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TOPIC:

Design and Development of Tomato Charcoal Cooler Storage for Smallholder Farmers

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Declaration

I MUZIMBA KATE (B1851547), declare that all the research carried out in this dissertation is truly my original work and not a duplication of any thesis or dissertation for any degree program in any other University.

Signature...

Date..

ABSTRACT

The supply of food can be induced either by an increase in production or a reduction in loss. Post-harvest losses of tomatoes are high for the smallholder farmers in Zimbabwe mainly due to an increase in ripening that leads to deterioration and senescence. Ripening of tomatoes is further increased by lack of appropriate post-harvest infrastructure, technology to increase shelf life, high field temperatures on tomatoes before and after harvesting, pest and disease attack. One of the methods that can be used to increase the shelf life of tomatoes is the use of a charcoal cooler storage that removes ethylene, a gaseous plant hormone that accelerates ripening and senescence during storage.

The study aimed to help in enhancing the quality and increase the shelf life of tomatoes through the use of charcoal cooler storage that is economical, easily operated, and socially friendly in terms of operation. The study objectives were to design and develop a charcoal cooler storage, evaluate the performance of the charcoal storage in the reduction of temperature of tomatoes, maintaining the quality and increase the shelf life of tomatoes stored in the charcoal storage. Charcoal cooler storage is more effective due to the availability of pores that absorb and store water, in-turn reducing the temperature and ethylene inside that makes the tomatoes deteriorate.

The charcoal cooler storage was made from a wooden framework by joining, hammering, and tightening the hexagonal wire mesh. The chamber works on the principle of evaporative cooling. The device was made of an open timber frame with the sides filled with charcoal, which was continually kept moist. As warm, dry air passes through the moist charcoal, it draws energy from its surrounding which produces considerable cooling.

On day 1, the temperature was taken without watering the charcoal to see if the charcoal itself can reduce the temperature inside the cooler. The cooler had a significantly ($p<0.05$) low temperatures as compared to the control and the ambient. On day two, water was applied once to the charcoal walls at 08:00hrs.The temperature in the cooler was significantly ($p<0.05$) low. On day 3 the water was applied twice to the charcoal walls at 08:00hrs and 10:00hrs and the temperature readings registered a significant ($p<0.05$) reduction in the cooler. On day 4 the water was applied three times to the charcoal walls at 08:00hrs, 11:00hrs and 14:00hrs and the temperature was reduced significantly ($p<0.05$). On day 5 water was applied after every two hours from 08:00hrs to 16:00hrs, water had a significant effect ($p<0.05$) on the reduction of temperature. The low temperatures that were maintained by the cooler were able to reduce the production of ethylene, rate of respiration of the fruit was also reduced which leads to the long shelf life of the commodity.

In maintaining the quality of tomatoes titratable acids experiments were carried out. In experiment 1, (day 1) the tomatoes were all at the breaker stage in both the cooler and the control and the acid content was 1.037g/l. In experiment 2, (day 4) the TA had no significant difference between the cooler and the control ($p>0.05$). In experiment 3, (day 8) the cooler had a significantly ($p<0.05$) higher value of titratable acids than in the control due to reduced temperatures. In experiment 4, (day 12) tomatoes ripening in the cooler had significantly ($p<0.05$) higher TA values than those ripening in the control. In experiment 5, the cooler had significantly ($p<0.05$) high TA values due to reduced production of ethylene and low temperatures registered by the cooler. In experiment 6 day 20, tomatoes that were ripening in the cooler had significantly ($p<0.05$) high TA values than in the control. Low TA in the control results in accelerated ripening and senescence-related alterations. Tomatoes with low TA values may have used their acids in the metabolism of living tissues, which depletes organic acids.

DEDICATION

This paper is dedicated to my father Mr. I. Muzimba and my mother Mrs. T. F. Muzimba and my siblings for they raised and supported me from the beginning of my time up to this moment. Patience, endurance, and passion are fundamentals and they gave which have been taking me to different levels in my life. My right doings are all rooted in these two special persons, I am proud to be your daughter.

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CHAPTER 1: INTRODUCTION

1.1 Background of Study

Tomato has its origin in the South American Andes, *Lycopersicon esculentum Mill* is its scientific name and belongs to the *Solanaceae* family. Tomato is one of the most important vegetables worldwide and it contributes to a well-balanced, healthy diet which are rich in minerals, vitamins, essential amino acids, sugars and dietary fibres. Tomato contains much vitamin B and C, iron and phosphorus. (Naika *et al.*, 2005). It is high yielding and economically attractive, hence, the area under cultivation is increasing daily, for instance, world tomato production in 2001 was 105 million tons of fresh fruit from an estimated 3.9 million hectares (Naika *et al.*, 2005).

The growing of tomatoes among many other fruit vegetables produces a whole lot of opportunities to both small holder and commercial farmers around the world because tomatoes are used as an ingredient in many dishes and sources and also in drinks. The tomato fruit is also consumed fresh in salads. They can be processed into purées, juices and ketchup. Canned and dried tomatoes are economically important processed products(Naika *et al.*, 2005).In addition tomato has become an important cash and industrial crop in various parts of the world. One of the reasons for this increase is that tomato cultivation is now being moved to places and seasons that are originally unsuitable for its productivity thereby increasing the economic importance of the crop(Fred, 2014).

After growth and harvesting of the fruit, it is noteworthy that tomato is highly perishable due to its nature as a climacteric fruit, and thus cannot be stored for long periods. A climacteric fruit exhibits increased respiration and ethylene production during ripening (Barry and Giovannoni, 2007). Ripening of climacteric fruit after harvest typically involves softening and a change in colour and taste in terms of sweetness(Barry and Giovannoni, 2007). High eethylene has both beneficial and harmful effects on the quality of horticultural produce. Ethylene enhances produce quality by promoting desirable colour development and stimulating the ripening of climacteric fruit. However, its undesirable effects include accelerated ripening and softening of fruits, accelerated senescence and deterioration of the fruit (Adepoju, 2014)

Perishability of tomatoes is also due to the continued respiration of the produce where respiration involves the breakdown of carbohydrate (example sugars) and other food reserves (organic and fatty acids) in the harvested produce and results in the production of carbon dioxide, water and heat (Manyoo *et al.*, 2018). In the post-harvest phase, respiration is supported by carbohydrate reserves of the produce; this leads to a net loss in its dry weight or negative growth. The more rapid the respiration rate, the faster the produce will consume its carbohydrate reserves, the greater will be the heat produced and the shorter will be the post-harvest life of the fruit. Carbohydrate breakdown during respiration leads to losses in food value, flavour, texture and weight, and thus to overall quality loss. Loss in weight, in particular, results in economic loss to the producer. Post-harvest losses of tomatoes can be significant due to ignorance of suitable post-harvest technology, such as packaging, temperature control, and post-harvest treatments. The production of tomato fruit has increased thanks to research efforts, but maximum profits won't be reached unless equivalent efforts are made to reduce post-harvest losses and lengthen the fruit's shelf life (Adepoju, 2014) .

The main objectives of applying post-harvest technologies is to maintain quality of the produce, to protect food safety and to reduce the losses between harvest and consumption. (FAO, 2011). However, despite tomato being climacteric fruit, the deterioration of the fruit can be increased by excessive field heats, lack of on farm storage facilities, inappropriate harvesting stages or periods, lack of appropriate harvesting containers and poor field sanitation, lack of pre-cooling systems. Smallholder farmers prioritize and concentrate on the tomato crop's production activities, but they have little to no interest in the crop's post-harvest and marketing efforts (Ayomide, Ajayi and Ajayi, 2019). Fruits and vegetables are transported directly to markets after harvest because farmers are unable to store extremely perishable goods for extended periods of time. Because tomatoes are so perishable, farmers are compelled to sell when there is a market oversupply and prices are low. As a result, farmers' welfare may suffer(Adepoju, 2014). This lowers their revenue. The majority of communal farmers in Zimbabwe preserve horticultural products using conventional techniques, these storage systems comprise of open-air sheds, kitchens, granaries, bedrooms, and/or the conventional pit (Heri, 2000).

There are methods used to slow down the respiration rate of produce and delay the production of ethylene, to minimise quality losses, extend shelf life and minimise economic losses to the producer. Use of refrigeration or cold rooms, modified atmosphere packaging (plastic containers or film packaging's ability to modify gas composition and reduce moisture loss), edible coating to put barriers against gaseous exchange and water loss, and submerging the produce in calcium chloride (Arah *et al.*, 2016) all help to delay the ripening of produce. Other techniques that can be used include those that use chemicals to remove ethylene, such as 1-Methyl-cyclopropene (1-MCP), amino-ethoxyvinyl glycine (AVG), amino-oxyacetic acid (AOA), or silver thiosulfate (STS), or UV or ozone exposure. However, the approaches are typically out of reach for small-holder farmers because to a lack of funding. Additionally, about 60% of Zimbabwe's rural areas lack access to electricity and refrigerators, making it impossible to adopt such technology.

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Development of a charcoal cooler storage ensures that a low temperature is maintained during the postharvest handling which is critical for the preservation of perishable commodities and the reduction of postharvest losses. The low cooler temperature is accompanied by an increase in the relative humidity within the storage bin which minimizes the moisture loss from the tomatoes. A lack of knowledge on the appropriate quality preservation practices and technologies can result in high qualitative and quantitative losses in such fresh produce. High postharvest losses (upwards of 50%), especially in vegetables, are attributed to various biological and environmental factors (Ambuko *et al.*, 2017).It is against this background that the design and development of the tomato charcoal cooler storage is necessary.

The charcoal cooler is developed to provide an environment which is both lower than ambient temperature and at a higher level of relative humidity for the storage of fresh produce. Charcoal (thermal conductivity of 0.084 W·mK–1) is used because of its porous structure that can hold water (Ronoh, Kanali and Ndirangu, 2020)and its affordable and available in many places in Zimbabwe. Due to its pore structure it works on the principle of holding the water which is added to it, as air flows across this “wet wall” the air temperature is decreased due to the loss of heat through the evaporation of water. The temperature is normally lowered by about $5-10℃$ (Ronoh, Kanali and Ndirangu, 2020), depending on the relative humidity of the ambient air.

Charcoal is made traditionally from the burning of wood that has been heated in the absence of oxygen. This process drives off the water and other volatile compounds, leaving a lightweight, porous material with high carbon content (Jason Klein et al, 2022). The carbon content in the charcoal has multifunction which includes remarkable absorption potential, able to remove pathogenic bacterial such as E.coli from aqueous, eliminate harmful toxins from water and it can be able to recover an aroma compound from processed effluent(Agegnehu, Srivastava and Bird, 2017).It can also emit antimicrobial agents in the vapor phase and nanoparticles inside the food packaging. The application of activated carbon for scavenging of factors affecting food quality such as water vapor, oxygen, ethylene and odor(Agegnehu, Srivastava and Bird, 2017)is necessary to increase the shelf-life of the tomato produce.

1.2 Problem Statement

In Zimbabwe, 40% of all fruits and vegetables produced are not consumed as a result of postharvest losses. Farmers encounter major problems of storing tomatoes to increase their shelf life due to quick deterioration of the produce at storage. Demand in the consumption of tomatoes has increased across the country which comes with high concern in storage of these perishables to maintain their quality. Some of the challenges are excessive field heats on the product causing it to continually loose water resulting in shrivel, wither or rot away rapidly, inappropriate harvesting stages, lack of harvesting containers and poor field sanitation.

Lack of on farm storage facilities, small-holder farmers cannot install cooling systems (refrigerators) for tomatoes due to lack of electricity in rural areas. Quick deterioration of the product, causes the small-holder farmer to ferry the produce to the market as soon as possible before it start to deteriorate therefore losses are minimized. Availability of market is another biggest challenge facing most small holder tomato producers. This challenge includes the pattern of production which results in gluts of tomatoes in the market and prices are low and it reduces the farmer's income. During traditional storage of tomatoes, the fruit undergoes a lot of physiological changes and pathological attack as a result of lack of o farm storage facilities of the fruit. These actions render the fruit undesirable especially to the consumers.

1.3 Objectives

1.3.1 Main Objective

To design and develop a tomato charcoal cooler storage for small-holder farmers

1.3.2 Specific Objectives

- To design and develop a charcoal cooler storage for tomatoes
- To evaluate the performance/ effectiveness of charcoal storage in reducing temperature of tomatoes
- To maintain the quality and increase shelf life of tomatoes stored in the charcoal cooler by reducing the temperature.

