EFFECT OF EVAPORATIVE COOLING ON QUALITY ATTRIBUTES AND SHELF LIFE OF TOMATO (*Solanum lycopersicum* L.) – A CASE OF DESICCANT USE

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DECLARATION AND RECOMMENDATION

Declaration

This Thesis is my original work and has not been presented in this university or any other for the award of a degree.

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Recommendation

This Thesis has been submitted with our approval as University Supervisors

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DEDICATION

I dedicate this work to my family for blessing me with success in every sphere of life.

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ABSTRACT

The limited availability of proper storage facilities in developing countries is one of the main factors contributing to postharvest losses of horticulture fresh produce; thus new strategies and approaches are needed to reduce food losses and improve the sustainability and efficiency of the entire supply chain. This study aimed to assess the effectiveness of a desiccant evaporative cooling system on tomatoes' quality and shelf life. Three evaporative coolers (with desiccant, without desiccant, and charcoal) were constructed and evaluated on their cooling efficiencies before being tested with tomatoes. The cooling efficiency of the evaporative cooler with desiccant was 87%, followed by the evaporative charcoal cooler (79.3%), and the evaporative cooler without desiccant with 67.2%. The incorporation of a desiccant (air preconditioning component) in an evaporative cooler increased its performance to provide a good environment (temperature and relative humidity) for fresh produce storage. It was then experimented on its effect on the quality attributes (physicochemical properties and microbial loads) of tomatoes during 20 days of storage. Open-field fresh three tomato varieties (Ansal F1, Bolgan F1, and Pendo F1) were harvested and brought immediately to the different storage conditions (desiccant evaporative cooler, evaporative charcoal cooler, and ambient room environment). Firmness, total soluble solids, weight loss, beta-carotene, total viable counts (TVC), and yeasts and moulds (YM) were analysed during storage to measure the quality and shelf life of the fruits. The firmness of the fruit was used to determine tomatoes' shelf life. The results showed that the cooler with desiccant, the charcoal cooler, and the ambient are significantly different ($P \leq 0.05$) on all analysed parameters after 20 days of storage. The results were also affected by the variety of tomatoes whereby variety Pendo F1 had significantly ($P \leq 0.05$) high firmness of 2.79 Nmm^{-1}, and Bolgan F1 had higher TSS (6.58 ^{o}Brix). Ansal F1 lost more weight (3.74%), and recorded more beta carotene (1.81 mg/100g), TVC, YM of 5.40 cfu/g, and 4.89 cfu/g, respectively. The mean shelf life of tomatoes was significantly ($P \leq 0.05$) longest in the desiccant evaporative cooler desiccant (61 days), followed by the evaporative charcoal cooler (37 days), and least in the ambient environment (24 days). The overall performance of the desiccant evaporative cooler was significantly higher ($P \leq 0.05$) than the evaporative charcoal cooler and ambient room storage. Therefore, using the desiccant evaporative cooler to preserve tomatoes can help reduce the postharvest losses of tomatoes, increasing food security.

Keywords: Desiccant, evaporative cooler, cooling performance, tomato quality, shelf life

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LIST OF ABREVIATIONS AND ACRONYMES

ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemists
cfu/g	Colony Forming Units per gram of the sample
CRD	Completely Randomized Design
Dbt	Dry Bulb Temperature
ECC	Evaporative Charcoal Chamber
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
IEHX	Indirect Evaporative Heat Exchanger
KALRO	Kenya Agricultural and Livestock Research Organization
PVC	Polyvinyl Chloride
RH	Relative Humidity
SAS	Statistical Analysis System
UN	United Nations
SDG	Sustainable Development Goal
TSS	Total soluble solids
TVC	Total Viable Counts
Wbt	Wet Bulb Temperature
W/Mk	Thermal conductivity
YM	Yeasts and Moulds
ZECC	Zero Energy Cooling Chamber

LIST OF SYMBOLS

%	Percentage
ºB	Degree Bix
°C	Degree Celcius
º	Degrees
η	Cooling efficiency
ΔT	Temperature drop

CHAPTER ONE
INTRODUCTION

1.1 Background Information

The advances in reducing postharvest losses and waste have not been universally translated across global agricultural systems (Jarman *et al.*, 2023). The lack of adequate, and limited access to storage and cooling facilities has been noted to be one of the reasons for postharvest losses of fruits and vegetables estimated to be 40 percent in Sub-Saharan Africa (FAO, 2019). New strategies and approaches to reduce food losses are needed to improve the sustainability and efficiency of the entire supply chain. Tomato (*Solanum lycopersicum* L.) is one of the most widely cultivated horticultural crops, which is botanically classified as a fruit but often regarded as a vegetable by many people who use it in their everyday lives (Ochida *et al*., 2019). Unless Post-harvest losses of tomatoes are minimized, the gains from production and the potential income cannot be reached (Esguerra *et al*., 2018). These losses are a threat to farmers and the countries' economic sales. Current studies on extending the shelf life of tomatoes are focused on optimizing the use of evaporative storage systems through the use of inexpensive and environmentally friendly locally available materials. Among the improvements that have been done to the solar-powered evaporative cooling systems to preserve fresh produce, little or no information is available on incorporating a desiccant to pre-condition the air, and evaluate its effectiveness in increasing the shelf life of tomatoes, and on resistance to deterioration of tomatoes varieties grown in Kenya during their postharvest storage.

Evaporative cooling is based on the fact that water must absorb heat to change from a liquid state to a vapour state, converting sensible heat to the enthalpy of vapour, and reducing system temperature by humidifying the air (Yang *et al*., 2019). The humid air should constantly be moved away from the evaporation surface of the water to prevent the rises in humidity which could slow down the rate of evaporation. Apart from lowering the temperature of the air surrounding the produce, the evaporative cooling systems also increase the humidity of the air in the storage chamber, this has increased its use for on-farm storage of fruits and vegetables. Categories of evaporative cooling systems include direct, indirect, and two-and multistage (Narayanan, 2017). Evaporative cooling has many advantages over refrigeration systems such as does not necessarily require connection to the national grid, it does not use refrigerants so there is no emission of carbon dioxide into the environment, and it can be constructed from locally available materials (Umar *e.t al*., 2016). Improvements in desiccant sub-cooling systems presented advantages in energy recovery and power saving. The performance of conventional solid desiccant evaporative cooling systems could be improved by novel system configuration and proper evaporative cooler arrangements, and the systems could meet cooling requirements in hot and humid areas (Lai *et al*., 2021).

Environmental conditions (inlet air temperature and relative humidity), pad material, pad thickness and density, pad air face velocity, and water flow in pads are among the factors affecting the performance of evaporative cooling systems (Ndukwu & Manuwa, 2014). The results of the study conducted by Poku *et al.* (2017) showed that evaporative cooling is more efficient in periods of high ambient temperatures; the greater the difference between dry bulb temperature and wet bulb temperature, the greater the evaporative cooling effects. According to Ayomide *et al*. (2019), air with a relatively low humidity increases the rate of evaporation due to its capability to hold additional moisture. Thus, when the surrounding air is saturated with moisture, little or no evaporation can occur in the evaporative cooler. The same to air temperature, when it is low, less water vapour can be held, and less evaporation and cooling will take place. The combination of all these factors plays a significant effect on the effectiveness of evaporative cooling systems.

Studies that have been done on the performance of evaporative cooling systems showed that their performance directly influences the shelf life of fresh commodities (Adekanye *et al*., 2019; Kale & Sundaram, 2015; Mogaji & Fapetu, 2011). A drip cooling chamber with gunny bag walls performed well in extending the shelf life of tomatoes compared to a Drip cooling chamber with vetiver mat walls and a Charcoal cooling chamber in the study conducted by Jadhav *et al*. (2010). The evaporative cooler developed by Burbade *et al*. (2017) that had a cooling pad made of pieces of burned bricks mixed with the coursed sand to maintain the porosity for water absorption, retention, and evaporation rate showed a cooling efficiency of 89.9% by maintaining low temperature and high relative humidity of the storage environment for 10 days of tomato storage. A Zero Energy Cooling Chamber (ZECC) developed by Khalid *et al*. (2020) increased the postharvest life of strawberries packed in three different packaging materials for 3 days compared to ambient conditions. Spinaches were kept fresh for four days in the ZECC during the summer period compared to one day at room temperature Ghosal *et al*. (2019). Another ZECC was tested on its performance on pointed gourd and okra, and it enhanced their quality and storability until the fifth day of storage Mishra *et al*. (2020). An active evaporative cooling system (incorporated with a suction fan and a water pump) developed by Adekanye *et al*. (2019) for the storage of citrus fruit and tomatoes was able to store already ripe tomatoes without deterioration for seven days.

Most agrifood systems in Near East Africa need to be transformed to strengthen food security and sustainability which is characterised by high food losses and waste (Gustavo *et al.*, 2023). According to the report of Sibanda and Workneh (2020) on the potential causes of postharvest losses, low-cost cooling technology for fresh produce farmers in Sub-Saharan Africa, and the incorporation of the desiccant unit for sensible cooling can be used to find expression in hot and humid areas. In the review of Yang *et al*. (2019) on developments in evaporative cooling and enhanced evaporative cooling, a novel approach of pre-treating ambient air to be used in evaporative coolers using desiccants to greatly increase the cooling efficiency and minimize the side effects in association with the high humidity and the cross contaminations was proposed. For this reason, this study was carried out to develop and evaluate the performance of an eco-friendly temperature and humidity-controlled desiccant evaporative cooling system for the storage of fresh produce. The humidity of the inlet air was reduced by a desiccant that was placed before the cooling pad of the evaporative cooler to increase the rate of evaporation. The fabricated system was experimentally investigated to evaluate the effects of operating on the quality of the three tomato Kenyan varieties during storage.

1.2 Statement of the problem

Among the fruits and vegetables grown in Kenya, tomato is one of the most significant crops that contribute immensely towards the economic well-being of farmers and the overall nutritional security of the population. It is difficult to maintain the harvest quality of tomatoes without control of the physiology of the harvested tissue, pathogens, and interaction of the commodity with the environment. The limited access to effective storage facilities in rural areas has been pointed out as the main factor for tomato postharvest losses. This causes farmers to travel daily to sell their produce at the market, losing time and money. Storage systems that are currently in use such as evaporative coolers could help to solve this problem, but they depend on the condition of the environment in which they are developed, they are not effective when the surrounding air is saturated with moisture. Therefore, there is a need to develop a novel evaporative cooling system with an air preconditioning component to increase their performance. Hence, this study focused on evaluating the performance and effectiveness of the evaporative cooling system with an air preconditioning component by use of a desiccant in controlling conditions that lead to tomato spoilage to reduce post-harvest losses.

1.3 Objectives

1.3.1 Main Objective

Contribute to enhancing the performance of evaporative cooling systems on tomatoes' quality and shelf life through air pre-conditioning by a desiccant.

1.3.2 Specific Objectives

1. Determine the effect of preconditioning air with a desiccant on the cooling performance of the experimental solar evaporative cooler
2. Evaluate the effect of a desiccant evaporative cooler on the physicochemical properties of different tomato varieties
3. Evaluate the effect of a desiccant evaporative cooler on the microbial load of different tomato varieties

1.4 Hypotheses

1. Preconditioning air with a desiccant has no significant effect on the cooling performance of the experimental solar evaporative cooler
2. A desiccant evaporative cooler has no significant effect on the physicochemical properties of different tomato varieties
3. A desiccant evaporative cooler has no significant effect on the microbial load of different tomato varieties

1.5 Justification

Postharvest losses of fruits and vegetables are far higher than those of cereal crops and this is due to their high perishability. As a consequence, postharvest losses affect the nutritional security of the population. Evaporative cooling technologies have the potential benefit of maintaining the quality of fresh produce, increasing the marketing period, reducing food losses, and increasing income for farmers and traders. Tomato is among the crops that contribute significantly to the Gross Domestic Product (GDP) of Kenya, the generation of foreign exchange earnings, and the creation of employment. This study will contribute to the reduction of tomatoes' postharvest losses, thus improving on producer's income, and increasing the resilience of the value chain. This will encourage more cultivation of tomatoes as farmers will be sure of the storage method that would extend the shelf life of their harvested produce when they are waiting for the future market, thus contributing to the achievement of the UN-SDG12:3 (by 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses.). It will also contribute to attaining food and nutrition security as it is anchored in the Kenya climate-smart agriculture strategy (2017-2026) that envisions a climate resilient and low carbon growth sustainable agriculture that contributes to the national development goals in line with Kenya's vision 2030 (Gabriel & Lydia, 2023).

1.6 Scope and Limitations of the study

The research was on tomato varieties (Ansal F1, Bolgan F1, and Pendo F1) from only Balingo-Mogotio. This is because it was the nearest place where we could find three different varieties under same treatments (they were in the same farm and were treated the same way). Varieties of tomatoes grown in Kenya differ from one region to another due to their marketability, tolerance to pests and diseases, and cost of seeds, continuous release of new tomato varieties which seems to be embraced by farmers (Fredrick *et al*., 2022). It was also a way of preventing variations due to harvesting, handling in the field, and transportation as they highly affect the postharvest life of tomatoes (Rajapaksha *et al*., 2021). The study focused on evaluating the performance of the desiccant evaporative cooling system on three tomato varieties.

1.7 Definition of Terms

Cooling efficiency is the measure of the effectiveness of cooling storage structure which indicates whether the structure is viable for storage or not (Chandegara *et al*., 2016).

Food quality is the assemblage of properties that differentiate individual units and influence the degree of acceptability of the food by the consumer or user (Taoukls & Giannakourou, 2018).

Food loss is the decrease in the quantity or quality of food resulting from decisions and actions by food suppliers in the chain, excluding retail, food service providers, and consumers (FAO, 2019).

Food quality loss or waste refers to the decrease of a quality attribute of food (nutrition, aspect, etc.), linked to the degradation of the product, at all stages of the food chain from harvest to consumption (HLPE, 2014).

Food waste refers to food that moves through the food supply chain up to a product fit for human consumption but is not consumed because it is discarded, whether or not after it is kept beyond its expiry date or left to spoil. Food waste is the result of negligence or a conscious decision to throw food away (FAO, 2013b).

Shelf Life means the date until which the food retains its specific properties when properly stored, this is according to regulation No 1169/2011 (European Union).

CHAPTER TWO
LITERATURE REVIEW

2.1 Evaporative cooling in the storage of food products

In the last few decades, the total energy consumption has increased by a significant increase in per capita energy demand due to technological advancement, increasing population, and a rise in living standards (Sahlot & Riffat, 2016). Temperature effects on the vapour pressure difference and increased water retention generated by evaporative cooling systems help to reduce the weight loss of fresh commodities which is primarily increased by transpiration and respiration (Umar *et al*., 2016). Evaporative cooling is based on the principle that when dry warm air from outside the cooling chamber is forced through the porous wetted wall, some water from the wetted surface evaporates into the air. Figure 2.1 shows the basic principle of a typical evaporative cooling system. The air loses its sensible heat but gains latent heat due to the transfer of water vapour which diffuses into the air above the produce and causes a drop in the dry-bulb temperature and a rise in the relative humidity (Chinenye, 2011).

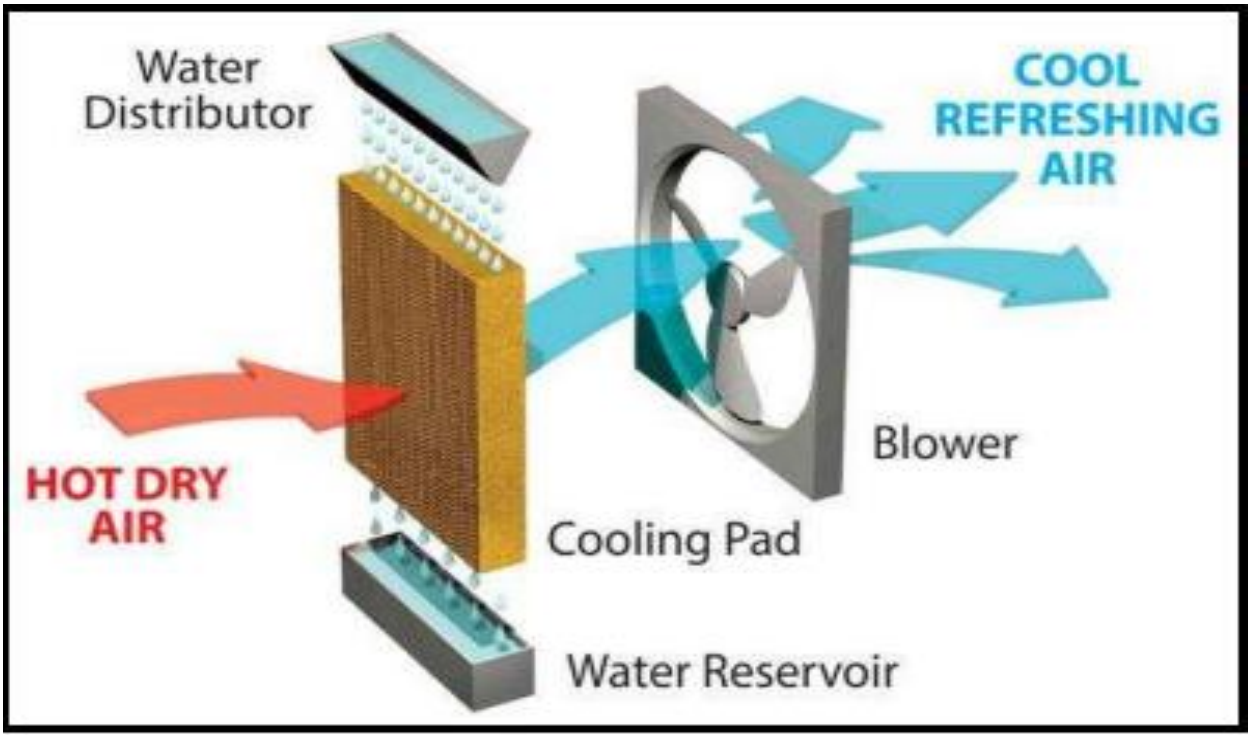

Figure 2. 1*: Schematic showing the basic principles of evaporative cooling*

Source: Dharme and Gawande (2017)

2.1.1 Structures of evaporative coolers

Refrigerated cold storage systems are highly energy-intensive and require enormous capital investment. Researchers looked for a solution and came up with cooling systems that do not use electricity and can be used on-farm storage in rural areas, where farmers may need to store the produce for a couple of days to make it in sufficient quantities before carrying it to the market (Devi & Singh, 2018). In 1995, Mohammed Bah Abba in Nigeria popularized the pot-in-pot design which is commonly known as a “Zeer Pot” (Verploegen *et al*., 2018). In these devices, a small pot is put into the big ones, and the space between the two clay walls is filled with sand which is kept wet by the addition of water for a cooling effect on stored vegetables and fruits (Verploegen & Shanka, 2021). The medium for water storage is served by sand, and a wet cloth is used as an evaporation surface and lid (Khalid *et al*., 2020). The exterior pot serves also as an evaporation surface.

The zero energy cool chamber (ZECC) works on the principle of evaporative cooling, it is made from locally available materials such as bricks, and river sand, with a cover made from plant materials and sacs or cloth (Ghosal & Rath, 2019). Ashita *et al*. (2021) applied the principle of evaporative cooling to build and experiment with a ZECC that was able to reduce the temperature of the environment to 10-15℃. ZECC can maintain the quality and quantity attributes of tomatoes by slowing down the rate of respiration and transpiration (Ishaq *et al*., 2022). These systems are typically used by larger producers or community groups due to their relatively large size (Verploegen *et al*., 2019). Some of the ancient designs were using constructing material that deteriorates quickly and might be susceptible to rodent attack, this pushed researchers to improve the designs of evaporative coolers.

CoolBots that use air-conditioning units to maintain low temperatures and high relative humidity in the storage rooms were developed and evaluated on their performance in increasing the shelf life of perishable crops (Ridolfi *et al*., 2018). These designs improved the performance of evaporative coolers in terms of lowering temperature and increasing relative humidity.

2.1.2 Types of evaporative cooling systems

Evaporative cooling could be achieved directly where product air is in direct contact with a moist medium, indirectly where coolers use paired dry and wet channels, or multistage where direct and indirect cooling systems are combined (Kapilan *et al*., 2023).

Direct evaporative coolers are the most popular and their designs are simple. They use cooled and humidified air from the ambient to reduce the air's dry bulb temperature and increase its moisture content (Chandak *et al*., 2019). These coolers supply fresh, good-quality cool air in the cooling room because the impurities such as dust and dirt in the surrounding air are washed out by circulating water. The pump sends water to the sump tank which is at the top level of the pad, and the pad is made wet by the water that gradually drips down. The fan draws the low humid dry air through a porous wetted pad or a spray which results in reducing and increasing air temperature and relative humidity (Robert, 1998). The heat from air is absorbed by water through direct contact between cool water and hot air. The transfer of heat in these coolers is assumed to be adiabatic (Ndukwu & Manuwa, 2014). In this case, increasing the relative humidity of the inlet air becomes easier thus lowering its temperature. When the outside temperature and moisture content are high, many of these systems may not be able to provide cooling comfort. The lowest temperature limit these coolers can achieve is the wet bulb temperature (Narayanan, 2017).

