EFFECTIVENESS OF SELECTED POSTHARVEST HANDLING PRACTICES AND TECHNOLOGIES TO PRESERVE THE POSTHARVEST QUALITY OF MANGO FRUIT

AMWOKA EMMANUEL MUHUYI

A56/88292/2016

A Thesis Submitted in Partial Fulfillment of the Requirement for the Award of the Degree of Master of Science in Horticulture

Department of Plant Science and Crop Protection

Faculty of Agriculture

University of Nairobi

2021

DECLARATION

This thesis is my original work and has not been presented for award of a degree in any other University.

Amwoka Emmanuel Muhuyi (A56/88292/2016)

Signature: Date: 07/11/2021

This thesis has been submitted with our approval as university supervisors

1. **Prof. Jane Ambuko**

Department of Plant Science & Crop Protection

University of Nairobi

P.O BOX 29053-00625, Nairobi Kenya

Signature……………Ambuko………………………………………Date…08/11/2021……………………

2. **Prof. Margaret Hutchinson**

Department of Plant Science & Crop Protection

University of Nairobi

P.O BOX 29053-00625, Nairobi Kenya

Signature………mjhutchinson……………………………………Date..November 08, 2021..

3. **Prof. Willis Owino**

Department of Food Science and Technology

Jomo Kenyatta University of Agriculture and Technology

P.O Box 62000-00200, Nairobi

Signature: Date: ……08/11/2021…………

UNIVERSITY OF NAIROBI

DECLARATION OF ORIGINALITY FORM FOR STUDENTS

Name of Student: **Emmanuel Muhuyi Amwoka**

Registration Number: **A56/88292/2016**

College: **College of Agriculture and Veterinary Sciences**

Faculty/School/Institute: **Faculty of Agriculture**

Department: **Department of Plant Science and Crop Protection**

Course Name: **Master of Science in Horticulture**

Title of the work: **EFFECTIVENESS OF SELECTED POSTHARVEST HANDLING PRACTICES AND TECHNOLOGIES TO PRESERVE THE POSTHARVEST QUALITY OF MANGO FRUIT.**

DECLARATION

1. I understand what Plagiarism is and I am aware of the University's policy in this regard
2. I declare that this **thesis** is my original work and has not been submitted elsewhere for examination, award of a degree or publication. Where other peoples' work or my own work has been used, this has properly been acknowledged and referenced in accordance with the University of Nairobi's requirements.
3. I have not sought or used the services of any professional agencies to produce this work.
4. I have not allowed, and shall not allow anyone to copy my work with the intention of passing it off as his/her own work.
5. I understand that any false claim in respect of this work shall result in disciplinary action, in accordance with University Plagiarism Policy.

Signature Date: 07/11/2021

DEDICATION

I dedicate this thesis to my loving parents; Mr. Peter Amwoka and Mrs. Agnes Mukasia together with all my brothers and sisters for their prayers, encouragement and support during my entire study period.

ACKNOWLEDGEMENTS

Great appreciation to the almighty God for granting me life and good health as I undertook my studies. For sure He has been my source of solace during hard times throughout this period.

Am grateful to the University of Nairobi for awarding me the graduate scholarship to finance my studies and to The Rockefeller Foundation for funding my research project through the research grant under the Yieldwise Project (Grant number: 2016 YWS 328) awarded to Prof. Jane Ambuko who gave me a chance as one of the student beneficiaries.

Much appreciation to my supervisors; Prof Jane Ambuko for trusting and giving me a chance to benefit from the project funding, thanks for your efforts to ensure that I do what was right pertaining my study, guidance and support through professional networks that I made through you. Prof. Hutchinson Jesang' you were like a mother to me, thanks for giving me an ear during tough times and for your academic input. To Prof. Willis Owino, God bless you for your guidance during the lab analysis phase and continuous support during the entire study, thank you!

Special thanks to Karurumo Horticultural Farmer's Self-help Group in Embu County through the leadership of Mr. Alloys Mbogo and the entire executive committee of the group for according me permission to use their aggregation centre to do the shelf life studies.

Am also grateful to Jomo Kenyatta University of Agriculture and Technology for allowing me to use their lab premises to do the nutritional analysis. Specifically, I thank technologists and classmates who helped me in achieving this including David, Jessica, Kamathi, James, Benson, Loreto, Isaac, Dorah, and Beryl.

