al.* (2013).

$$n=\frac{v * 30}{\pi * r} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 6$$

Where: v, is the assumed mean wind velocity = 2.18 m/s (The maximum wind speed from 5 years TMA weather data)

r, is the vane radius; n is the number of vanes revolution per minute

$$n=\frac{2.18 * 30}{3.14 * 1.2}=17.3567=17\,rpm$$

However, using the same Equation 6 (in reference to 5 years SUA meteorological minimum wind data of 0.46 m/s) gives approximately 4 rpm.

3.3.2.7 The tip velocity of the fan blade

The tip velocity of a fan blade is a good reference in calculating the angular velocity of the fan blade using the relationship by Seo *et al.* (2008), as:-

$$v=\frac{w * D}{2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 7$$

Where: v = is the tip velocity of the fan blade

w= is the angular velocity which is the ratio of the total angular measurement through which the blade rotates in a given unit of time and this was calculated from the relationship (Equation 8);

$$w = 2\pi n * 60\, rad/hour \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 8$$

¿ $2\pi * 17 * 60$ = 6408.85 rad/hour

$$v = \frac{w * D}{2} = \frac{6408.85 * 2.4}{2 * 3600} = 2.14\, m/s$$

3.3.2.8 The wind power

The theoretical power available in the wind was calculated using Equation 9, if the swept area of the blades and the wind speed are known as described by Sarkar and Behera (2012).

$$pw = \frac{1}{2} \rho A v^3 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 9$$

Where;

pw, is the wind power

ρ , is the air density= 1.293kg/m^3

v, is the tip velocity of the blade fan = 2.14 m/s

A, is the vertical swept area of the fan impeller calculated from the relation below by Cevik (2010).

$A = D * h = 2.4 * 0.14$ = 0.336 m^2

Where:

D, is vane rotor diameter (see Appendix 3); and h, is the swept height by the blades (14 cm)

Therefore,

$$pw = \frac{1}{2} * 1.293 * 0.336 * 2.14^3 \text{ = 2.13 Watts}$$

However, using the same Equation 9 (about 5 years SUA meteorological minimum average wind speed data of 0.46 m/s) gives the available wind power for 0f 0.021 Watts.

3.3.2.9 The fan pressure

The fan is designed to produce a pressure difference, and hence force, to cause a flow through the fan. Factors which determine the performance of the fan include the number and shape of the blades (Panigrahi, 2014). As the number of blades goes up, the fan tends to be quieter and increase the proportionality distribution of dragged air, the standard design is four or five blades. Fan pressure was calculated from the formula Equation (10) by Shim *et al*. (2014).

$$pw = PQ * number\ of\ blades \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. 10$$

Where: Q, is the discharge (m^3/s)

pw, is the wind power (Watts)

P, is the fan pressure (N/m^2)

Then, $$P = \frac{pw}{number\ of\ blades * Q} = \frac{2.13}{5 * 53.52} = 0.008 \text{ N/m}^2$$

Using the same Equation (10) in reference to the fan power of 0.021 Watts in the wind yields minimum fan pressure of $7.85\, x\, 10^{-5}$ N/m^2. This minimum fan pressure shows despite intermittent of wind, there is availability of free energy most of the time to power the IWOPEC structure.

3.3.3 Experimental materials and set up

The experiment was carried out in June 2021 at the School of Engineering and Technology, Sokoine University of Agriculture, Morogoro, Tanzania. Eight hundred unblemished mature green tomato fruits of fairly uniform size of Asila F_1 and Imara F_1 varieties were harvested in Mlali village. Harvesting was done during evening hours, packed in wooden crates and immediately transported to the experimental site at SUA. A total of 450 fruits were manually sorted and graded. Then tomatoes were divided into three lots of 75 fruits from each variety, labelled, weighed and packed in 18 small plastic crates, each with 25 tomato fruits and stored in different conditioned environments.

The experiment was laid out in a completely randomized block design in three replicates (Fig. 3.5). The treatments consider a 2×3 factorial combination of variety and storage environment. Three storage environments in three replicates were used in this study i.e. IWOPEC, cold room (CR) and ambient temperature (AT). According to Godana *et al.* (2020), temperature and relative humidity in the cold room was controlled at 120C and 94% respectively with dark light intensity at the laboratory in the Food Quality and Technology department at Sokoine University of Agriculture, SUA. The variation in temperature and relative humidity for the IWOPEC and AT storage environments were measured using Arduino sensors (Model: UNO R3, Italy) at 20 minutes intervals.

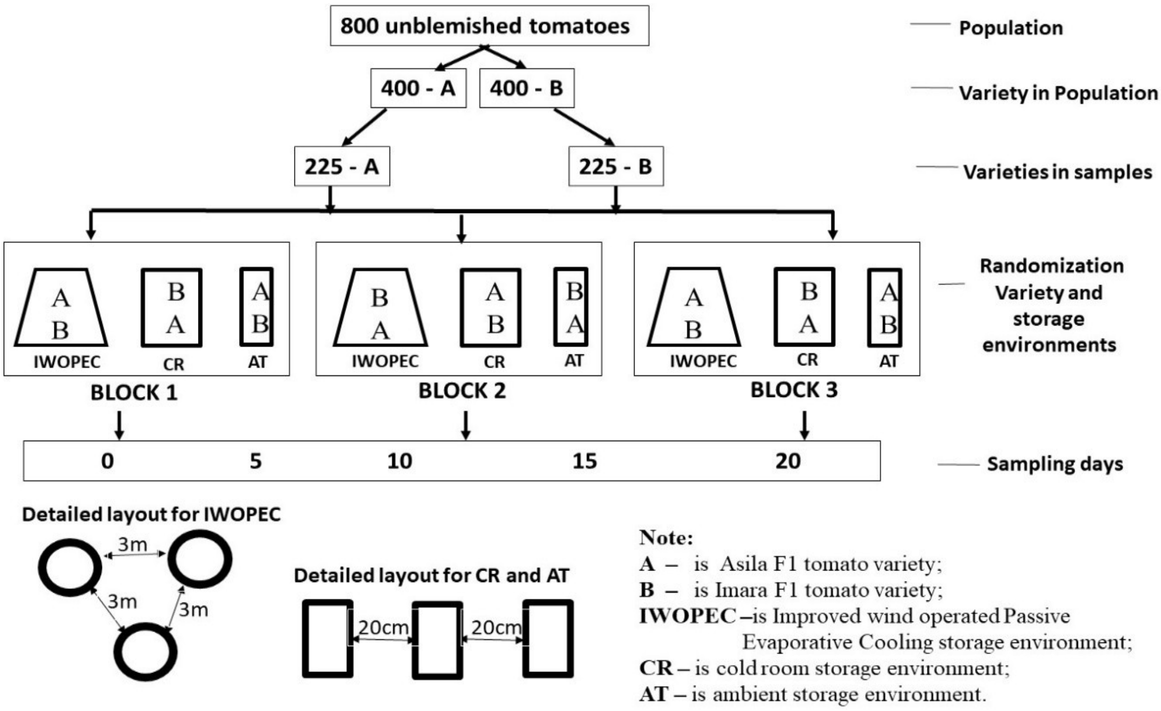


Figure 3.5: Experimental layout of the study

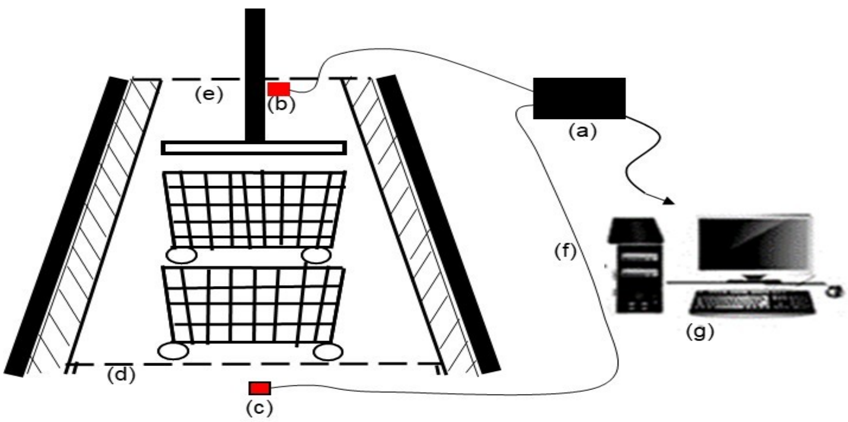


Figure 3.6: Experimental layout used to test the effect of IWOPEC to increase the shelf life of tomatoes

Note: a = Arduino micro-controller, b = DHT22 temperature-relative humidity sensor of exit air, c = DHT22 temperature-relative humidity sensor of ambient air, d = Perforated base, e = perforated cover, f = Usb cable, g = Computer

3.3.4 Data collection

The tomato storage performance of the IWOPEC structure was evaluated through the analysis of stored tomatoes. A sample of five (5) tomatoes of each variety was randomly selected from each storage unit to assess the deterioration rate as it defines the storage performance of the storage environment (IWOPEC structure, CR and AT). The performance was evaluated at the interval of five days for 20 days storage period (Zakari *et al.,* 2016; Nkolisa *et al.,* 2018). The following parameters were collected to assess the performance of IWOPEC: Temperature, Relative humidity, Wind speed, percentage weight loss, Firmness, Total soluble solids and Total Titratable acids.