The indirect evaporative cooling system can produce cool air without contact with evaporated water. The primary air (or product air) and the secondary air (or working air) flow in separate passages in the typical indirect evaporative heat exchangers (Cui *et al*., 2018). The previous works on the indirect evaporative heat exchanger showed several system parameters that influence its performance, such as channel height, channel length, intake air temperature, intake air humidity ratio, and intake air velocity (Cui *et al*., 2016). Wet-bulb and dew point effectiveness were employed in the study done by Cui *et al*. (2018) to investigate the performance of a novel indirect evaporative heat exchange. Although an indirect evaporative cooler is suitable for many applications such as public buildings, agriculture, and industrial areas, it still has limitations in areas with hot and humid conditions where high wet-bulb temperature of ambient air limits the supply air temperature which therefore restricts its applications (Zhou *et al*., 2021).

2.2 Factors affecting the performance of evaporative coolers

2.2.1 Temperature

Evaporation of water is at a high rate when the temperature of the surrounding air is at its peak. Air with a relatively high temperature will provide sufficient energy to change water from liquid to gas, thus evaporation occurs (Kumar *et al*., 2018). The lower the air temperature the less water it will evaporate and less cooling will take place. An increase in ambient temperature resulted in much drying of the ambient air in the experiment done by Ahmadu *et al*. (2022).

2.2.2 Relative humidity

When the humidity ratio of the air is close to its saturation, the capacity to hold more water reduces. So for the evaporative cooling to take place the air should have low relative humidity. In the case of highly humid air, desiccants such as silica gel can be used to remove moisture from the air before it is cooled (Kale & Sundaram, 2015). The low humidity environment allowed for temperature decrease to be achieved with high cooling efficiency in the clay pot evaporative cooler made by Verploegen *et al*. (2019).

2.2.3 Air Movement

The rate of evaporation is influenced by either natural (wind) or artificial (fan) movement of the air. Evaporation of the water raises the humidity of the closest air, which may reduce the rate of evaporation if this air is not replaced. In this case, a fan can be installed in the evaporative cooler to remove this air (Kale & Sundaram, 2015).

2.2.4 Surface area

The rate of evaporation is also affected by the surface area of the evaporation. The greater the surface area of the evaporation the greater the rate of evaporation will be. The reduction of surface area for water evaporation for the ZECC developed by Verploegen *et al*. (2019) affected the cooling efficiency of the chamber. It got a cooling efficiency of 4% while the other one with an optimised design that had enough surface area for water evaporation achieved 77% cooling efficiency.

2.3 Overview of tomato production

The tomato originated from South America, it was domestically cultivated in Central America by early Indian civilizations of Mexico and later taken to all other parts of the world (Vincent *et al.*, 2016). Over five million hectares of cultivated land are thought to generate more than 171 million metric tons of tomatoes annually, with China, the United States, Turkey, Egypt, and India being the top producers. Africa makes about 11.8% of the world’s total tomato production. Because of their flexibility, tomatoes are one of the most extensively produced vegetable in Africa. Depending on the agricultural conditions across the continent, different production systems from greenhouses to open fields with differing degrees of technological application are used (Dube *et al*., 2020). Kenya grows more than 400,000 tonnes of tomatoes every year, in terms of production the crop is the second most valuable after potatoes and it is grown in all 47 counties (Kansiime *et al.*, 2020). Varieties of tomatoes grown in Kenya differ from one region to another due to their marketability, tolerance to pests and diseases, and cost of seeds. It may also be caused by the continuous release of new tomato varieties which seems to be embraced by farmers (Fredrick *et al*., 2022).

Tomatoes are an important crop in Kenya destined mainly for the local market, with a small share exported to neighbouring East African countries and high demand for both domestic use and markets (Ridolfi *et al*., 2018). Tomato has high economic value and the fruit can be utilized in the manufacture of a wide range of products such as tomato paste which is subsequently used as an ingredient in many food products, mainly soups, sauces, and ketchup (Huffman, 2021). The crop also plays an important role in the provision of food and nutrition security, especially among impoverished rural communities. Additionally, tomatoes reach urban markets through traders and middlemen thus generating income for various actors along the value chain (Ogutu *et al*., 2022).

2.4 Nutritional composition of tomatoes

Tomato contains a significant amount of dietary nutrients, including dietary fibres, reducing sugars, vitamins, minerals, protein, essential fatty acids, phytosterols, and carotenoids (Ali *et al*., 2021). It is an important source of phenolic compounds and carotenoids which are important for human health; and may be influenced by various factors such as genetics, environmental conditions, ripeness, and postharvest conditions (Lima *et al*., 2022). Carotenoids in tomatoes are responsible for red, yellow, and orange pigments; they play an essential role as antioxidants to protect the cells and tissues from risks of cancer and cardiovascular diseases (Soytong *et al*., 2021). They increase the body’s level of antioxidants. Trapping reactive oxygen species and reducing oxidative damage to important biomolecules such as membrane lipids, enzymatic proteins, and DNA, thereby ameliorating oxidative stress (Ali *et al*., 2021). Thus consumption of tomato fruits with high levels of antioxidants is important in the prevention of diseases (Lima *et al*., 2022). Table 2.1 below shows the antioxidant constituents in tomatoes:

Table 2. 1: Antioxidants in Tomatoes

Antioxidant (in mg/100g)	**Range**
Total tocopherol	1.02-1.44
Vitamin C	10.86-85.00
Beta-carotene	3.67-10.21
Lycopene	5.02-9.49
Phenolic acids	21.34-31.23
Flavonoids	3.06-6.36
Anthocyanins	0.23-1.36

Source: Ali *et al*. (2021)

2.5 Postharvest life of tomatoes

Once tomatoes are harvested quality deterioration starts due to the biological cycle broken by harvesting and accelerated by environmental factors such as temperature and relative humidity (Ochida *et al*., 2019). A study by Adhikari *et al*. (2020) that evaluated the effect of different polymeric plastic packaging on the quality parameters of tomatoes found that tomato quality was affected by the packaging though their findings were suggested to be affected by ineffective temperature and relative humidity and difference in pack construction. The combination of physiological processes that cause the deterioration of tomatoes such as respiration, transpiration, and ethylene production with an appropriate physical storage condition may give the required basics for tomato storage (Ayomide., 2019). The quality of harvested produce is maintained by rapid cooling after harvest and as well as low-temperature storage, the growth rate of micro-organisms responsible for postharvest rots is controlled by temperature (Rani *et al*., 2021). Chilling injuries may be detrimental to the quality of tomatoes as they promote deterioration of tomato compounds, such as low lycopene, formation of ice crystals and damage to cell integrity, blotchy colouration, and phenolic oxidation which is induced by the release of polyphenol oxidase of the vacuole (Lima *et al*., 2022).

Losses that take place after harvesting the crop are called post-harvest losses (Alan & Erwin, 2021). These do not include loss of production due to diseases or pests while the crop is growing in the field. Apart from storage conditions, the postharvest losses of fruits and vegetables may also be caused by incorrect harvesting before reaching correct maturity, improper handling procedures in the field, improper packaging at various stages of the food chain, and improper transportation and incorrect retail selling approach (Rajapaksha *et al*., 2021). The type of variety has been also found to have a significant effect on the shelf life of tomatoes during postharvest (Hephzibah, 2019). Sinha *et al*. (2019) studied the effects of varieties, heat treatment, modified atmosphere packaging, and low temperatures on the shelf life, and postharvest quality attributes of tomatoes during storage. Tomato varieties showed a significant variation in the shelf life extension of tomatoes.

2.5.1 Factors affecting the deterioration of tomatoes after harvest

The shelf life of tomatoes is dependent on postharvest handling practices which have a direct impact on the nutritional and sensory qualities (Ziv & Fallik, 2021). Tomatoes are highly perishable and can be stored only for limited days under normal tropical ambient conditions. The postharvest storage environment of tomatoes is critical for maintaining their quality in further marketing chains and consumptions. Temperature and relative humidity are known to be significant factors for the biological and chemical degradation of tomatoes, especially in tropical countries including Kenya due to their geographical position. In addition, respiration is one of the contributing factors to the deterioration of harvested tomatoes since they continue to respire even after being detached from the plant.

1) Ethylene

Ethylene gas is a plant hormone that determines the ripening of climacteric fruits including tomatoes and regulates the responses of plants to cold stress (Zhu *et al*., 2019). The contribution of ethylene to the ripening of tomatoes is not only caused by a change in chemical composition but also by an increase in respiration rate. According to Paul *et al.* (2011) review, stresses such as wounding, water stress, and disease during the course of the fruit development induce ethylene production and this can be controlled by the ability of the tissue to synthesize 1-aminocyclopropane-1-carboxilic acid (AECC) and to convert it to ethylene, the permeability of the skin surface, change in fruit growth and temperature. The studies conducted by Ali *et al*. (2022; Zhao *et al*. (2015) proved the effect of ethylene gas on the quality attributes of harvested tomatoes, it enhances the breakdown of chlorophyll and accumulation of lycopene and other carotenoids, which increases red colour, which is an indicator of ripening. Ethylene damage can be reduced by adequate ventilation and reducing storage temperature. High temperature can accelerate the respiration rate, while low humidity causes tomato shrivelling, thus the low temperature of approximately 10-13 ℃ and high humidity of 85-95% and 90-95% for mature green and firmer ripe tomatoes, respectively are required to maintain the freshness of tomatoes (Kabir *et al*., 2020).

2) Temperature

From the customers' viewpoint, the key parameters that can boost sales and increase profit are colour and texture. The role of temperature in determining the postharvest quality and shelf life of tropical fruit and vegetables has been reported. The temperature induces rapid utilization of stored carbohydrates to produce energy during respiration, which affects the sweetness, Flavour, weight, turgor, and nutritional value loss during postharvest of the fresh produce (Zainalabidin *et al.*, 2019). Though the use of chillers in preserving tomatoes has been in practice, the handlers must be aware that keeping tomatoes below 10 ℃ can lead to chilling injuries, fungal infestation, improper ripening, and pitting (Karthick *et al.*, 2022). To reduce the chilling injury by either retarding the development of injury symptoms or increasing the tolerance of commodities the following methods can be employed: postharvest storage at optimum temperature, temperature conditioning, intermittent warming technique, controlled atmosphere storage, chemical treatment, and application of growth regulator (Zainalabidin *et al.*, 2019). Thus there is a necessity of being capable of regulating temperature for practitioners before investing in cold storage equipment. It is recommended to maintain a storage temperature of about 10-15 ℃, which can be achieved by using evaporative cooling systems (Arah *et al.*, 2016).

3) Relative Humidity (RH)

Relative humidity is another key factor to consider in the storage of tomato fruit. In Sub-Saharan Africa, the importance of humidity in reducing postharvest losses has been highlighted (Daniele *et al.*, 2022). The nutritional quality of harvested fruits such as appearance, weight, and flavour is maintained at very high relative humidity, and the rate at which wilting, softening, and juiciness occur is also reduced (Arah *et al.*, 2015). The loss of water from fresh stored tomatoes is caused by the moisture existing in the storage environment, the optimum relative humidity of 90 to 95% will result in preventing tomatoes from shrivelling (Shimeles *et al.*, 2017). On the other hand, much care should be taken to avoid fungal development which is favoured by the high relative humidity of about 100%.

4) Respiration

Respiration is a process that involves the breakdown of organically stored materials such as carbohydrates, proteins, and fats simple energy-providing molecules, and some specific molecules used in various cellular reactions, it indicates cellular metabolic activities (Ariwaodo, 2022). It involves the oxidation of sugar that generates carbon dioxide, water, and heat. Thus, making its storage life dependent on its respiratory activity. When the tomato fruit is left to ripen on or off the plant, a marked increase in its respiration is observed as it passes from the mature green phase to the ripe phase.

2.5.2 Postharvest handling of tomatoes

Postharvest handling practices or treatment methods cannot improve the quality of any fruit after harvest but they can however maintain it, the common practices include refrigeration storage, postharvest heat treatment, modified atmosphere packaging, and the use of chemicals to retard tomato deterioration (Arah *et al*., 2016). Texture is an important quality indicator for eating and cooking, in fruits and vegetables it is often interpreted in their firmness, crispness, juiciness, and toughness. The decrease in fruit firmness is due to the activity of softening enzymes that destroy the fruit cell wall, the influence of high respiration, and fruit senescence (Tolasa *et al*., 2021). On the other hand, the nutritional value of tomatoes is improved during ripening as the ripening is accompanied by increases in carotenoids and Alpha-tocopherol, as well as polyunsaturated fatty acids (Saini *et al*., 2017). There is a finite length of time after harvesting tomatoes for which it will retain an acceptable level of quality.

Kenya is a tropical country, with relatively warm temperatures and high relative humidity, which exist throughout the year, so it is not easy to keep the life of fresh produce at room conditions. Despite the above factors responsible for the deterioration of perishable crops, temperature, and relative humidity need to be controlled to reduce metabolic reactions, weight loss, and freshness of tomatoes. Some fruit and vegetable farmers store their produce in uncovered baskets, basins, or jars (Mogannam *et al*., 2022), which makes it hard to control the environment for proper storage. The quality of the tomatoes is perceived by consumers based on the factors like colour, size, shape, defects, decay, firmness, and Flavour. Parameters such as firmness which gradually decreases as tomatoes become mature and decrease rapidly as they ripen, colour, and weight loss can also be analysed in the laboratory to determine the quality of the fruit, and the results are as well used for quality control, postharvest studies (Evabeta *et al.,* 2016).

2.6 Advances in technologies for tomato storage

Cold storage, was found to play an important role in delaying changes such as ethylene production, softening, colour change, respiration rate, and weight loss. The process of cooling tomatoes to increase their shelf life should be adjusted and optimised for each specific type of produce to avoid risks of chilling injuries (Zainalabidin *et al*., 2019). However, low-temperature storage is not enough to preserve the fruit quality at optimum levels during transportation and marketing. Factors such as surrounding humidity, level of oxygen, and carbon dioxide should also be considered in extending the shelf life of tomatoes. Plastic packaging creates a modified atmosphere for the packed tomatoes which also increases their shelf life (Adhikari *et al.,* 2020), but the use of plastics is another concern in environment conservation.

The combination of biodegradable edible coatings and films from gums in packaging with cold storage was suggested to tackle the problem (Salehi, 2020). It has many benefits such as serving as a moisture barrier, oxygen scavenger, ethylene scavenger, antimicrobial properties, and anti-browning properties. Edible coatings increase the shelf life of the fruit by creating a semi-permeable protective covering around the fruit surface, which reduces the respiration rate and ethylene biosynthesis, thus delaying the ripening-associated changes in the fruit (Razali *et al*., 2021). Factors such as the high cost of biopolymers, the development of coating as per the specific commodity requirements, and lack of studies on the consumer acceptance of coated products, have reduced the adoption of the technology at the commercial level application (Yadav *et al*., 2022). Methods such as dipping, foaming and spraying, brushing, layer by layer, and vacuum impregnation techniques are used to apply these coatings on the food materials (Owusu & Oduro, 2021).

Infections caused by bacteria, yeasts, and moulds were also attributed to the loss of tomato quality during postharvest. Recent studies have found that some fungi have developed strong resistance against chemical control and fungicides that have been considered effective in controlling these pathogens. This leads to the increase in dose or intensive use of these chemicals which may result in chemical residues and environmental damage. Biological control has been proposed to be an alternative to protect tomatoes from postharvest diseases (Lanhuang *et al*., 2022). Natural-origin environmental products such as neem oil that offer inhibition to the growth of some fungi, can be used in the postharvest management of diseases (Jumps *et al*., 2019). The incorporation of nanoparticles into food packaging due to their antimicrobial properties to extend shelf life has been noted to be used in the food industry soon (Ariwaodo, 2022). Anti-microbial and antioxidant effects can also be reduced by bioactive compounds that are added to the edible coating (Yadav *et al*., 2022). Therefore, the interest in making improvements to reduce postharvest losses of tomatoes during storage shows the need to develop proper storage systems that will contribute to loss reduction.

2.7 Summary of the literature

Storage of agricultural products can be at the household level (privately), community level (community warehouses), or regionally in large warehouses (Alan & Erwin, 2021). Tomatoes like other perishable crops can only be stored for short periods at ambient temperature without wilting or spoiling. Methods such as drying, preserving, processing, or curing can add value to tomatoes but they are time-consuming and sometimes require technologies that are not readily available. Storing tomato fruit in its fresh form requires maintaining it at low temperatures and high relative humidity. Existing cold storage systems in Kenya require reliable electricity which is often not present in rural areas, and high initial cost which limits their use for smallholder farmers. Recent innovations employed solar energy to power cold rooms and CoolBots, but they are not widely available in Kenya.

Food production and distribution contribute to greenhouse gas emissions, this caused a strong environmental argument for reducing food loss and waste. Methods to reduce postharvest losses have been studied to reduce greenhouse gas emissions (Cattaneo *et al*., 2021). Despite the high perishability of tomatoes that leads to a high level of loss after they are harvested, the losses are also due to inadequate harvesting techniques, lack of appropriate storage systems, and handling practices though loss levels might not be the same in all varieties. These losses affect the farmers' and retailers' returns as their income depends on the tomato value chain. Consumers too are affected by the increased price of tomatoes due to less quantity that reaches the market (Kansiime *et al*., 2020). When storing tomatoes, parameters such as temperature, and relative humidity that play an important role in increasing the shelf should be taken into account. So, innovations that are taking place should use new technologies to extend the shelf life of perishable products including tomatoes.

2.8 Conceptual Framework

The conceptual framework for the study is shown in Figure 2.2.

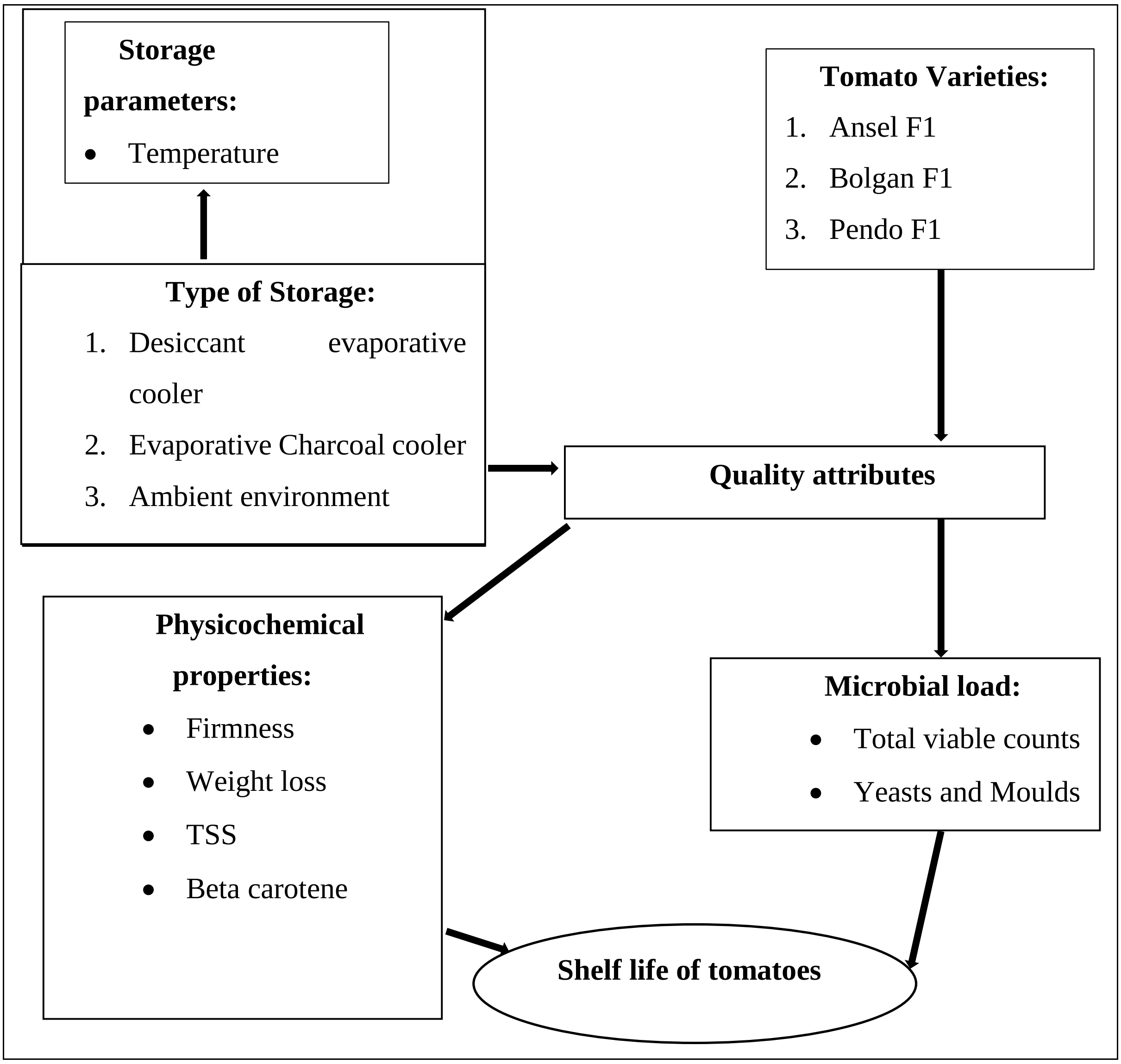

***Figure 2. 2:** Conceptual framework for the study*

The conceptual framework of this study was based on the relationship between factors affecting the shelf life of tomatoes. It shows the independent and dependent variables of the study. In this case independent variables were the type of storage and tomato variety while the dependent variables were storage parameters and quality attributes (Physicochemical properties and microbial loads).