Thank you so much to my classmates and friends (Penina, Benson, Manyozo, Jovia, Samuel, Caleb, Rufas, Esther, Chomba and Dennis) for your support and company, you are the best.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND ACRONYMS

AFA	Agriculture and Food Authority
CRD	Complete Randomized Design
ECC	Evaporative Charcoal Cooler
EZPC	Export Zones Promotion Council
FPEAK	Fresh Produce Exporters Association of Kenya
GNP	Gross National Product
HCD	Horticultural Crops Directorate
MAP	Modified Atmospheric Package
MAPs	Medicinal and Aromatic Plants
TSS	Total Soluble Solids
TTA	Titratable Acidity
ZEBC	Zero Energy Brick Cooler

GENERAL ABSTRACT

Mango (*Mangifera Indica L.*) is one of the major fruits produced in Kenya mainly for the domestic market. Production of mango is dominated by the smallholder farmers, majority of whom depend on it for their livelihoods. Mango fruit is a highly perishable climacteric fruit whose shelf life is limited after maturity, resulting in high post-harvest losses. Postharvest deterioration and subsequent losses are as a result of various metabolic processes including respiration and transpiration whose rate depends on temperature management. Cold chain management which entails handling perishable produce at cool (safe) temperature from harvest until the produce reaches the end-user is critical for the preservation of quality. The aim of this study was to evaluate the effectiveness of selected postharvest handling practices and simple technologies to achieve cold chain, extend shelf life and preserve quality of mango fruit. This was achieved through two related on-farm and laboratory experiments.

In the first experiment, four mango varieties namely 'Apple', 'Ngowe', 'Kent' and 'Tommy Atkins' harvested at the mature green stage from the farmers' orchards were used in an on-farm study. To demonstrate proper cold chain management, fruits were harvested early in the morning (before 8 am) and transported in crates which were lined with dampened newspapers to cool the fruits during transit. Upon arrival at the experimental site (Karurumo Aggregation Center), the fruits were precooled using evaporative coolers to remove field heat then stored in the Coolbot™ cold room (10±2°C). The described proper cold chain practices were compared with the common practices among farmers (poor cold chain practices). In this case, the fruits were harvested at midday (noon), transported to the aggregation centre in open crates and then stored at ambient room conditions (Temperatures of 25±7°C, Relative Humidity of 55±15%). The air and fruit pulp temperatures from harvest and subsequent handling and storage at the various conditions were monitored regularly using HUATO® data loggers. During storage, a random sample of 3 fruits (per variety) was taken from each of the storage options after every 3 days to evaluate ripening-related changes including physiological weight loss, colour, firmness and total soluble solids.

In the second experiment, a homogenous sample of mature green 'Apple' and 'Kent' mango fruits were divided into 10 batches of 60 fruits each to evaluate the effectiveness of four different low-cost storage technologies to preserve quality and extend the shelf life of mango fruits. The technologies evaluated include Coolbot™ cold room (10±2°C, 75±20%RH), Evaporative charcoal cooler (20±5°C, 95±5%RH), Zero energy brick cooler (20±5°C, 90±10%RH) and Wakati™ tent (25±5°C, 95±5%RH). The different technologies were compared with storage at ambient room conditions (25±°C, 55±15%RH). For each storage option, the fruits were divided into two batches where one batch was packaged using Activebag® modified atmosphere packaging (MAP) and the second batch left open (unpackaged). The experiment was laid out as a completely randomized design with a factorial arrangement of treatments. Three fruits per treatment were sampled after every 3 days to evaluate ripening and quality-related changes including physiological weight loss, colour, firmness, and total soluble solids, titratable acidity, B-carotene, sugars, and vitamin C.

Results showed that harvesting time significantly affected fruit pulp temperatures at harvest with fruits harvested before 8 am recording lower pulp temperatures (average 16.4 °C) compared to the fruits harvested at noon (average 31.4 °C). Proper cold chain management delayed ripening as evidenced by slower softening and increase in percentage TSS. Flesh firmness of ‘Apple’ mango reduced by 37% and 91% under the proper cold chain and poor cold chain management respectively by day 12 of storage while TSS increased by 17% and 63% respectively. Proper cold chain management extended shelf life by at least 18 days compared to poor cold chain management. In the second experiment, cold storage significantly extended mango shelf life for ‘Apple’ and ‘Kent’ mango fruits compared to storage at ambient room conditions. This was evidenced by lower respiration rate, slower rate of softening and colour changes compared to ambient room conditions. Fruits under cold storage combined with MAP had a longer shelf life (up to 9 days more) and retained better quality attributes at the end of storage. At the end of storage, unpackaged ‘Apple’ mango retained 50%, 49%, 47%, 46%, and 45% of the initial vitamin C for Coolbot^{TM} cold room, ECC, ZEBC, Wakati^{TM} tent and ambient conditions respectively. On the other hand, the same fruits under cold storage combined with MAP retained 53 %, 52%, 51%, 51%, and 46% of the initial Vitamin C under Coolbot™ cold room, ECC, ZEBC, Wakati™ tent, and ambient conditions storage respectively.