3.3.4.1 Temperature and relative humidity

In IWOPEC and ambient storage environment data for temperature and relative humidity were collected using an Arduino sensors data logger (Model: UNO R3, Italy) after every 20 minutes during the 20 days study period. Also, wind speed data was collected using a calibrated Testo 416 vane thermometer (Model: Best ell-Nr., Germany) was used. The readings were taken at 8.00 am, 11.00, 14.00 and 17.00 pm daily.

3.3.4.2 Cooling efficiency

Cooling efficiency was determined by using the relationship described by Lotfizadeh and Layeghi (2014) (Equation 11).

$$Cooling\,Efficiency = \frac{Tdb - Tc}{Tdb - Twb}\,x\,100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 11$$

Where:

Tdb is the ambient dry bulb temperature °C,

Tc is the dry bulb temperature in the cooling structure in °C,

Twb is the wet bulb temperature (from psychrometric chart) in °C.

3.3.4.3 Percentage weight loss

The percentage weight loss of the stored tomato fruits was determined using (Equation 12) as described by Nkolisa, (2017). The evaluation was done every five days for the period of storage of the tomato fruits. The weight of tomato samples from the different storage environments was weighed using an electronic balance.

$$\% \, Weight \, loss \in Tomato = \frac{Total \, weight \, stored \, (M1) - Final \, weight \, (M2)}{Total \, weight \, stored \, (M1)} * 100 \quad \ldots\ldots\ldots \; 12$$

3.3.4.4 Firmness changes after storage

The firmness (N/mm) of tomato fruits was measured using Instron universal testing machine (M10-16280-EN, United States of America) using T372 – 34 punching probe test anvil which is specifically for soft fruits. The probe was placed on two different points of each fruit (opposite each other and free of blemishes) with a constant pressure to test the firmness as described by Nicolaï *et al.* (2008).

3.3.4.5 Total soluble solids (TSS)

Total soluble solids of each sample fruit were determined using a digital refractometer CNT95 with a Brix scale between 0 to 35%, division of 0.1% and accuracy of ± 0.2. The samples were prepared using the method explained by (Taha and Mustafa, 2018) where a tomato sample was macerated and filtered with a cloth to get clear juice, then using 2 to 3 clear juice drops were to measure TSS. The measurements obtained were recorded in % Brix. One degree Brix is equal to 1 gram of sucrose in 100 grams of solution, which is equal to 1% Brix.

3.3.4.6 Total titratable acids (TTA)

Total titratable acids were obtained by mixing 6 g of tomato juice with 50 ml of distilled water then adding 3 drops of phenolphthalein indicator and titrating the mixture with 0.1N NaOH up to a point where the sample changed from a clear colourless to a pink colour. Percentage acid was then calculated using Equation 13 (Sadler and Murphy, 2010).

$$\% TTA = \frac{(mls\ NaOH)\ x\ (Milliequivalent\ acid\ factor)}{grams \vee ml\ of\ sample}\ x\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 13$$

3.3.5 Data analysis

Collected data were subjected to two way Analysis of Variance (ANOVA) using Genstat® 15th Edition statistical software. Duncan’s multiple range tests (DMRT) was used to establish the multiple comparisons of mean values at 5% significant level.

3.4 Results

3.4.1 Temperature and relative humidity variation

The effect of different storage environments on temperature and relative humidity variation for daytime hours over the storage period was studied and the results are presented in Fig. 3.7 and 3.8. Results from the study indicated that storage temperature and relative humidity had a significant effect ($p<0.05$) among different storage environments over the entire storage period (Fig. 3.7 and 3.8). Temperature differences amongst the three storage environments (AT, IWOPEC and CR) were highly significant ($p=0.009$) during day hours throughout the study period. However, ambient environment data had higher variation and recorded higher temperatures and lower RH compared to CR and IWOPEC storage environments. Temperature and RH under ambient ranged between 22.9°C to 30.7°C and 55.38% to 71.44% respectively. For the IWOPEC structures, temperature and relative humidity ranged between 21.7°C to 25.1°C and

78.34% to 90.85 % respectively (Fig. 3.7 and 3.8). Cold room, temperature and relative humidity ranged between 11.7°C to 12.3°C and 91.69% to 95.31% respectively.

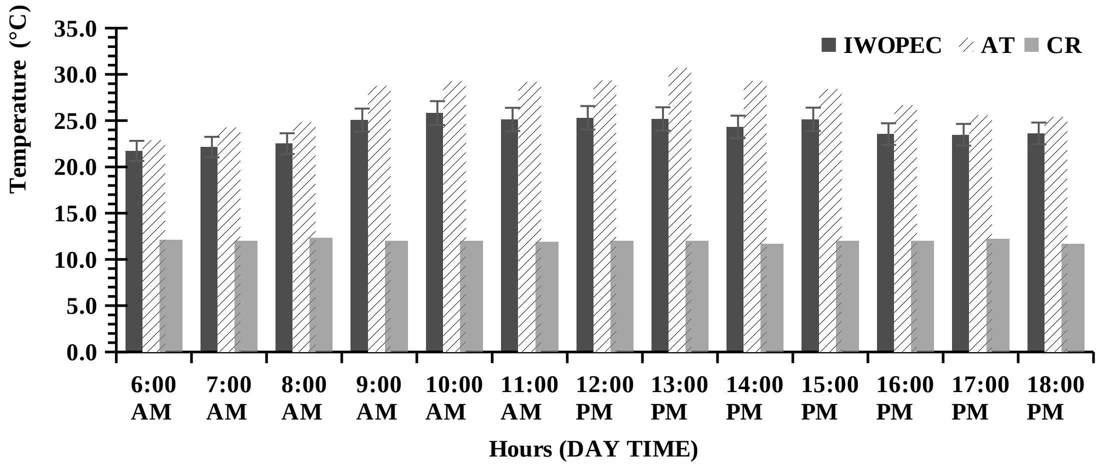


Figure 3.7: Temperature variation for IWOPEC, AT and CR (9^Th to 28^Th June, 2021)

Key: IWOPEC, Improved wind operated passive evaporative cooler. AT, ambient storage condition; CR, Cold room storage condition.

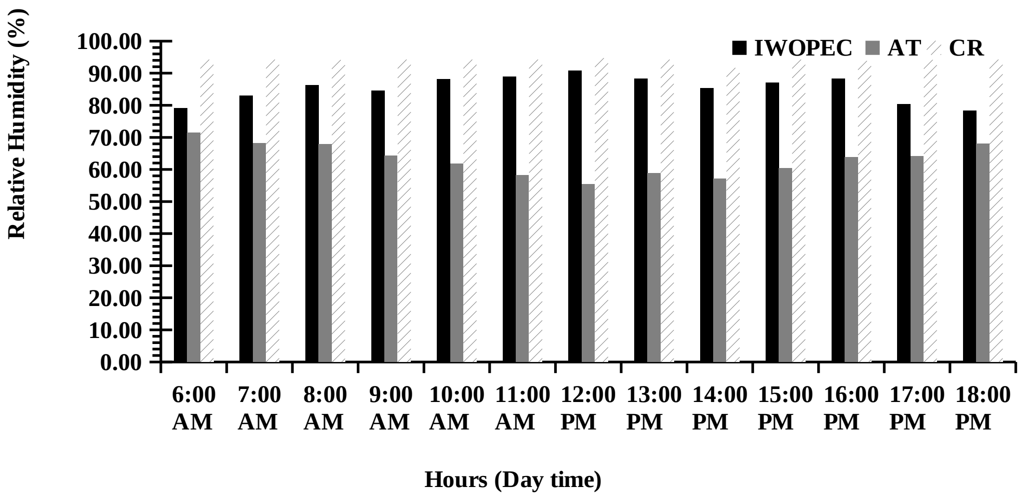


Figure 3.8: Relative humidity variation for IWOPEC, AT and CR (9Th to 28Th June, 2021)

Key: IWOPEC, Improved wind operated passive evaporative cooler. AT, ambient storage condition; CR, Cold room storage condition.