CHAPTER THREE

PERFORMANCE OF EXPERIMENTAL SOLAR EVAPORATIVE COOLING SYSTEMS

Abstract

Evaporative cooling systems have many advantages over refrigeration systems, such as not necessarily requiring connection to the national grid, not using refrigerants that emit ozone-depleting substances into the environment, and can be constructed from locally available materials. However, little information on incorporating desiccant as an air preconditioning component to increase the performance of these coolers is available. In this regard, this study aimed to examine the efficacy of three cooling systems: an evaporative cooler with a silica gel desiccant component (desiccant cooler), an evaporative cooler without desiccant (desiccant-free cooler), and an evaporative charcoal cooler (charcoal cooler). Dry and wet bulb temperatures and relative humidity were recorded during the experiment and used to determine the cooling efficiencies of the systems; temperature drops; and humidity increases, which are used as performance indicators. Results demonstrate a significant ($P \leq 0.05$) impact of the coolers on all analysed parameters. The desiccant cooler achieved the highest cooling efficiency at 87.2%, followed by the charcoal cooler at 79.3%, and the desiccant-free cooler at 67.2%. Temperature reduction was most pronounced in the desiccant cooler (3.7°C), followed by the charcoal cooler (3.2°C) and the desiccant-free cooler (2.8°C). Relative humidity levels increased by 30.7%, 23%, and 26.1% in the desiccant, desiccant-free, and charcoal coolers, respectively. Importantly, the evaporative cooler with desiccant operated without ozone-depleting refrigerants and utilized solar energy, offering an environmentally friendly solution. Its capacity to provide appropriate storage conditions for a wide range of fruits and vegetables makes it particularly beneficial for farmers lacking access to adequate cooling storage facilities, enabling them to preserve their produce effectively.

3.1 Introduction

Maintenance of low temperatures is a great challenge in tropical countries, especially in remote areas where refrigeration systems are not easily found because they are energy-intensive, expensive, and difficult to install (Chandegara *et al*., 2016). Due to their advantage of lowering the surrounding air temperature and raising the moisture content of the air, evaporative coolers are increasingly being used for on-farm storage of fruits and vegetables. Most agrifood systems in Near East Africa need to be transformed to strengthen food security and sustainability, which are characterised by high food losses and waste (Gustavo *et al*., 2023). The lack of appropriate cold storage facilities for fresh produce in Kenya results in a reduction in the quantity that gets to the market. It directly affects the economic distribution and consumption of the needed quantity for human sustainability.

Many researchers are looking for strategies to create and build comparatively inexpensive cooling systems that utilise the evaporative cooling principle because of the insufficiency of affordable refrigeration systems. Zakari *et al*. (2016) dessigned and constructed an evaporative cooler from which they were able to attain a temperature of 13.75℃ to 14.74℃, and its performance was estimated by the cooling efficiency of 83% in an experiment. The cooling efficiency, which is given by the ratios of both inlet and outlet temperature, tells the extent to which the temperature can be lowered (Chandak *et al*., 2019). The relatively low temperature and high relative humidity were achieved by the evaporative charcoal cooler developed by Ronoh *et al*., (2020) compared to the ambient room during the measurement period. The cooler attained a cooling efficiency of 91.5% at a maximum temperature drop of 9℃. Ambient air temperature and relative humidity were found to impact the inside environment of the cooler, which affected its cooling potential. Evaporative cooling could be achieved directly where product air is in direct contact with a moist medium, indirectly where coolers use paired dry and wet channels, or multistage where direct and indirect cooling systems are combined (Kapilan *et al*., 2023).

Air dehumidification by desiccant in evaporative cooling systems has increased as an alternative to conventional vapour compression systems in equatorial and tropical climates (Ralph, 2017). The energy crisis and the need to develop environmentally friendly technologies have prompted the introduction of solar-driven desiccant cooling systems for humidity management in agricultural industries, such as postharvest crop storage units (Sahlot & Riffat, 2016). These designs have proven their ability to extend the shelf life of fresh produce. But still, some of them require being located in areas with wind to drive their turbines, which might reduce their efficiency in cases of limited wind.

Evaporative cooling has also been disadvantaged by high water consumption in its operation, which is a scarce resource in dry and hot climates; big space requirements; and their inability to cool in hot humid climates (Dhakulkar *et al*., 2018). According to the report of Sibanda and Workneh (2020) on the potential causes of postharvest losses, low-cost cooling technology for fresh produce farmers in Sub-Saharan Africa, and the incorporation of the desiccant unit for sensible cooling can be used to find expression in hot and humid areas. In the review by Yang *et al*. (2019) on developments in evaporative cooling and enhanced evaporative cooling, a novel approach of pre-treating ambient air to be used in evaporative coolers using desiccants to greatly increase the cooling efficiency and minimize the side effects in association with the high humidity and cross-contaminations was proposed. For this reason, this study is carried out to develop an eco-friendly temperature- and humidity-controlled desiccant evaporative cooling system and evaluate its performance in achieving appropriate storage conditions for fruits and vegetables. It details the effect of using a desiccant to dry air for evaporative cooling.

3.2 Materials and Methods

3.2.1 Study Site

The study was carried out at the Department of Dairy and Food Science and Technology, Egerton University.

3.2.2 Fabrication of the coolers

The experimental evaporative coolers were constructed using locally sourced materials including stainless steel sheets, plastic (PVC) pipes, metal frames, and wire meshes. The assembly of an evaporative cooling system is comprised of a counter-flow tubular heat exchanger, an evaporator (storage chamber), a suction fan, two water tanks for recirculation, and a desiccator for desiccant placement. All components were integrated to minimize the overall working surface area. For convenience of access, the storage chamber was elevated to one meter above the ground. A double-walled stainless steel structure with a water-filled hollow and 60mm thick polystyrene foam insulation was used to optimize insulation and reduce heat gain. The cuboid shape offered a large surface area for optimal cooling, and the stainless-steel walls ensured durability. The layout of the developed indirect evaporative cooler is shown in Figure 3.1.

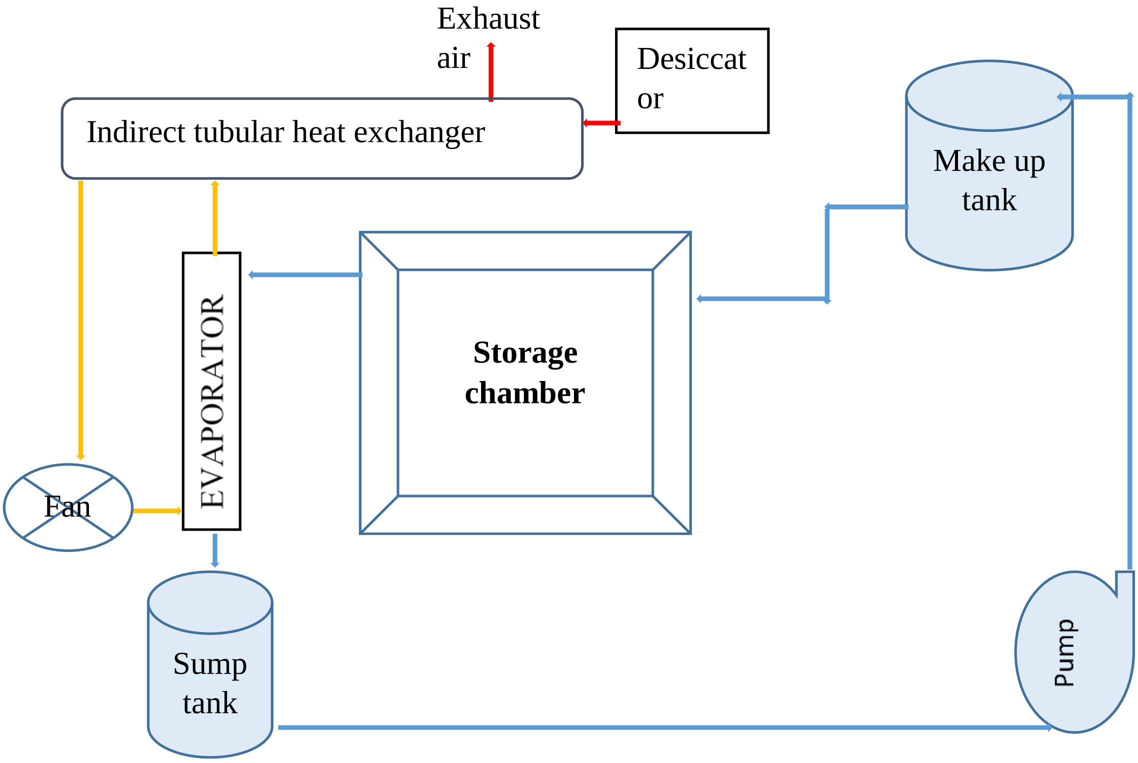

Figure 3. 1: Schematic layout of the developed evaporative cooling system

Air circulation within the chamber was achieved using a fan strategically placed on one side, promoting the even distribution of cool air. The outside air was drawn through a cooling pad by another fan and directed toward the evaporator. Before entering the evaporator, the air passes through a desiccator containing desiccant to remove moisture, thus enhancing the evaporative cooling effect. This dry air flowed through the evaporator in a counter-flow configuration, cooling the water contained within the cavity of the cooling chamber. Notably, the same air was reused for two purposes: pre-cooling the incoming air passing through the desiccator and ultimately exiting the system. Indirect cooling of the storage chamber was achieved by the circulation of cooled water within the chamber cavity. The compartments of the developed evaporative cooler are shown in Figure 3.2.

Figure 3. 2: A plate showing components of the indirect evaporative cooling system

Key: 1= Make up water tank, 2= desiccator for desiccant, 3= Indirect tubular heat exchanger, 4= Evaporator, 5= Storage chamber, 6= Solar panel batteries for power supply, 7= Water pump for water recirculation, 8= Sucking fan, 9= sump tank, 10= Water level sensors

Solar panels provided sustainable power for the fans, pumps, and water level sensors of all three cooling systems: the evaporative cooler with desiccant, the evaporative cooler without desiccant, and the evaporative charcoal cooler. Two water tanks were employed for each system, with one positioned at the top serving as a distribution tank and the other situated at the bottom. To ensure uninterrupted water circulation throughout the systems, water level sensors and pumps were strategically installed. For optimal performance and protection from external elements, the entire structure was housed indoors, shielded from direct sunlight and rain.

3.2.3 Experimental design

For equipment performance, a 4 x 5 completely randomized design (CRD) factorial arrangement was used to assess the performance of different cooling systems over time. The first factor included four levels: evaporative cooler with desiccant (desiccant cooler), evaporative cooler without desiccant (free-desiccant cooler), evaporative charcoal cooler (charcoal cooler), and ambient room (no cooling). The second factor consisted of five time points: days 1, 2, 3, 4, and 5. All measurements were performed in duplicate for increased accuracy.

3.2.4 Evaluation of evaporative cooling systems on cooling performance

Three hygrometers were put inside the cooling systems at approximately the centre, while another one was placed in the room to monitor the storage conditions. Temperatures (dry bulb inlet, wet bulb, and dry bulb outlet) and relative humidity were recorded twice a day (10 a.m. and 4 p.m. local time) for five different days following the modified procedure of Zakari *et al.* (2016) to measure the cooling efficiency of the system. Both inside and outside temperatures were recorded using Mason's hygrometer (a wet and dry bulb humidity meter). The recorded temperatures were then used to calculate the relative humidity from the psychometric chart.

The performances of the experimented evaporative cooling systems were assessed on the cooling or saturation efficiency (η), as defined by Dhakulkar *et al.* (2018) using Equation 3.1.

$$\eta \boldsymbol{i} = \frac{(\boldsymbol{t1-t2})}{(\boldsymbol{t1-ts})}\,\boldsymbol{x}\ \mathbf{100}\ldots\ldots\ldots\ldots\ldots\text{Equation 3.1}$$

where $\eta \boldsymbol{i}$ is the efficiency of the cooling system; t_1 and t_2 are the dry bulb temperatures of the air at the inlet and outlet of the system, and ts is the wet bulb temperature of the air at the inlet of the system.

Cooling efficiency indicates whether the cooling structure is viable or not. To simplify the equation, the least affecting factors were neglected, and the following assumptions were made in analysing the machine's performance: the convective heat transfer coefficient and mass transfer coefficient of moist air on the surface of the water film is constant; heat flux transferred from surrounding areas was neglected; water-air interface temperature is assumed to be uniform and constant; thermal properties of water and air are constant; and air temperature changes only in the flow direction.

The effectiveness of the cooling systems on the temperature drop achievable and the percentage increase in humidity was calculated using the equations according to Dhakulkar *et al.* (2018).

Temperature drop achievable:

$$(\boldsymbol{\Delta T}) = (\boldsymbol{t1} - \boldsymbol{ts})\boldsymbol{x}\ \eta \ldots\ldots\text{Equation 3.2}$$

where: t_1= Inlet dry bulb temperature, t_s= Inlet wet bulb temperature, η= Cooling Efficiency

The increase in humidity was calculated as follows:

$$\boldsymbol{Increase\ in\ humidity} = \boldsymbol{Final\ humidity} - \boldsymbol{initial\ humidity} \ldots\ldots\text{Equation 3.3}$$

3.2.5. Data Analysis

The temperature and relative humidity data obtained from this study were tested for normality using the measure of central tendency test, the results then informed on whether or not data transformation is needed. The Analysis of Variance (ANOVA) was then conducted to test the study hypothesis in SAS software (version 9.4) using the General Linear Model (GLM) procedure. Post-hoc analysis was performed using Tukey’s Honestly Significant Difference (HSD) at a 95% confidence level.

3.3 Results

Analysis of variance showed that the type of coolers used had a significant influence on the dry bulb temperature and relative humidity but not the wet bulb temperature (Table 3.1). On the other hand, dry bulb temperature and wet bulb temperature were significantly affected over time, but not relative humidity. The interaction between the type of cooler and time was not significant for all the properties.

Table 3. 1: Mean squares of ANOVA for the different types of coolers on dry bulb temperature, wet bulb temperature, and relative humidity for different days.

S.O.V	DF	Dbt (°C)	Wbt (°C)	RH (%)
Type of cooler	3	27.46***	0.15^{NS}	1866.92***
Time in days	4	2.34**	1.58*	3.21^{NS}
Replication	1	27.06	21.17	1.41
Cooler*Time	12	0.08^{NS}	0.03^{NS}	8.56^{NS}
Error	19	0.36	0.38	12.92
R^2	-	0.95	0.8	0.96
C.V	-	3.37	3.9	4.35

Key: Dbt= Dry bulb temperature; Wbt= Wet bulb temperature; RH= Relative Humidity; S.O.V= Source of Variation; D.F= Degrees of Freedom; R^2= Coefficient of Determination; C.V= Coefficient of Variation; *= Significant at $P \leq 0.05$; ^{NS}= not significant at $P \leq 0.05$

The effect of the type of cooler on the dry bulb temperature, wet bulb temperature, and relative humidity of the storage chamber is shown in Table 3.2. The ambient room recorded a significantly highest dry Dbt of 20.15 ℃, and the lowest RH of 62.60% as compared to the other three types of storage. The desiccant cooler had a slightly lower Dbt of 16.46 ℃ and a significantly higher RH of 93%. There was no significant difference between the desiccant-free cooler and the charcoal cooler on all analysed parameters. All types of coolers did not differ significantly for Wbt.

Table 3. 2: Effect of type of cooler on dry bulb temperature, wet bulb temperature, and relative humidity of storage chamber.

Cooler type	Dbt (℃)	Wbt (℃)	RH (%)
Desiccant cooler	16.46 ± 0.29^{c}	15.68 ± 0.28^{a}	93.30 ± 0.72^{a}
Desiccant-free cooler	17.37 ± 0.33^{b}	15.95 ± 0.28^{a}	85.60 ± 1.31^{b}
Charcoal cooler	16.93 ± 0.30^{bc}	15.84 ± 0.30^{a}	88.65 ± 0.67^{b}
Ambient room (no cooling)	20.15 ± 0.45^{a}	15.92 ± 0.37^{a}	62.60 ± 1.16^{c}

Key: Results are means ± standard deviations of duplicate data; Means with the same letter along the columns are not significantly different at $P\leq 0.05$.

The temperatures and relative humidity of the experimental evaporative coolers and ambient room for the 5 days are shown in Table 3.3. Low temperatures in desiccant and desiccant-free coolers were fairly constant during the experiment. It ranged from 16.0 to 16.9℃, and 16.8 to 17.8℃ for the desiccant cooler, and the desiccant-free cooler, respectively.

Table 3. 3: Average temperatures and relative humidities in the different coolers with time (days)

Time	Ambient room		Desiccant cooler		Desiccant-free cooler		Charcoal cooler	
(Day)	Dbt	RH	Dbt	RH	Dbt	RH	Dbt	RH
1	19.0	67.5	16.0	92.0	16.8	84.5	16.3	89.5
2	21.0	60.0	16.9	93.5	17.8	87.5	17.4	90.0
3	20.8	61.3	16.9	95.0	17.9	84.0	17.3	87.0
4	19.8	61.8	16.0	92.0	17.0	87.0	16.8	87.3
5	20.3	62.5	16.6	94.0	17.5	85.0	17.0	89.5

The temperature for the charcoal cooler ranged from 16.3 to 17.4. Relative humidity was high in the desiccant cooler, ranging from 92% to 95%, followed by the charcoal cooler, which ranged between 70.6 and 85.9%, and the desiccant-free cooler (57.6 to 78.6%).

With a cooling efficiency of 87.2%, the desiccant cooler outperformed the charcoal cooler (79.3%) and the desiccant-free cooler (67.3%), as shown by Figure 3.3 of the results on the cooling efficiencies of experimental coolers. It was also noted that the efficiency of the desiccant cooler recorded a fairly constant efficiency over time, while the charcoal cooler showed fluctuating efficiency.

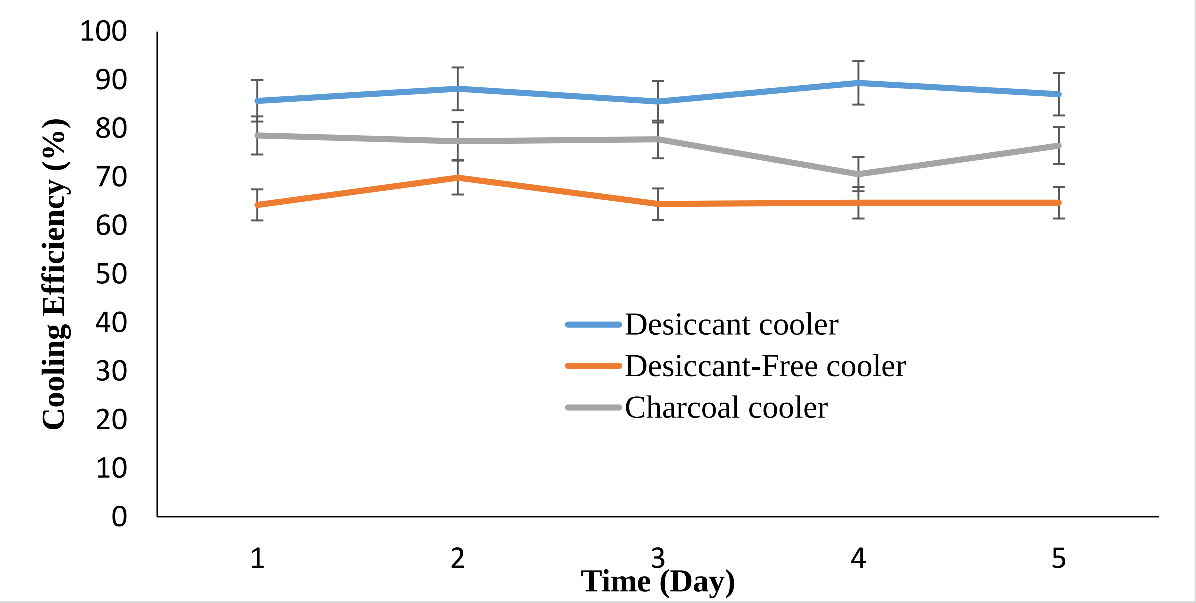

Figure 3. 3: Cooling efficiencies of different evaporative cooling systems

Temperature drops and humidity increase for experimental coolers are shown in Figure 3.4. The evaporative cooler with desiccant dropped 3.7℃, followed by a charcoal cooler (3.2℃), and the desiccant-free cooler (2.8℃). The average humidity increased by the desiccant, desiccant-free, and charcoal coolers are 30.7%, 23%, and 26.1%, respectively.