The results of this study show that proper harvest and postharvest handling practices coupled with simple cold storage technologies can be used by smallholder farmers to attain desirable cold chain and preserve the postharvest quality of perishable fruits such as mango. Harvesting mango fruits during the cooler times of the day is recommended as this minimizes the negative effect of high heat load on harvested fruits. The Coolbot^{TM} cold room can be promoted for adoption by farmer groups that have access to electricity (on-grid) while the evaporative coolers can be promoted for farmers and farmer groups without access to electricity (off-grid).

Application of these practices and technologies can extend the fruits' shelf life and marketing period thereby minimize postharvest losses in the mango value chain.

CHAPTER ONE

1.0 Introduction

1.1 Background Information

Horticultural sub-sector in Kenya which comprises fruits, flowers and vegetables has great importance to the economy, ranked 3rd after dairy and tea sub sectors (HCD, 2017). In 2016, the subsector contributed 1.45% to the Gross National Product (GNP). Horticulture is one of the leading foreign exchange earners in the country with a total domestic value of Ksh.248.47 billion and a total production of 6.696 MT, of which Ksh.63.8 billion is contributed by fruits leaving the rest to flowers, vegetables and medicinal plants. The main fruits grown arranged by significance are; bananas, mangoes, pineapples, avocado, water melon and pawpaw (HCD, 2017).

Mango being one of the key horticultural commodities in Kenya has significant domestic and export market. Its value has been ranked 2nd after Avocado in the export market (HCD, 2017). Mango production in Kenya is dominated by the small and medium holder farmers who contribute to up to 80% of the total producers registered by the Fresh Produce Exporters Association of Kenya (FPEAK).

Despite the growth of this subsector in the country and region, its potential has not been fully exploited. This has been linked to the various challenges in the horticultural value chains. Some of these challenges facing practitioners in the mango value chain include costly farm inputs, low quality planting materials, pests/diseases, edaphic factors, climatic limitations among others on the production side. After harvest, the key challenges include poor market access, poor infrastructure, lack of access to affordable technologies to preserve quality, all of which contribute to high postharvest losses.

Post-harvest losses along the mango value chain estimated at 40% (Gor et al., 2012) happen at every stage. The critical stages where these losses occur include at harvesting, transportation, storage and at the retail stage. Mango is prone to post-harvest losses due to its inherent perishability which is aggravated by seasonality. Mango fruiting in Kenya is seasonal with a glut during the peak season between November and February where the highest losses are reported (Maloba et al., 2017).

Post-harvest losses at the harvest stage are attributed to inability to determine fruit maturity which often results in harvesting of immature fruits (Ingle et al., 2000). Other drivers of losses at this stage include, harvesting when the environment is not cool (Samtani and Kushad, 2015: Kader and Rolle, 2004), improper harvesting methods and inappropriate handling that leads to bruising and mechanical injuries. Mechanical injuries provide entry point to pathogens, release wound ethylene and increase deterioration by increasing metabolic reactions (Kader, 2002).

During transportation, post-harvest losses occur due to improper packaging that results to suffocation and mechanical injury (Kader and Rolle, 2004), poor infrastructure causing delays (Rolle, 2006), mixing with high ethylene producing fruits thus accelerating ripening and deterioration (Kader and Rolle, 2004) and transporting in non-refrigerated trucks that require high energy levels to lower temperatures (Kader, 2002).

At the storage stage, losses are mainly due to poor storage conditions which lead to deterioration of the fruits due to various environmental and commodity factors. Losses can also be as a result of mixing fruits with different ethylene sensitivity and overloading in the stores (Pathak et al., 2017). For majority of smallholders involved in mango production, appropriate storage including cold storage facilities is expensive and out of reach. In addition, the scale of production does not justify individual farmer’s investment in cold storage facilities.

Cold chain management is important in horticultural/perishable produce to slow deterioration process by reducing respiration, transpiration, ethylene production and action, and decreases the activities of microorganisms thus slowing ripening and senescence (Ambuko et al., 2018a; Kitinoja, 2013). Maintaining internal (pulp) and the temperature around the stored fruit at a low (safe) temperature is critical for preservation of postharvest quality. Low temperature slows down the metabolic processes such as respiration, transpiration and softening which lead to deterioration perishable produce (Aung and Chang, 2014).

Various post-harvest technologies have been used to address the factors that contribute to deterioration and spoilage of the perishable horticultural produce such as mango fruit. However, there is low adoption of applicable postharvest technologies and practices among smallholder farmers. Studies conducted on projects focusing on postharvest technologies in horticultural value chains between 1996 and 2012 showed that about 83% of the projects were successful but the adoption thereafter was low (Kitinoja, 2010). The low adoption rates are due to; high cost of initial investment, sophisticated postharvest infrastructure, lack of awareness, different group dynamics and limited market access of the products (Kitinoja, 2010).