1.4 Justification

Tomato production has increased in recent years due to the economic and nutritional importance of the crop. The increase is made possible by the numerous research advances made along the entire value chain. However, scientific research has focused mainly on production whilst neglecting postharvest issues (Gatahi, 2020). Tomato producers have therefore enjoyed good harvests in recent times, though the good harvests of those from developing countries do not translate into profit as most are lost after harvest(Kitinoja and Thompson, 2010)

Spoilage of produce and having access to a cost effective coolers among small holder farmers are some of the constraints they face. Mostly about 60 % rural parts of Zimbabwe do not have access to refrigerators and electricity. Tomatoes requires very stables temperatures of 10-15ºC for it to have a longer shelf life (Chinenye *et al.*, 2013).The preservation procedure therefore requires a cool storage system and facilities but the implementation of this method can be quite difficult due to lack of technical skills and lack of money and lack of electricity that the small holder farmers are faced with. Therefore to enhance the shelf life of fresh produce there is an alternative method for enhancing and promoting the life span of harvested tomatoes is the design and develop a charcoal cooler storage bin for tomatoes which is cost effective and most small holder farmers can afford.

A charcoal cooler storage bin is effective because charcoal has pores which absorbs and store water and this reduce temperature inside. These properties of charcoal make it a good material for making good storage cooler bin for tomatoes. The technology is very economical it does not require any mechanical or electrical energy input to operate and therefore appropriate for smallholder in rural areas without electricity (Ambuko *et al.*, 2017). Additionally, the chambers can be constructed from locally available materials using unskilled labor, thereby making the cost affordable for the resource –poor smallholder farmers(Chinenye *et al.*, 2013).The charcoal can be produced from heating locally available waste wood or organic materials (coconut shells) above 400℃ in a oxygen-starved environment. The use of improved metal kiln in the production of charcoal does not only increase the production efficiency, but also reduces the release of harmful gases into the environment. This, in turn, results in reduced release of greenhouse gases and thus global warming and its effects.

1.5 Hypothesis

- **H_0:** There is no significant difference on tomatoes subjected to charcoal cooler and those which are subjected to shade.
- **H_1:** The charcoal cooler systems will be able to increase shelf life of tomatoes.
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1.6 Limitation

- Lack of funding
- Variation in weather conditions
- Lack of resources
- Lack of enough time to experiment on all seasons

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Tomato is a highly perishable fruit, and this chapter mainly focuses on the causes of perishability, ways to improve the shelf life of the commodity, the healthy benefits of tomatoes and the economic and industrial value of the fruit and other storage systems that were employed in the preservation of the tomato fruit. A low cost method that can be used to preserve the tomatoes and increase their shelf life is the use of a charcoal cooler storage.

2.2 Tomato Production

2.2.1 Importance of Tomato to Communities

Tomato is one of the popular vegetable worldwide (Beckles, 2012)Tomatoes contribute to a healthy, well-balanced diet. They are rich in minerals, vitamins, essential amino acids, sugars and dietary fibres. Tomato contains much vitamin B and C, iron and phosphorus(Naika *et al.*, 2005). According to (Swetha and Banothu, 2018), tomatoes have higher concentrations of lycopene, a carotenoid with antioxidant qualities that helps lower the risk of several chronic diseases like cancer and several cardiovascular ailments. Fresh tomato fruits are used in salads, and cooked tomatoes are used in sauces, soups, and dishes with meat or fish. They are capable of being turned into purées, juices, and ketchup. Canned and dried tomatoes are economically important processed products(Naika *et al.*, 2005).

2.2.2 Market Trends of Tomatoes

The season has a big impact on how readily available tomatoes are on the market. Tomatoes are in high supply in Zimbabwe from January to May but are in short supply from August to November. According to (Hailu, G., Derbew, 2015), the period of tomato fruit abundance is marked by a market glut, degradation, and spoilage that results in low market pricing and wastage. In January 2015-June 2015, tomato sales at the biggest informal markets in Zimbabwe, Mbare Musika, generated US$8 335 413.00, contributing 60% of the total revenue generated from the sales of fruits and vegetables in the same period (Lesley Macheka *et al* 2017), however, post-harvest losses are a major problem. Despite the presence of fertile soils conducive to agricultural development in southern Africa, food security is endangered after harvest (Mandisvika, Chirisa and Bandauko, *et al* 2015). This is since many smallholder farmers lack the resources to invest in the technologies required for processing fruits and vegetables after harvest. To meet its domestic demand, Zimbabwe, for instance, imported 603 000 tons of fresh tomatoes from South Africa in 2010 due to this problem (Lesley Macheka et al, 2017). If locally grown tomatoes of high quality are accessible all year round, a situation like this would not occur.

2.2.3 Post Harvest Losses of Tomato in Zimbabwe

In Zimbabwe, there have been reports of significant losses for farm products of over 30%, particularly for perishable and semi-perishable crops (Lesley Macheka et al, 2017). Farmers have continued to rely on conventional food preservation techniques despite their losses, which are commonly used for short storage of small quantities of produce. Tomatoes are vulnerable to post harvest losses due to their perishability nature and humid conditions in tropical climates. Globally, post-harvest losses in tomatoes supply chain ranges from 10%-40% of the harvested tomatoes(Gogh *et al.*, 2013)

Constraints to transportation, a lack of marketing information, and spoiling are some of the challenges faced by growers of fruits and vegetables (Norman Mhazo, 2012). Their main priorities are production and post-harvest and marketing activities. . Marketing ensures that there is efficient processing and packaging of produce, preparation of marketing facilities and storage, and facilitation of transportation to market (Mandisvika, Chirisa and Bandauko, 2015). Due to excessive fruit output and production without a defined target market, farmers are dealing with oversupplies of perishable goods in the market. The unavailability of adequate postharvest infrastructure to smallholder farmers such as pack houses, pre-cooling and sorting facilities results in improper sorting and storage of the produce with significant losses. Improved storage allows farmers to extend their selling season; since farmers can sell their produce during off-peak periods they receive higher premiums. Reducing the post-harvest and market losses improves the income of the farmer by more than 50%.

2.3 Post Harvest Physiology of Tomatoes

According to (Guillén *et al.*, 2007), citric and malic acids are responsible for the tomato's sour flavor, which coincides with titratable acidity. Acid levels decrease during storage due to quality losses, which has an impact on consumer acceptance.

2.3.1 Ethylene Production in Tomatoes

Fruits can be classified based on their ability to produce high ethylene (C_2H_4) levels that is associated with increased respiration at the onset of ripening. Climateric fruits are fruits that produce high levels of ethylene foe examples tomatoes and avocados whereas non-climateric fruits are fruits that produce less ethylene as compared to the climacteric and these includes grapes and oranges(Barry and Giovannoni, 2007)

The creation of ethylene, the buildup of pigments like carotene and lycopene, the formation of aroma and flavor, the softening of fruit tissues, and an increased sensitivity to infections are all factors in the ripening of fleshy fruits. Ethylene regulates several physiological and morphological processes, such as seedling growth, leaf and flower senescence, floral sex identification, fruit ripening induction, disease resistance, and stress tolerance. Internal signals are responsible for controlling ethylene production both during growth and in response to environmental stimuli from biotic for example pathogen attack (Barry and Giovannoni, 2007) and abiotic stresses which includes wounding, ozone, cooling, or freezing(Martínez-Romero *et al.*, 2007).

There are two systems of ethylene production in plants namely; System 1, which functions during normal growth and development and stress responses, and System 2, which functions during floral senescence and fruit ripening. System 1 is said to be auto-inhibitory, which means that exogenous ethylene inhibits synthesis, and inhibitors of ethylene action can stimulate ethylene production. System 2 is stimulated by ethylene, thus it is autocatalytic, and inhibitors of ethylene action inhibit ethylene production(Moeder *et al.*, 2002)

S-adenosylmethionine (S-AdoMet) is the precursor to ethylene biosynthesis and ethylene is synthesized from methionine in three steps: (1) conversion of methionine to S-adenosyl-L-methionine (SAM) catalyzed by the enzyme SAM synthetase, (2) formation of 1-aminocyclopropane-1-carboxylic acid (ACC) from SAM via ACC synthase (ACS) activity, and (3) the conversion of ACC to ethylene, which is catalyzed by ACC oxidase (ACO)(Moeder *et al.*, 2002). The formation of ACC also leads to the production of 5¢-methylthioadenosine (MTA), which is recycled via the methionine cycle to yield a new molecule of methionine. S.AdoMet is the methyl group donor for many cellular molecules (Methylated Acceptors) including nucleic acids, proteins and lipids. In addition, S.AdoMet is the precursor of the polyamine synthesis pathway(Martínez-Romero *et al.,* 2007). Increased respiration provides the ATP required for the methionine cycle and can lead to high rates of ethylene production without high levels of intracellular methionine. SAM is an important methyl donor and is involved in multiple aspects of cellular metabolism. The two crucial steps in the synthesis of ethylene are the formation of ACC and its conversion to ethylene(Moeder *et al.*, 2002)

To make tomato fruits more palatable, ethylene is required during ripening. However, once ripening has begun, ethylene's positive benefits may be offset by its tendency to promote over ripening and deterioration. When compared to when they are developing, tomato fruits emit up to 1000 times more ethylene when they are ripening (Wills, R.B.H., Warton, M.A. & Ku, 2000). Due to the great sensitivity of tomato fruits to exogenous ethylene, the exposure of mature-green to this gas will initiate the ripening process, and then followed by over-ripening(Wills, R.B.H., Warton, M.A. & Ku, 2000). To increase the shelf life of tomatoes, ethylene must be removed from areas used for marketing and storage.

Fresh food can lose 10 to 30% of its shelf life due to ethylene levels from other ripening fruits in storage rooms or exhaust fumes from forklift trucks and other vehicles. Because ethylene effects build up over time, even prolonged exposure to low amounts in storage and marketing might have unsettling consequences (Wills, R.B.H., Warton, M.A. & Ku, 2000).By avoiding ethylene buildup around the product, the negative impacts of ethylene can be mitigated.

2.4 Tomato Post Harvest Management, Ethylene Control and Storage Systems

2.4.1 Temperature Control

Temperature management is the most important tool for fruit shelf-life extension and freshness maintenance. Most of the physiological, biochemical and microbiological activities contributing to the deterioration of produce quality are largely dependent on temperature(Swetha and Banothu, 2018) The harvested produce contains a substantial amount of heat associated with its temperature, known as field heat, which is a significant part of the cooling load .As the heat increases so as the rate of respiration, deterioration of the produce and ethylene sensitivity(Martínez-Romero *et al.*, 2007). Every 10°C rise in temperature doubles or triples the pace at which horticultural produce degrades (Lal Basediya, Samuel and Beera, 2013). Therefore, efforts must be concentrated on reducing the rate of produce respiration to increase shelf life, maintain quality, and reduce economic losses. To increase the shelf life of tomato fruits in the cold, the optimal storage temperature is between 10-15 C. Chilling injury, which can mostly happen at lower temperatures, might have an impact on the fruit's flavor. Although fruit can be stored cold to extend their shelf life, doing so results in higher energy costs and environmental carbon emissions (Wills, R.B.H., Warton, M.A. & Ku, 2000).

2.4.2 Edible Coatings

The use of edible coating on fruit surfaces has also been studied to extend shelf life. A suitable edible coating composition may offer a great barrier against water loss and gaseous exchange, which are unfavorable to post-harvest quality. Lipids, such as waxes, acylglycerols, and fatty acids, are the major components of edible coating (Swetha and Banothu, 2018). According to (Martínez-Romero *et al.*, 2007), the use of edible coatings on tomato fruit slows ripening because they reduce respiration and ethylene production as well as ethylene-related alterations like color change and firmness loss.

2.4.3 Controlled Atmosphere (CA) and Modified Atmosphere Packaging (MAP)

By lowering ethylene-related deterioration, changes in the gaseous composition of the atmosphere can increase fruit's shelf life (Chinenye *et al.*, 2013). Both controlled atmospheres (CA) and modified atmospheres (MA) entail intentional alterations to the gases in the environment for increased fresh food storage. To prevent the senescence of tomato fruits, the carbon dioxide content is raised to 1-5% (v/v) while the oxygen content is lowered to 3-5%(Gil, Aguayo and Kader, 2006). Increasing the concentration of carbon dioxide both delays fruit softening and prevents fruit degradation by fungi static action (Kim and Wills, 2015). Anaerobiosis is caused by oxygen levels below the necessary 3% and leads to bad flavors and a decrease in the quality of food(Gil, Aguayo and Kader, 2006) . Quality of the fruit is also maintained by correct calibration of relative humidity of the storage area.