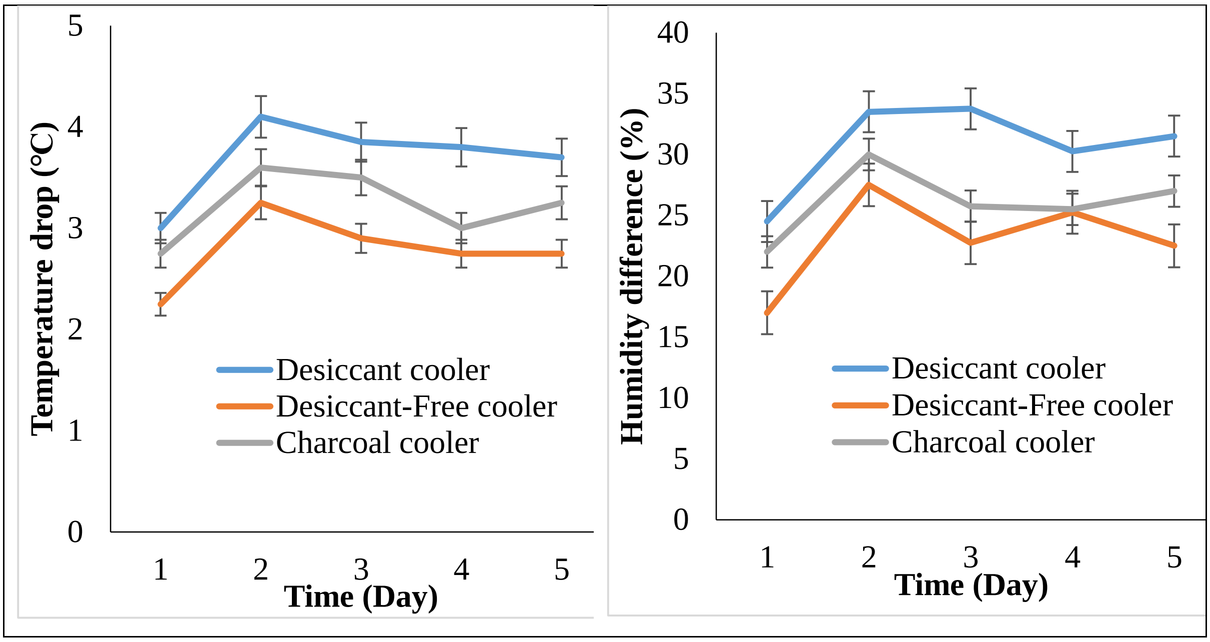

Figure 3. 4: Temperature drop and relative humidity increase of coolers

It was also noted that the desiccant cooler was significantly different from the desiccant-free cooler according to the temperatures they dropped and the humidity they increased.

3.4 Discussion

An evaporative cooler works on the principle of evaporative cooling, where the evaporation of water draws energy from its surroundings and then produces a cooling effect (Ndukwu *et al*., 2013). The charcoal cooler that was used in this study was developed through modification of the one developed by Ronoh *et al*. (2018). The cooler has charcoal-laden walls of 15 cm thickness, held by chicken wire meshes and stainless steel sheets on the outer and inner sides. Charcoal was used because of its thermal conductivity of 0.084 W/(mK). It also has a porous structure that plays a big role in holding water. Water was made to drip from the rooftop of the cooler and then flow up to the reservoir tank at the bottom.

The difference in temperature between the internal controlled atmosphere and external ambient conditions indicates the performance of the cooling system (Adekanye *et al*., 2019). According to Nkolisa *et al*. (2018), improving an evaporative cooling system with a water circulation pump, and powerful solar panels to power the air circulation fan would have helped to reduce the temperature to below 17.24℃ and increase relative humidity to above 83.1% in the storage chamber. In our case, the temperature achieved by the improved evaporative cooler with a desiccant is 16.5 ℃, the evaporative cooler without a desiccant 17.4 ℃, and the Evaporative charcoal cooler 16.9 ℃. Low temperature and higher relative humidity were maintained in the evaporative cooler with desiccant compared to others. The relative humidity of the evaporative cooler with desiccant ranged from 92 to 95%, this agrees with Chinenye *et al*. (2013) whose cooler ranged between 85.6 and 96.8%.

Dehumidifying ambient air using a desiccant plays a vital role in increasing the cooling efficiency of evaporative cooling (Kapilan *et al*., 2023; Yang *et al*., 2019). The results for cooling efficiency, temperature drop, and percentage humidity increase are different from the ones reported by Dhakulkar *et al*. (2018). This is due to the different environmental conditions in which the evaporative cooler is developed. The maximum cooling efficiency for the desiccant cooler was recorded when the ambient temperature increased, this agrees with Ishaq *et al*. (2022), who found it to be affected by ambient environmental conditions. The average cooling efficiency of the evaporative cooler with desiccant obtained was 87.2% which agrees with Seweh *et al*. (2016), who attained a cooling efficiency of 87.17%. Additionally, it is in line with the findings of Chinenye *et al*. (2013) and Chandegara *et al*. (2016), who obtained cooling efficiency ranges of 77 to 98% and 63.6 to 95.83%, respectively. The low cooling efficiency in the evaporative charcoal cooler and the evaporative cooler without a desiccant was due to the high humidity in the inlet air (Chen & Shi, 2022). This limits their use in hot humid places because they are not effective.

The improved evaporative cooler with an air preconditioning component (desiccant) was able to achieve the storage temperature and humidity of 16.5 ℃ and 93.3%, respectively. These are close to the recommended temperature of 10-15 ℃ and relative humidity of 85-95% for extending the different fruits and vegetables (Ochida *et al*., 2019). The cooling performance achieved could be the result of operating conditions and the structure of airflow passages (Cui *et al*., 2018). Preconditioning the inlet air by using a desiccant affected significantly the performance of the evaporative cooler. This could be due to the reduction of the humidity ratio of the inlet air by the desiccant which resulted in more moisture absorption into the working air thus greater capacity to cool the storage chamber (Cui *et al*., 2018).

3.5 Conclusion and Recommendation

The difference between the partial vapour pressure on the desiccant surface and in the surroundings directs the absorption of water vapours by that desiccant. The incorporation of a desiccant as an air preconditioning component in an evaporative cooling system significantly influenced the effectiveness and efficiency of cooling based on various performance parameters (temperature drop, percentage humidity increase, and cooling efficiency). Three types of evaporative cooling systems i.e., evaporative cooler with desiccant, evaporative cooler without a desiccant, and Evaporative charcoal cooler were studied. Silica Gel desiccant was used in the model of one evaporative cooler for analysis. The temperature achieved was also lower in an evaporative cooler with desiccant as compared to others. It also achieved higher humidity than the evaporative cooler without a desiccant, and the Evaporative charcoal cooler. This resulted in a higher temperature drop, humidity increase, and cooling efficiency for the evaporative cooler with a desiccant compared to others. The desiccant evaporative cooler did not use any ozone-depleting refrigerants, and it operated successfully on solar energy. Hence, a solar-powered desiccant evaporative cooler provides conditions that can enhance the shelf life of a wide range of fruits and vegetables.

CHAPTER FOUR

EFFECT OF STORAGE CONDITIONS ON PHYSICOCHEMICAL PROPERTIES AND MICROBIAL LOAD OF DIFFERENT TOMATO VARIETIES

Abstract

Kenya is one of the countries where produce gets wasted due to a lack of appropriate cooling facilities. The failure to meet desired quality attributes in the supply chain of tomatoes due to a lack of ventilated storage facilities might cause serious losses for producers and vendors. In the current study, different tomato varieties (Ansal, Bolgan, and Pendo) were harvested at the red maturity stage and brought immediately to the storage area. They were sorted and cleaned with potable water before being stored in different conditions (a desiccant evaporative cooler, an evaporative charcoal cooler, and others in an ambient room). Tomato's physicochemical properties such as firmness, total soluble solids (TSS), percentage weight loss (PWL), beta carotene, as well as microbial load including total viable counts (TVC), and yeasts and moulds (YM) were monitored during 20 days of storage and used to evaluate the performance of these storage conditions on quality and shelf life of tomatoes. The results showed that only tomatoes that were stored in a desiccant evaporative cooler did not significantly ($P \leq 0.05$) have changes in both physicochemical and microbial parameters, which their means were found to be 2.71 Nmm^{-1} for firmness, TSS (6.21 ^{o}B), weight loss (2.16%), beta carotene (1.45 mg/100g), total viable counts (5.18 cfu/g) and yeasts and moulds (4.59 cfu/g) after 20 days of storage. The results also showed effects of the variety of tomatoes whereby variety Pendo F1 had significantly ($P \leq 0.05$) highest firmness of 2.79 Nmm^{-1}, Bolgan F1 had higher TSS (6.58 ^{o}B), and lowest weight loss of 3.3%, TVC (5.7 cfu/g) and YM (5.2 cfu/g), respectively. The tomatoes were edible and in good condition in the desiccant evaporative cooler for up to 61 days, followed by the evaporative charcoal cooler (37 days), and Ambient room (30 days). The desiccant evaporative cooler significantly increased the shelf life of tomatoes by maintaining quality compared to the evaporative charcoal cooler and ambient room which are currently used by farmers to keep their fresh produce. Thus the use of desiccant evaporative cooler can be employed to reduce postharvest losses of tomatoes and other perishable produce.

4.1 Introduction

In most developing countries including Kenya, the use of refrigeration storage in tomato handling is a huge initial cost that is beyond the reach of under-resourced handlers, and farmers from remote areas without a national electricity grid (Arah *et al.*, 2016). Factors causing postharvest losses along the supply chain of fresh produce include the nature of the product, sensitivity, required storage facilities, transportation, and handling facilities before they reach the market, marketing problems, improper harvesting, and other causes due to infections (Pathare *et al*., 2021). Tomato (*Solanum lycopersicum* L.) is one of the most widely cultivated horticultural crops and is highly perishable; thus maintaining the optimal conditions of the storage environment helps to reduce the rate at which its deterioration happens. Tomatoes with turgid appearance, firmness, shiny and uniform colour with no sign of decay, injury, and shrivelling are the most preferred by consumers in the market (Mbunde *et al*., 2022). The information on using desiccant evaporative cooling to preserve tomatoes is little or missing.

In most parts of the world, tomato postharvest losses of up to 40% are recorded, and they result in low returns for all actors in the value chain of this crop (Sundari & Tasikmalaya, 2023). Research indicates that these losses are often the largest in nations with higher food needs; some experts estimate that tomato losses can reach 50% (Geetha & Indhu, 2020). According to Lydia (2023), the tomato postharvest losses were estimated to be 72%, and this was only in Mweya, Kirinyaga County, Kenya. In most parts of Kenya, postharvest estimates have not been quantified, despite the fact that they do not span a sufficient amount of time. The capacity to obtain non-ripening mutants and naturally occurring variations has allowed tomato cultivars with extended shelf life to be developed. However, the storage environment has an impact on these cultivars. Increasing the fruit's antioxidant, phytonutrient, and other nutrient levels and shelf life not only increases the marketing skills to benefit farmers, producers, and suppliers monetarily but also raises hopes for bettering human health and preventing diseases (Wang *et al*., 2017). The fundamental knowledge arising from various research angles will enable new strategies to counteract the detrimental impacts of senescence and preserve optimal tomato fruit quality, which will be advantageous to the horticulture industry.

In Kenya, tomatoes are among the promising commodities in horticultural expansion and development. It plays an important role in the creation of employment, the generation of income and foreign exchange earnings, and meeting domestic and nutritional food requirements (Karuku *et al*., 2017). Tomato production is preferred to be done in the greenhouse because of the high benefits accrued to it, but most of the varieties are grown in the open field by low-income farmers who cannot afford greenhouse setup costs. Some tomato varieties are grown specifically for the fresh market, others for processing companies who use them as raw materials for tomato sauce, tomato juice, chili sauce, and chili cubes (Gabriel & Lydia, 2023). The rate at which the quality characteristics of tomatoes change after harvest depends on ambient temperatures (Mbunde *et al*., 2022).

The preference for fresh products by consumers is based on colour, texture, and other quality parameters. The evaporative cooling systems have the potential to provide optimum temperature and relative humidity for fresh produce storage. Postharvest handling practices and treatments determine the quality of the tomato which starts deteriorating 2-3 days after harvesting (Ochida *et al*., 2019). Though the use of evaporative cooling technology would reduce food losses, their adoption in Kenya is still low due to lack of information, lack of access to these facilities, and lack of need for storage to extend the shelf life (Maina *et al*., 2020). This study aimed to evaluate the effect of a desiccant evaporative cooler on the physico-chemical properties and microbial load of different tomato varieties.

4.2 Materials and Methods

4.2.1 Materials and Evaporative coolers

The study was carried out at the Department of Dairy and Food Science and Technology, Egerton University. Different storage conditions namely desiccant evaporative cooler, evaporative charcoal cooler, and ambient room environment henceforth in this study will be called desiccant cooler, charcoal cooler, and ambient room were evaluated on their performance in maintaining the quality attributes and shelf life of tomatoes. The open field three determinate tomato varieties namely: Ansal F1 (Ansal), Bolgan F1 (Bolgan), and Pendo F1 (Pendo) were harvested at commercial maturity (late red ripe) stage from the Mogotio-Baringo (Nakuru) and brought immediately to the storage systems (desiccant cooler, charcoal cooler, and ambient room). The collected tomato varieties were from the same farm and they were expected to be treated in the same way to avoid unnecessary variations in data recording (Verploegen *et al*., 2019).

4.2.2 Experimental set-up

A completely randomized design (CRD) in a 3 x 3 x 5 factorial arrangement was implemented to investigate the influence of cooler type, tomato variety, and storage time on physicochemical properties, and microbial growth. The first factor encompassed three levels: a desiccant cooler, a charcoal cooler, and an ambient room (no cooling). The second factor included three tomato varieties: Ansal F1 (Ansal), Bolgan F1 (Bolgan), and Pendo F1 (Pendo). The final factor comprised five storage time points: days 0, 5, 10, 15, and 20. All measurements were performed in duplicate for increased accuracy.

The model was as follow:

$$Y_{ijk}= \mu+ \alpha_i+ \beta_j+ \gamma_k+ \alpha\beta_{ij}+ \alpha\gamma_{ik}+ \beta_{jk}+ \alpha\beta\gamma_{ijk}+ \varepsilon_{ijk}$$

where:

Y_{ijk}= Observation in the i^{th} storage condition at j^{th} Variety

μ= Overall mean

α_i, β_j, and γ_k= Effect of the i^{th}, j^{th}, γ^{th} main factors in the experiment

$\alpha\beta_{ij}$, $\alpha\gamma_{ik}$, β_{jk}, $\alpha\beta\gamma_{ijk=}$ Effect of interaction between main factors in the experiment

ε_{ijk}: Random error effect associated with the experiment; ε_{ijk}~N(0,δ^2): Error is normally distributed

4.2.3 Physicochemical properties and microbial load

Tomato samples were collected from each storage condition and taken to a food analysis laboratory as outlined in the subsequent subsections below. After the initial analysis on day 0, the tomatoes were put into different storage conditions and analysed again after 5, 10, 15, and 20 storage days according to the modified procedure of Kabir *et al.* (2020). The firmness, total soluble solids (TSS) weight loss, and beta-carotene, were used to determine the quality loss of tomatoes stored under different storage conditions.

1. Firmness

Firmness indicates the freshness of the product, and it is highly affected by the loss of moisture from the product, which might retard the product's marketability and its nutritional value. The firmness of tomatoes was measured using a texture analyser, Instron Universal Testing Machine (Model 3345, Buckingham, United Kingdom). The firmness measurements were taken using the modified procedure of Wu and Abbott (2002). The measurements obtained were recorded in Newton per milimeter.

2. Total Soluble Solids

Total soluble solids (TSS) were measured according to the procedure given by Dong *et al.* (2004). A digital handheld pocket refractometer Bellinghan and Stanley RFM 340+ refractometer with a measurement performance between 0-20 °Brix was used to read the percentage of TSS. Tomato fruit samples from each treatment were ground in an electric juice extractor for freshly prepared juice. Two drops of the clear juice were dropped on the prism. Distilled water (0^{o}Brix) was used to standardise and clean the refractometer before use and between each sample. The results values were expressed as ^{o}Brix.

3. Weight loss

To determine the weight loss of the tomato samples, the difference between the initial and final weights of a tested tomato divided by the initial weight was considered on a fresh weight basis (William, 2010). The weight loss was assessed by weighing five samples of tomatoes at the beginning of the experiment and after placing them into each storage treatment during each storage interval. The weight loss of the tomato samples was expressed as a cumulated percentage of weight loss from the initial weight (Kabir *et al.*, 2020).

$$\text{Weight loss } (\%) = \frac{\text{Initial weight} - \text{final weight}}{\text{Initial weight}} \text{x } 100 \ldots\ldots\ldots\ldots.. \text{Equation 4.1}$$

4. Analysis of Beta Carotene

The beta-carotene concentration was determined using an AOAC (2005) method 974.29 with little modifications. Standard of β-carotene type I (95% purity, UV) and Acetone were the main reagents used in the analysis (Kopec *et al.*, 2012). The standard stock solution at 1 mg/mL concentration was prepared by dissolving the standard in acetone. The working standard solutions of 16, 8, 4, 2, 1, 0.50, 0.25, and 0.125 mg/ml were prepared. All solutions were protected against the light with aluminium foil and maintained at 4 °C for 20 days of the experiment.

For extraction, a representative portion of the sample (1 g) was accurately weighed in a glass test tube. Then 5 ml of chilled acetone was added to it, and the tube was held for 15 min with occasional shaking vortexed at high speed for 10 min, and finally centrifuged at 1370 X g for 10 min. The supernatant was collected into a separate test tube, and the compound was re-extracted with 5 ml of acetone followed by centrifugation once again as above. Both of the supernatants were pooled together and then passed through the Whatman filter paper No. 42. The absorbance of the extract was determined at 449 nm wavelength in a UV-Vis spectrophotometer.

5. Microbial load (TVC and YM)

By using the aerobic pour plate count method (AOAC, 2000), Method 42-11, and Method 42-50, respectively, the microbiological analysis of TVC and YM was conducted. A 25-gram sample of tomatoes was weighed and mixed with 225 mL of a sterile peptone–water solution. A serial of homogenized sample dilutions from 1 to 1 × 10^{-4} was then prepared. One millilitre of each sample dilution was pipetted onto a corresponding labelled Petri dish containing 12–15 mL of plate count agar (PCA) for TVC and potato dextrose agar (PDA) for YM and inoculated on the agar surface by rotating the plates slowly. The added inoculated agar was allowed to solidify, inverted, and incubated at 37 °C for 48 hours for TVC and at 25 °C for 5 days for YM plates in a microbiological incubator. The colonies were counted, and the average value was taken after a duplicate count. To determine the colony-forming units per gram (CFUs) of tomatoes, the number of CFUs was multiplied by the dilution factor and divided by the inoculation amount. The analysis was repeated every five days to monitor the changes in microbial load up to day 20.

4.2.4 Shelf life determination

To determine the shelf life, samples were treated as described in 4.2.2. Tomato's firmness was used as an indicator of shelf life as proposed by Batu (2004). The shelf life was calculated by following the basic principles for shelf life determination that suggest its kinetic equation (Taoukls & Giannakourou, 2018).

$$r_A = -\frac{d[A]}{dt} = k[A]^n \text{............Equation 4.2}$$

where A is the firmness, k is the reaction rate constant, t is time, and n is the order of the reaction.

1. Firstly, firmness in Nmm^{-1} for every sample was plotted against storage time for each of the three storage conditions, and three tomato varieties to determine the kinetics order of reaction.
2. After establishing that the order of the reaction is first order, a regression plot of $[A]/[A_0]$ against storage time was carried out to get a linear model according to Equation 4.3.

   $$Ln\frac{[A]}{[A0]} = kt \text{..............Equation 4.3}$$

   where $[A]$ is the firmness of the tomato on a given storage day while $[A_0]$ is the initial firmness on the day of harvest (day 0), t is the storage time in days, and k is the reaction constant.

4.3 Data analysis

Microbial counts were transformed by the $\log_{10}$ method before analysis. The physicochemical properties and microbial load data obtained from this study were tested for normality using the measure of central tendency test, the results then informed on whether or not data transformation is needed. Analysis of Variance (ANOVA) was then conducted following a completely randomized design with SAS software (version 9.4; general linear model). The data was analysed by considering storage treatments, tomato varieties, replication, storage period, and observations as factors in the statistical analysis. Comparisons among the means were performed by Tukey's Honestly Significant Difference at a 5% level of significance.