1.2 Problem Statement

High postharvest losses estimated at 40% are reported in the mango value chain in Kenya (Gor et al., 2012). One of the major causes of increased post-harvest losses among perishable commodities such as mango is poor cold chain management (Kitinoja, 2002). The high postharvest losses reported in mango are attributed to seasonality which results to excess/glut during the high season; high perishability leading to short shelf life once harvested, improper post-harvest handling, poor infrastructure and limited market access (Yahaya and Mardiyya, 2019). Proper cold chain management is the continuous handling of the product within cool/low temperature environment from harvest, collection, packing, processing, storage, transport and marketing until it reaches the final consumer (Kitinoja, 2013). The time of harvest and subsequent handling temperatures determine longevity of the harvested produce. Simple practices such as harvesting produce early in the morning, pre-cooling under a tree, transportation during cooler times of the day followed by cold storage have been reported to contribute to postharvest quality preservation (Ambuko et al., 2018a). Harvesting of fruits and vegetables during cool hours of the day minimizes excessive field heat generation (Arah et al., 2015). Simple storage technologies including evaporative cooling technologies (zero energy brick cooler and evaporative charcoal cooler); Coolbot™ cold storage; Wakati™ are examples of affordable cold storage technologies which have recently been introduced in Kenya (Ambuko et al., 2018a). Previous studies have shown effectiveness of the evaporative cooling technologies (Ambuko et al., 2016; Manyonzo et. al., 2018) and the Coolbot™ cold room (Ambuko et al. 2018b and Karithi, 2016). Previous studies have also shown that effectiveness cold storage technologies to preserve quality of harvested produce is enhanced through modified atmosphere packaging (Karithi 2016; Githiga et al., 2014). Despite their proven effectiveness to preserve quality and extend the shelf life of perishable produce, the adoption of these technologies in Kenya is very low. The low adoption is partly attributed to lack of evaluation of some of the practices and technologies as well as lack of awareness among the potential users of these technologies. Therefore, there is need to evaluate the effectiveness of the selected postharvest technologies and practices and create awareness to enhance adoption.

1.3 Justification

Cold chain management is critical for postharvest quality preservation and post-harvest loss reduction in the mango value chain. Application of low-cost cold storage technologies and simple cold chain management practices to preserve quality of harvested produce is necessary to reduce postharvest losses and extend the marketing period of highly perishable produce such as mango fruit.

The proposed technologies are not only simple and affordable but can be fabricated from locally available materials, making them appropriate for local contexts. Therefore, the study evaluated different simple and affordable but effective practices and technologies that can be utilized to achieve required cold chain for perishable commodities such as mango for shelf-life extension and quality preservation without one having to invest in expensive and sophisticated conventional cold rooms and that proper cold chain management can be achieved in areas without and/or with unstable electricity supply.

1.4 Objectives

Overall Objective

To reduce postharvest losses in the mango value chain through application of proper cold chain management practices.

Specific Objectives

- To evaluate the effectiveness of harvest time, handling practices and cold storage to extend the shelf life of mango fruits.
- To compare the effectiveness of different storage technologies (Coolbot™, Zero Energy Brick Cooler, Evaporative Charcoal Cooler and Wakati™) to preserve the post-harvest quality of mango fruits.

1.5 Hypothesis

- Harvest time, handling practices and cold storage have no effect on the shelf-life extension of mango fruits.
- The effectiveness of different storage technologies (Coolbot™, Zero Energy Brick Cooler, Evaporative Charcoal Cooler and Wakati™) to preserve the post-harvest quality of mango fruits will be the same.

CHAPTER TWO

2.0 Literature Review

2.1 Horticultural subsector in Kenya

Agriculture is the main source of Kenyan economy with key roles in the provision of employment, livelihoods, income, food and nutritional security and foreign exchange earnings contributing to the GDP (Irungu, 2011). The horticultural industry is a key sub-sector of the agricultural industry in Kenya contributing to the largest turnover to the GDP from the export of fruits, flowers, vegetables and medicinal and aromatic plants (MAPs) (HCD 2017). Fruits such as avocadoes, pineapples, passion fruits and mangoes are grown for export as well as local markets (EZPC, 2017).

The horticultural industry provides employment and poverty alleviation to many rural households (Wahome et al., 2013; Odero et al., 2013). Since most of the fruits, vegetables and aromatic plants are produced on a small-scale basis in Kenya, many farmers are directly involved in the production and depend on it as a source of their livelihoods.

The horticultural subsector offers the best alternative for increased food self-sufficiency, improved nutrition and high income and employment rate (Irungu, 2011). There is direct employment in production at farm level as well as after production during value addition and marketing. The growth of the horticultural industry has led to increased employment by shifting from small scale production to plantations ran by exporters who use skilled labour to produce quality commodities as per consumer demands (Humphrey et al., 2004).