3.4.2 Cooling efficiency of the IWOPEC structure

The cooling efficiency of the IWOPEC structure loaded with tomato fruits was investigated based on daytime hours over the entire storage period are presented in Fig. 3.9. The cooling efficiency of the IWOPEC system increased with time and varied from 32.48% at 6:00 am to 65.50% at 12.00 pm. At 13:00 pm cooling efficiency increased sharply to 84.89% with the recorded ambient temperatures of 30.76°C. Results showed that there was a decreasing trend in cooling efficiency from 82.27% at 14.00 pm to 40.67% at 18:00 pm (Table 3.1).

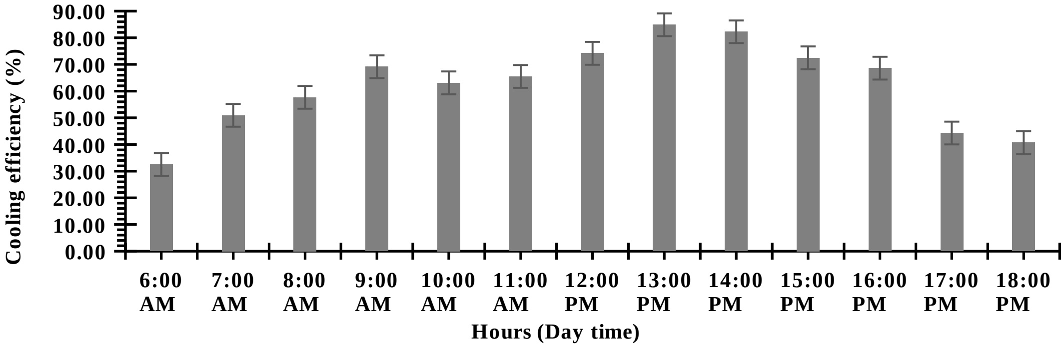


Figure 3.9: Average daily percentage cooling efficiency of the IWOPEC structure for day time hours

Table 3.1: Average daily cooling efficiency for 13 hours of the IWOPEC structures

					COOLING EFFICIENCY (% Eff)					
Hrs	**A.RH%**	**AT °C**	**IWOPEC 1**	**IWOPEC 2**	**IWOPEC 3**	**wet bulb °C**	**Eff 1 %**	**Eff 2 %**	**Eff 3 %**	**Avg. Eff %**
6:00 AM	71.44	22.91	21.69	21.79	21.73	19.30	33.76	31.08	32.60	32.48
7:00 AM	68.13	24.27	22.13	22.16	22.14	20.10	51.20	50.56	51.04	50.93
8:00 AM	67.81	24.85	22.43	22.63	22.48	20.80	59.72	54.78	58.49	57.66
9:00 AM	64.19	28.76	25.22	24.96	24.98	23.40	66.03	70.89	70.51	69.14
10:00AM	61.75	29.27	25.87	25.78	25.81	23.80	62.17	63.81	63.27	63.08
11:00AM	58.27	29.17	25.31	25.41	24.67	23.00	62.58	60.96	72.95	65.50
12:00AM	57.38	29.36	25.16	25.29	25.48	23.90	76.92	74.54	71.06	74.18
13:00PM	56.79	30.73	25.22	25.13	25.21	24.20	84.38	85.76	84.53	84.89
14:00PM	57.04	29.98	24.46	24.32	24.18	23.10	80.23	82.27	84.30	82.27
15:00PM	60.32	28.42	25.13	25.22	25.08	23.90	72.78	70.79	73.88	72.48
16:00PM	63.76	26.68	23.56	23.47	23.58	22.10	68.11	70.00	67.67	68.60
17:00PM	64.10	25.58	23.24	23.53	23.62	20.80	48.95	42.89	41.00	44.28
18:00PM	67.93	25.41	23.57	23.62	23.65	21.00	41.66	40.52	39.84	40.67
							Grand average = 62.01%			

Key: % Effic, percentage cooling efficiency; % Avg. Eff, Average percentage cooling efficiency; IWOPEC, Improved wind operated passive evaporative cooler; A.RH%, percentage ambient relative humidity; AT, Ambient temperature in degrees centigrade; °C (wet bulb), wet bulb temperature from psychrometric chart and Hrs, hours in day time.

3.4.3 Weight loss during storage period

The observed weight loss in all the two tomato varieties was due to the storage environments and time. It was found that the rate of weight loss was significant ($p<0.05$) affected by storage time in all conditioned storage environments for both tomato varieties (Fig. 3.10 and 3.11). The mean rate of weight loss for the Imara F1 variety was significant ($p=0.008$) in the conditioned storage environment during storage time. The rate of weight loss in the two tomato varieties was higher in tomatoes stored under AT compared to tomatoes stored in IWOPEC and CR.

Results show that at day 20, ambient environment weight losses were 7.35% and 8.62% for Asila F1 and Imara F1 varieties, respectively. The percentage of weight loss in the IWOPEC environment was observed to be 3.16% and 3.47% for Asila F1 and Imara F1, CR recorded the lowest percentage of weight losses compared to the other storage environments which were 2.26% and 1.98% for Asila F1 and Imara F1 varieties, respectively.

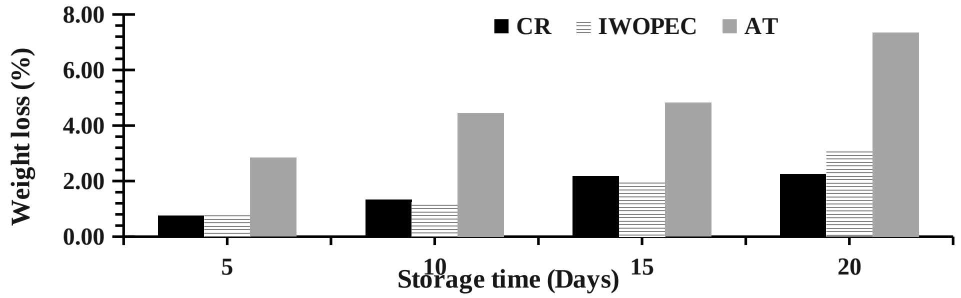


Figure 3.10: Average percentage weight loss for Asila F1 tomato variety during storage

Key: IWOPEC, Improved wind operated passive evaporative cooler
AT, ambient storage condition; CR, Cold room storage condition.

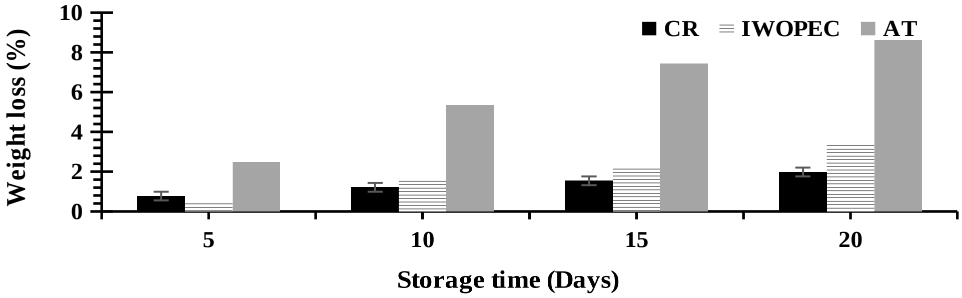


Figure 3.11: Average percentage weight loss for Imara F_1 tomato variety during storage

Key: IWOPEC, Improved wind operated passive evaporative cooler
AT, ambient storage condition; CR, Cold room storage condition.