4.4 Results

The storage condition, variety of tomatoes, and storage time significantly ($P \leq 0.05$) affected both the physicochemical properties and microbial load of tomatoes as shown by the ANOVA table of results in Appendix E. The interaction between the storage condition and the variety of tomatoes did not significantly affect the firmness and TSS of tomatoes during storage. Apart from TSS, the interaction between storage condition and time significantly affected the physicochemical properties and microbial load of tomatoes. Weight loss, beta carotene, and total viable counts were also the only ones that were significantly affected by the interaction between the type of storage condition, variety of tomato, and time at $P \leq 0.05$. On the 20th day, tomatoes stored in a desiccant cooler marked a difference; variety Pendo had the highest firmness of 2.5 Nmm^{-1}, lowest TSS of 6.5 ^{o}Brix, and beta carotene of 1.8 mg/100g. Tomatoes that were stored in an ambient room were found to have the lowest firmness of 1.65 Nmm^{-1} and highest TSS of 7.85 ^{o}Brix in variety Bolgan F1, variety Ansel F1 had the highest PWL (9.39%), beta carotene content of 3.62 mg/100g, TVC and YM of 6.145 cfu/g and 6.110 cfu/g, respectively.

4.4.1 Effect of the storage condition on the physicochemical properties and microbial load of different tomato varieties

The results for the effect of storage condition on the physicochemical and microbial load of tomatoes are shown in Table 4.1. The desiccant cooler, charcoal cooler, and the ambient room showed a significant difference at $P \leq 0.05$ on firmness, TSS, percentage weight losses (PWL), and beta carotene content total viable counts (TVC), yeasts and moulds (YM) of tomatoes after 20 days of storage. Apart from firmness; TVC, YM, TSS, PWL, and beta carotene were higher in the ambient room followed by the Evaporative charcoal cooler, and the desiccant evaporative cooler had the lowest.

Table 4. 1: Effect of storage condition on firmness, total soluble solids, weight loss, beta carotene, TVC, and YM

Storage	Firmness	TSS	PWL	BC	TVC	YM
Amb.	2.363±0.09^{c}	6.569±0.13^{a}	5.026±0.57^{a}	2.01±0.14^{a}	5.374±0.11^{a}	4.912±0.11^{a}
ECC	2.560±0.08^{b}	6.389±0.10^{b}	2.562±0.33^{b}	1.671±0.09^{b}	5.321±0.11^{b}	4.781±0.11^{b}
EvC	2.707±0.06^{a}	6.213±0.08^{c}	2.162±0.28^{c}	1.448±0.07^{c}	5.176±0.10^{c}	4.590±0.10^{c}

Key: Results are means ± standard deviation of duplicate samples; Amb= Ambient room ECC= Evaporative charcoal cooler, EvC= Desiccant evaporative cooler, TSS= Total soluble solids, PWL= Percentage Weight Loss, BC= Beta Carotene (mg/100g), TVC= Total Viable Counts, YM= yeasts and Moulds. TVC and YM mean values are in cfu/g, firmness in newton, TSS in degree brix, PWL in percentage, and beta carotene in mg/100g. The Means with the same letter along the columns are not significantly different at $P \leq 0.05$.

1. Firmness

The initial tomato firmness was 3.03 Nmm^{-1} which was similar to all storage conditions, then the firmness declined with time of storage as shown in Figure 4.1. However, the rate of decrease was significantly lower in tomatoes that were stored in a desiccant cooler compared to a charcoal cooler, and an ambient room. The firmness of tomatoes in control reduced continuously to 1.78 Nmm^{-1} over 20 days of storage which was not significantly different from the ones in charcoal cooler that had 2.05 Nmm^{-1}.

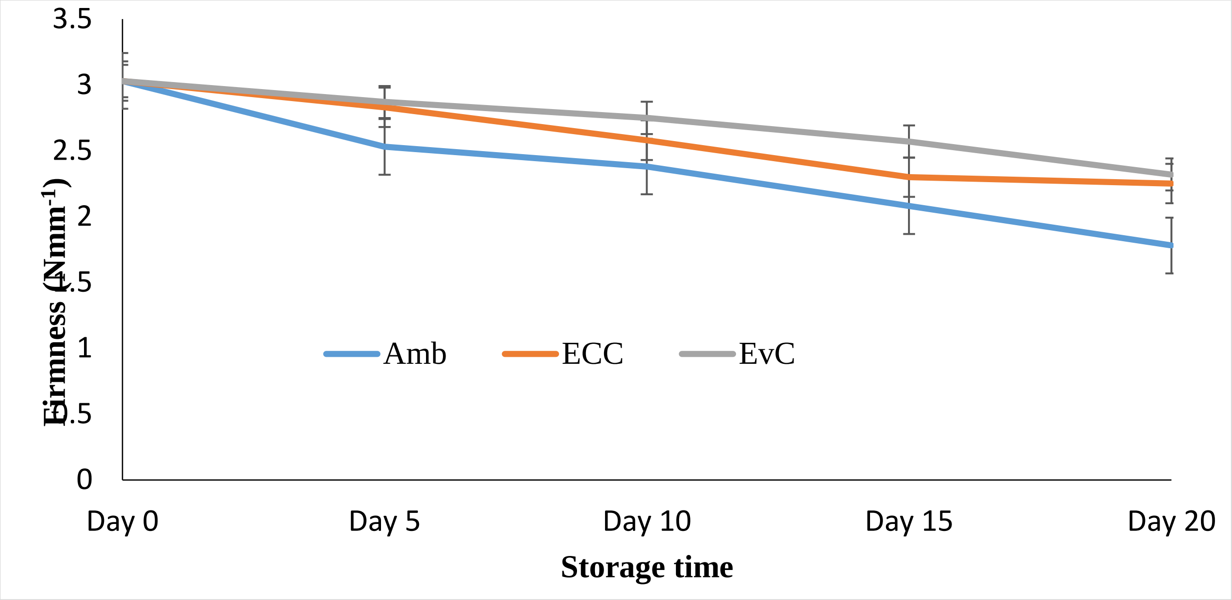

Figure 4. 1: *Changes in tomatoes' firmness during storage*

Key: Amb= Ambient room, ECC= Evaporative charcoal cooler, EvC= Desiccant evaporative cooler

2. TSS

The Total soluble solids of tomatoes increased generally with time of storage. Tomatoes that were stored in the ambient room recorded 6.57 ^{o}B while the ones in an evaporative charcoal cooler and desiccant evaporative cooler recorded 6.39 ^{o}B and 6.21 ^{o}B, respectively after 20 days of storage as shown in Figure 4.2. At day zero all tomatoes in all storage conditions had recorded an average of 5.6 ^{o}B, but it kept increasing with time though the changes were significantly different in all storage conditions.

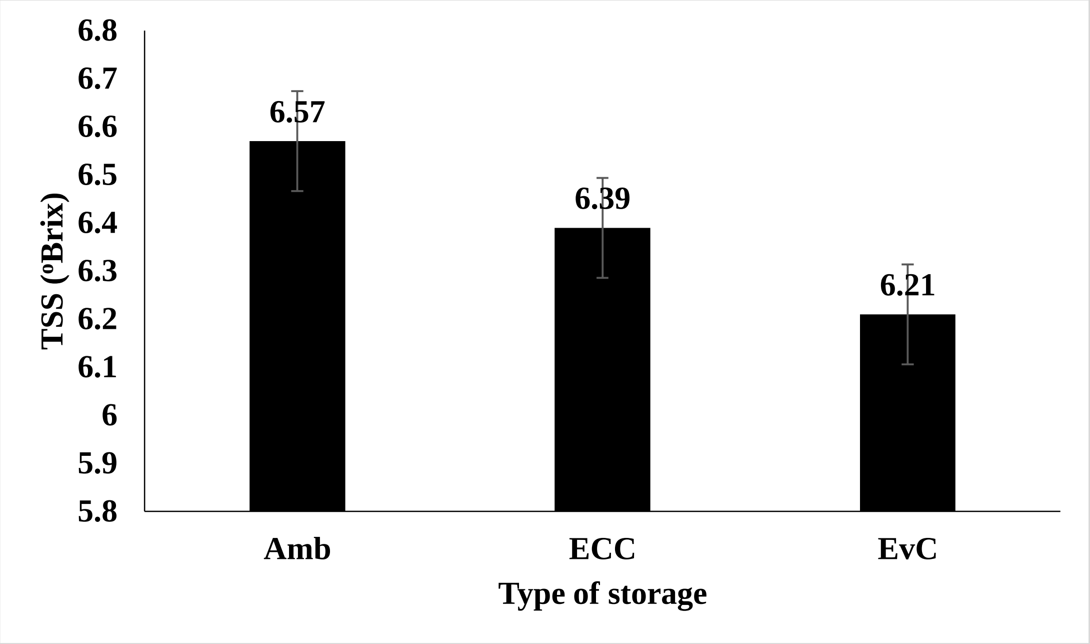

Figure 4. 2: *Total soluble solids of tomatoes stored under different conditions*

Key: Amb= Ambient room, ECC= Evaporative charcoal cooler, EvC= Desiccant evaporative cooler, TSS= Total Soluble Solids

3. Weight Loss

The results showed a significant effect of storage condition on tomato weight loss at $P < 0.05$ in the current study, the lowest average weight loss of 2.16% was recorded in tomatoes stored in an evaporative cooler with desiccant followed by an Evaporative charcoal cooler that had 2.56% after 20 days of storage period. Tomatoes that were stored in an ambient environment showed a significant highest weight loss of 5.03% after 20 days of storage time. The weight of tomatoes changed with time as shown in Figure 4.3.

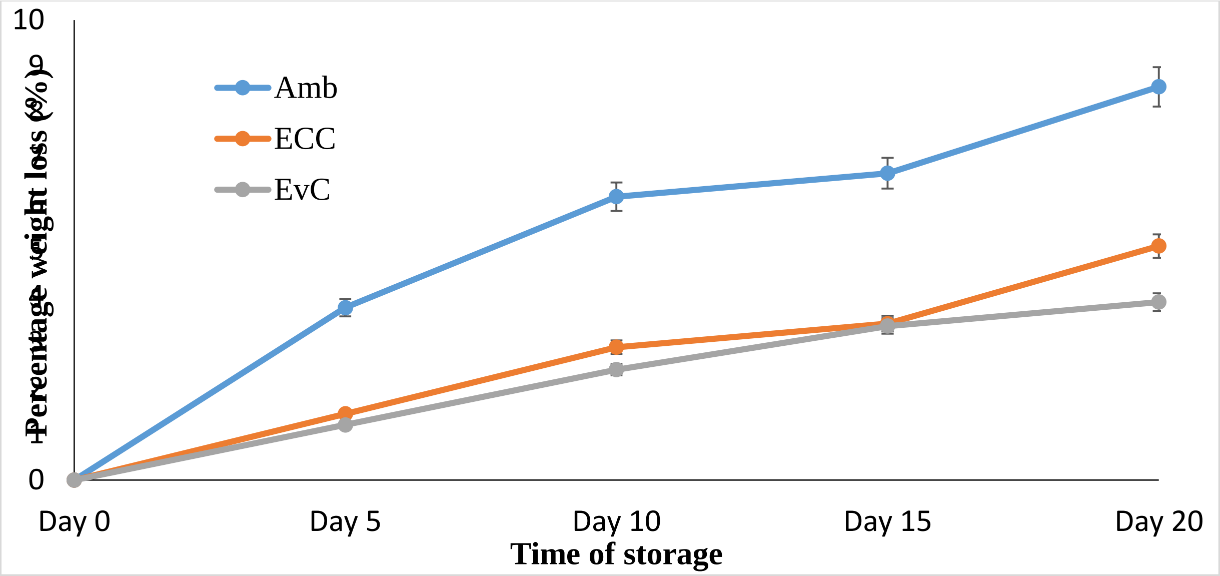

Figure 4. 3: *Tomatoes' percentage weight loss in different storage conditions*

Key: Amb= Ambient room, ECC= Evaporative charcoal cooler, EvC= Desiccant evaporative cooler

4. Beta Carotene

The trend of beta carotene in tomatoes stored under different conditions is shown in Figure 4.4. The concentration of beta carotene was significantly affected by the storage conditions. Initially, all the tomatoes in all conditions averaged the beta carotene content of 1.03 mg/100g. After 20 days of storage, the tomatoes that were stored in the ambient room recorded significantly higher beta-carotene content compared to other storage conditions.

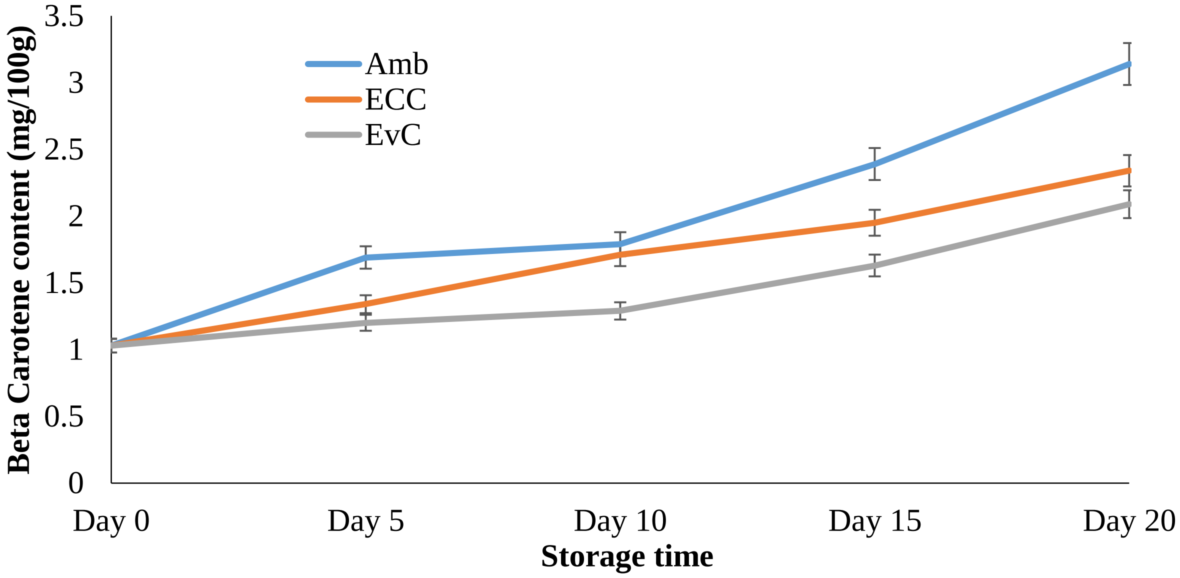

Figure 4. 4: *Changes in beta Carotene content in tomatoes during storage*

Key: Amb= Ambient room, ECC= Evaporative charcoal cooler, EvC= Desiccant evaporative cooler

5. Microbial load

The microbial load of tomatoes increased generally with time, though it was found to be significantly affected by the storage conditions as shown in Figure 4.5. TVC changed from 4.4 cfu/g in all storage conditions to 6.06 cfu/g, 5.95 cfu/g, and 5.85 cfu/g for tomatoes that were stored in the ambient room, charcoal cooler, and desiccant cooler, respectively. YM for tomatoes in the ambient room, charcoal cooler, and desiccant cooler changed from 4.18 cfu/g to 5.88 cfu/g, 5.76 cfu/g, and 5.48 cfu/g, respectively. The desiccant cooler recorded low colonies for both TVC and YM.

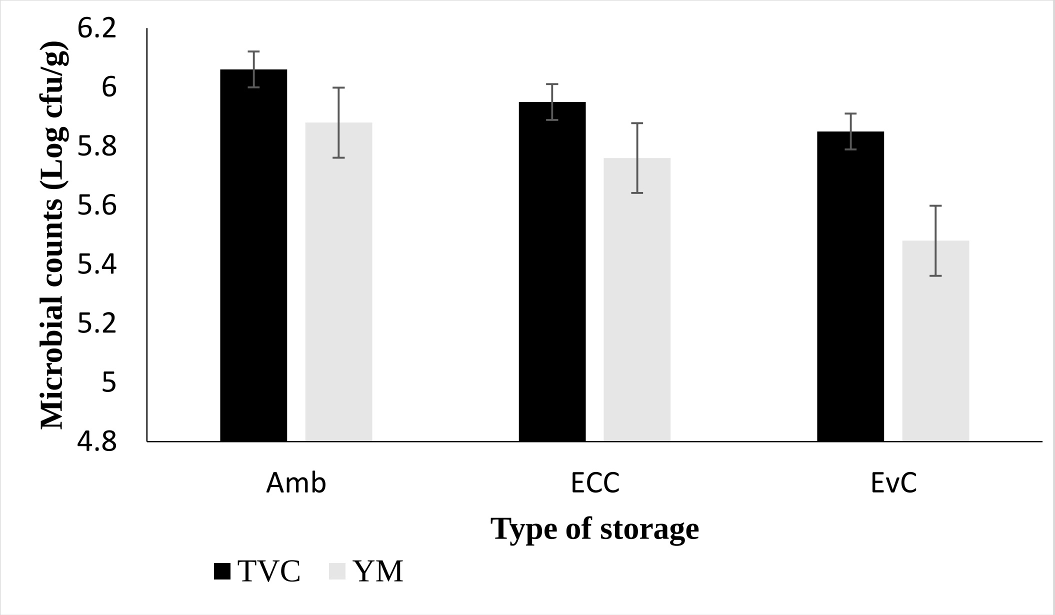

Figure 4. 5: *TVC and YM of tomatoes under different types of storage conditions after 20 days of storage*

Key: TVC= total viable counts, YM= yeasts and moulds, Amb= Ambient room, ECC= Evaporative charcoal cooler, EvC= Desiccant evaporative cooler

4.4.2 Effect of the variety of tomato on the physicochemical properties and microbial load

The varieties of tomatoes were tested on their effect on physicochemical and microbial load during storage, and the results are presented in Table 4.2. The varieties that were studied are Ansal F1, Bolgan F1, and Pendo F1. Ansal had significantly ($P \leq 0.05$) higher loss of weight (3.74%), and beta carotene (1.81mg/100g), higher TVC, and YM of 5.33 cfu/g and 4.89 cfu/g, respectively. Bolgan showed a significantly ($P \leq 0.05$) higher TSS of 5.58^{o}B while Pendo F1 recorded significantly higher firmness of 2.79Nmm^{-1} after 20 days of storage. The lowest firmness of 1.65 Nmm^{-1} was recorded in variety Bolgan F1, the highest TSS of 7.85 ^{o}Brix in variety Bolgan, variety Ansel had the highest PWL (9.39%), beta carotene content of 3.62 mg/100g, TVC and YM of 6.145 cfu/g and 6.110 cfu/g, respectively on the 20th day of tomato that was stored in ambient room.

Table 4. 2: Effect of variety of the tomato on firmness, total soluble solids, weight loss, beta carotene, TVC, and YM

Variety	Firmness	TSS	PWL	BC	TVC	YM
Ansal	2.373±0.06^{c}	6.260±0.10^{b}	3.736±0.53^{a}	1.809±0.12^{a}	5.397±0.11^{a}	4.894±0.12^{a}
Bolgan	2.467±0.08^{b}	6.578±0.13^{a}	2.917±0.45^{c}	1.747±0.12^{b}	5.331±0.08^{b}	4.693±0.09^{b}
Pendo	2.790±0.08^{a}	6.333±0.07^{b}	3.097±0.43^{b}	1.573±0.10^{c}	5.143±0.12^{c}	4.696±0.08^{b}

Key: Results are means ± standard deviation of duplicate samples; A= Ansal, B= Bolgan, P= Pendo, TVC= Total Viable Counts, YM= yeasts and Moulds, TSS= Total soluble solids, PWL= Percentage Weight Loss, BC= Beta Carotene. TVC and YM mean values are in cfu/g, firmness in newton, TSS in degree brix, PWL in percentage, and beta carotene in mg/100g. The means with the same letter along the columns are not significantly different at $P \leq 0.05$.

4.4.3 Effect of storage time on the physicochemical properties and microbial load of different tomato varieties

It was clear that all quality parameters of tomatoes changed over storage time, the results are shown in table 4.3. Apart from firmness that decreased from 3.03 Nmm^{-1} to 2.05 Nmm^{-1} during the storage period, TSS, weight loss, and beta carotene increased gradually with time. The same trend was also seen in microbial load (total viable counts and yeasts and moulds). There was no significant difference between the tomatoes’ TSS analysed on days 10 and 15 of storage.

Table 4. 3: Influence of storage time on firmness, total soluble solids, weight loss, beta carotene, TVC, and YM

Day	**Firmness**	**TSS**	**PWL**	**BC**	**TVC**	**YM**
0	3.033±0.05^{a}	5.597±0.09^{d}	0±0.00^{e}	1.032±0.03^{e}	4.395±0.04^{e}	4.178±0.02^{e}
5	2.744±0.07^{b}	6.167±0.5^{c}	2.131±0.33^{d}	1.409±0.07^{d}	5.021±0.06^{d}	4.374±0.06^{d}
10	2.572±0.08^{c}	6.489±0.07^{b}	3.815±0.46^{c}	1.597±0.06^{c}	5.448±0.05^{c}	4.599±0.04^{c}
15	2.317±0.06^{d}	6.711±0.09^{b}	4.472±0.41^{b}	1.988±0.10^{b}	5.641±0.06^{b}	4.946±0.05^{b}
20	2.050±0.07^{e}	6.989±0.09^{a}	5.833±0.50^{a}	2.523±..0.13^{a}	5.949±0.03^{a}	5.707±0.07^{a}

Key: Results are means ± standard deviation of duplicate samples; TVC= Total Viable Counts, YM= yeasts and Moulds, TSS= Total soluble solids, PWL= Percentage Weight Loss, BC= Beta Carotene. TVC and YM mean values are in cfu/g, firmness in newton, TSS in degree brix, PWL in percentage, and beta carotene in mg/100g. Means with the same letter along the columns are not significantly different at P≤ 0.05.