The horticultural industry is a major foreign exchange earner directly contributing to Kenya's GDP. In 2017, the total domestic value for the horticultural industry was 236.45 billion Kenya shillings which was an 11% increase from the previous year (HCD, 2017). The individual contributions by different crops were; Cut flowers (34.8%), Exotic vegetables (32%), fruits (25.7%), indigenous vegetables (3.4%), summer flowers (1.5%), aromatic plants (2.2%), Asian vegetables (0.4%) and Medicinal plants (0.1%). Horticultural exports contributed to over 115.32 billion Kenya shillings with over 304.15 metric tonnes of horticultural produce being exported of which fruits contributed to over 9 billion Kenya shillings (HCD, 2017).

The horticultural industry, mainly fruits and vegetables contributes to food and nutritional security to many households in Kenya (Kebede and Bokelmann, 2017). Most households in Kenya obtain their daily nutritional requirements through domestic production or local markets. Horticultural production improves the productivity of the land leading to food production, income generation, and employment creation while enhancing exports thus providing incomes that is used to meet food and nutritional security of many households in Kenya. The nutritional value found in mangoes has been important in providing essential vitamins, prebiotic dietary fibre, polyphenolic flavonoid antioxidants, sugar, proteins, fats and other minerals to many families especially in rural areas (Ara et al., 2014).

2.2 Challenges facing the horticultural industry

Horticultural industry in Kenya faces several challenges that result in limited production and therefore less beneficial to the players along these value chains (Muthoka and Ogutu, 2014). The challenges occur during the production stage, harvest time, postharvest handling and marketing stages of perishable horticultural produce. These challenges include inadequate and low-quality planting materials, high cost of farm inputs, land fragmentation, unpredictable climatic conditions, poor infrastructure, pest and diseases. Additionally, low availability of capital and limited access to affordable credit especially for smallholder farmers due to lack of collateral, obsolete technology, high taxes imposed by both national and local levies, stringent international standards that facilitate trade, poor marketing information and channels. Furthermore, inadequate legal and policy framework that results to inadequate funding for research and development thus low effectiveness of extension services due to low budgetary allocation, weak leverage of farmers due to mismanagement of cooperative societies and farmer organizations, inadequate storage and processing facilities and poor postharvest handling (AFA, 2020). The challenges leading to high postharvest losses include poor temperature management, rough handling, inappropriate packaging materials and general lack of education regarding need to maintain quality and safety of perishable goods (Kitinoja et al., 2011).

Temperature management is the key step in achieving sustainable and unbroken cold chain (Abad et al., 2009). Freshly harvested horticultural produce is still living and therefore demand proper temperature control from the time of harvest till consumption to preserve quality (Rathore et al., 2007). Low temperatures of the surrounding during harvest minimizes water loss from harvested fruits due to low field heat. Lower field heat means a lower internal fruit temperature which will subsequently require less cooling of the fruit before storage (Samtani and Kushad, 2015). With increased heat load especially in the tropics, harvested horticultural produce require precooling before cold storage to remove field heat since the cold rooms are customized to maintain the temperature of the commodity loaded but not removing additional heat (James et al., 2006). The period between harvest time and precooling is critical due to high temperatures experienced and therefore high shelf-life deterioration. Reducing this period by pre-cooling as soon as possible after harvest significantly improves commodity shelf life (Nunes et al., 2014). Cool storage of precooled horticultural commodity maintains low internal temperatures of stored commodities thus reducing most of the metabolic reactions such as respiration responsible for ripening and deterioration (Aung and Chang, 2014). Sometimes high temperatures are observed inside domestic refrigerators which are due to frequent opening of the cold room, inappropriate temperature setting on the gadget, and overloading or inadequate placing of the produce. This indicates that to improve preservation of perishable commodities, more consumer practices are needed (Mercier et al., 2017). Nevertheless, it is challenging to maintain the proper perishable commodity temperature in optimal range along the cold chain stages. Therefore, to ensure the integrity of the cold chain for temperature-sensitive food products, it involves additional requirements related to proper packaging, temperature protection, and regular monitoring (Mercier et al., 2017).

Harvested horticultural produce should be handled with utmost care to minimize mechanical injuries such as bruising, cutting or abrasion which trigger the evolution of wound ethylene in climacteric fruits like mango that may cause ripening and senescence (Chang and Brecht, 2020).

Packaging is important in the preservation of quality among perishable horticultural produce. Proper packaging during transit or storage in a cool-chained mode of preservation protects the fruits against forced air action that causes shrivelling and wilting of the fresh commodities (Holcroft, 2015). Use of modified atmospheric packaging creates a microclimate around the wrapped produce thus minimizing water losses and respiration is kept in check due to controlled amount of oxygen and carbon dioxide inside the package thereby retard senescence and ripening (Githiga et al., 2015). Proper packaging material for a specific commodity and the volume to be loaded should be considered when packaging horticultural produce. With producers, traders and consumers sensitized on the importance of produce preservation after harvest bearing in mind the above factors, shelf life will be enhanced thus reducing the high postharvest losses reported in such perishable commodities (Kitinoja, 2013).