3.4.4 Firmness during storage period

The results on the firmness of stored tomatoes are presented in Table 3.2. It was found that all the storage environments affected tomato firmness. The results indicated that there was a decrease in firmness of stored tomatoes with storage time and storage environments for both varieties. At the end of storage, tomatoes (Imara F1 and Asila F1) stored in CR had larger firmness values 34.15N and 24.59N respectively, followed by those stored at IWOPEC 24.41N and 19.39 N respectively, and the ambient condition was 22.27N and 16.92N respectively (Table 3.2).

At the beginning of storage (day 0), firmness data show no significant difference ($p<0.001$) within tomato varieties. However, there was a significant difference ($p<0.\ 001$) between the two varieties (Table 3.2). The average firmness values for Asila F1 and Imara F1 varieties were 31.24 and 54.34 Newton (N), respectively. After 5 days of storage, there was no significant difference ($p<0.001$) in the firmness of tomatoes stored under CR and IWOPEC for Asila F1 variety. Results for firmness in Asila F1 variety stored in AT, CR and IWOPEC were 25.45, 29.37and 28.62 N, respectively. In the case of Imara F1 variety, firmness was 37.68, 46.06 and 39.89 N for AT, CR and IWOPEC, respectively

(Table 3.2). For storage days 10 and 15, there was significant ($p<0.001$) variation in firmness in the different storage environments. On day 15, results for firmness in Asila F1 variety stored in AT, CR and IWOPEC were 19.83N, 26.78N and 22.45 N, respectively. In the case of Imara F1 variety, firmness was 24.33N, 38.00N and 26.61N for AT, CR and IWOPEC, respectively (Table 3.2). Lastly, after 20 days, a highly significant difference ($p<0.001$) was seen only on tomato varieties stored in AT against CR and IWOPEC. Results for firmness in Asila F1 variety stored in AT, CR and IWOPEC were 16.92N, 24.59N and 19.39N, respectively. In the case of Imara F1 variety, firmness was 22.27N, 34.15N and 24.41N for AT, CR and IWOPEC, respectively (Table 3.2).

3.4. Total soluble solids (TSS) during storage period

Results on total soluble solids for tomato samples stored in different storage environments are presented in Table 3.2. The results showed that there was an increase in TSS for both varieties under all storage environments until the end of the storage period. Both Asila F1 and Imara F1 varieties indicated there was a significant difference ($p<0.05$) in TSS as affected by different storage environments and storage time during the experiment. The results at the beginning of storage, TSS average values in Asila F1 and Imara F1 varieties were 2.66 and 3.02% Brix respectively. After 5 days, Asila F1 variety indicated the change of TSS was not significant ($p>0.05$) in the CR environment. Also on day 10 Imara F1 variety indicated the change of TSS was not significant ($p>0.05$) in AT and IWOPEC environments. Also, on day 15 still, there was no significant difference ($p>0.05$) in the IWOPEC environment (Table 3.2). From day 5 to day 20 of the experiment, total soluble solids ranged between 3.087 to 4.056 in Asila F1 variety tomato stored in AT. Under the CR and the IWOPEC total soluble solids ranged between 2.682 to 3.655 and 2.983 to 3.655, respectively. Imara F1 variety, total soluble solids ranged between 3.396 to 4.202

for tomatoes stored under AT, 3.267 to 3.925 for those stored under CR and between 3.125 to 3.982 for those stored in the IWOPEC.

3.4.6 Total titratable acids (TTA) during storage period

Total titratable acids values measured from tomato juice samples for both varieties indicated that they were affected significantly ($p<0.05$) due to the storage environments and storage time. Before storage (at 0 days), results showed there was no significant difference ($p>0.05$) in titratable acids for both varieties (Table 3.2). The average TTA values in Asila F1 and Imara F1 varieties were 9.835 and 10.376, respectively. On day 5, there was no significant difference ($p>0.05$) existed between tomatoes stored in CR and IWOPEC for Asila F1 variety. Total titratable acid values in Asila F1 variety samples from AT, CR and IWOPEC were 7.662, 9.835 and 8.762, respectively (Table 3.2). For Imara F1 variety TTA values were 7.151, 9.371 and 8.213 for tomatoes stored in AT, CR and IWOPEC, respectively. After 10 storage days, results show there was a significant difference ($p < 0.05$) in TTA for both varieties under all storage environments. However, on day 20 there was no significant difference ($p<0.05$) in total titratable acids for tomatoes stored in AT and IWOPEC environments for both varieties (Table 3.2).

Table 3.2: Average changes in firmness, total soluble solids (TSS) and total titratable acids (TTA) of two varieties stored under the three different storage environments

Variety	Storage Environment	Days	Firmness	TSS	TTA
	AT	0	31.24 h	2.66 a	9.835 h
		5	25.45 de	3.087 bc	7.662 f
		10	21.88 c	3.477 de	7.098 f
		15	19.83 b	3.725 fg	5.253 cd
		20	16.92 a	4.056 h	2.678 a
	CR	0	31.24 h	2.66 a	9.835 h
		5	29.37 g	2.682 a	9.082 g
Asila F1		10	28.79 g	3.160 bc	7.640 f
		15	26.78 ef	3.567 efg	5.896 de
		20	24.59 d	3.655 efg	4.339 b
	IWOPEC	0	31.24 h	2.66 a	9.857 h
		5	28.62 g	2.983 b	8.762 g
		10	27.92 fg	3.283 cd	6.322 e
		15	22.45 c	3.525 ef	4.689 bc
		20	19.39 b	3.800 g	3.040 a
	AT	0	54.34 h	3.020 a	10.376 h
		5	37.68 e	3.396 cd	7.151 efg
		10	30.63 c	3.717 ef	6.720 cdef
		15	24.33 ab	3.950 gh	5.698 bc
		20	22.27 a	4.202 i	4.222 a
	CR	0	54.34 h	3.020 a	10.376 h
		5	46.06 g	3.267 bc	9.371 h
Imara F1		10	41.59 f	3.518 de	7.618 fg
		15	38.00 e	3.758 fg	6.076 bcde
		20	34.15 d	3.925 gh	5.043 ab
	IWOPEC	0	54.34 h	3.020 a	10.376 h
		5	39.89 ef	3.125 ab	8.213 g
		10	31.66 cd	3.617 ef	6.929 def
		15	26.61 b	3.720 ef	5.809 bcd
		20	24.41 ab	3.982 h	4.606 a
	P-value for Asila F1 variety		$p < 0.001$	$p< 0.05$	$p< 0.05$
	P-value for Imara F1 variety		$p < 0.001$	$p< 0.05$	$p< 0.05$

Note: Means with similar letters within the same column are not significantly different ($p< 0.05$) according to Duncan's multiple range test.

Key: AT, CR and IWOPEC are ambient condition temperature, cold room and improved wind operated passive evaporative cooling system; TSS is the total soluble solids and TTA is the total titratable acids.

3.5 Discussion

3.5.1 Temperature and relative humidity

Temperature and relative humidity are among the major environmental factors affecting the postharvest quality of most fruits and vegetables (Arah *et al.,* 2015). The current study results demonstrated the efficiency of the IWOPEC structure against the ambient environment on the shelf life of stored tomatoes. The IWOPEC structure achieved an average temperature reduction of 5.54ºC and an increase in relative humidity by 29.5 % against the ambient condition for the three replications of the IWOPEC structures loaded with tomatoes. The average relative humidity of 89.04% was achieved in the IWOPEC cooling chamber compared to 58.79% under AT as measured in this study (Figures 3.7 and 3.8).

This may be attributed to the cooling effect of the IWOPEC design structure including the fan effect, wetting of the sisal sacks and sands, the structure shade, evaporation of water from the sand around the cooling chamber, vents on the base and wooden cover to allow for air circulation. Additionally, the higher saturation efficiency of sisal bags might also have contributed to higher values of relative humidity in evaporative cooling structures (Sunmonu *et al.,* 2016). The observed higher relative humidity in the IWOPEC is in line with a relative humidity of 82% to 100% reported in the studies by Babarinsa (2006); Mogaji and Fapetu (2011); and Jahun *et al.* (2013).

Similar results are due to Lal Basediya *et al.* (2013); Ndukwu and Manuwa (2014); Sunmonu *et al.* (2016); and Verploegen *et al.* (2019), who reported temperature reduction of up to 10 ºC and an increase in relative humidity of the air from 40% under the ambient condition to 92% of the ECSs storage chamber which is favorable for most fruit and vegetables. Also, the current study findings are similar to the findings from the studies by

Mogaju and Fapetu (2011); and Nkolisa *et al.* (2017) who reported that an evaporative cooling structure can maintain the temperature between 16 and 26 ºC and relative humidity between 43 and 98% during the hottest time of the day.