The gas constituents of a CA are constant whilst those of a MA vary continuously. CA and MA may be applied in storage rooms and shipping containers or in small packages(Guillén *et al.*, 2007)The effectiveness of this method depends on fruit variety, maturity, initial quality, storage temperature, and duration of exposure to either a CA or MA(Arah *et al.*, 2016). Modified atmosphere packaging (MAP) involves enclosing products in special packages with altered gaseous composition and reduce water losses from fruits, bruises and spread of diseases which may be enhanced by inclusion of ethylene scrubbers in the package(Beckles, 2012).

2.4.4 Chemical Control of Ethylene

2.4.4.1 1-Methylcyclopropene (1-MCP).

The use of 1-methylcy-clopropene (1-MCP) has been shown to suppress the action of ethylene in many fruits and vegetables(Swetha and Banothu, 2018).1-MCP treatments present some advantages such as it is active at very low concentrations, resulting in residual residue, lower quality changes and processes in fruits such as primary and secondary metabolisms, lower physiological disorders, enzymatic activity increase or reduction depending of products treated, inhibition of ethylene production and thereby extension of fruits storage (Kim and Wills, 2015).The efficiency of the 1-MCP application can be limited by cultivar, maturity, uneven ripening, and achieving increases in storage potential without excessively delayed ripening that can increase decay development or prevent proper ripening(Barry and Giovannoni, 2007) . The delay of softening, red color development and respiratory rate of tomato fruits may be desirable, and are the major factors in successful commercial development of 1-MCP technology (Swetha and Banothu, 2018).

By inhibiting the enzyme activities of ACC Synthase (ACS) and ACC Oxidase (ACO), 1-aminocyclopropane-1-carboxylic acid (ACC) synthesis can be suppressed, hence limiting the production of ethylene. ACO is inhibited by substances including ethanol, cobalt, and acetaldehyde, while ACS activity is inhibited by aminoethoxyvinylglycine (AVG) and amino-oxyacetic acid (AOA). AVG can be used in pre- and post-harvest treatments to inhibit the synthesis of ethylene, which has been shown to delay softening, accumulate soluble sugars, and diminish volatiles linked to flavor(Saltveit, 2005).

2.4.4.2 Application of ethanol and acetaldehyde

The application of ethanol and acetaldehyde to suppress ACO activity has delayed softening, reduced chlorophyll degradation, and increased lycopene synthesis. Acetaldehyde, on the other hand, has a limited commercial use due to its carcinogenic effect, and ethanol has a limited commercial use due to the difficulty in concluding because the response depends on other factors, such as cultivar, ripening stage, and concentration, among others(Martínez-Romero *et al.*, 2007).

Cobalt inhibits the autocatalytic generation of ethylene, which is how it works to reduce ethylene production. Since cobalt is a poisonous heavy metal and cannot be used in the food sector, its usage is restricted even though it has been found to extend the shelf life of tomato fruits(Martínez-Romero *et al.*, 2007)

2.4.4.3 Silver thiosulfate

The silver ion has proven to be a potent inhibitor of ethylene action in ornamentals. Silver thiosulfate works at ethylene's receptor sites to suppress synthesis. Fruit's shelf life is lengthened when ethylene action is reduced. Silver's commercial application in the food business is constrained since it is a heavy metal, a pollutant of the environment, and explosive at high concentrations (Serek *et al.*, 2006).

2.4.4.4 Heat Treatment and Ozone

Heat treatment is an environmentally friendly technique that can be used as pre-treatment after harvest to prolong the shelf life of fruit and vegetables by minimizing pathogen decay (Papoutsis and Edelenbos, 2021). In general, heat treatment can be applied in fruit and vegetables by hot air, dipping, spraying, or steam (plant sauna) applications. In fruits and vegetable, heat treatment has mainly been applied as steam. It is important to note that steam temperature is an important parameter that significantly affects the post-treated fruit quality(Papoutsis and Edelenbos, 2021).

Ozone is an oxidizing agent and its sterilization activity has been attributed to its ability to oxidize organic matter and if commonly used to reduce ethylene and is normally used or applied in cold rooms. The 1- aminocyclopropane-1-carboxylic acid synthase (ACS) enzyme is inhibited by ozone activity, which thus prevents the manufacture of ethylene. However, the levels needed to achieve this action may hasten lesion formation and cell death. Additionally, ozone is a photochemical oxidant that can encourage the synthesis of ethylene and damages many plant species when used in excess(Papoutsis and Edelenbos, 2021) . Only 0.1 ppm of ozone is considered safe for human health. Ozone's instability makes it challenging to maintain concentration in storage rooms, and depending on the amount inhaled, its toxicity can result in illness or even death.

2.4.4.5 Potassium permanganate

Potassium permanganate is an ethylene scrubber that combines with ethylene to form acids, followed by CO2 and H2O in an oxidation reaction. The ethylene and oxygen concentrations in the atmosphere, relative humidity (low humidity decreases scrubbing capacity), temperature of atmosphere/absorbent, and size of absorbent/scrubbers employed all have an impact on the scrubbing capacity. However, because the KMNO4 depletes quickly and needs to be replaced frequently, the approach is frequently appropriate to tiny storage spaces. Due to the substantial accumulation of ethylene in packaging, which necessitates a considerable amount of oxidizer, KMnO4 is more effective at scrubbing when dispersed across a vast surface area(Martínez-Romero *et al.*, 2007)

Potassium permanganate can be made more effective in oxidizing low levels of ethylene by absorbing KMNO4 onto porous inert minerals like celite, vermiculite, alumina, zeolite, and clay. High surface area exposed to the environment is what accounts for the increased efficiency(Wills, R.B.H., Warton, M.A. & Ku, 2000). However, due to its toxicity, potassium permanganate must be packaged specifically to prevent contact with food.

2.4.4.6 Activated carbon and zeolite

To delay fruit ripening and retain fruit quality, ethylene is removed from the storage environment using adsorbents such activated carbon and zeolite (Martínez-Romero *et al.*, 2007). The act of trapping molecules of a gas, liquid, or solute as a thin film on the surface of a solid substance is known as adsorption. Ethylene is eliminated by building up a monolayer on the adsorbent's surface. Material can bond through van der Waals forces or form chemical connections during adsorption, (Papoutsis and Edelenbos, 2021) Temperature, relative humidity, and adsorbate concentration all have a significant impact on the adsorption rate. Due to its caption exchange capacity, molecular sieving, and high adsorption, zeolite—natural or synthetic—has long been employed in the agro-industry to remove ethylene (Limtrakul *et al.*, 2001). Zeolite can be found in a variety of components, including polyethylene films and inorganic membranes for filtering. Zeolite and plastic sheets have been used to preserve fruit longer and prevent microbiological deterioration(Limtrakul *et al.*, 2001)

The pore structure, surface area, and surface chemistry of the carbon all have an impact on its capacity to absorb ethylene in storage rooms when used with activated carbon or charcoal. The activated carbon's adsorption capability increases with surface area and pore volume. In the agro-industry, activated carbons/or charcoal are frequently employed as decolorizing and purifying agents. Their surface areas range from 300 to 2000 m2/g(Gaikwad, Singh and Negi, 2020).Any carbonaceous material can be converted into activated carbon or charcoal, but it's important to keep in mind that the raw material should be simple to activate, contain little inorganic materials, be inexpensive and readily available, and degrade slowly when stored(Dąbrowski *et al.*, 2005).

Both chemical and physical methods can be used to activate carbon, but chemical activation provides several advantages over the former, including higher yields, activation at lower temperatures, and improved development of the porous structure (Dąbrowski *et al.*, 2005).Granular activated carbon is the most often used form because it is easy to regenerate, adaptable, and its adsorption capacity is unaffected by temperatures between 2 and 20 °C (Martínez-Romero *et al.*, 2007)

The shelf life of tomatoes can be extended with the application of a number of catalysts, including copper, cobalt, palladium, and activated carbon, even though ethylene may not be eliminated (Bailen *et al.*, 2013).In addition to enhancing ethylene adsorption, catalysts added to activated carbon have the effect of increasing ethylene oxidation. The greatest barrier to their utilization is their expensive cost, even though these catalysts effectively extend fruit shelf life(Dąbrowski *et al.*, 2005).

2.4.5 STORAGE SYSTEMS

2.4.5.1 The Zeer pot

The Zeer pot was created in the 1990s by a Nigerian educator by the name of Mohammed Bah Abba. It comprises of a small-scale storage pot-in-pot system that utilizes two pots constructed of regional materials that are slightly different sizes(Gustafsson and Simson, 2016). The larger pot is placed inside the smaller pot, which has the option of being glazed. The space between the two pots is filled with moistened 33sand. Water evaporates from the sad via the porous pottery when the sun shines on the outer pot, cooling the food in the little pot inside. Fruits and vegetables can be preserved for up to 12 kg.

Practical Action and the Women’s Association for Earthenware Manufacturing have tested the efficiency of Mohammed Bah Abba's Zeer Pot storage design in Sudan. The outcomes are displayed in the subsequent table(Gunadasa, Awanthi and Rupasinghe, 2017).

Table 3: The shelf life of fresh produce when using a Zeer pot.

Produce	Shelf-life without using Zeer	Shelf-life using Zeer
Tomatoes	2 days	20 days
Guavas	2 days	20 days
Okra	4 days	17 days
Carrots	4 days	20 days

Figure 1: The Zeer pot: source – (Gunadasa, Awanthi and Rupasinghe, 2017)

2.4.5.2 A BAMBOO COOLER

Sand, metal plate, bags, bamboo, jute, buckets, jugs, ink, and bricks were chosen for construction projects based on their porosity, rate of water absorption or evaporation, availability, affordability, and ease of construction. For the bamboo and pot-in-pot evaporative coolers, respectively, the holding capacity were 10 and 40 kg of tomatoes. However, the coolers' design needs to be modified to allow air to flow between layers of tomatoes as the quantity of tomatoes grows(Woldemariam and Abera, 2014).

The varieties of evaporative coolers used were mostly determined by the affordability, accessibility, and simplicity of the building materials. Additionally, it was to be made available based on user desire.

A jute cloth was used to cover the bamboo baskets. The rim of the basket was covered with jute fabric and stitched. The lower end of the cloth extended beyond the length dip into the water and draped loosely around the bottom. This facilitates the capillary action via the jute cloth that lifts the water. A woven lid with a loose fit covered the basket. Jute fabric was used to cover the lid as well [Figure 1(a)]. It was built with a height of 1 m, a diameter of 60 cm, and a thickness of 2cm. It was developed in Ethiopia(Woldemariam and Abera, 2014)

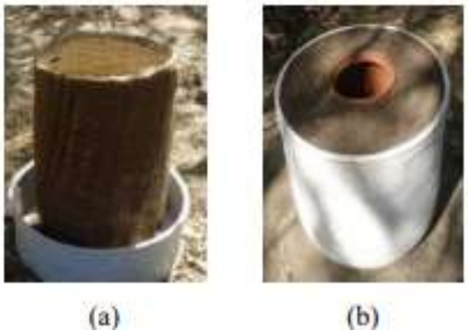

(a) (b)

Figure 2: (a) Bamboo jute cooler (b) Pot in pot cooler: source-(Woldemariam and Abera, 2014)

To store tomatoes, a porous outer earthenware pot measuring 50 cm in diameter and 2 cm thick and an inside pot measuring 20 cm in diameter and 2 cm thick were built during the creation of the second type of evaporative cooler [Figure 2(b)]

2.4.5.3 STATIC COOLING CHAMPERS

A cover made of cane or other plant material, bags, or cloth can be placed over the cooling chamber's basic framework, which can be constructed from bricks and river sand. Additionally, there must be a water supply close by. Construction is rather easy. Bricks are first laid down to form the floor, which is then surrounded by a cavity wall with a gap of approximately 75mm (3 inches) between the inner and outside walls. Sand is then used to fill up this cavity(AMDEBASISH ROUT, BISWAJIT, DEBASISH SUBUDHI , MANORANJAN SAHOO , RAJESH KUMAR PANI and DAS, 2014). A chamber with a capacity of around 100kg that is the size depicted in Figure 3 requires roughly 400 bricks to construct. Canes coated in sacking are put on a bamboo frame to create a covering for the chamber. By constructing a roof to offer shade, the entire structure should be shaded from the sun. After construction, water is completely soaked into the walls, floor, sand in the cavity, and cover. Once the chamber is entirely saturated, a twice-daily sprinkle of water is sufficient to keep it moist and warm(ROUT, BISWAJIT, SUBUDHI , SAHOO , PANI and DAS, *et al* 2014).