4.4.4 Interaction effect of the type of storage condition and variety on physicochemical properties and microbial load of different tomato varieties

The results of the effect of the type of storage condition and variety on the physicochemical properties and microbial load of tomatoes during 20 days of storage are shown in Table 4.4. The ansal variety that was stored in open air recorded significantly lower firmness (2.17 Nmm^{-1}), higher weight loss, beta carotene, TVC, and YM of 6.07%, 2.18 mg/100g, 5.45 cfu/g, and 5 cfu/g, respectively. The higher firmness was recorded in variety Pendo that was stored in a desiccant cooler (2.97 Nmm^{-1}) followed by a charcoal cooler (2.80 Nmm^{-1}). The beta carotene content of variety pendo that was stored in the charcoal cooler did not show a significant difference (P≤ 0.05) from variety ansal and bolgan which were stored in the desiccant cooler.

Table 4. 4: Effect of type of storage*variety on, firmness, total soluble solids, weight loss, beta carotene, total viable counts, yeasts and moulds

C*V	Firmness	TSS	PWL	BC	TVC	YM
Amb*A	2.17±0.12^{e}	6.41±0.20^{bc}	6.07±1.11^{a}	2.18±0.28^{a}	5.45±0.19^{a}	5±0.21^{a}
Amb*B	2.32±0.17^{de}	6.85±0.28^{a}	4.72±0.98^{b}	1.96±0.26^{b}	5.41±0.16^{abc}	4.89±0.17^{abc}
Amb*P	2.60±0.15^{b}	6.45±0.15^{bc}	4.29±0.90^{c}	1.884±0.22^{bc}	5.26±0.23^{d}	4.84±0.20^{bcd}
ECC*A	2.40±0.10^{cd}	6.26±0.19^{bc}	2.64±0.57^{d}	1.73±0.15^{d}	5.43±0.20^{ab}	4.91±0.21^{ab}
ECC*B	2.48±0.13^{bcd}	6.54±0.22^{ab}	2.22±0.52^{e}	1.78±0.18^{cd}	5.32±0.15^{bcd}	4.70±0.16^{e}
ECC*P	2.80±0.14^{a}	6.37±0.11^{bc}	2.82±0.67^{d}	1.50±0.14^{e}	5.22±0.22^{d}	4.73±0.18^{de}
EvC*A	2.55±0.06^{bc}	6.11±0.15^{c}	2.49±0.55^{de}	1.51±0.15^{e}	5.31±0.17^{cd}	4.69±0.21^{cde}
EvC*B	2.60±0.11^{b}	6.35±0.18^{bc}	1.81±0.38^{f}	1.49±0.13^{e}	5.27±0.14^{ad}	4.49±0.15^{f}
EvC*P	2.97±0.09^{a}	6.18±0.08^{bc}	2.18±0.52^{e}	1.34±0.11^{f}	4.95±0.20^{e}	4.51±0.15^{f}

Key: Results are means ± standard deviation of duplicate samples; C*V= interaction between cooler and variety, Amb= Ambient room, ECC= Evaporative charcoal cooler, EvC= Desiccant evaporative cooler, A= Ansal, B= Bolgan, P= Pendo, TVC= Total Viable Counts, YM= Yeasts and Moulds, TSS= Total soluble solids, PWL= Percentage Weight Loss, BC= Beta Carotene. TVC and YM mean values are in cfu/g, firmness in Nmm^{-1}, TSS in degree brix, PWL in percentage, and beta carotene in mg/100g. The means with the same letter along the columns are not significantly different at $P \leq 0.05$.

4.4.5 Association among parameters of tomato's quality

The relationship between tomato's quality parameters is presented in Table 4.5. During storage, tomato firmness was found to be strongly negatively significantly correlated with TVC (r= -0.84), YM (r= -0.805), TSS (r= -0.738), PWL (r= -829), and beta carotene (r= -0.863). Total soluble solids were strongly positively and significantly correlated with TVC (r= 0.793), YM (r= 0.731), weight loss (r= 0.776), and beta carotene (r=0.769). Percentage weight loss was strongly positively significantly correlated with TVC (r= 0.825), YM (r= 0.804), and beta carotene (r= 0.874). Beta carotene was also strongly positively significantly correlated with TVC (r= 0.805), and YM (r= 0.871).

Table 4. 5: Association among parameters of tomato's quality

Study parameters	TVC	YM	Firmness	TSS	PWL	BC
TVC (Log10cfu/g)	1					
YM (Log10cfu/g)	0.843***	1				
Firmness (Newton)	-0.840***	-0.805***	1			
TSS (ºBrix)	0.793***	0.731***	-0.738***	1		
PWL (%)	0.825***	0.804***	-0.829***	0.776***	1	
BC (mg/100g)	0.805***	0.871***	-0.863***	0.769***	0.874***	1

Key: ***= $P<0.001$, TVC= Total viable counts, YM= Yeast and Moulds, TSS= Total soluble solids, PWL, percentage weight loss, BC= Beta carotene.

4.5 Shelf life of tomatoes during storage

The firmness of the tomato fruit shows its texture and it plays a significant importance in consumer acceptability (Pathare *et al.*, 2021). According to Batu (2004), the firmness of good marketable tomatoes should be above 1.45 Nmm^{-1}. The change in firmness towards this limit was used to determine the shelf life of tomatoes stored in the desiccant cooler, charcoal cooler, and the ambient room. Tomatoes in the desiccant cooler had a significantly ($P\leq 0.05$) longest shelf life compared to other storage conditions as shown in Figure 4.6. The tomatoes were edible and in good condition in the desiccant cooler for up to 61 days, followed by the evaporative charcoal cooler (37 days), and ambient room (30 days). The shelf life of tomatoes in the desiccant cooler is significantly higher than other storage conditions at ($P\leq 0.05$).

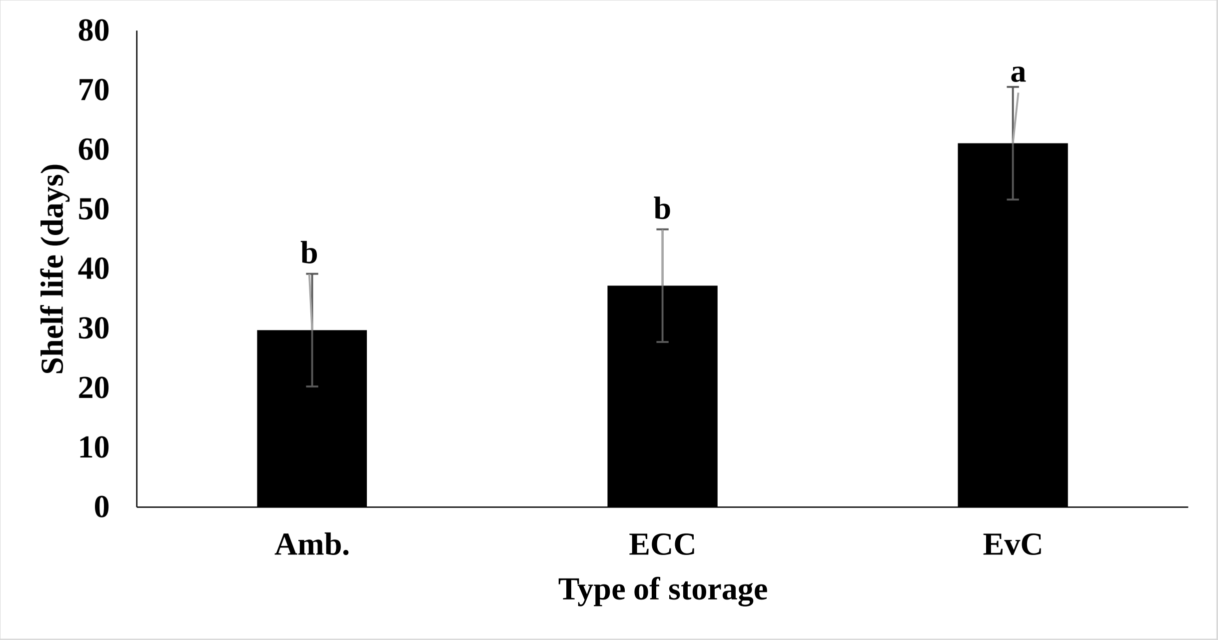

Figure 4. 6: *Effect of the storage conditions of tomatoes shelf life*

Key: Amb= Ambient environment, ECC= Evaporative Charcoal Cooler, EvC= desiccant evaporative cooler

The shelf life data for different tomato varieties in different storage conditions followed the first order of reaction and are presented in Table 4.6. Variety Pendo has a longer shelf life compared to the others in ambient while Ansal has a long shelf life in both desiccant and charcoal cooler. Bolgan lost its firmness at a higher rate compared to other varieties.

Table 4. 6: Number of days different tomato varieties lasted in different storage conditions

Variety	Ambient room	Charcoal cooler	Desiccant cooler
Ansal F1	31	38	77
Bolgan F1	24	35	40
Pendo F1	34	38	67

Variety Pendo and Ansal have the same shelf life in the charcoal cooler. Bolgan has a short shelf life in all storage conditions compared to the other varieties.

4.6. Discussion

Farmers prefer growing a diversity of tomato varieties on one farm due to differences in tomato attributes and the desire to serve heterogeneous preferences of customers (Fredrick *et al.*, 2022). Storage methods for perishable produce like tomatoes should aim at minimising the respiration from the product to enhance their keeping quality and marketability which is increasingly being taken into account by consumers (Esguerra *et al.*, 2018). The present study aimed at assessing changes in physicochemical properties and microbial load of tomatoes that are kept under different storage conditions. The results showed that the type of storage condition affected significantly the firmness, TSS, weight loss, beta carotene, and microbial load of tomatoes. This was due to the corresponding temperature and relative humidity (Ishaq *et al.*, 2022). The variations in physicochemical parameters of different varieties are because the respiration rate during storage is related to the variety of tomato (Ustun *et al.*, 2022). The difference might also be due to the genetic attributes between the varieties (Ayarna *et al.*, 2020; Salim *et al.*, 2020). The variation of tomatoes' quality parameters with the increase in storage duration was also confirmed by the study of Sinha *et al.* (2019). The overall loss of tomatoes' quality shown by physicochemical parameters might be due to microbial activity during storage as it was shown by their correlation in Table 4.5.

4.6.1 physicochemical properties

According to Dhall and Singh (2013), the decrease in firmness is due to the breakdown of insoluble protopectin into soluble pectin, or cellular disintegration that leads to membrane permeability which results in loss of cell integrity during ripening. The decrease in firmness and weight happened to all samples as similarly reported by Evabeta *et al.* (2016). During the growth of the tomato fruit, the protective layer (thickness), which is made of cutin and cuticular wax, increases gradually to maintain its structure integrity. Genes encoding enzymes responsible for wall degradation drive changes in the thickness when they are upregulated (Roy *et al.*, 2024). The less decrease in firmness of tomatoes stored in the desiccant cooler as proved by the findings of this study could be due to the low temperature in the desiccant cooler compared to other storage conditions which agrees with the findings of Nkolisa *et al.* (2018).

The tasting quality of tomatoes is reflected by their soluble solids and these later are considered as an index of ripening and an indicator of soluble minerals and sugar present in the fruit. Though some wild tomato species accumulate sucrose, the main components of TSS are fructose and sucrose (Shimeles *et al.*, 2017). The increase in TSS in all treatments might be due to an increase in the concentration of organic solutes as a result of water loss, hydrolysis of starch, and other polysaccharides to the soluble form of sugar (Dhall & Singh, 2013; Singh *et al.*, 2017). The samples that did not show much difference between days 10 and 15 were because the fruits had already undergone biochemical processes and accumulated all the sugars (Razali *et al.*, 2021). In this study, the tomatoes that were stored under an ambient environment showed the most significant changes in TSS compared to the desiccant cooler. This was due to the temperature difference between the two storage conditions and this agrees with the findings of Al-Dairi *et al*. (2021) who reported the same effect of temperature on TSS.

Weight loss in tomato during storage is an indication of moisture loss which renders the fruit unmarketable as it loses freshness. The moisture loss from tomatoes is directly linked to loss of appearance, taste, and even nutrients which might result in economic loss of the produce (Ghosal *et al*., 2019). The lower percentage of weight loss in tomatoes stored in a desiccant evaporative cooler was due to the low temperature and high relative humidity surrounding the produce that reduces the moisture loss, which agrees with Umar *et al*. (2016) who reported the same. High respiration in uncontrolled ripening in the ambient room could be the main cause of the high PWL of tomatoes (Ashenafi & Tura, 2018). Water comprises a large portion of the tomato fruit, it can no longer be replaced when it is lost during postharvest (Esguerra *et al*., 2018).

Delaying ripening of tomatoes helps to reduce the accumulation of beta carotene (Rahman *et al*., 2017). An increase in beta carotene was also recorded in all samples during the storage period, though their levels were different from one variety to another. The increase of respiration during ripening results in oxidative degradation of proteins and chlorophyll that leads to an increase of beta carotene levels (Saini *et al*., 2017). Hence, this justifies the reason for the low increase in beta carotene content of samples that were stored in the desiccant cooler, because the ripening process was low due to the storage conditions provided by the cooler. Furthermore, the high increase of beta carotene in the ambient environment is in line with Al-Dairi *et al*. (2021) who reported the effect of temperature on carotenoids.

4.6.2 Microbial Load

From the results of this study, the desiccant evaporative cooler slowed down the development of TVC and YM. This could be due to the unfavourable growing conditions provided by this cooler for these organisms. Microbial growth increased with higher temperatures until an optimum temperature in the study of Cruz-paredes *et al*. (2021). The microbial activity decreased over optimum temperature and was attributed to the gradual loss of molecular integrity, therefore, enzyme activity at a certain temperature is due to the substantial heat capacity that the enzyme has. Low temperatures can prolong the lag phase and decrease the growth rate of microbes (Rawat, 2015). The growth and reproduction of decay organisms are influenced by the relative humidity of the surrounding environment. Tomato samples that were kept in the ambient room showed a greater microbial load compared to other storage conditions. This could be due to a slightly high temperature (close to optimum) in the ambient environment.

Tomatoes have high levels of sugar and a low PH that favours the growth of yeasts, moulds, and some acid-tolerant bacteria. The rate of respiration and multiplication of decay organisms in fruits and vegetables during storage are accelerated by uncontrolled temperature and relative humidity (Yahaya & Mardiyya, 2019). The high humidity in the desiccant and charcoal coolers would cause high growth of microorganisms as literature says, but it was reduced by continuous ventilation by the fans that were installed on these coolers. Ventilation effects on reducing microbial growth are stronger than reducing the humidity (Qiu *et al*., 2022). The fruit harvested from the diseased plant can also cause variations in the microbial quality of tomatoes (Thole *et al*., 2020).

4.6.3 Shelf Life

Tomato firmness plays a pivotal role in consumer perception of the fruits quality (Thole *et al*., 2020). Depending on the ripening stage of a certain variety, and environmental factors, tomato fruit displays various uniformities, which can be maintained to many months without discarding the fruit. Poor management of temperature above optimum and relative humidity below optimum is responsible for the high percentage losses in fruits and vegetables (Jarman *et al*., 2023). Increased rate of respiration at high temperatures determines the shelf life of tomatoes and their marketability (Shimeles *et al*., 2017). The life of tomatoes was increased up to 61 days by the desiccant cooler, followed by the charcoal cooler (37 days), and the ambient room (30 days). This is due to the ability of the cooler to provide optimum temperature and relative humidity that play a vital role in extending the fruit's shelf life (Ishaq *et al.*, 2022). The quick deterioration of tomatoes stored in an ambient environment is attributed to the rapid heat build-up and depletion of their high moisture content caused by fast respiration rate (Ariwaodo, 2022). The suitable storage temperature and relative humidity should be managed properly for the tomatoes to fulfil their economic and nutritional potential.

4.7 Conclusion and Recommendation.

Tomato farmers are sometimes forced to sell their produce at low prices offered in the nearby market due to a lack of proper storage facilities that could extend the life of their produce for future markets. On the other hand, the consumers are also getting poor quality produce due to the same constraint. The changes related to ripening, softening, pigment changes, and decrease in weight continued after the harvesting of tomatoes. These changes cannot be stopped but can be regulated in controlled environment conditions thereby extending the shelf life of tomatoes. This is achieved through reducing the metabolic rates and water loss that leads to quality and weight loss. Based on tomato quality parameters tested in this study, we can conclude that storing tomatoes in a desiccant evaporative cooler can reduce the loss of fruit quality, thus increasing their shelf life. Evaporative charcoal cooler and ambient room environment have a greater quality loss in tomatoes than desiccant evaporative cooler. This environmentally friendly desiccant evaporative cooler can be installed at different centres to condition the storage rooms to reduce postharvest losses of tomatoes caused by lack of proper storage techniques and hence increase income from tomato sales.

CHAPTER FIVE

GENERAL DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

5.1 Rationale for the study

Environmental sustainability, food security and nutrition, and reduction of production costs are achieved through reducing food loss and waste. Sufficient intervention to reduce food loss will have a significant effect on prices in the whole supply chain (FAO, 2019). Food loss and waste levels at different stages of the agrifood system can be brought down, with improved storage technologies (Gustavo *et al*., 2023). The evaporative cooling system is increasingly being used to preserve tomatoes as it not only lowers the temperature of the air surrounding the produce, it also increases the humidity of the air. Maintenance of tomato quality in the desiccant evaporative cooler is attributed to low temperatures that lower metabolic activities, reducing water loss, and delaying ripening and senescence. Evaporative cooling has been recommended to be an alternative to conventional cooling systems that are used to preserve fresh produce. Solar energy has been used to support evaporative cooling because glid electricity is not available in remote and rural areas in Sub-Saharan Africa (Sibanda & Workneh, 2020). Dealers in horticulture crops are familiar with postharvest storage techniques that may help them to increase the shelf life of their agricultural fresh produce, spend less time traveling to the market, and increase the availability of fruits and vegetables for consumption.

Therefore, this study investigated the performance of an evaporative cooler with an air preconditioning component (desiccant) to extend the shelf life of the tomatoes. Parameters that affect the cooling performance of the evaporative cooling system were evaluated, as well as the quality parameters of the tomatoes stored in those cooling systems. The thesis then addresses the main research hypotheses which include: (i) Preconditioning air with a desiccant has no significant effect on the cooling efficiency of the experimental solar evaporative cooler, (ii) A desiccant evaporative cooler has no significant effect on the physicochemical properties of different tomato varieties, (iii) A desiccant evaporative cooler has no significant effect on the microbial load of different tomato varieties. Findings that test these hypotheses have been presented in Chapters 3, and 4, respectively.

It was clear that the integration of a desiccant to dehumidify the air increased the performance of the evaporative cooler. This is in line with literature that suggested the use of desiccants to enhance the performance of evaporative cooling systems (Kapilan *et al*., 2023). The desiccant evaporative cooler was able to achieve a cooling efficiency of 87.2% which helped to provide a conducive environment for tomato storage. The tomatoes in this cooler had less quality loss compared to other storage conditions and their shelf life was increased up to 31 days from the ambient room environment. Among the quality parameters, firmness was used to determine the shelf life of tomatoes because it affects the appearance of the fruit which has a significant influence on consumer acceptability (Pathare *et al.*, 2021).

5.2 Conclusions

i. The use of desiccant to precondition inlet air in an evaporative cooling system enhances its performance as shown by the results of this study
ii. When compared to other storage conditions, the desiccant evaporative cooler significantly maintains the physicochemical properties of the studied tomato varieties
iii. The desiccant evaporative cooler has a significant influence on the microbial load of tomatoes.

5.3 Recommendations

i. The desiccant evaporative cooler can be used to increase the shelf life of fresh tomatoes for up to two months; hence it will provide enough time for farmers to seek for suitable market resulting in better prices.
ii. The cooler can also be utilised as an alternative to non-environmental friendly conventional vapour-compression air conditioning systems that are currently used to condition the temperature and relative humidity of the storage air.
iii. Dealers in the tomato value chain especially those in remote areas without access to conventional storage cooling systems are recommended to use desiccant evaporative coolers to prolong the shelf life of their produce which will be vital in poverty alleviation.
iv. It is important to test the cooler with a wide variety of fruits and vegetables to elucidate its potential in future studies.
v. Cost analysis of the desiccant evaporative cooler is also needed.