3.5.2 Cooling efficiency of the IWOPEC structure

The results from the current study have shown that the IWOPEC structure performed efficiently, with a significant effect on the cooling of stored tomatoes during daytime hours. The findings indicate that the average peak cooling efficiency of 84.89% (Figure 3.9) was achieved around 13:00 hrs when dry bulb temperature recorded a higher value of 30.7°C (Table 3.1). The peak efficiency was attained around 13:00 hrs, probably as a sign of hours with high solar radiation intensity with low variation. This could also be contributed by the working fan speed because noon hours were observed to have high wind speed compared to the morning and evening hours. The average wind speed ranged between 1.57 and 2.03 m/s across daytime hours. These results are supported by the findings from the study conducted by Bell *et al.* (2000); and Hussin *et al.* (2010) who stated that the pattern of temperature distribution slightly rises with increasing solar irradiance from 7:00 am to the peak value at 13:00 hours after which it falls smoothly until midnight around equatorial climate. The average cooling efficiency of IWOPEC was 62.01% (see Table 3.1). This result is supported by the results from the study conducted by Nkolisa (2017), who reported the average cooling efficiency of evaporative cooling structures of 67.6% and 67.17%, respectively. Others include the findings of Zakari *et al.* (2006) who reported an average cooling efficiency of 83% and Chinenye *et al.* (2013) who reported an average cooling efficiency of 77 to 98%.

The current study findings on cooling efficiency are nevertheless slightly lower than some of the reported findings above, this could be attributed to the dependence on the wind which is intermittent and the fact that the IWOPEC structure differs from other evaporative coolers developed and used by the different researchers. Some of the structural differences as sourced from the literature concerning the developed ECSs by other researchers include the provision of solar panels, water pumps and suction fans. Also, the other researchers mentioned did not indicate the time of the year their studies were done as it is known in a year there are different seasons with different weather conditions. Though it can be admitted that the cooling efficiency of the IWOPEC was relatively lower than the values reported by other researchers on ECSs, the IWOPEC can still be considered to be good for the storage of tomatoes at small scale farmers' and retailers' levels, pending the some design improvements.

3.5.3 Percentage weight loss during storage period

There was a significant difference ($p<0.05$) in tomato weight loss due to the effects of the storage environments and storage time (Fig. 3.10 and 3.11). It was observed in this study that within the period of evaluation the IWOPEC system registered lower temperatures and higher relative humidity compared to the AT storage environment at all times. The tomato stored in the IWOPEC structure registered a lower average percentage of weight loss compared to those stored at ambient temperature. Temperature and relative humidity inside the different storage environments are the major driving forces to the stored produce weight loss (Jalali *et al.*, 2020). The average percentage weight loss for Asila F1 tomato variety within 10 storage days kept in the IWOPEC structure and AT was 1.25% and 4.46% respectively. For Imara F1 variety kept in the IWOPEC structure and AT, the observed percentage weight loss was 1.69% and 5.34%, respectively (Fig. 3.10 and Fig. 3.11).

This study findings correlate to the findings of Mogaji and Fapetu (2011); Abiso *et al.* (2015); and Nkolisa *et al.* (2018) who kept tomato fruits in the evaporative cooling system and reported percentage weight loss to be around 2.58% to 11.45% within 10 days of storage. The study by Liberty *et al.* (2014); Arah *et al.* (2015) reported that higher temperatures and lower RH caused moisture losses consequently resulting in the decrease of the produce weight by 5% to 10% of its fresh. Furthermore, the percentage of weight loss observed in this study progressively increased with the increase in storage time irrespective of the type of storage environment and variety. However, at the end of the experiment, tomatoes stored inside the IWOPEC structure were still usable but tomatoes stored under ambient conditions were not at all usable (Appendix 2). Differences in weight loss between the investigated Asila F1 and Imara F1 varieties in this study could have been attributed to differences in their material properties and genetic composition.

3.5.4 Firmness changes during storage period

Under normal circumstances, firmness can be tested by personal feelings by using finger or thumb pressure but the more precise objective measurement is the one that gives a numerical expression of firmness done with a fruit firmness tester (Askar and Treptow, 2013). The findings of this study have shown that there was a decreasing trend in firmness with storage days for both tomato varieties (Table 3.2). It was also observed that firmness decreased more for tomatoes kept at AT, with the decrease hypothesized to occur due to high temperatures and lower relative humidity. These findings are in line with those of Habib *et al.* (2017) who reported that firmness is related to storage temperatures. Also in support of this study are the findings by Al-Dairi *et al.* (2021), where it was stated that temperature affected firmness in stored grape tomatoes. The findings in support of firmness as reported by the different researchers reveal that temperature affects the ripening rate of any stored produce and in turn, it affects the firmness. The IWOPEC structure was able to maintain the firmness of tomatoes for a longer period compared to the ambient condition due to its atmospheric condition having lower temperatures and higher relative humidity.

3.5.5 Total soluble solids (TSS) changes during storage period

There was a significant difference ($p<0.05$) in TSS due to the effects of the storage environment and time for all tomato varieties (Table 3.2). TSS was observed to be higher on tomato samples stored at AT compared to those stored in CR and IWOPEC due to higher detected temperatures in this storage environment. This implies that tomato samples in AT succumbed to a higher rate of metabolism in comparison to samples in the other storage environments. The findings of this study are coherent with the findings by Nkolisa *et al.* (2018) and Wang *et al.* (2021) who explained that the increase in TSS value is the outcome of the conversion of pectin substances, starch, hemicellulose or other polysaccharides into soluble sugars. Similarly, in this study TSS values increased with time probably due to the ripening of the tomato samples. It can be hypothesized that the tomato fruits stored at AT ripened faster because they were exposed to the environment that had the highest temperatures. The IWOPEC structure was able to retard the ripening rate of tomato fruits compared to the AT as a result registered lower TSS values compared to AT environment. Consequently, the IWOPEC was revealed to have the ability to increase the shelf life of the stored products compared to storage under AT. Siddiqui *et al.* (2015) established that TSS content in tomatoes is varietal dependent and is frequently correlated with higher tomato yield. This explains the differences in TSS content observed between Asila F1 variety and Imara F1 variety, with the former bearing relatively higher yields.

3.5.6 Total titratable acids (TTA) changes during storage period

In this study, it was observed that there was a significant difference ($p<0.05$) in TTA due to the effects of storage environment and storage time. Acidity is often used as an indicator of maturity, which decreases during the ripening of fruits (Julhia *et al.,* 2019; Yeshiwas and Tolesa, 2018). There was more decrease in TTA for tomatoes stored under AT compared to those stored in IWOPEC and CR environments (Table 3.2). This could be due to a higher respiration rate as a result of higher temperature in the AT storage environment. The current study findings for the two tomato varieties showed there was a higher rate of TTA decrease in Asila F1 compared to the Imara F1 variety for storage time. In line with the findings from this study, Siddiqui *et al.* (2015) explained that the observed acid ratio ranging between 9 and 9.7 was due to the different tomato varieties investigated. Messina *et al.* (2012) reported a similar decreasing trend in the changes of titratable acid of tomatoes during ripening and storage. Furthermore, Tilahun *et al.* (2018) described that titratable acidity in tomatoes decreases with increasing storage due to the conversion of organic acids into sugars and their utilization in respiration. Sadler and Murphy (2010) and Nkolisa *et al.* (2018) further argued that variations in titratable acids in tomatoes could be affected by differences in fruit weight.

3.6 Conclusion

Development of the IWOPEC, as a simple, affordable and effective system of reducing post-harvest losses of fresh tomatoes was successfully done. The designed and fabricated IWOPEC structure was able to reduce temperature, increase relative humidity and gave peak and daily average cooling efficiency of 84.89% and 61.67%, respectively. The IWOPEC structure was a better means for retarding tomato metabolic rate and efficient in maintaining firmness, weight loss, total soluble solids and total titratable acids for tomatoes stored for 20 days with little visible deterioration. Therefore it can be concluded that the IWOPEC structure can be used as a storage facility for small scale tomato retailers and farmers who currently have no suitable storage facility to help increase shelf life and maintain the quality of their tomatoes. For future studies, we recommend the improvement of the IWOPEC structure by installing a water boot samp under the structure platform and a wind-powered water pump to help in automatic wetting and circulating water in the system from the water reservoir to increase cooling efficiency of the storage atmosphere also testing of IWOPEC to other perishables. Progress on technological economic performance is required for policy making and adoption by tomato stakeholders.