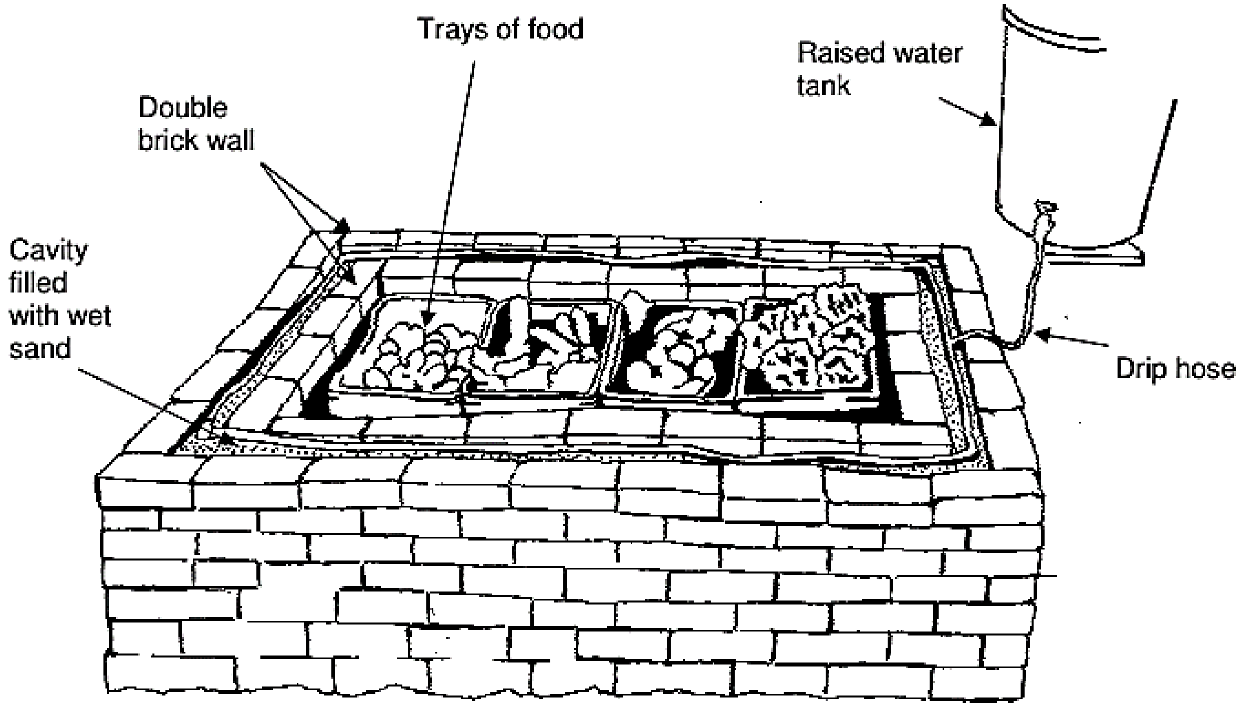


Figure 3: a static cooling champer :source-(ROUT, BISWAJIT, SUBUDHI , SAHOO , PANI and DAS, *et al* 2014).

2.4.5.4: NAYA CELLAR STORAGE

Useful Action Particularly in rural areas, Nepal has been effective in disseminating cooler technology that is similar to the design from the Indian Agricultural Research Institute. Its original creators, Mr. Joshi and Dr. Gyan Shresthra from the Green Energy Mission, gave it the name Naya Cellar Storage. The construction is created from materials that are readily available locally, and the design is relatively simple to modify to meet the needs of the users. For rural food producers who had little to no income and couldn't afford pricey refrigerators, the results have been good(AMDEBASISH ROUT, BISWAJIT, DEBASISH SUBUDHI , MANORANJAN SAHOO , RAJESH KUMAR PANI and DAS, 2014). To build the Naya Cellar Storage, the following materials are needed:

1. Bricks -1200-1500

2. Sand - 400-500 Kilograms

3. Polythene hose - 6 meters

4. Water tank/bucket – 100 litre capacity

5. Bamboo/wood – 1.82 meters two pieces and 2.15 meters two pieces

6. Straw - 2 bundles

7. Sack

CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter outlines how a charcoal cooler box was designed, constructed and used for the storage of tomatoes. It also outlines the fabrication of the box by the use of wood and size reduction of the charcoal that was put in between the mesh wire. The way the temperature was measured inside the charcoal cooler the control and the ambient temperature. The objective and subjective fruit ripening tests that were done on tomatoes are outlined. Experimental design, data analysis and data presentation are explained. The materials and methods adopted are presented following the objective.

3.2 Phase A: Site Selection

Selected site: five metres from the source of water (tap), a clear environment so that both the cooler and the control receives the same temperature and also free air circulation.

3.3 Phase B: design and development of a charcoal cooler storage

The device was made of open timer frame with sides filled with charcoal, which was continually kept moist. As warm, dry air passes through the moist charcoal, it draws energy from its surrounding which produces a considerable cooling. The cooler is a 0.58m by 0.58m by 0.54m wooden box with charcoal walls. Charcoal was chosen because it is a substance that is easily obtained in Zimbabwe and also has very porous structure that can hold water and it contains carbon that act as a scrubber for ethylene as well as odors from the fruit. The walls and top of the storage box was supported by a wooden frame. The cooler consist of two frames the inside frame and the outside frame, the gap between these frames thus where the charcoal was, and it was supported by a wire mesh. The cooler was constructed from wooden pluck of from eucalyptus tree since it is readily available and cheap with a thickness of 0.04m. There was the outside frame with the following dimensions 0,58m length, 0.58m width and 0.54m height. The dimensions of the inside frame were 0.5m length, 0.5m width and 0.54m height.

Therefore volume of the outside; $0.58 \times 0.58 \times 0.54 = 0.182m^3$

Volume of the inside frame:$0.5 \times 0.5 \times 0.54 = 0.135m^3$

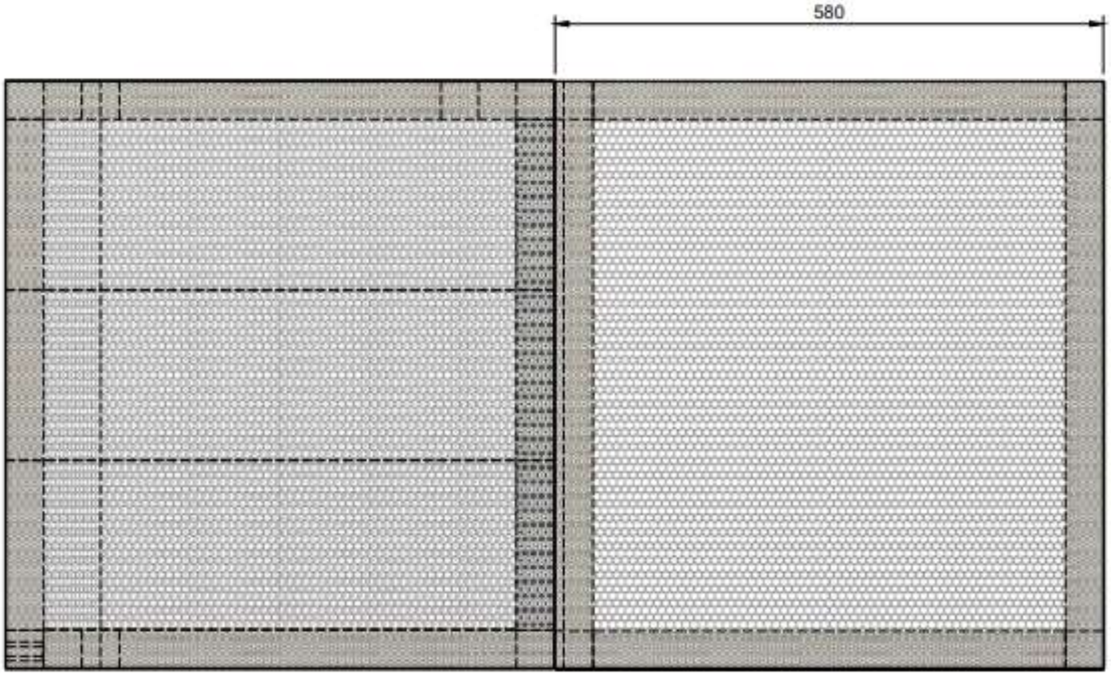


Figure 4: the front view of the cooler

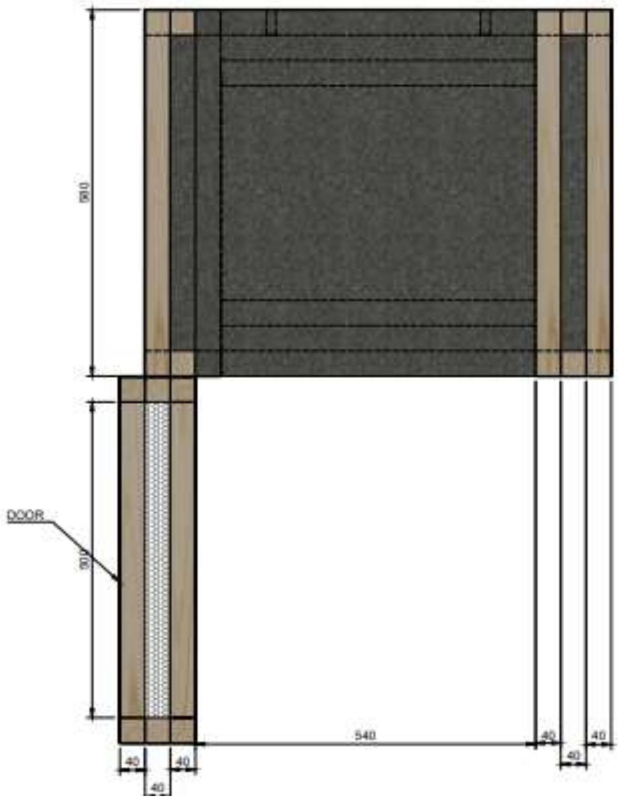


Figure 5: the side view of the cooler

3.3.2 Materials that were used to make the cooler

Table 4: BOQ for the cooler

Quantity	Description	Unit Price ($)	Total Price ($)
12 metres	0.04 m thickness wooden plunk	0.50	6.00
4 m	Mesh wire	0.50	2.00
1m	Wooden board	1.00	1.00
20kg	charcoal	15.00	15.00
1kg	nails	1.00	1.00
2	hinges	0.50	1.00
TOTAL			**26.00**

3.3.3 The charcoal walls

The walls were constructed from wire mesh which was mounted on the inner and the outer frame so that they will support the charcoal inside. Obtain charcoal from local market. The charcoal was sold as big logs, they were crushed into medium size each with an average diameter of almost 0.004m so that they can fit in between the mesh. The charcoal was also crushed to almost the same surface area so that they can absorb water at almost the same rate.

Volume of charcoal $= volume\ of\ outside\ frame - volume\ of\ inside\ frame$

$$= 0.182m^3 - 0.135m^3$$

$$= 0.047m^3$$

3.3.4 Cooler shelves

The cooler was composed of three shelves, there was a wire mesh at the base of the shelve. The dimensions of each shelve are 0.5m length, 0.5m width and 0.18m and each has a capacity of carrying a volume of 0.045m^3 of tomatoes.