2.3 Mango Production in Kenya

Mango fruit is adapted to different agro-ecological zones hence it is produced in many tropical countries worldwide. For instance, in Kenya mango is produced in many AEZ ranging from sub-humid to semi-arid areas (Griesbach, 2003). This leads to increased productivity since the fruits are produced in lower potential areas (Eastern and North Eastern regions) as well as high potential areas (Central and parts of Rift-valley) with each area offering diversity in terms of fruit quality and the beginning of the mango season. This is attributed to the diverse environmental conditions in those areas in terms of temperature, water availability, light intensity, edaphic factors and the agronomic activities in the management of the orchard which greatly affect the fruit growth and development, in the end affects the postharvest characteristics of the fruits (Kemunto et al., 2013).

Mango production in Kenya is dominated by the smallholder farmers whose livelihood is dependent on it. They earn from the sales made and their families are nourished by the rich nutrients present in the fruit. This has been made possible by several factors owing to the successful production in the field offering several opportunities to players involved. However, the full potential of mango has not been realized due to several challenges facing the value chain.

2.3.1 Production statistics

In recent years, the rise in demand for fresh market fruits, processing and health concerns has led to increased mango production. For instance, in 2017 which is a decrease in production and value when compared with 2016 (due to reduced rainfall received), the area under mango production was 50,550Ha producing 705,195 Metric tonnes that were valued at KES 11.73 billion as indicated in table 2.1 below (HCD, 2017). This increase was as a result of expansive production areas in North Rift and Eastern region, new marketing systems by various government and private sector initiatives across the value chain and recent increased consumption of mango juice and salads.

Table 2.1: Production of Mangoes in selected counties, 2016-2017 (Source: HCD, 2017)

County	**2016**			**2017**			**% of Total Value**
	Area (Ha)	**Volume (MT)**	**Value (Million KES)**	**Area (Ha)**	**Volume (MT)**	**Value (Million KES)**	
Makueni	12,422	225,300	3,617,524,000	12,344	179,978	3,297,988,000	**28.2**
Machakos	6,387	168,552	2,764,574,500	6,475	135,345	2,523,955,000	**21.5**
Kilifi	9,155	108,139	1,844,181,000	9,733	107,328	1,751,980,000	**15.0**
Kwale	3,898	53,339	934,555,000	4,181	54,075	904,175,490	**7.7**
Lamu	2,543	40,566	607,723,820	2,555	42,594	639,610,011	**5.5**
Meru	3,025	27,742	533,531,950	3,550	32,824	427,613,950	**3.7**
Tana River	1,356	32,066	211,268,000	1,363	33,669	221,831,400	**1.9**
Elgeyo Marakwet	751	14,343	132,782,530	881	16,308	221,768,720	**1.9**
Embu	850	14,450	332,000,000	947	14,733	215,040,000	**1.8**
Kitui	1,359	12,580	122,331,600	1,405	15,370	187,170,000	**1.6**
Murang’a	926	9,192	130,583,000	911	9,660	155,960,500	**1.3**
Tharaka Nithi	1,165	10,233	124,448,750	1,257	12,950	142,580,000	**1.2**
Siaya	258	4,885	107,300,000	276	4,819	117,069,000	**1.0**
West Pokot	331	4,118	83,040,000	332	5,259	99,350,400	**0.8**
Busia	408	4,643	86,282,250	450	5,002	82,049,548	**0.7**
Migori	393	4,295	63,978,000	438	5,109	71,792,400	**0.6**
Garissa	589	5,186	67,052,500	592	5,445	70,405,125	**0.6**
Mombasa	152	2,040	36,800,000	162	2,330	47,400,000	**0.4**
Homabay	238	2,330	44,254,000	250	2,549	40,365,225	**0.3**
Others	2892	37148	48047519	2448	19,848	495,101,846	**4.2**
Total	**49,098**	**781,147**	**11,892,258,419**	**50,550**	**705,195**	**11,713,206,615**	**100.0**

2.3.2. Nutritional benefits of mango fruits

The mango fruit is referred to as “the king of fruits” because of its delicacy, flavor and nutritional composition (Singh et al., 2013). This has been shown by the increasing demand for fresh and processed mango products. Of recent, mango is a good dessert for meals and has also become part of the diet for the people in developing countries (Crane et al., 2009).