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CHAPTER FOUR

4.0 Technical Economic Analysis of the Improved Wind Operated Passive Evaporative Cooler (IWOPEC) Structure for Storage of Fresh Tomatoes

4.1 Abstract

The perishable nature of most agricultural produce and the simultaneous need for effective marketing outlets carry with them huge economic consequences, especially in developing countries like Tanzania. This study examines the economic feasibility of using an improved wind operated passive evaporative cooler (IWOPEC) structure for tomato storage at the farm and retail level in Morogoro, Tanzania. Data on the cost of development of the IWOPEC structure, operation, and other associated costs were cross-sectional collected from three IWOPEC structures with stored tomatoes. Based on the price of tomatoes during the study and comparative storage days at ambient temperature conditions (AT), cold room temperature conditions (CR), and in the IWOPEC structure, the economic analysis of using the IWOPEC technology was evaluated using the benefit-cost ratio (BCR). The results show that using the IWOPEC structure was feasible as it gave a benefit-cost ratio (BCR) of 2.51 with the net financial return of TZS 1.7 million per structure per year. The obtained BRC value could raise concern since it has implications for the benefits and profit generation of using IWOPEC structures for fresh tomato storage. Therefore, there is a need for tomato growers and retailers to use the IWOPEC structures on-farm, at aggregation centers, and during tomato retail. Government to concoct policies aimed at minimizing losses using the IWOPEC structure. Future researchers may also estimate the BCR on other perishables using the IWOPEC structure.

Keywords: Benefits-costs ratio (BCR), Tomato (es), costs, benefits, IWOPEC

4.2 Introduction

Agriculture is a central sector in most developing countries, like Tanzania. An increase in agricultural productivity like tomatoes mostly depends on demand and marketability. The chain flow of tomato fruits from the initial points of production confronts a myriad of problems, including poor post-harvest handling practices, which have been fingered as a major culprit in the tomatoes' shelf life until they reach the hands of the ultimate consumers. The bad weather of high temperatures and low relative humidity accelerates the over-ripening of fruits as a result losses in quality and quantity occurs. It is interested in everything that happens to crops after they leave the farm gate; making the decision, taking action and bearing the responsibility of the action.

Tomatoes are an important part of daily meal preparation since they can be eaten raw or cooked. Larger quantities are used to produce soups, juices, and sauces, kinds of ketchup, purees, and pastes. The seeds which are extracted from the pulp and its residues contain 24% oil, which is used for salad dressing and in the manufacturing of margarine and soap. The residual press cake is used as stock feed as well as fertilizer. In addition, vegetables such as tomatoes, apart from being consumed at home, also earn foreign exchange for the producer countries, due to exportation (Obayelu *et al.*, 2014).

A well-developed tomato storage structure is expected to complement the farm's production effort towards the realization of its desired goals through extended shelf life and profit. The production and marketing system of tomatoes consists of a myriad of relationships and arrangements which are based on structured conduct-relationship paradigms at the production and storage level, that is, from the farm to the consumers (Wongnaa *et al.*, 2014). To ensure profitability and a stable supply of tomatoes throughout the year, a storage structure like an evaporative cooler structure should be considered first, as they are costless. This can best be achieved through a critical analysis of the factors influencing the profitability of tomato marketing (Paine and Paine, 2012).

The IWOPEC structure is intended for use by retailers and small scale farmers who sell to consumers who buy small amounts at a time; however, an IWOPEC structure can be extrapolated to large scale, particularly at tomato collection centres. The functions performed by retailers of farm produce include: reducing produce to small units that relatively low-income consumers can easily afford or buy; buying and displaying produce for sale at places that are convenient to consumers; and sorting, processing, and repackaging produce to suit consumers' needs.

Storage of perishable produce is released slowly to feed consumers, and the market is a beacon for the marketing of perishable food items at all levels because domestic food security is closely related to it. The problem of food insecurity is made worse by the rising prices of staple foods, a large percentage of which arises through the operation of the price mechanism (Alesso-Bendisch, 2021). However, Nwaru *et al.* (2011) noted that serious inefficiencies characterized the operation of the marketing system in most developing countries as a result of so many socioeconomic, political, and other constraints militating against marketing efficiency. Cochoy *et al.* (2018) noted that in the marketing of food products, wholesalers and retailers exercised strong economic power in price determination and that this was responsible for wide variations in their mark-ups and unpredictable fluctuations in the prices of foodstuffs. The current study specifically undertook an economic analysis of using the IWOPEC structure in the storage of tomatoes at retail and small scale farmers' level in tomato marketing in the Morogoro region of Tanzania by evaluating the benefit-cost ratio to see its viability.

4.3 Material and Methods

4.3.1 Study area

This study was conducted at Sokoine University of Agriculture (SUA) in Morogoro Municipality, located on the foot slopes of the Uluguru Mountains (6^{o} 49’ 15.67” South in latitude and 37^{o} 39’40.39” East in longitude with an elevation of around 500 m above mean sea level) in the eastern part of Tanzania, 196 kilometres West of Dar es Salaam.

4.3.2 Economic analysis

The study focuses on the economic performance of using the IWOPEC structure for the storage of fresh tomatoes. Technical and economic analyses combined engineering design and economic evaluation (Dai *et al.*, 2018). The technicality of how to evaluate the performance of the IWOPEC structure for the storage of fresh tomatoes is elaborated on in the previous subsection of this chapter. Brisson and Edmunds, (2006) stated that economic analysis includes costs, benefits, risks, uncertainties, and timeframes to evaluate the attributes of the technology. The current study assessed in principle the benefit-cost ratio (BCR) of using the IWOPEC structure.

The total cost (C_{tot}) data for the IWOPEC structure and the total benefit (b_{tot}) of using it in the storage of tomatoes were determined. In terms of cost analysis, the study was able to determine the costs of all items used to fabricate the IWOPEC structures. The costs included aluminum sheets, labour charges, running costs, sand volume and its cost, sisal bags, bearings, shafts, wood pieces, vanes, fans, ropes, operating costs for 20 days, bolts and nuts. On the other hand, the study determined the benefits (see table 4.1) of using the IWOPEC structure in the storage of tomatoes and the lifetime of the structure.

4.4 Data Collection

The cost-benefit analysis of the IWOPEC structure for the storage of fresh tomatoes was done. Economic analysis was evaluated based on the benefit-cost ratio (BCR), which determines the return per unit of investment by using Equation 1 by Chen *et al.* (1994); and Ndukwu and Manuwa, (2014). Recommendations were made based on the outcome of the calculated BCR values.

$$BCR = \frac{b_{tot}}{C_{tot}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..1$$

$Where: b_{tot}, is\ the\ benefit\ at\ specified\ period$

$C_{tot,}\ is\ the\ cost\ at\ specified\ period$

4.5 Data Processing and Analysis

Computations were done by use of electronic spreadsheets (XLSTAT and Excel). The computed benefit-cost ratio (BCR) value was interpreted based on: 'BCR' < 1, as a project that is not economically viable and 'BCR' ≥ 1 as a project that is viable in terms of economic efficiency.

4.6 Results

The results on the evaluation of the cost-benefit ratio of the IWOPEC structure for storage of tomatoes are hereby presented. The total cost (C_{tot}) and total benefit (b_{tot}) of using the IWOPEC structure were TZS 679 470 and 1 703 520, respectively, with a cost-benefit ratio (CBR) of about 2.51 (Table 4.1). Since CBR > 1, it means the IWOPEC structure is viable.