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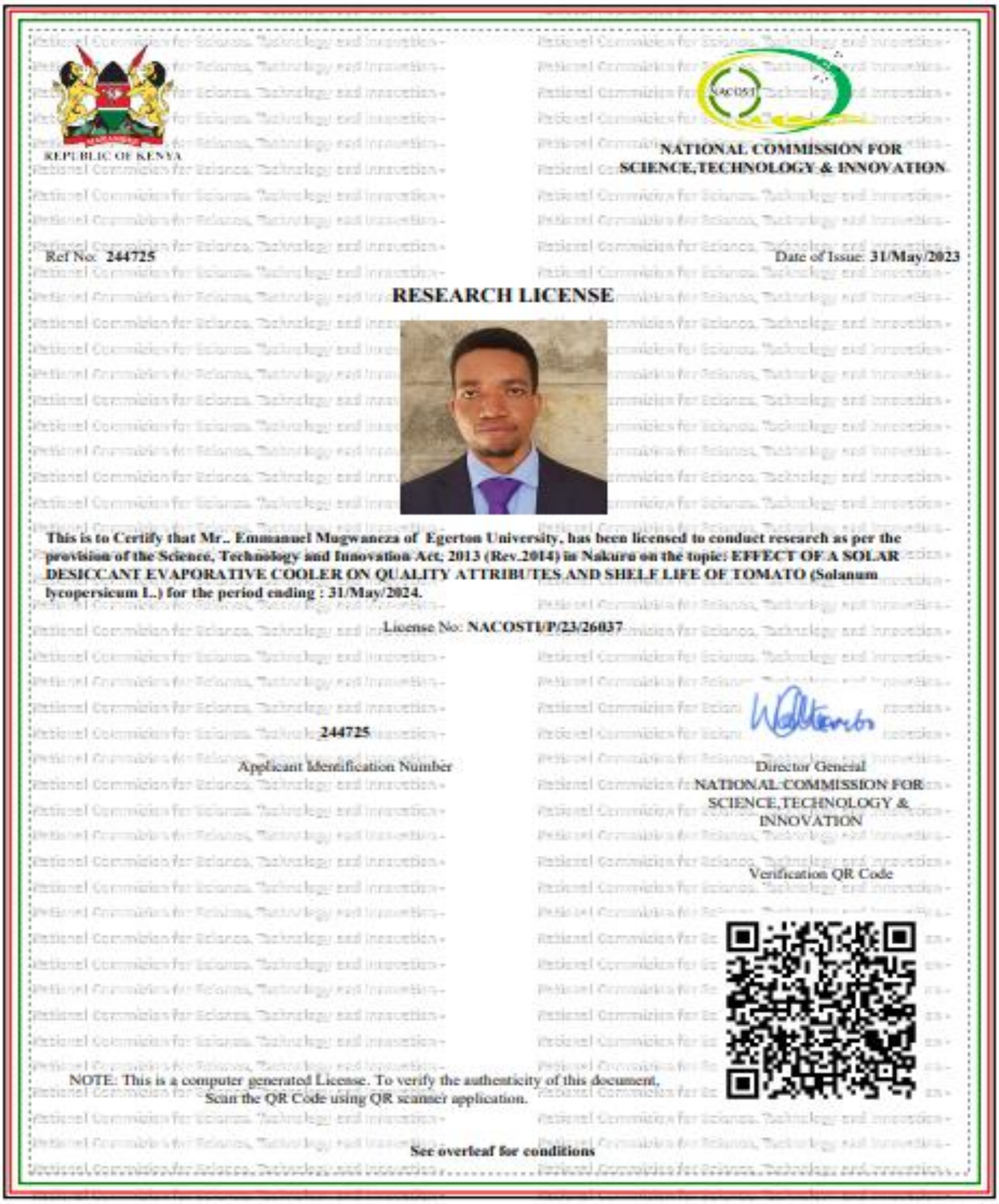
APPENDICES

Appendix A: NACOSTI License



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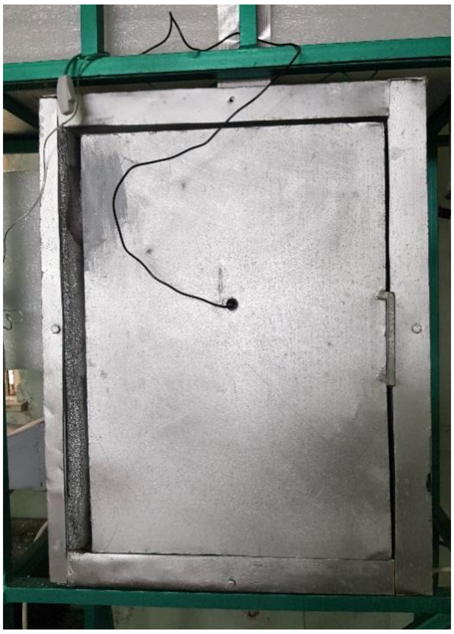
Appendix B: Images of evaporative cooler fabrication




Appendix C: Table for Comparison of storage conditions

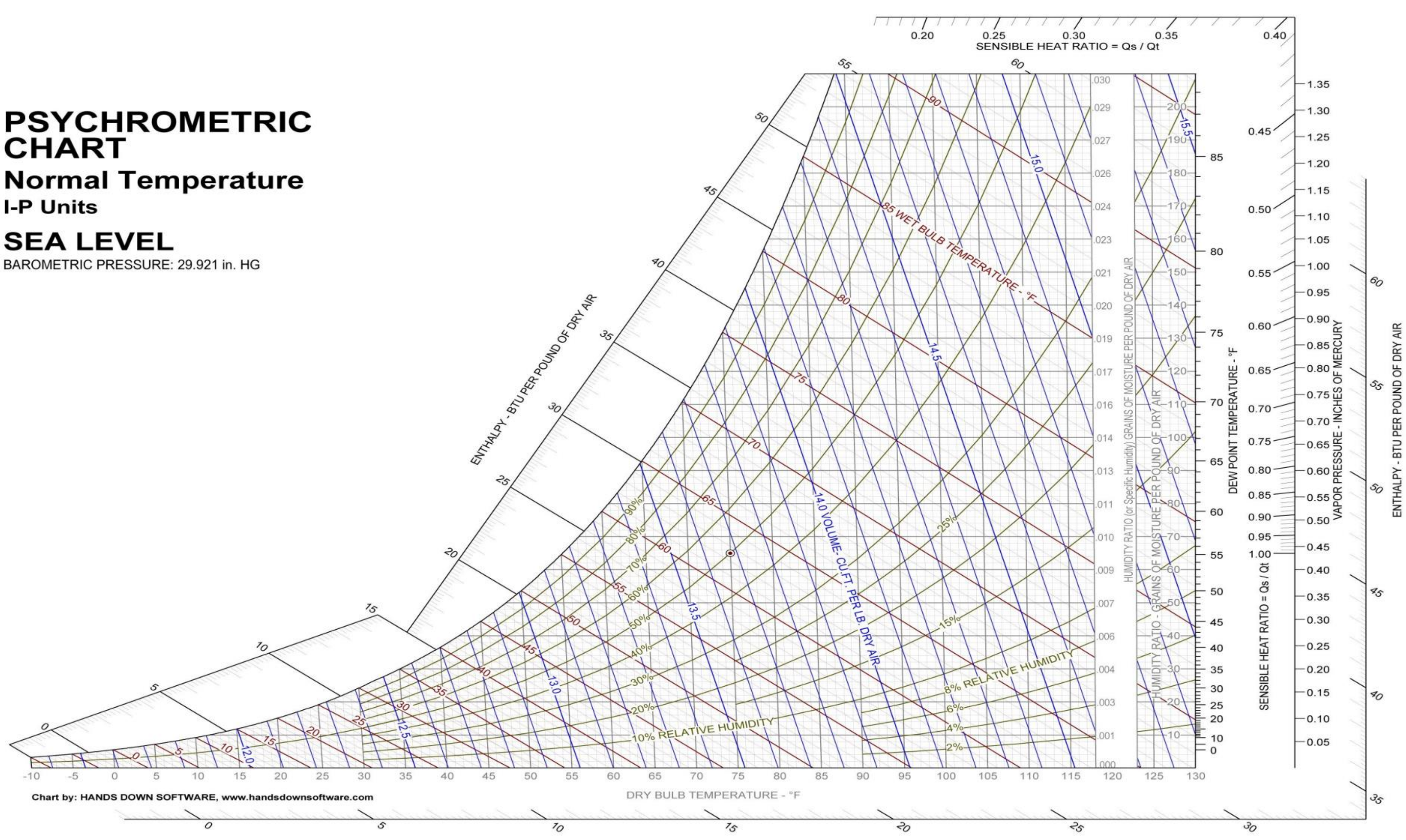
To evaluate the effect of a solar desiccant evaporative cooler on temperature and relative humidity

Time(Day)	Parameter	Evaporative cooler with Desiccant				Evaporative cooler without Desiccant				Evaporative charcoal cooler				Ambient		
		10h00'	16h00'	Average	Efficiency	10h00'	16h00'	Average	Efficiency	10h00'	16h00'	Average	Efficiency	10h00'	16h00'	Average
1	Dbt	15	17	16	85.7	16.0	17.5	16.8	64.3	15.0	17.5	16.3	78.6	18.0	20.0	19.0
	Wbt	14.5	16	15.25		15.0	15.5	15.3		14.0	16.5	15.3		15.0	16.0	15.5
	Depression	0.5	1	0.75		1.0	2.0	1.5		1.0	1.0	1.0		3.0	4.0	3.5
	Rh	94	90	92		89.0	80.0	84.5		89.0	90.0	89.5		71.0	64.0	67.5
2	Dbt	16.5	17.3	16.9	88.2	17.5	18.0	17.8	69.9	17.0	17.8	17.4	77.4	20.0	22.0	21.0
	Wbt	16	16.5	16.25		16.5	16.5	16.5		16.0	16.9	16.5		15.7	17.0	16.4
	Depression	0.5	0.8	0.65		1.0	1.5	1.3		1.0	0.9	0.9		4.3	5.0	4.7
	Rh	95	92	93.5		90.0	85.0	87.5		90.0	90.0	90.0		62.0	58.0	60.0
3	Dbt	16.3	17.5	16.9	85.6	18.0	17.7	17.9	64.4	16.5	18.0	17.3	77.8	19.5	22.0	20.8
	Wbt	15.7	16	15.85		16.0	16.5	16.3		15.5	16.5	16.0		15.0	17.5	16.3
	Depression	0.6	0.5	0.55		2.0	1.2	1.6		1.0	1.5	1.3		4.5	4.5	4.5

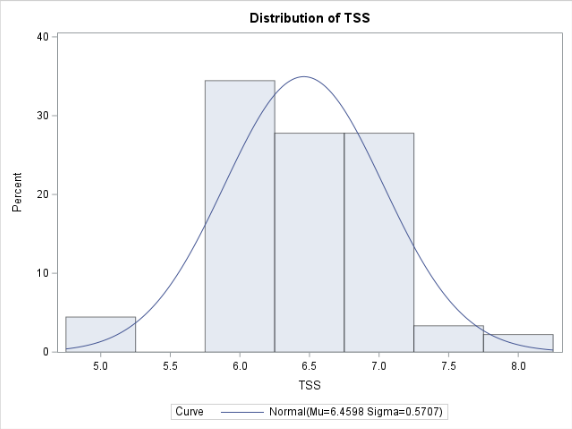
	Rh	95	95	95		80.0	88.0	84.0		89.0	85.0	87.0		60.5	62.0	61.3
4	Dbt	15	16.9	15.95	89.4	16.0	18.0	17.0	64.7	16.5	17.0	16.8	70.6	18.5	21.0	19.8
	Wbt	14	16.3	15.15		14.5	17.0	15.8		15.0	16.0	15.5		14.0	17.0	15.5
	Depression	1	0.6	0.8		1.5	1.0	1.3		1.5	1.0	1.3		4.5	4.0	4.3
	Rh	89	95	92		84.0	90.0	87.0		84.5	90.0	87.3		58.5	65.0	61.8
5	Dbt	15.8	17.3	16.55	87.1	16.0	19.0	17.5	64.7	16.0	18.0	17.0	76.5	19.0	21.5	20.3
	Wbt	15	16.8	15.9		15.0	17.0	16.0		15.0	17.0	16.0		15.0	17.0	16.0
	Depression	0.8	0.5	0.65		1.0	2.0	1.5		1.0	1.0	1.0		4.0	4.5	4.3
	Rh	93	95	94		89.0	81.0	85.0		89.0	90.0	89.5		63.0	62.0	62.5
Average	Dbt	15.7	17.2	16.5	87.2	16.7	18.0	17.4	65.6	16.2	17.7	16.9	76.2	19.0	21.3	20.2
	Wbt	15.0	16.3	15.7		15.4	16.5	16.0		15.1	16.6	15.8		14.9	16.9	15.9
	Depression	0.7	0.7	0.7		1.3	1.5	1.4		1.1	1.1	1.1		4.1	4.4	4.2
	Rh	93.2	93.4	93.3		86.4	84.8	85.6		88.3	89.0	88.7		63.0	62.2	62.6

Key: Dbt= Dry bulb temperature, Wbt= Wet bulb temperature, RH= Relative Humidity

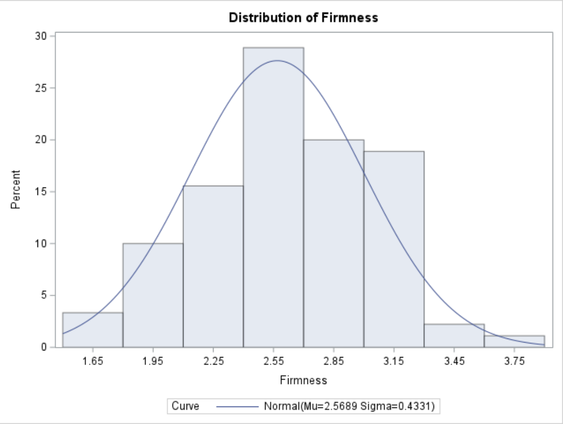
Appendix D: Psychrometric Chart



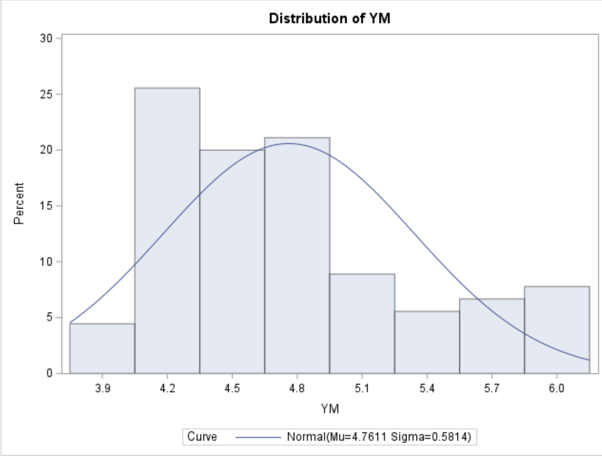
Appendix E: Example of Normality Test outputs for Quality attributes



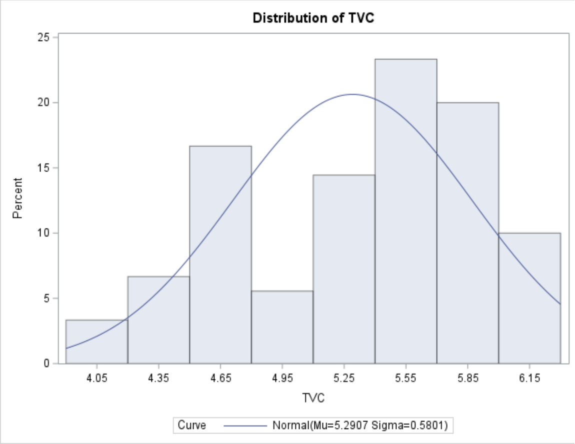
1. Total soluble solids Normality Curve



2. Firmness Normality Curve



3. Yeasts and Moulds Normality curve



4. TVC normality curve

Appendix F. ANOVA table for Effect of cooler type, variety of tomato, and time on TVC, YM, Firmness, TSS, PWL, and beta carotene

S.O.V	D.F	TVC	YM	Firmness	TSS	PWL	BC
C	2	0.317***	0.785***	0.890***	0.954***	72.151***	2.397***
V	2	0.519***	0.399***	1.434***	0.832***	5.559***	0.450***
D	4	6.549***	6.501***	2.593***	5.179***	91.342***	5.856***
Rep	1	0	0.005	0.005	0.003	2.272	0.867
C*V	4	0.037***	0.021*	0.008^{NS}	0.050^{NS}	2.604***	0.057***
V*D	8	0.107***	0.083***	0.068**	0.293***	0.674***	0.055***
C*D	8	0.041***	0.055***	0.073**	0.110^{NS}	5.495***	0.281***
C*V*D	16	0.028***	0.010^{NS}	0.009^{NS}	0.024^{NS}	0.435***	0.098***
Error	44	0.007	0.008	0.017	0.062	0.055	0.007
R2	-	0.991	0.988	0.956	0.912	0.996	0.991
CV	-	1.527	1.881	5.132	3.886	7.209	4.906

Key: S.O.V= Source of Variation, C= Cooler, V= Variety; D= Day, D.F= Degree of Freedom, R^2= Coefficient of Determination, *= Significant at P≤ 0.05, ^{NS}= not significant at P≤ 0.05, TVC= Total Viable Count, YM= Yeasts and Moulds, TSS= Total soluble solids, PWL= Percentage Weight Loss, BC= Beta Carotene, TVC and YM mean values are in cfu/g, firmness in Nmm^{-1}, TSS in degree brix, PWL in percentage, and beta carotene in mg/100g.

Appendix G. Interaction effect between type of storage and time of storage on TVC, Yeasts and Moulds, Firmness, TSS, Weight Loss, and beta carotene

Cooler*Day	TVC	Yeast and Moulds	Firmness	TSS	Weight Loss	Beta Carotene
Amb*0	4.395±0.07^{j}	4.178±0.04^{h}	3.033±0.09^{a}	5.597±0.16^{g}	0±0.00^{j}	1.032±0.05^{g}
Amb*5	5.12±0.12^{gh}	4.568±0.05^{fg}	2.533±0.11^{def}	6.3±0.12^{def}	3.753±0.54^{ef}	1.688±0.14^{e}
Amb*10	5.588±0.04^{de}	4.760±0.01^{de}	2.383±0.14^{ef}	6.667±0.14^{bcde}	6.158±0.61^{c}	1.793±0.08^{de}
Amb*15	5.713±0.02^{cd}	5.178±0.04^{c}	2.083±0.09^{g}	7.000±0.14^{ab}	6.673±0.34^{b}	2.392±0.18^{b}
Amb*20	6.055±0.03^{a}	5.875±0.08^{a}	1.783±0.06^{h}	7.318±0.17^{a}	8.545±0.34^{a}	3.143±0.18^{a}
ECC*0	4.395±0.07^{j}	4.178±0.04^{h}	3.033±0.09^{a}	5.597±0.16^{g}	0±0.00^{j}	1.032±0.05^{g}
ECC*5	5.010±0.10^{hi}	4.410±0.05^{g}	2.833±0.11^{abc}	6.133±0.09^{ef}	1.443±0.13^{i}	1.335±0.06^{f}
ECC*10	5.473±0.02^{e}	4.615±0.04^{ef}	2.583±0.13^{cde}	6.600±0.08^{bcde}	2.888±0.26^{g}	1.705±0.08^{e}
ECC*15	5.713±0.07^{bc}	4.938±0.05^{d}	2.300±0.07^{fg}	6.667±0.16^{bcd}	3.395±0.19^{ef}	1.945±0.04^{cd}
ECC*20	5.945±0.06^{ab}	5.763±0.10^{a}	2.250±0.07^{gh}	6.950±0.10^{abc}	5.085±0.25^{d}	2.338±0.13^{b}
EvC*0	4.395±007^{j}	4.178±0.04^{h}	3.033±0.09^{a}	5.597±0.16^{g}	0±0.00^{j}	1.032±0.05^{g}
EvC*5	4.933±0.10^{i}	4.145±0.09^{h}	2.867±0.11^{ab}	6.067±0.03^{fg}	1.197±0.07^{i}	1.203±0.03^{fg}
EvC*10	5.282±0.12^{fg}	4.423±0.06^{g}	2.750±0.12^{bcd}	6.233±0.07^{def}	2.398±0.14^{h}	1.293±0.02^{f}
EvC*15	5.423±0.12^{ef}	4.722±0.06^{ef}	2.567±0.08^{cdef}	6.467±0.11^{cdef}	3.348±0.38^{fg}	1.627±0.08^{e}
EvC*20	5.847±0.06^{bc}	5.483±0.14^{b}	2.317±0.10^{efg}	6.700±0.10^{bcd}	3.868±0.19^{e}	2.087±0.11^{c}

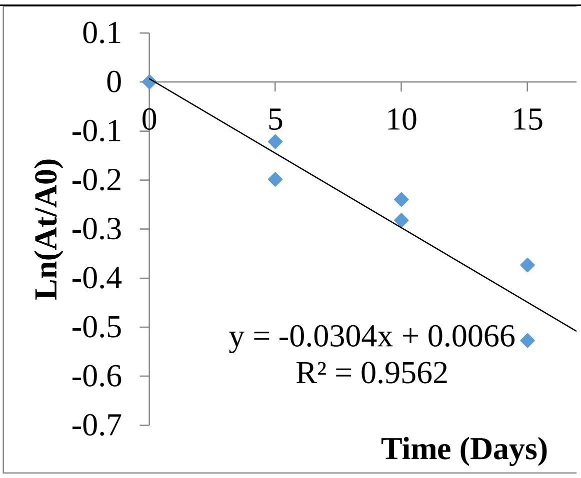
Key: Results are means ± standard deviation of duplicate samples; C*V= interaction between cooler and variety, Amb= Ambient, ECC= Evaporative charcoal cooler, EvC= Evaporative Cooler, TVC= Total Viable Counts, TSS= Total soluble solids. TVC and YM mean values are in cfu/g, firmness in Nmm^{-1}, TSS in degree brix, PWL in percentage, and beta carotene in mg/100g. The means with the same letter along the columns are not significantly different at $P \leq 0.05$.