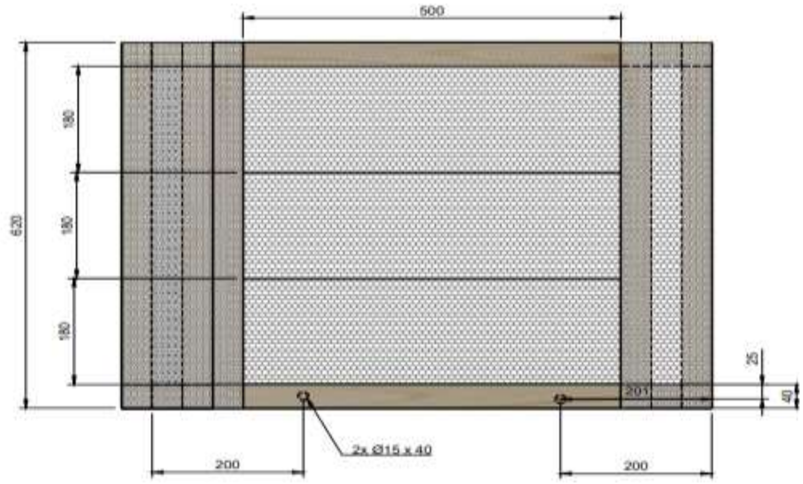


Figure 6: the cooler shelves

3.3.5 Roof, door and floor

The roof was constructed from a wooden board to provide a shade for the tomatoes inside the cooler. The door was constructed from charcoal which was in between the mesh wire supported by the wooden frame. The mesh wire was also used as the floor as it allows air circulation inside the cooler.

3.4 Phase C: To evaluate the performance/ effectiveness of charcoal bin in reducing storage temperature of tomatoes

Alcohol Thermometers were placed lying vertically to the x-axis both in the cooler and control for reading the temperatures differences. The temperature readings were taken under different water regimes. Firstly temperature was taken the charcoal walls were not applied water, on the second day the charcoal walls were applied water once at 08:00hrs, on the third day water was applied to the charcoal wall twice a day at 08:00hrs and 12:00hrs. On the fourth day, water was applied three times on the charcoal walls at 08:00hrs, 11:00hrs and 14:00hrs, on the fifth day water was applied to the charcoal walls after every two hours from 08:00hrs to 16:00hrs. Water application on the charcoal walls was done to find the efficiency of water on the cooling effect of the cooler.

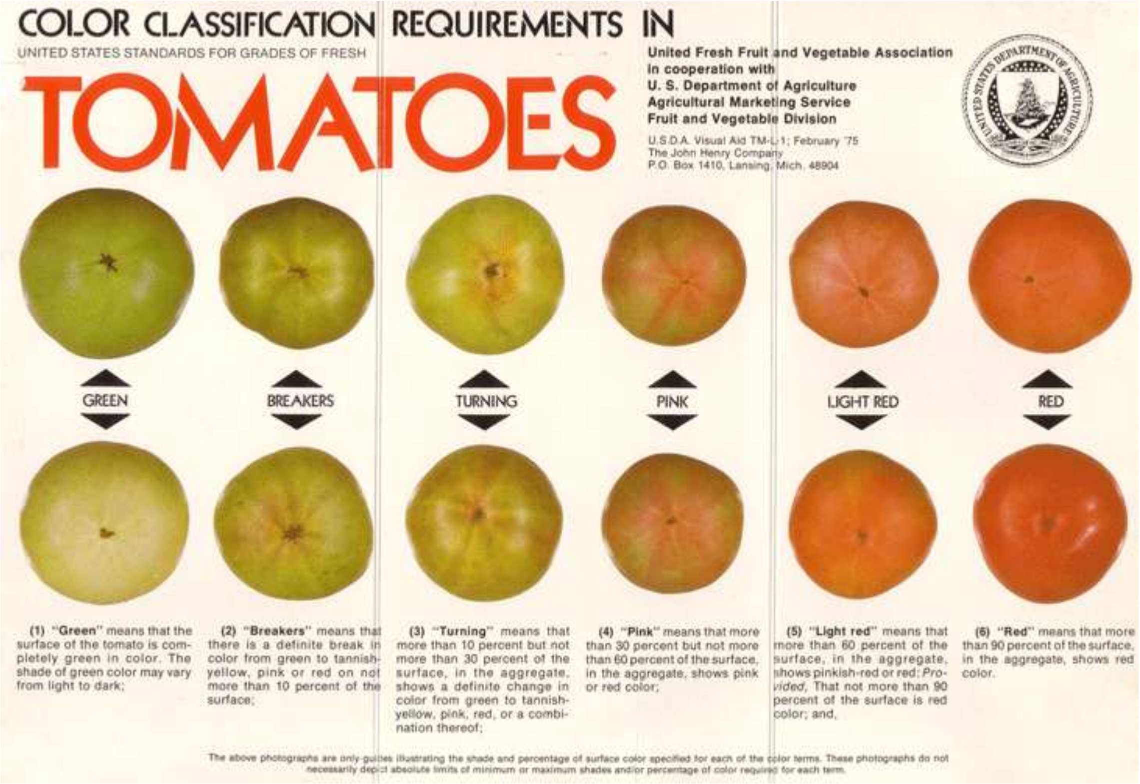
3.5 Investigation of the quality of tomatoes stored in the charcoal cooler bin

3.5 1 Tomatoes Collection

Tomatoes, Tengeru variety, were collected from Mr. Murefu farm near Arcadia dam in Bindura District of Mashonaland Central Province, Zimbabwe. The farm is located in Natural Farming Region IIa and IIb with annual rainfall ranges from 600mm to 1000.The plot was located near a dam, the used drag horse to irrigate the tomatoes. Tomatoes at breaker stage with almost the same weight and without defects, such as harvesting damage and bruises, were harvested late at night and ferried in a 24 litres cooler box, to Bindura University of Science Education, Environmental Science Laboratory.

Figure 7: tomatoes of almost the same size at breaker stage

The USDA colour classification chart below was used to determine the maturity stage of the tomatoes when they were harvested from the farm.



COLOR CLASSIFICATION REQUIREMENTS IN
UNITED STATES STANDARDS FOR GRADES OF FRESH
TOMATOES

United Fresh Fruit and Vegetable Association
in cooperation with
U. S. Department of Agriculture
Agricultural Marketing Service
Fruit and Vegetable Division

U.S.D.A. Visual Aid TM-L-1; February '75
The John Henry Company
P.O. Box 1410, Lansing, Mich. 48904

(1) "**Green**" means that the surface of the tomato is completely green in color. The shade of green color may vary from light to dark;

(2) "**Breakers**" means that there is a definite break in color from green to tannish-yellow, pink or red on not more than 10 percent of the surface;

(3) "**Turning**" means that more than 10 percent but not more than 30 percent of the surface, in the aggregate, shows a definite change in color from green to tannish-yellow, pink, red, or a combination thereof;

(4) "**Pink**" means that more than 30 percent but not more than 60 percent of the surface, in the aggregate, shows pink or red color;

(5) "**Light red**" means that more than 60 percent of the surface, in the aggregate, shows pinkish-red or red: *Provided*, That not more than 90 percent of the surface is red color; and,

(6) "**Red**" means that more than 90 percent of the surface, in the aggregate, shows red color.

The above photographs are only guides illustrating the shade and percentage of surface color specified for each of the color terms. These photographs do not necessarily depict absolute limits of minimum or maximum shades and/or percentage of color required for each term.

Figure 8: The USDA chart: Source-(Batu, 2004)

3.5.3 Objective Fruit Maturity Tests

The post-harvest parameters of fruit ripening that cane used to determine its quality are total soluble solids (TSS), penetrability, titratable acidity (TA) and sugar acid ratio. In this case the objective test that was done was titratable acids. Citric and malic acids are responsible for the tomato's sour flavor, which coincides with titratable acidity. Acid levels decrease during storage due to quality losses, which has an impact on consumer acceptance.

3.5.3.1 Titratable Acidity (TA)

According to OECD guidelines (2003), TA was estimated by titration of tomato juice extracted during TSS with 0.1 M NaOH. A clean and dry 10 ml pipette was used to draw 5 ml of juice and discharge into a 250 ml beaker. 25 ml of distilled water were drawn using another clean pipette and added to juice in the beaker. Three drops of phenolphthalein were added in this juice/water solution with a dropping pipette. A funnel was used to pour 0.1M NaOH into a burette until it reached a zero mark whilst ensuring that the tap was shut. NaOH was slowly titrated into the juice/water solution whilst solution swirling was continuously done. Towards the end of titration, NaOH drops were added a drop at a time. Titration was stopped when colourless solution changed to light pink. The amount of NaOH used was read off on the burette and figure recorded. All results were recorded to one decimal place and percent acidity as citric acid was calculated using Equation 8 and the sugar/acid ratio using Equation 9.

$$\text{Titratable acidity (g/l)} = \frac{ml\ NaOH \times M\ (NaOH) \times acid\ meq.factor}{ml\ Juice\ Titrated} \times 100 \quad \text{.........Equation 8}$$

The acid meq. Factor used was 0.0064.

3.6 Data Analysis

Data collected in the experiments were subjected to Analysis of Variance (ANOVA) using Genstat Version 14 statistical package. Means were separated using least significant difference (LSD) when treatment effects were significant at P<0.05. The means on interaction diagrams were separated using ± standard error of the difference when interaction effects were significant at P<0.05.

CHAPTER 4: RESULTS

4.1 Introduction

This chapter outlines the results following objectives and methodology. The section shows results of designing, fabricating and testing of a tomato charcoal cooler and also to what extent was it ale to reduce the temperatures and also how it was able to decrease deterioration of the tomatoes inside to extend their shelf life.

4.2 Design and development of a tomato charcoal cooler storage

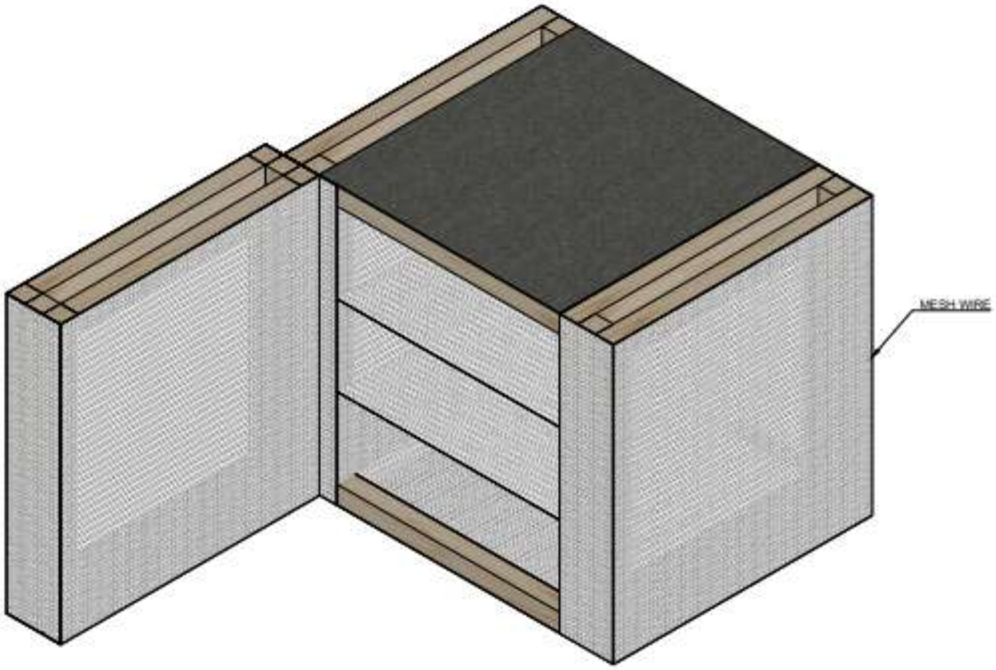


Figure 9: charcoal cooler.

Figure 10: The charcoal cooler:

4.3 To evaluate the performance/ effectiveness of charcoal bin in reducing storage temperature of tomatoes

4.3.1 Temperature readings under different water regimes

On day 1, temperature was when charcoal was dry (no watering) to see if the charcoal itself have the ability to reduce the temperature inside the cooler. It turned out that dry charcoal reduced temperature significantly ($p<0.05$).The pore spaces between the charcoal structure allowed the air to enter inside the cooler and reduce the temperature of the produce.