Table 3.1: The cost-benefit ratio of using IWOPEC structure for one year effective utilization

No.	MATERIALS	UNIT	QUANTITY	AMOUNT (TZS)	COST (C_{tot})	BENEFIT (b_{tot})
1	Aluminium sheets	Sheet	3	78 000	234 000	
2	Labour charges	Person	1	100 000	100 000	
3	Sand	bucket	4	2500	10 000	
4	Sisal bags	Piece	7	3000	21 000	
5	Bearings	Piece	3	8000	24 000	
6	shaft	Piece	3	10 000	30 000	
7	wood pieces	Piece	3	2000	6000	
8	vanes and fans	Piece	3	0	-	
9	Ropes	Roll	1	1500	1500	
10	Operating Cost	Person	1	50 000	50 000	
11	Security cost	Person	2	20 000	40 000	
12	Shade area preparation	Person	1	100 000	100 000	
13	Bolt and nuts	Set	6	200	1200	
14	Value of stored Tomato	Piece	450	20		9 000
15	Storage frequency (Three times in a month)	Piece	1350	20		27 000
16	1 years to maintenance - (Rescued monetary loss)	Piece	162 000	20		3 240 000
	Total (TZS)				**617 700**	**3 276 000**
	Consider 48% losses from chain	Percentage	0.48	3 312 000		**1 572 480**
	Contingency (for risks and uncertainty)	Percentage	0.1	617 700	**61 770**	
	GRAND TOTAL (TZS)				**679 470**	**1 703 520**
					BCR =	**2.51**

(Note: (C_{tot}), is the total cost; (b_{tot}), is the total benefit of using WOPEC structure).

4.7 Discussion

The results of this study showed that the economic analysis done of the IWOPEC structure gave a benefit-cost ratio (BCR) of 2.51 (Table 4.1). Since the BCR is greater than one, the IWOPEC structure is economically viable for use as an intervention in tomato losses at the small scale farmer and retailer levels. The analysis took into account material selection, lower tomato prices (20 TZS per fruit), the storage capacity of the

IWOPEC structure, and the cost of fabricating and operating the system of the IWOPEC storage structure. To avoid inconsistent ranking in the identified IWOPEC structure costs and benefits, the current study uses cost-benefit analysis without considering the internal rate of return (IRR) in ranking mutually exclusive options.

These study findings support the report by James and Predo (2015) and Logar *et al.* (2019) that the principles and practices of cost-benefit analysis most frequently studied are those related to construction, transport, environmental regulation, and property values, and the available data show that the benefit usually outweighs the costs. Similar to Thiagu *et al.* (1991) they reported a BCR of 1.59 when evaluating the effect of evaporative cooling storage on the ripening and quality of tomatoes. The current study findings are also in line with the findings reported in the study by Marikar and Wijerathnam (2010) who reported Benefits to Cost Ratio (BCR) of 1.7 for stored lemons using ZECC, the estimated evaluation of a 1-year project lifespan. Therefore, the benefit-cost analysis method used was valid and the results obtained are authentic, implying that the IWOPEC structure is economically viable to use for retailers and small scale farmers in the study areas.

4.8 Conclusions

The IWOPEC structure was better for retarding tomato metabolic rate and was efficient in maintaining firmness, weight loss, total soluble solids, and titratable acids for tomatoes stored for 20 days with little visible deterioration. The IWOPEC structure gave a benefit-cost ratio (BCR > 1), which signifies that it is economically viable for use as an intervention in tomato losses. Therefore, it can be concluded that the IWOPEC structure can be used as a storage facility for small scale tomato retailers and farmers who currently have no suitable storage facility to help increase shelf life and maintain the quality of their tomatoes.

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CHAPTER FIVE

5.0 General Discussion

Agriculture in Tanzania employs over 80% of the population. Horticulture is one of the vital subsectors in agriculture, efforts are required to eradicate poverty and improve the livelihoods of small scale subsistent farming and retailers. In Mlali ward small scale farmers show interest in some varieties (Fig. 2.2). Their interest is attributed to the ability of these varieties to resist diseases, large fruit size, high yields, long shelf life, attractive appearance, and toughness of the fruit mesocarp. Results on experienced huge tomato post-harvest losses (PHLs) of 29.7% at the farmers' level and 18.4% at the small scale retailers' level during handling and marketing. These losses can be due to a lack of appropriate post-harvest processing techniques, low awareness on the part of good harvesting and packaging practices or techniques, and lack of storage facilities (Table 2.1). Also, the study reveals most of the PHL losses were influenced by many factors (Table 2.2) including hot weather, lack of air circulation, attack by microorganisms, poor transportation means and handling methods, and pests (including insects).

The developed IWOPEC structure and its investigation of the shelf life of tomatoes into physiological and nutritional parameters for 20 storage days, shows to be another perishables storage option. During the period of evaluation, the IWOPEC system registered lower temperatures and higher relative humidity compared to the AT storage environment at all times. Tomatoes stored in the IWOPEC structures registered a progressively slower decrease in (weight, TTA, Firmness) and an increase in (TSS) compared to those stored at AT, although CR was the best of all. Differences in physiological and nutritional parameters between the investigated Asila F1 and Imara F1 varieties in this study could have been attributed to differences in their material properties and genetic composition.

The BCR value of 2.51 obtained and its financial return of TZS 1.7 million /structure/ year under this study reveal the IWOPEC structure is economically viable for use as an intervention in tomato losses at the small scale farmer and retailer levels. Therefore, the benefit-cost analysis method used was valid and the results obtained are authentic, implying that the IWOPEC structure is economically viable to use for retailers and small scale farmers in the study areas.

CHAPTER SIX

6.0 General Conclusions and Recommendations

6.1 General Conclusions

The common tomato varieties grown in Mlali ward and the factors contributing to high post-harvest losses of fresh tomatoes were revealed. The common tomato varieties grown in Mlali ward are Asila F1 and Imara F1. Mlali ward is potentially good at producing excess tomatoes, which are also abundantly traded in Morogoro Municipality retail markets. The drawback that both farmers and retailers are facing is the large number of tomatoes lost due to improper postharvest handling methods used by the various actors in the supply chain, including farmers and retailers themselves. Inappropriate storage facilities to store tomatoes after harvest were a major challenge faced by farmers that prompted a need for proper means of storage to be introduced to increase tomatoes' shelf life and reduce losses. Most tomato retailers and farmers were not aware of evaporative cooling systems, which could help them increase produce shelf life. About 70% of the farmers and retailers were interested in owning an IWOPEC structure that could be very useful to them and would help reduce tomato postharvest losses. The development of the IWOPEC as a simple, affordable and effective system of reducing post-harvest losses of fresh tomatoes was successfully completed. The IWOPEC structure was designed and built to reduce temperature, increase relative humidity, and provide a peak and daily average cooling efficiency of 84.89% and 61.67%, respectively. The IWOPEC structure was better for maintaining tomato shelf life and was efficient in maintaining firmness, weight loss, total soluble solids, and titratable acids for tomatoes stored for 20 days with little visible deterioration. The IWOPEC structure gave a cost-benefit ratio (CBR > 1), which means it is economically viable for use as an intervention in tomato losses. Therefore, it can be concluded that the IWOPEC structure can be used as a storage facility for small scale tomato retailers and farmers who currently have no suitable storage facility to help increase shelf life and maintain the quality of their tomatoes.

6.2 General Recommendations

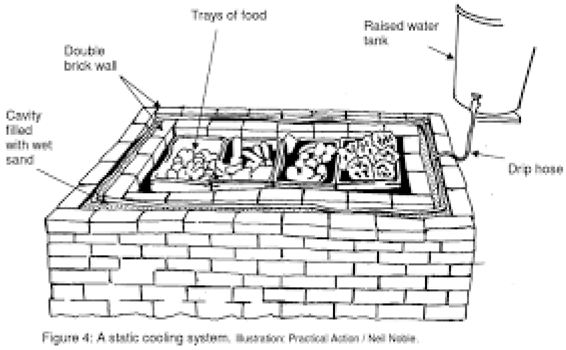
Based on the above conclusion, it is recommended that

1. Improvement of the IWOPEC structure for further increasing the cooling efficiency of the storage atmosphere "Among the areas of improvement include the installation of a water boot sump under the structure platform and a wind-powered water pump to help in the wetting and circulation of water in the system from the water reservoir."
2. Further studies for in-depth techno-economic performance are required for policymaking, adoption, and use of IWOPEC structures by tomato handlers.
3. The IWOPEC system should be tested for other perishable produces.
4. Small scale farmers and tomato retailers should be made aware of the use of evaporative cooling systems, including IWOPEC structures, by stakeholders such as extension officers.