Although different mango varieties differ in flavor and nutritional characteristics, they are generally sources for vitamins, beta carotenes, fibres, sugars, proteins, and various minerals. For every 100g of mango consumed, 64-86 calories of energy is received by human diet depending on the variety, ecological zone and ripening stage of the mango (Okoth et al., 2013). For water-soluble nutrients such as Vitamin C content, the range is from 32-200mg/100g (Rathore et al., 2007). Vitamin C is important for deficiencies leading to scurvy disease in human especially the young. Okoth et al., (2013) found 'Apple' mangoes from Makueni County, Kenya to contain vitamin C content of 10.35mg/100g. Similar results were recorded by Rajwana et al., (2010) on analysis of 3 mango varieties namely Aiz Kareem, Anwar Ratole and Chaunsa in Pakistan. Beta Carotene, another dominant nutrient in mango gives the yellow colouring of mango flesh when ripe which have antioxidant health benefits. It ranges from 5-26mg/kg depending on variety (Perkins-Veazie, 2007). Maina et al., (2019) found 'Ngowe' mangoes ripened under ambient conditions to contain 11.09 µg/100 ml by day 22. 'Apple' has high total soluble solids (<16 ^{o}brix) while Kent has lower (>14 ^{o}brix). Fruits with high ^{o}brix level can be used for making mango nectars and wine while those with lower levels used for making mango chutney, powders and canned mango. Ripened mangoes have their starch broken down into simple sugars of fructose, glucose and sucrose for energy provision. Fructose amounts in 'Ngowe' and 'Apple' were averagely found to be 21.57mg/ml while highest Glucose content in 'Apple' was 13.02mg/ml and sucrose content of 87.73mg/ml in 'Ngowe' variety (Okoth et al., 2013). Similar results were reported by Maina et al., (2019). Mango also contains small amounts of crude fibre (0.91%), fat (0.37%) and proteins (0.11%). Fibre is essential for maintaining healthy gastrointestinal tract, however, excess of it leads to zinc and iron deficiencies by binding these trace elements (Mbogo et al., 2010).

2.3.3. Opportunities in the mango value chain

There are plenty of mangoes during the peak season of mango production leading to increased postharvest losses. Thus, mango can be processed into shelf-stable products hence consumed all year round especially when the mango fruits are out of season. Mango could be processed into a wide diversity of products namely; green fruits are used to make chutney, pickles, slices and dehydrated products (when at mature green) while frozen slices, purée, juices, nectar, jam, wine, jelly and various dried products (chips and rolls) are processed from ripe mangoes (Elias, 2007). Once processed, the products can be sold to the consumers during any time of the year when mangoes are off-season. This will ensure continuous access to the nutrient content of mango by consumers.

Fresh mango fruits and processed mango products can be exported to Western and Middle East countries to fetch more income through foreign exchange. However, quality must be observed to meet the stringent market measures set by the importing countries. To export fresh mango fruits, proper pest management should be put in place with proper traceability especially for banned agrochemicals and MRIs for various chemicals to guarantee the consumer of safety (Chomchalow and Songkhla, 2008). The major pest hindering this opportunity is the control of fruit flies and mango seed weevil which are rampant in mango production. The fruits must also market themselves by being of good quality by their physical attributes and chemical composition. This can be enhanced by utilizing postharvest practices such as sorting & grading and packaging technologies such as the use of modified atmospheric packaging and waxing (Githiga et al., 2015; Maina et al., 2019). This can effectively be done at an aggregation centre that has cold storage facilities to ensure proper cold chain management (Van Der Waal and Zongo, 2011). Processing should be done from high-quality raw materials (mango fruit and clean water) under clean environment observing the required sanitation and all food safety procedures as provided by the regulatory bodies. Proper packaging is key to ensure products remain shelf-stable as indicated at processing and also done with good designs as a marketing component (Maneepun and Yunchalad, 2004). Mango export to European countries and other lucrative markets in the recent past has been limited by the prevalence of fruit flies which reduces the mango value and lowers the revenue to farmers (Muriithi et al., 2016). Multisector organizations and players in the value chain have come up with interventions such as use of fruit fly traps and use of integrated pest management in the quest to control the fruit flies in mango, a measure that will see the resumption of these oversee market hence an opportunity that can be explored to realize more returns (Korir et al., 2015).

2.3.4. Challenges facing mango value chain actors

The challenges faced by the mango value chain players occur at the production level, harvesting stage, during postharvest handling & storage as well as during the marketing stage. They include seasonality, lack of market or sellers not meeting market requirements/standards, exploitation from middlemen and high postharvest losses.

2.3.4.1 Seasonality

Mango like any other tropical fruits can flower and fruit all year round but in Kenya, mango trees fruit seasonally. The mango season in Kenya peaks between November to April. This makes mango picking season in Kenya to fall at the same time as that of other competing mango producing countries e.g. Mexico, Brazil, India, Pakistan, Israel and South Africa and therefore limits Kenya mango export by fetching low prices (Maloba et al., 2017). This results in an excess supply of mangoes (glut) in the local market during the on-season leading to oversupply as compared to the demand hence wastage at the market. Smallholder farmers lack appropriate postharvest handling techniques and therefore are forced to sell their produce at lower prices to middlemen that dominate the mango market in Kenya (Mututo, 2011) or experience high postharvest losses at the farm through rotting due to lack of adequate market (Maloba et al., 2017). Mango seasonality contributes significantly to post-harvest losses by affecting mango processing activities. Mango processing factories are only adequately supplied with mangoes as raw materials for 7 months due to the seasonal production of the fruit. During the off-season, there are little or no mangoes at all which leads to industries involved in mango processing lacking capacity to be involved in processing all-year-round.