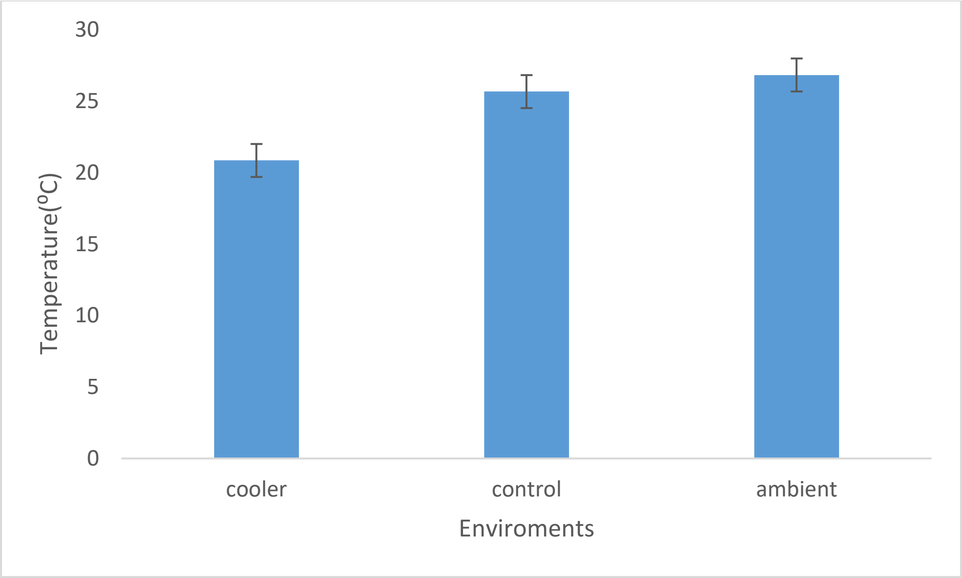


Figure 11: temperature readings when the charcoal was dry.

On day 2, water was applied to the charcoal once at 08:00hrs, the readings registered that the cooler significantly ($p<0.05$) reduced the temperature. The temperature readings in the control and ambient were high.

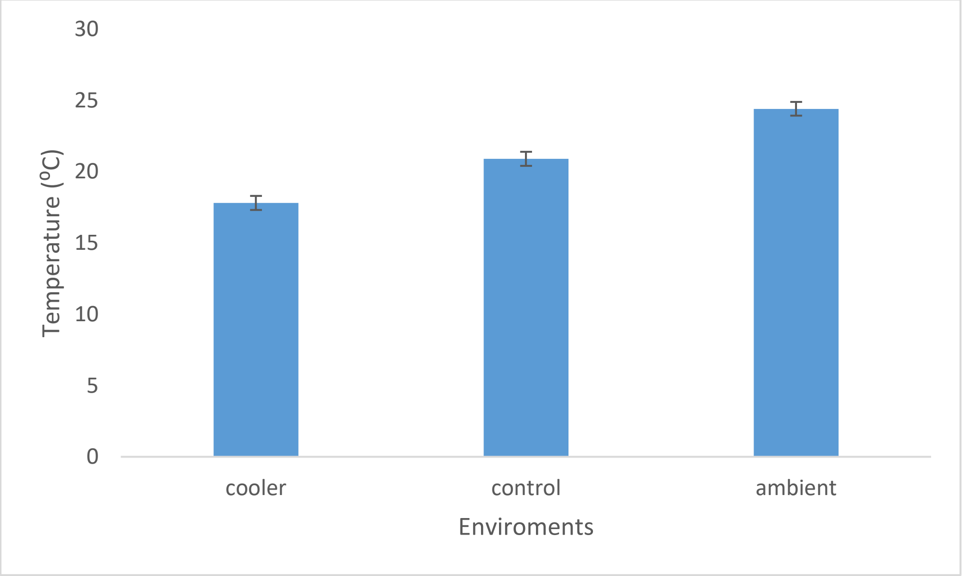


Figure12: temperature readings when water was applied once at 08:00hrs

On day 3, water was applied to the charcoal twice at 08:00hrs and 10:00hrs, the cooler reduced the temperature significantly ($p<0.05$) due to the ability of the charcoal structure in holding the water for a long time therefore as warm, dry air passes through the moist charcoal, it draws energy from its surrounding which produces a considerable cooling.

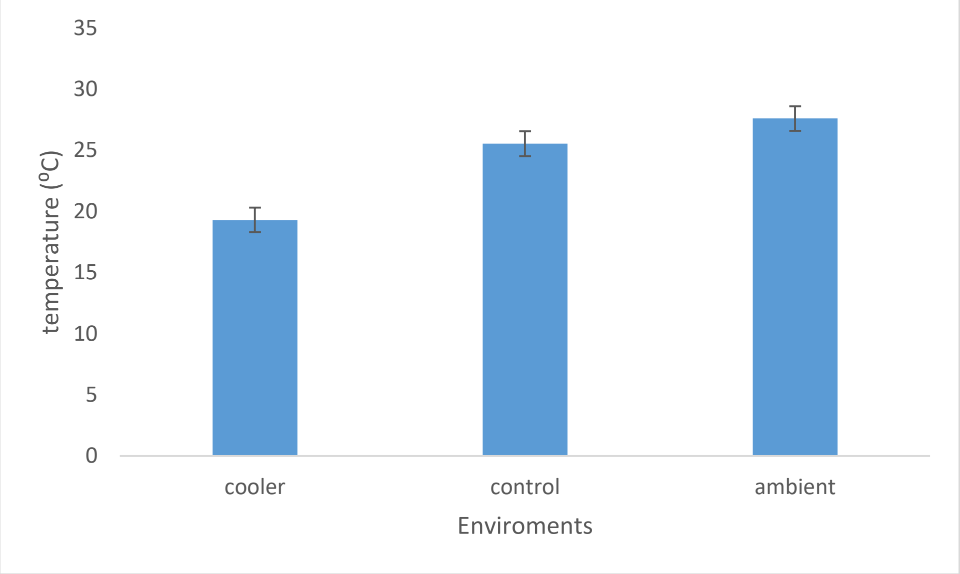


Figure 13: temperature readings when water was applied twice at 8:00hrs and 10:00hrs.

On day 4, water was applied to the charcoal three times a day at 08:00hrs, 11:00hrs and 14:00hrs.The application of water had a significant effect ($p<0.05$) on the temperature readings therefore the temperatures in the cooler were low than those in the control and ambient.

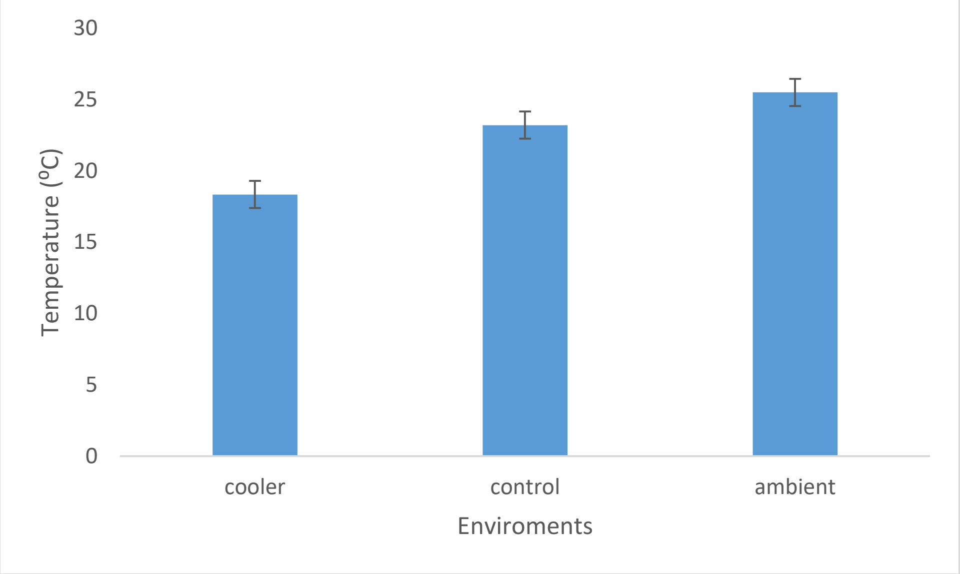


Figure 14: temperature readings when water was applied three times a day at 8:00hrs, 11:00hrs and 14:00hrs

On day 5, water was applied on the charcoal walls after every two hours from 08:00hrs to 16:00hrs and the cooler significantly ($p<0.05$) reduced the temperature than the control and the ambient. The more the water was applied on the charcoal walls the more the cooler walls remained moist and the more evaporative cooling occurs. The cooler was able to maintain the temperatures below 19℃, the cooler was able to reduce the temperature by at least 5℃ as compared to the control.

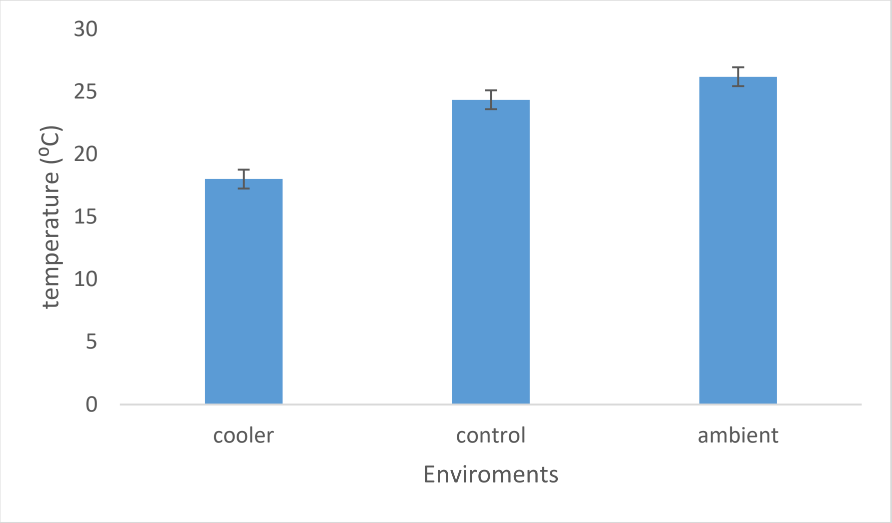


Figure 15: temperature readings when water was applied after every two hours from 8:00hrs to 16:00hrs.

Overall temperature readings.

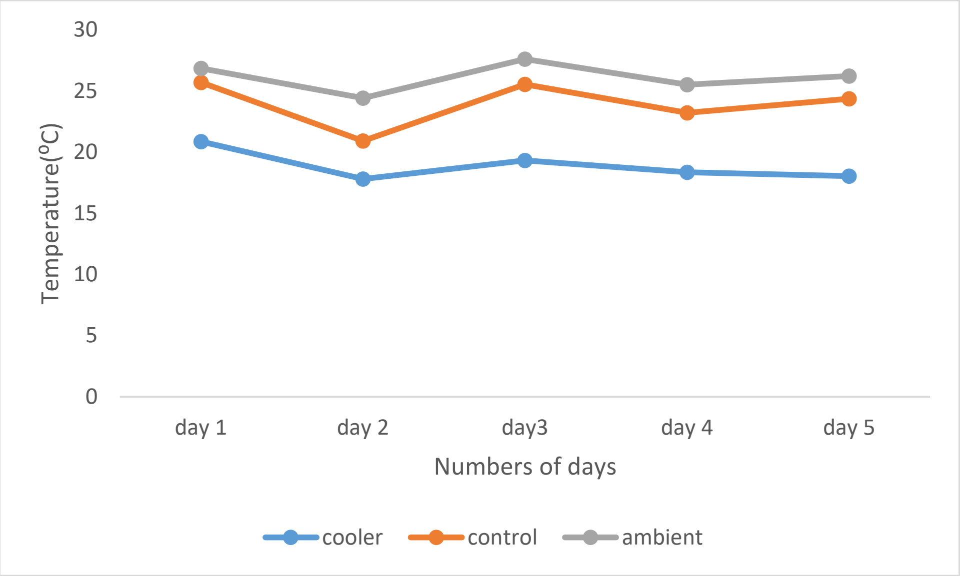


Figure 16: Temperature readings

4.4 Investigation of the quality of tomatoes stored in the charcoal cooler bin

4.4.3 Titratable Acidity (TA): Effect of cooler on TA during ripening of tomatoes

Titratable acids experiments were done periodically after every 4 days and the objective maturity (acid content) were being observed on each experiment. In experiment 1, (day 1) the tomatoes were all at breaker stage in both the cooler and the control and the acid content was 1.037g/l. In experiment 2, (day 4) the TA had no significant difference between the cooler and the shade ($p>0.05$).