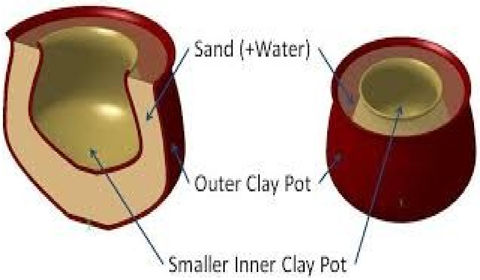
APPENDICES

Appendix 1: Sketch (or picture) of existing evaporative cooling structures

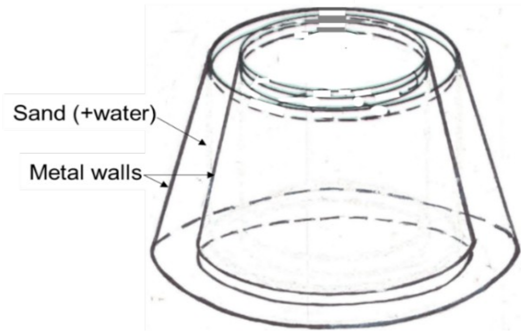
Wall in wall



Zero Energy Cooling Chamber (ZECC)

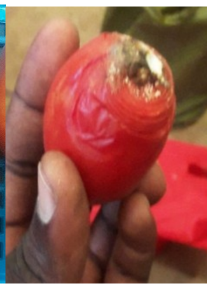


Pot in Pot refrigerator (or Zeer)



Metal double wall (e.g the IWOPEC)

Appendix 2: Tomatoes conditions after 20 days of storage in different conditions

Imara Day 20 AT IWOPEC CR



Asila Day 20 AT IWOPEC CR

Appendix 3: Loaded IWOPEC structures

Appendix 4: Questionnaire

Survey questionnaire to gather information on the existing tomato handling practices and the associated losses in Mlali ward and Morogoro municipality.

Date …………… Questionnaire number …..… Location (Village/Market) ……...……

Part A: Basic information of the respondent

A2. Main activities of respondent

i. Tomato grower ( )
ii. Tomato retailing ( )

Part B: Tomato production and postharvest handling

B1. Which source of water you are using in tomato farming? (For a farmer)

i. Rainfall ( )
ii. Only water table ( )
iii. Bore holes by using pumps ( )
iv. Bore holes using buckets ( )

B2. What time are you spending in tomato production?

i. Extra time ( )
ii. 6 hours a day ( )
iii. 12 hours a day ( )

B3. Which varieties are you most grow (or trading)?

i. Tanya F1 ( )
ii. To 135 ( )
iii. Galilea F1 ( )
iv. Asila F1 ( )
v. Rio grande ( )
vi. Bawito F1 ( )
vii. Imara F1 ( )
viii. To 150 F1 ( )
ix. Ansal F1 ( )

B4. What makes you prefer the chosen variety (in B5 above)?

i. Size of the fruit ( )
ii. Appearance of the fruit ( )
iii. Customers preferences ( )
iv. Yield of the variety ( )
v. Climatic tolerance of variety ( )
vi. Have high shelf life ( )
vii. Resistant to diseases ( )

B5. At what stage of tomato skin colour are you harvesting (or prefer to trade)?

i. Green ( )
ii. Pink ( )
iii. Light red ( )
iv. Red ( )

B6. Reasons (according to answer in B7 above)

i. Customers preference ( )
ii. Practices ( )
iii. Fear of deterioration ( )
iv. Safety for transportation ( )

B7. Choose amount of tomatoes you are producing in one season (For farmers)

i. 0.1 to 5 tons ( )
ii. 5.1 to 10 tons ( )
iii. 10.1 to 15 tons ( )
iv. 15.1 to 20 tons ( )
v. More than 20 tons ( )

B8. Choose the amount of tomatoes you are storing for trading per week?

i. Less than 50 Kg ( )
ii. 51 to 100 Kg ( )
iii. 101 to 150 Kg ( )
iv. 151 to 200 Kg ( )
v. Over 200 Kg ( )

B9. How many seasons you are growing tomatoes a year?

i. One ( )

ii. Twice ( )

B10. In average what are the prices of tomatoes per season

i. Rainy season TShs……………………………..per plastic tin

ii. Dry season TShs………………………………..per plastic tin

B11. What type of transport are you normally using in transportation of tomatoes?

i. Vehicle ( )

ii. Tricycle (Toyo) ( )

iii. Motorcycle ( )

iv. Bicycle ( )

v. Public transport ( )

vi. Head ( )

B12. Choose the packaging facilities you are most used during transportation (or trading)

i. Bamboo woven basket ( )

ii. Wooden crates ( )

iii. Plastic crates ( )

iv. Cardboard boxes ( )

v. Plastic bucket ( )

vi. Stalls ( )

vii. Open tables ( )

B13. From whom are you bought tomatoes (for retailers; tick in the box)

Wholesales ( ) Farmers ( )

Part C: Information on tomato Postharvest losses

C1.From your understanding at your area it takes how many days for postharvest tomatoes becomes unusable? (i.e. on waiting customers) (Mention) ……………. Days.

C2. Mention the amount of tomatoes disposed after becomes unusable …………………… (Kg), out of ……………………… Kg bought (or harvested).

C3. Understanding on the causes of tomato Postharvest losses (Tick in the space provided)

Losses causes	Kipera village	Mlali village	Mkuyuni village	Manzese market	Nane nane Market	Mawenzi market	Total reaction
Transportation means and handling methods							
Nature of storage and lack of ventilation							
Over ripening and moisture loss							
Hot weather and Marketing							
Over ripening, Microorganisms, insects and pests							
Harvesting method and lack of air circulation							
Hot weather over ripening							
Total respondents per area							

C4. Which methods are you using to prevent tomatoes deterioration? Mention the methods………………………………………………………………………………

C5. The amount declared (in C2) is equivalent to how much money (TZS)?

i. TZS ………………………………….. Price of …………. (mention a month price)
ii. TZS ………………………………….. Price of …………. (mention a month price)

Part D: Awareness on ECSs (Understanding ways to minimize Postharvest losses)

D1. Are you aware on the ways fresh tomatoes can be stored? (Tick in the box)

YES ( ) NO ( )

D2. Select methods which you are aware of or using to store tomatoes

Techniques or Methods	Response		How often			Time takes to tomatoes deteriorate
	YES	NO	Monthly	Weekly	Daily	
i. Hut						
ii. Ventilated stalls						
iii. Room						
iv. On the floor						
v. Moist surfaces						
vi. Refrigerator						
vii. Cold room						
viii. Others (Mention) ……………………						

D3. Which of the above (D2) is the best method to you?. Write ……………………….

D4. Are you aware on Evaporative cooling systems (ECSs)?

YES ( ) NO ( )

D5. Where have you seen an ECSs?. Mention …………………………………………...

D6. Have you ever tested an ECSs?.

YES ( ) NO ( )

D7. How was the looking of the ECSs you have seen (or used)?

i. Charcoal walls ( )
ii. Bricks walls ( )
iii. Pads covering walls ( )
iv. Metal walls ( )

D8. Select the power drives the mechanisms of the ECSs you have seen (or used)

i. Solar power ( )
ii. Grid electric power ( )
iii. Wind driven ( )
iv. No external power ( )

D9. Was the ECSs you have seen (or used) fulfill your need to store fresh tomatoes or other produce?

YES ( ) NO ( )

D10. Are you aware on how to make a ECSs you have seen (or used)?

YES ( ) NO ( )

D11. Have you ever seen a ECSs which store fresh tomatoes and its fan powered by wind?

YES ( ) NO ( )

D12. Are you interested to see and use a ECSs which store fresh tomatoes and its fan powered by wind?

YES ( ) NO ( )

D13. Mention below the reasons of interest (if the answer is YES in D.12 above)

…………………………………………………………………………………….

Before we windup our discussion, I would like to thank you very much for your cooperation and also to emphasize our agreement that, this discussion is confidential.

Appendix 5: Checklist to guide observational survey in gather information on the existing tomato handling practices and the associated losses.

1. Type of tomato varieties grown in Mlali (most grown/ reasons)
2. Losses on postharvest tomatoes (amount of tomatoes produced or bought/ amount becomes unusable/ equivalent monetary losses per seasons)
3. For the tomato losses, what are the causative factors of tomato losses (transport, hot weather, diseases, and storage facilities, others ………..)
4. Means you use to minimize tomato losses used in field..........................
5. Awareness on the tomatoes storage facilities (evaporative cooling structures, refrigerated, others ………… (seen/ where/unseen/ material for constructions, how it operates)
6. Interest in using improved evaporative cooling structure (interested/ uninterested)