Appendix H. Interaction effect between Variety and time of storage on TVC, YM, Firmness, TSS, PWL, and beta carotene

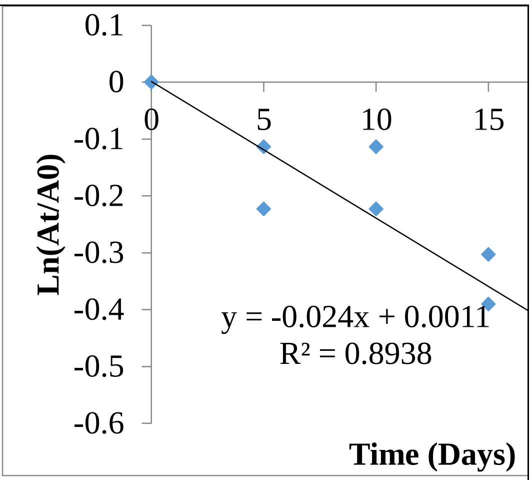
Variety*Day	TVC	YM	Firmness	TSS	PWL	Beta Carotene
Ansal F1*0	4.435±0.04^{g}	4.23±0.03^{gh}	2.800±0.04^{bcd}	5.400±0.18^{i}	0±0.00^{i}	1.075±0.02^{hi}
Ansal F1*5	5.192±0.05^{e}	4.495± 0.08^{ef}	2.533±0.10^{def}	6.183±0.11^{fgh}	2.820±0.81^{g}	1.510±0.16^{fg}
Ansal F1*10	5.515±0.05^{d}	4.690±0.04^{d}	2.283±0.08^{fg}	6.433±0.11^{cdefg}	4.725±1.05^{cd}	1.695±0.15^{de}
Ansal F1*15	5.768±0.07^{bc}	5.017±0.07^{c}	2.200±0.09^{g}	6.450±0.12^{cdefg}	5.000±0.89^{c}	2.042±0.10^{c}
Ansal F1*20	6.038±0.06^{a}	6.035±0.04^{a}	2.250±0.12^{gh}	6.833±0.10^{bc}	6.137±1.05^{a}	2.725±0.29^{a}
Bolgan F1*0	4.540±0.00^{fg}	4.230±0.01^{gh}	3.050±0.02^{ab}	5.490±0.14^{i}	0±0.00^{i}	1.115±02^{h}
Bolgan F1*5	5.182±0.03^{e}	4.257±0.13^{g}	2.683±0.07^{cde}	6.233±0.12^{efgh}	1.850±0.46^{h}	1.358±0.06^{g}
Bolgan F1*10	5.485±0.04^{d}	4.573±0.07^{de}	2.500±0.06^{ef}	6.733±0.12^{bcde}	3.315±0.66^{f}	1.558±0.09^{ef}
Bolgan F1*15	5.638±0.04^{cd}	4.945±0.09^{c}	2.217±0.10^{g}	7.083±0.11^{ab}	3.922±0.74^{e}	2.102±0.26^{bc}
Bolgan F1*20	5.810±0.05^{b}	5.458±0.10^{b}	1.883±0.08^{h}	7.350±0.17^{a}	5.500±1.04^{b}	2.600±0.17^{a}
Pendo F1*0	4.210±0.05^{h}	4.070±0.02^{h}	3.250±0.2^{a}	5.900±0.04^{hi}	0±0.00^{i}	0.905±0.02^{i}
Pendo F1*5	4.690±0.03^{f}	4.372±0.05^{fg}	3.017±0.10^{ab}	6.083±0.03^{gh}	1.723±0.31^{h}	1.358±0.13^{g}
Pendo F1*10	5.305±0.13^{e}	4.535±0.08^{def}	2.933±0.09^{bc}	6.300±0.06^{defgh}	3.405±0.58^{f}	1.508±0.10^{ef}
Pendo F1*15	5.515±0.14^{d}	4.877±0.11^{c}	2.533±0.10^{def}	6.600±0.12^{bcdef}	4.495±0.54^{d}	1.820±0.11^{d}
Pendo F1*20	5.998±0.03^{a}	5.628±0.10^{b}	2.217±0.12^{g}	6.783±0.09^{bcd}	5.862±0.60^{ab}	2.243±0.23^{b}

Key: Results are means ± standard deviation of duplicate samples; TVC= Total Viable Counts, YM= yeasts and Moulds, TSS= Total soluble solids, PWL= Percentage Weight Loss.

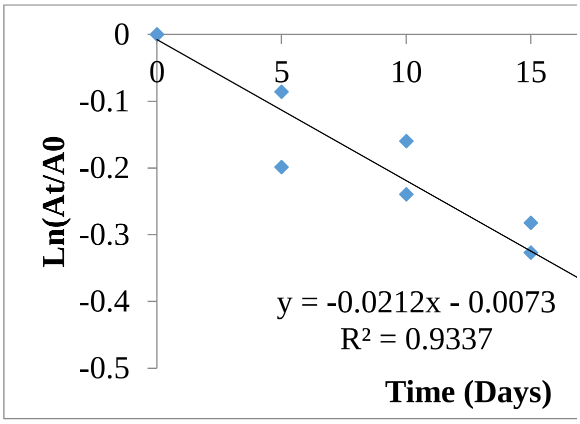
Appendix I. Examples of regression analysis for shelf life



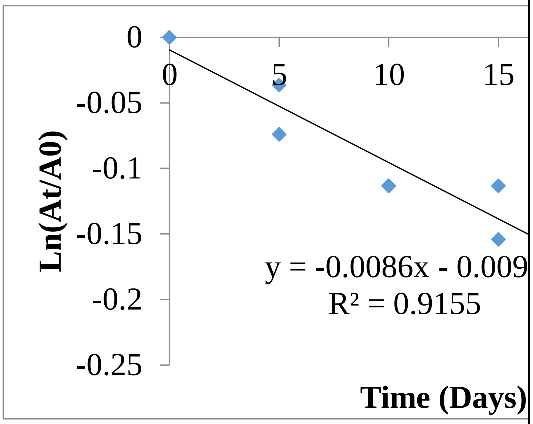
A: Regression analysis for Bolgan variety in Ambient room



B: Regression analysis for variety Pendo in ambient room

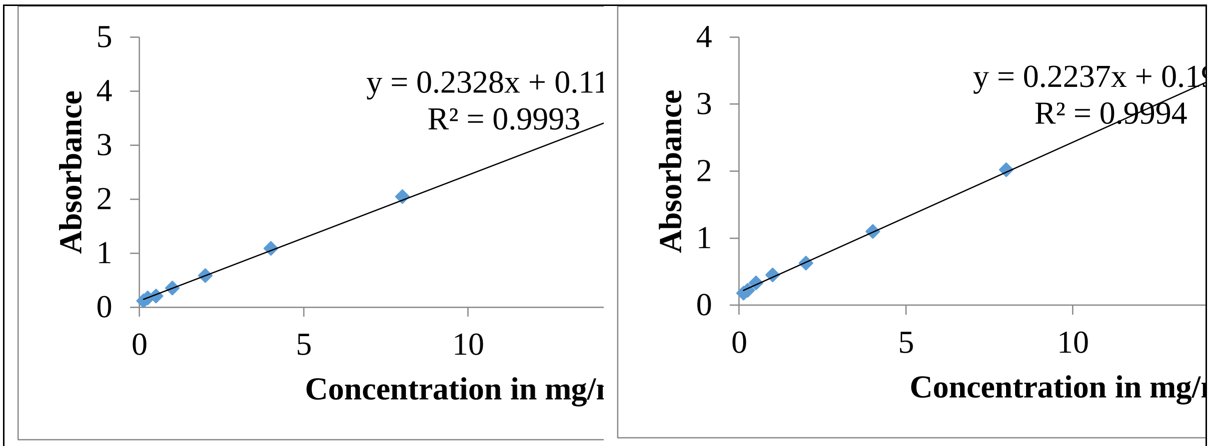


C: Regression analysis for variety Pendo in Charcoal cooler



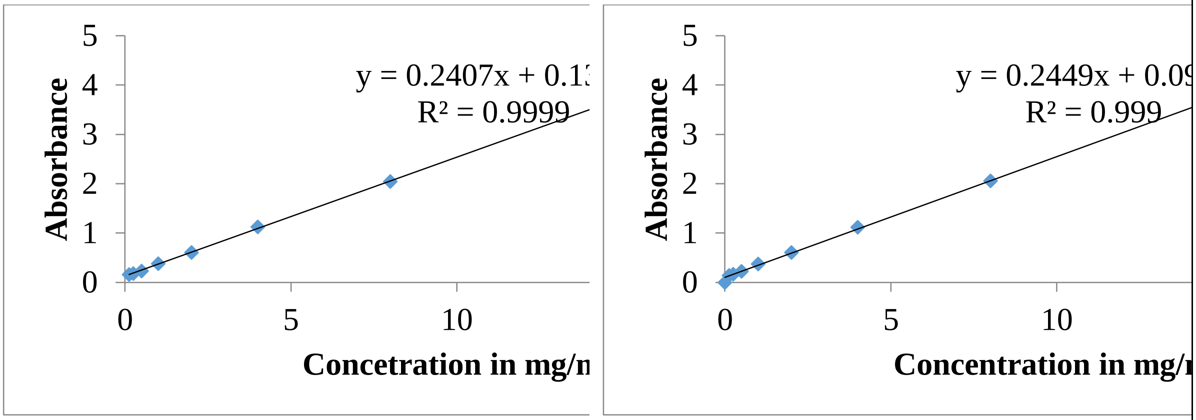
Regression analysis for variety Ansal in Desiccant cooler

Appendix J. Example of Standard calibration curves for Beta Carotene



a) Day 5 of storage

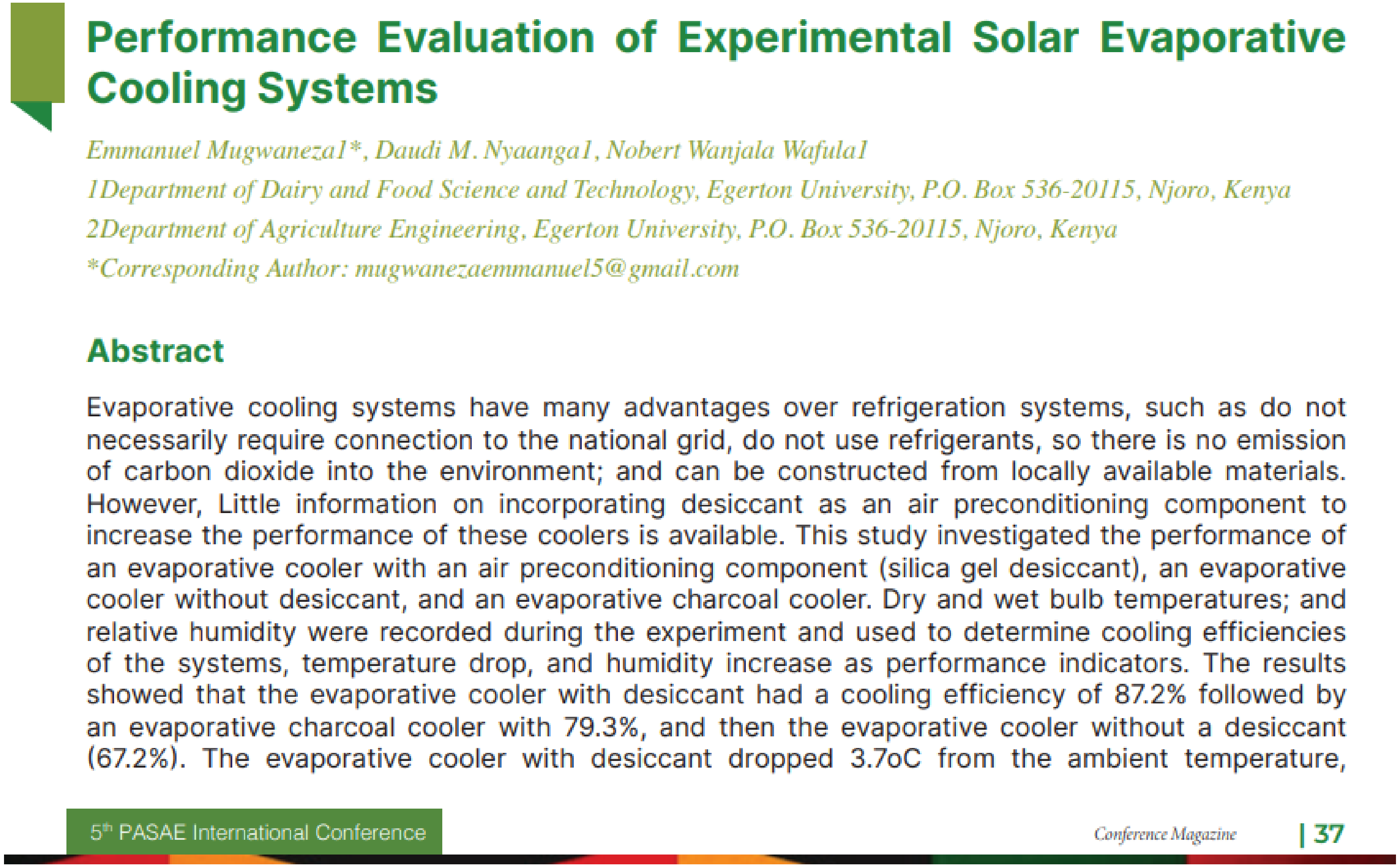
b) Day 10 of storage



c) Day 15 of storage

d) Day 20 of storage

Appendix K. Presentation of an abstract in a conference



Performance Evaluation of Experimental Solar Evaporative Cooling Systems

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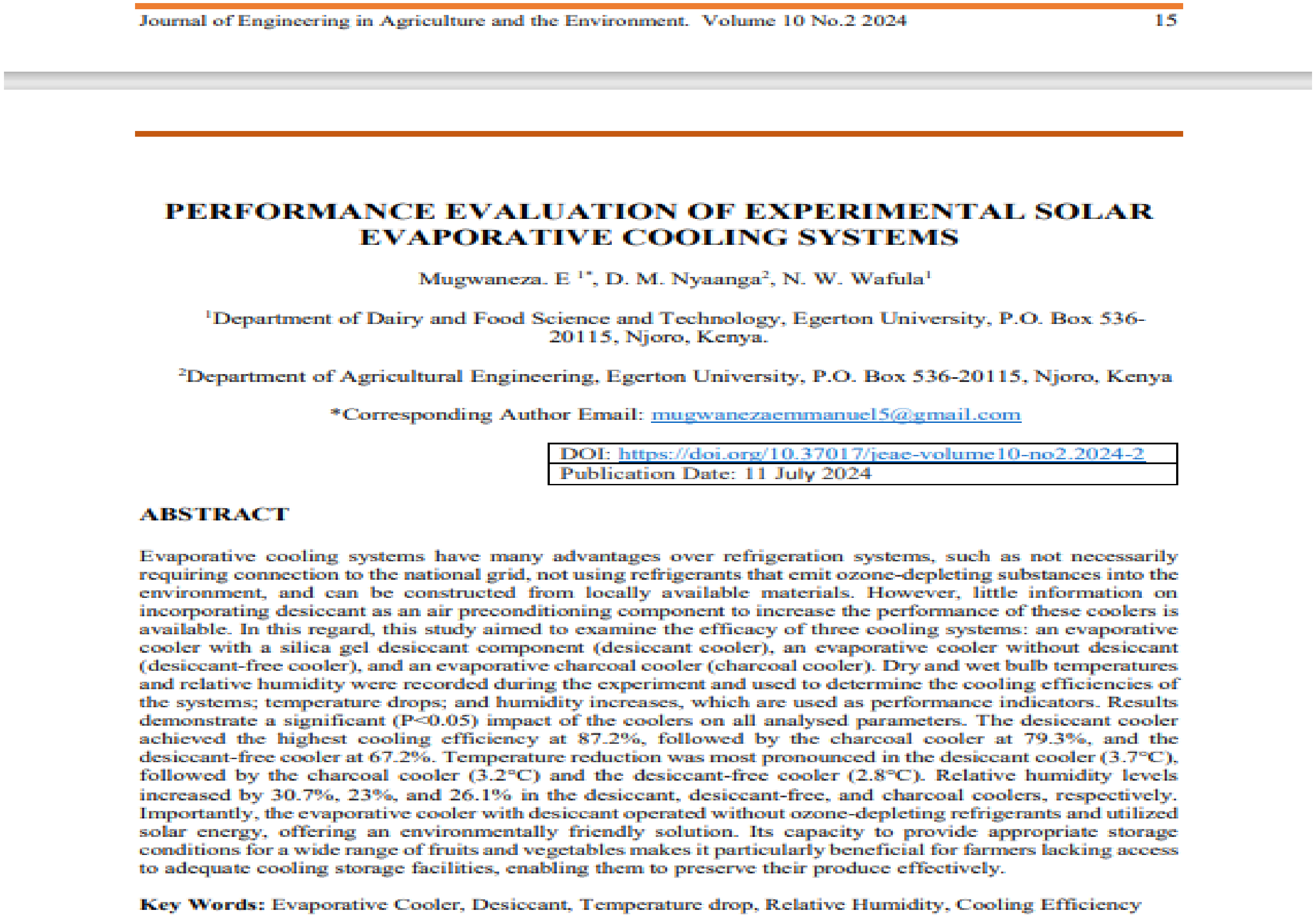
Abstract

Evaporative cooling systems have many advantages over refrigeration systems, such as do not necessarily require connection to the national grid, do not use refrigerants, so there is no emission of carbon dioxide into the environment; and can be constructed from locally available materials. However, Little information on incorporating desiccant as an air preconditioning component to increase the performance of these coolers is available. This study investigated the performance of an evaporative cooler with an air preconditioning component (silica gel desiccant), an evaporative cooler without desiccant, and an evaporative charcoal cooler. Dry and wet bulb temperatures; and relative humidity were recorded during the experiment and used to determine cooling efficiencies of the systems, temperature drop, and humidity increase as performance indicators. The results showed that the evaporative cooler with desiccant had a cooling efficiency of 87.2% followed by an evaporative charcoal cooler with 79.3%, and then the evaporative cooler without a desiccant (67.2%). The evaporative cooler with desiccant dropped 3.7oC from the ambient temperature,

Appendix L. Publication



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PERFORMANCE EVALUATION OF EXPERIMENTAL SOLAR EVAPORATIVE COOLING SYSTEMS

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ABSTRACT

Evaporative cooling systems have many advantages over refrigeration systems, such as not necessarily requiring connection to the national grid, not using refrigerants that emit ozone-depleting substances into the environment, and can be constructed from locally available materials. However, little information on incorporating desiccant as an air preconditioning component to increase the performance of these coolers is available. In this regard, this study aimed to examine the efficacy of three cooling systems: an evaporative cooler with a silica gel desiccant component (desiccant cooler), an evaporative cooler without desiccant (desiccant-free cooler), and an evaporative charcoal cooler (charcoal cooler). Dry and wet bulb temperatures and relative humidity were recorded during the experiment and used to determine the cooling efficiencies of the systems; temperature drops; and humidity increases, which are used as performance indicators. Results demonstrate a significant ($P<0.05$) impact of the coolers on all analysed parameters. The desiccant cooler achieved the highest cooling efficiency at 87.2%, followed by the charcoal cooler at 79.3%, and the desiccant-free cooler at 67.2%. Temperature reduction was most pronounced in the desiccant cooler (3.7°C), followed by the charcoal cooler (3.2°C) and the desiccant-free cooler (2.8°C). Relative humidity levels increased by 30.7%, 23%, and 26.1% in the desiccant, desiccant-free, and charcoal coolers, respectively. Importantly, the evaporative cooler with desiccant operated without ozone-depleting refrigerants and utilized solar energy, offering an environmentally friendly solution. Its capacity to provide appropriate storage conditions for a wide range of fruits and vegetables makes it particularly beneficial for farmers lacking access to adequate cooling storage facilities, enabling them to preserve their produce effectively.

Key Words: Evaporative Cooler, Desiccant, Temperature drop, Relative Humidity, Cooling Efficiency