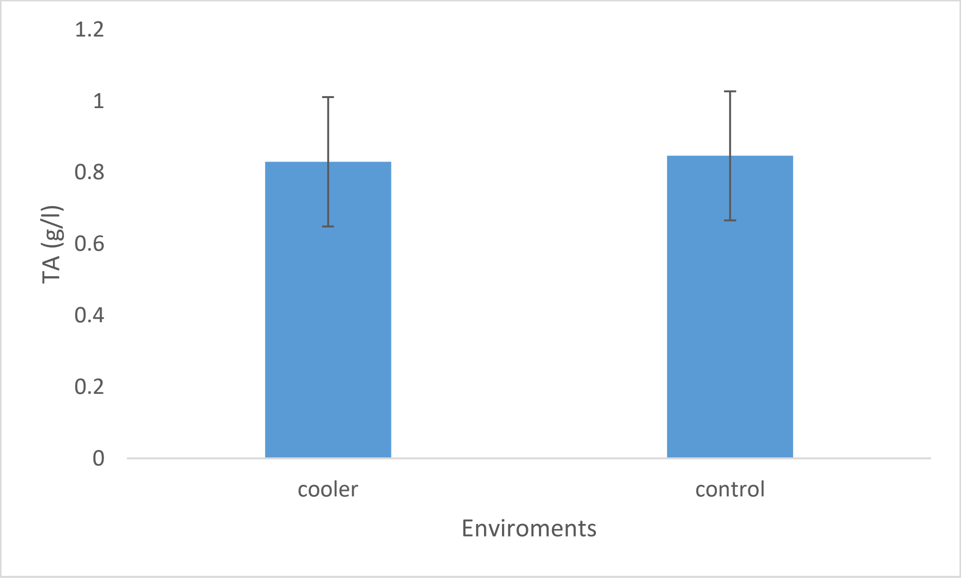


Figure 16: TA at day 4.

In experiment 3, (day 8) the cooler significantly ($p<0.05$) had a higher TA value as compared to the shade due to the reduced temperature.

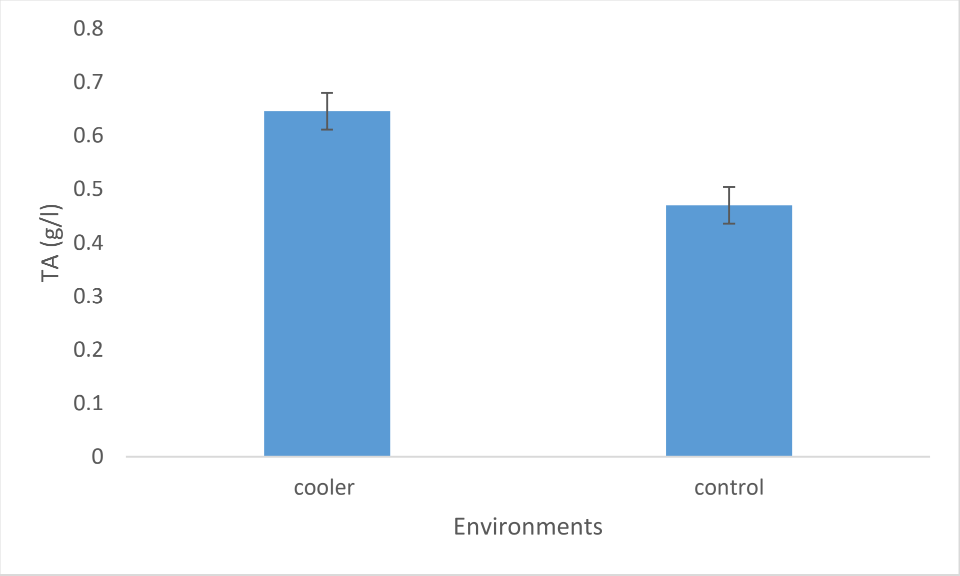


Figure 17: TA at day 8, experiment 3

In experiment 4, (day 12) the cooler significantly ($p<0.05$) had high acid content as compared to the cooler. Tomatoes in the control were ripening faster than those in the cooler.

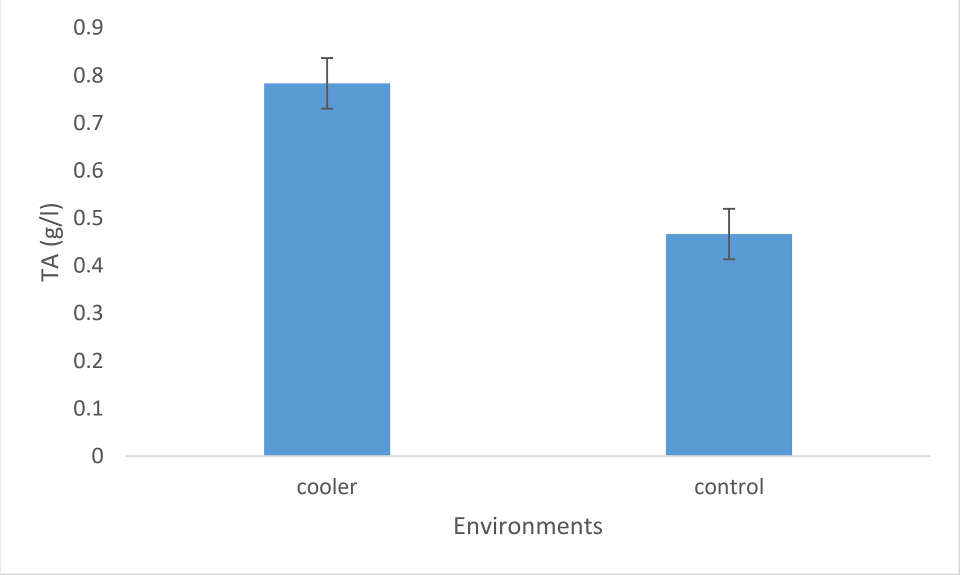


Figure18: TA at day 12, experiment 4

In experiment 5, (day 16) tomatoes ripening in the cooler had significantly ($p<0.05$) high TA values than those in the control. Tomatoes with TA values less than 0.4g/l are considered decay therefore those ripening in the control registered lower TA values of 0.3367g/l which showed that the tomatoes were already decaying.

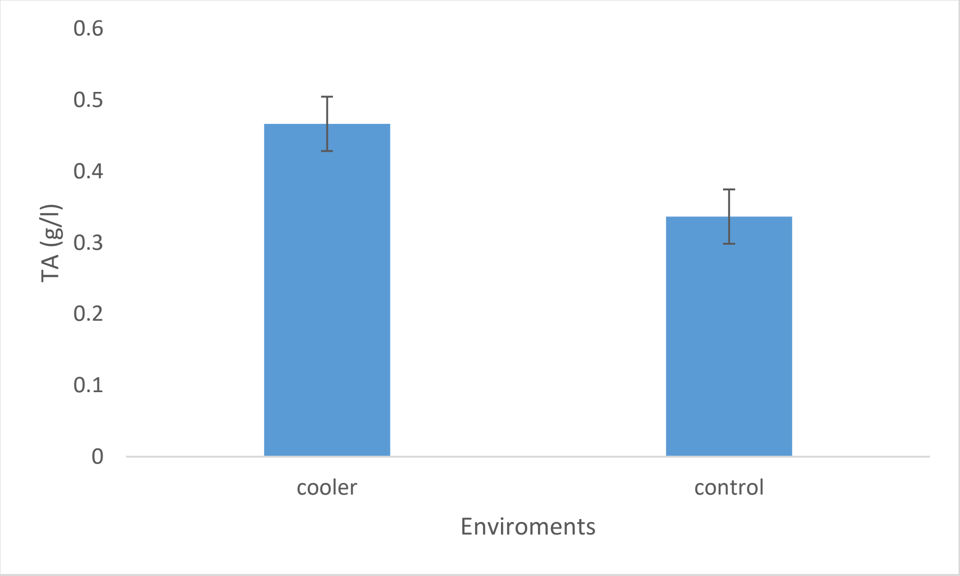


Figure 19: TA at day 16, experiment 5

The TA values in the cooler were significantly ($p<0.05$) higher than in control this was due to reduced temperatures that were registered by the cooler and also the charcoal was able to reduce the production of ethylene, a hormone which accelerates the perishability of the commodity.

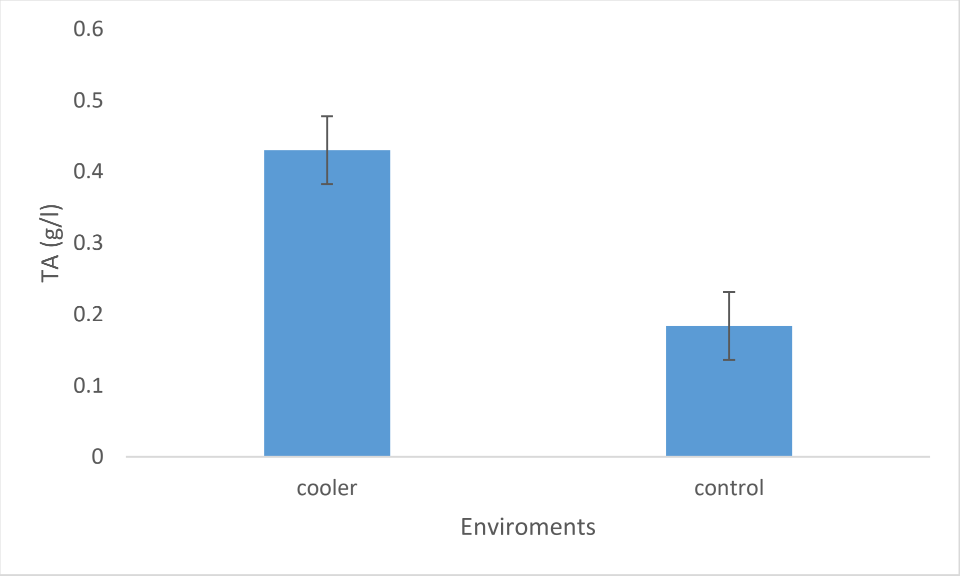


Figure 20: TA at day 20, experiment 6.

On day 1, the TA were the same and as the days goes by the control registered low TA values as compared to the cooler. Low TA in the control results in accelerated ripening and senescence-related alterations. The cooler extended the shelf life of the tomatoes by 8 days .The tomatoes in the control on day 12 had already decayed and their TA were low and tomatoes were acidic therefore not healthy for consumption.

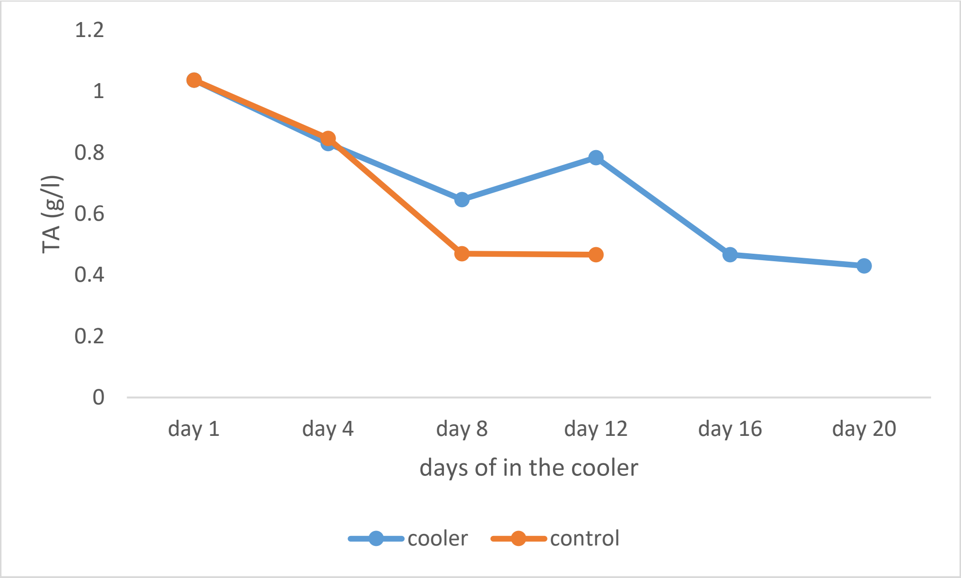


Figure 21: TA variations of tomatoes ripening in the cooler and control and the days they were in the cooler

CHAPTER 5: DISCUSSION

5.1 Introduction

This section outlines discussion of results in accordance with the objectives and methodology. The research activities include design and development of a charcoal cooler storage, the evaluation of the performance/ effectiveness of charcoal bin in reducing storage temperature of tomatoes and the maintenance of the quality of tomatoes stored in the charcoal cooler bin to increase its shelf life. Tomatoes taken at breaker stage were placed in the charcoal cooler and in the shade (control).Fruits ripening parameters tests were conducted on the fruits and the results were recorded in the previous chapter.

5.2 Designing and development of a charcoal cooler storage

The evaporative charcoal cooler with the capacity of 0.135 m^3 was built with a 0.04m thick charcoal wall for the purpose of storing tomato fruit. The cooler had three shelves made of mesh wire where tomatoes were stored. There was also mesh wire on the bottom of the last shelve for ventilation and drainage of the water that was dripping from the charcoal walls. The entire frame was assembled using a wooden framework. The cooler facilitates the use of evaporative cooling that operate on the idea of adiabatic cooling caused by the evaporation of water that is allowed to drip over the charcoal walls. In the cooler, water evaporates into the air and increases its humidity while simultaneously lowering the air's temperature.(Ronoh, Kanali and Ndirangu, 2020).

During the course of using the charcoal cooler, it was noted that the locally produced material used such as the iron mesh wire and charcoal became rusted and suffered from the accumulation of minerals respectively. Initially the charcoal that was black but it became grey-whitish(Ronoh, Kanali and Ndirangu, 2020).

Figure 22: mesh wire reacting with charcoal (rust)

5.3 The effect of the charcoal cooler in reducing temperature inside.

The charcoal cooler registered lower air temperature as compared to the shade (control) and the ambient .The cooler had a maximum temperature difference of 8.3°C from the ambient temperature. Low outside air temperatures result in a minor temperature drop since they slightly lower the interiorly cooled temperature. Therefore, it suggests that a better evaporative efficiency could potentially and greatly improve the cooler's capacity to cool(Ronoh, Kanali and Ndirangu, 2020).

Generally the temperature readings of the cooler were always low as compared to the control and the ambient, this showed that the charcoal cooler was effectively able to reduce the temperature of the commodity. The cooler was able to maintain temperatures of 19℃ and below. According to

(Swetha and Banothu, 2018), most of the physiological, biochemical and microbiological activities contributing to the deterioration of produce quality are largely dependent on temperature.

5.4 Effects of the quality of tomatoes stored in the charcoal cooler bin

5.4.1 Titratable Acidity (TA)

In the studies, the environments which the tomatoes were stored had a substantial impact on TA, in experiment 2 (day 4) there was no significance difference (p>0.05) between tomatoes which were ripening in the cooler and the control. The tomatoes were ripening at almost the same rate with those in the cooler. According to Suslow and Cantwell (2006), TA slightly changed when tomatoes were kept in the charcoal cooler. In experiment 3 (day 8) the TA in the cooler were significantly high and there was low TA in the control. Low TA in the control results in accelerated ripening and senescence-related alterations. Tomatoes with low TA values may have used their acids in the metabolism of living tissues, which depletes organic acids(Zewdie, Shonte and Woldetsadik, 2022)

In experiment 4 (day 12) the TA was high in the cooler a significant difference with that of the control. The tomatoes in the shade were almost at senescence stage. The pore structure, surface area, and surface chemistry of the carbon all have an impact on its capacity to absorb ethylene in storage rooms when used with activated carbon or charcoal(Gaikwad, Singh and Negi, 2020) therefore it was able to inhibit the ethylene production in the tomatoes that were in the cooler.

In experiment 5 and 6 (day 16 and day 20) the TA value of the cooler was significantly higher than those in the control. The tomatoes in the shade were already deteriorating while those in the cooler were still ripening. This is because tomatoes in the shade faced sun burns from shifting of the shade during the day, high temperature and they also lost water through evaporation and high respiration leading to completely deterioration of the fruit.(Wills, R.B.H., Warton, M.A. & Ku, 2000).The low temperatures that were maintained by the cooler were able to reduce the production of ethylene, rate of respiration of the fruit was also reduced which leads to the long shelf life of the commodity(Swetha and Banothu, 2018).

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

This study was carried out in an agricultural engineering research unit in order to provide an alternative accessible storage facility for fruits and vegetables. An evaporative charcoal cooler was designed, constructed and tested with tomatoes. The charcoal cooler was constructed with the cooling chamber (inner shelves) each having a storage capacity of $0.045m^3$. At the end of this study, the charcoal cooler was able to maintain an average temperature drop of 5-7℃ from ambient therefore making the cooler environment as cool as possible therefore the tomatoes takes time to deteriorate. There was significant difference between the TA of tomatoes inside the cooler and the shade, the tomatoes in the shade takes time to deteriorate thereby extending the shelf life. Low temperatures inside the cooler reduced the rate of respiration. The charcoal walls also absorbs the ethylene that was produced by the tomatoes during the ripening process. In conclusion the charcoal cooler storage was able to reduce the post-harvest losses that were faced by the farmers by increasing the shelf life of the tomatoes by 8 days.

6.2 RECOMMENDATIONS

- Farmers are recommended to have at least one charcoal cooler box for the storage of tomatoes or fresh vegetables in order to extend their shelf life.
- Welded wire or net mesh must be used to prevent corrosion between the charcoal and the wire.
- The tomatoes under investigation must be grown by the researcher so that all the records of fertilizer and chemicals application are recorded so as to avoid compromising results that might be caused by pre-harvest losses that occur during the production.

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APPENDICES

Appendix 1: Genstat Anova Outputs at day 1, temperature readings when charcoal was dry

Analysis of variance

```
Variate: day_1_T_C

Source of variation             d.f.        s.s.        m.s.     v.r.   F pr.

Block stratum                      4     126.136      31.534     9.49

Block.*Units* stratum
Treatment                          2     100.564      50.282    15.12   0.002
Residual                           8      26.596       3.325

Total                             14     253.296
```

Tables of means

```
Variate: day_1_T_C

Grand mean  24.46

   Treatment          1         2         3
                  20.86     25.68     26.84
```

Standard errors of differences of means

```
Table              Treatment
rep.                       5
d.f.                       8
s.e.d.                 1.153
```

Appendix 2: Genstat Anova Outputs at day 2, temperature readings when water was applied to the charcoal walls once at 8:00hrs.

Analysis of variance

```
Variate: day_2_T_C

Source of variation             d.f.        s.s.        m.s.     v.r.   F pr.

Block stratum                      4     23.9000      5.9750     9.96

Block.*Units* stratum
Treatment                          2    109.0333     54.5167    90.86   <.001
Residual                           8      4.8000      0.6000

Total                             14    137.7333
```

Tables of means

```
Variate: day_2_T_C

Grand mean  21.03

   Treatment          1          2          3
                  17.80      20.90      24.40
```

Standard errors of differences of means

```
Table                    Treatment
rep.                             5
d.f.                             8
s.e.d.    0.490
```

Appendix 3: Genstat Anova Outputs at day 3, temperature readings when water was applied twice a day on charcoal walls at 08:00hrs and 10:00hrs

Analysis of variance

```
Variate: day_3_T_C

Source of variation          d.f.        s.s.        m.s.      v.r.    F pr.

Block stratum                   4      82.044      20.511      8.02

Block.*Units* stratum
Treatment                       2     186.785      93.393     36.54    <.001
Residual                        8      20.448       2.556

Total                          14     289.277
```

Tables of means

```
Variate: day_3_T_C

Grand mean  24.15

   Treatment          1          2          3
                  19.30      25.54      27.60
```

Standard errors of differences of means

```
Table                    Treatment
rep.                             5
d.f.                             8
s.e.d.                       1.011
```

Appendix 4: Genstat Anova Outputs at day 4, temperature readings when water was applied to the charcoal walls three times at 08:00hrs, 11:watered three times a day

Analysis of variance

```
Variate: day_4_T_C

Source of variation            d.f.        s.s.        m.s.     v.r.   F pr.

Block stratum                     4      76.644      19.161     8.44

Block.*Units* stratum
Treatment                         2     133.625      66.813    29.42   <.001
Residual                          8      18.168       2.271

Total                            14     228.437
```

Tables of means

```
Variate: day_4_T_C

Grand mean  22.35

  Treatment         1         2         3
                18.34     23.20     25.50
```

Standard errors of differences of means

```
Table                   Treatment
rep.                            5
d.f.                            8
s.e.d.   0.953
```

Appendix 5: Genstat Anova Outputs at day 5, temperature readings when charcoal was watered after every two hours from 8:00 hrs to 16:00hrs

Analysis of variance

```
Variate: day_5_T_C

Source of variation            d.f.        s.s.        m.s.     v.r.   F pr.

Block stratum                     4     101.169      25.292    17.86

Block.*Units* stratum
Treatment                         2     184.156      92.078    65.01   <.001
Residual                          8      11.331       1.416

Total      14     296.656
```

Tables of means

```
Variate: day_5_T_C

Grand mean  22.86
```

```
    Treatment           1           2           3
                    18.02       24.36       26.20
```

Standard errors of differences of means

```
Table                     Treatment
rep.                              5
d.f.                              8
s.e.d.     0.753
```

Appendix 6: Genstat Anova Outputs of TA at day 4 (experiment 2) after the tomatoes were put in the cooler.

Summary

```
                                                                Standard        Standard error
Sample                 Size          Mean       Variance       deviation               of mean
control                   3        0.8467        0.05563          0.2359                0.1362
cooler                    3        0.8300        0.04270          0.2066                0.1193

Difference of means:                0.017
Standard error of difference:       0.181

95% confidence interval for difference in means: (-0.4860, 0.5193)
```

Test of null hypothesis that mean of control is equal to mean of cooler

```
Test statistic t = 0.09 on 4 d.f.

Probability = 0.931
```

Appendix 7: Genstat Anova Outputs of TA at day 8 (experiment 3) after the tomatoes were put in the cooler.

Summary

```
                                                                Standard        Standard error
Sample                 Size          Mean       Variance       deviation               of mean
control                   3        0.4700       0.001900         0.04359               0.02517
cooler                    3        0.6467       0.001633         0.04041               0.02333

Difference of means:              -0.1767
Standard error of difference:      0.0343

95% confidence interval for difference in means: (-0.2720, -0.08138)
```

Test of null hypothesis that mean of control is equal to mean of cooler

```
Test statistic t = -5.15 on 4 d.f.
```

```
Probability = 0.007
```

Appendix 8: Genstat Anova Outputs of TA at day 12 (experiment 4) after the tomatoes were put in the cooler.

Summary

```
                                                        Standard      Standard error
Sample           Size        Mean      Variance       deviation             of mean
control             3      0.4667      0.003033         0.05508             0.03180
cooler              3      0.7833      0.005433         0.07371             0.04256

Difference of means:                  -0.3167
Standard error of difference:          0.0531

95% confidence interval for difference in means: (-0.4642, -0.1692)
```

Test of null hypothesis that mean of control is equal to mean of cooler

```
Test statistic t = -5.96 on 4 d.f.

Probability = 0.004
```

Appendix 9: Genstat Anova Outputs of TA at day 16 (experiment 5) after the tomatoes were put in the cooler.

Summary

```
                                                        Standard      Standard error
Sample           Size        Mean      Variance       deviation             of mean
control             3      0.3367      0.001033         0.03215             0.01856
cooler              3      0.4667      0.003333         0.05774             0.03333

Difference of means:                 -0.1300
Standard error of difference:         0.0382

95% confidence interval for difference in means: (-0.2359, -0.02407)
```

Test of null hypothesis that mean of control is equal to mean of cooler

```
Test statistic t = -3.41 on 4 d.f.

Probability = 0.027
```

Appendix 10: Genstat Anova Outputs of TA at day 20 (experiment 6) after the tomatoes were put in the cooler

Summary

```
                                                        Standard      Standard error
```

```
Sample            Size      Mean     Variance    deviation          of mean
control              3    0.1833     0.005833      0.07638          0.04410
cooler               3    0.4300     0.000900      0.03000          0.01732

Difference of means:               -0.2467
Standard error of difference:       0.0474

95% confidence interval for the difference in means: (-0.3782, -0.1151)
```

Test of null hypothesis that mean of control is equal to mean of cooler

Test statistic t = -5.21 on 4 d.f.

Probability = 0.006