2.3.4.2 Poor mango market characteristics

Most of the smallholder produce is marketed shortly in local fresh fruit markets (Kassahun and Dawuro, 2014; Shukla and Jharkharia, 2013). There is high potential in both local and export market of both fresh and processed mango products but there are factors related to quality, supply and institutional arrangements that may result to high risks of the players involved along the value chain. This has led to minimal number of farmers being involved in structured marketing arrangement resulting in dominant buyers of mango. The dominance of buyers has resulted in the use of middle-men who influence the farm-gate prices at their benefit (Kassa, 2017). Furthermore, little is done by the farmers in terms of post-harvest handling, for example, sorting and grading leaving them at the mercies of the traders (Humble and Reneby, 2014). Farmers too lack proper coordination amongst themselves hence low bargaining power when selling individually. For the export market, there exists transparency in its market information systems and informal transaction which present a high risk to traders making most to shy away (Kassahun and Dawuro, 2014). Processing of mango products by smallholder farmers is limited due to high competition from seasoned wholesalers who import mango pulp and low priced mango juices from other countries (Kassa, 2017).

2.3.4.3 Low-quality produce

There is a disconnect between the standards required by buyers as well as what the farmers can produce. This is brought about by lack of quality standards to be followed by producers (Kassa, 2017). Quality of the harvested mango is regarded based on size, maturity, colour among other physical appearances (cosmetic). The low-quality produce leads to most fruits being rejected by the traders resulting in high postharvest losses.

2.3.4.4 High post-harvest losses in mango

Postharvest losses among horticultural fruits and vegetables e.g. mango are estimated at 45% (Kitinoja and Kader, 2015). These losses occur at harvest stage, during handling, while in storage, while on transit to the market, wastage at the market and wastage at the consumer level (Kader, 2010). However, some pre-harvest activities such as pests, diseases and weather conditions e.g. rainfall have an effect on fruit quality that results in a major impact on postharvest losses (Kitinoja and Kader, 2015).

2.3.5. Drivers of postharvest losses in the mango value chain

Post-harvest losses in mango can cause total economic loss especially in developing countries where the majority of the farmers operate on small scale basis and cannot afford recommended methods of storage such as cold storage that maintains produce quality (Kitinoja and Kader, 2002). The losses occur in any stage of the supply chain right from harvesting, transportation, grading & packing, storage and at the market places (Kader, 2010; Hodges et al., 2010). At harvest, losses occur due to improper harvesting methods that result in mechanical injuries due to bruising, harvesting when temperatures are high leading to increased heat load that raises the metabolic activities and harvesting before fruits attain right maturity indices which end up rotting (Sivakumar et al., 2011). During handling, losses occur as a result of bruising, poor storage due to lack of cold storage facilities and mixing of the different fruits while in storage (Kassahun and Dawuro, 2014). On Transit, the losses are associated with overloading of the fruits leading to decay and heat load, not loading in crates and poor roads that results in mechanical bruising (Msogoya and Kimaro, 2011). At the market, losses are associated with heat stress and decay due to lack of cold storage facilities at the market (Msogoya and Kimaro, 2011).

2.3.5.1. Poor harvest practices

Fruit maturity at harvest determines the flavor and keeping quality of the fruits. Mature or ripe fruits will result in quality fruits whereas the unripe fruits will compromise quality but have a longer shelf life (Toivonen, 2007). Immature fruits do not develop good eating quality on ripening. They also get damaged easily, suffer chilling injury under cold storage and transpire at a higher rate resulting to shrivelling and weight loss (Kader, 2008). To get a balance between quality and shelf-life, it is important to consider suitable maturity indices at harvest since harvesting horticulturally immature fruits or overripe ones can be among the factors leading to increased post-harvest losses (Ingle et al., 2000).

The time of the day when you harvest will significantly affect the heat load the produce absorbs which thereafter affects its quality and shelf life because deteriorative processes are enhanced by temperature (Chopra et al., 2003). Heat load also raises the energy needed to lower commodity temperatures (Kader, 2002). Fruits harvesting when ambient temperatures are high results to high pulp temperatures of the harvested fruits. This results in increased heat load that increases deterioration by the increasing rate of metabolic reactions in harvested fruits and will require a lot of energy during pre-cooling and cooling in the cold storage. High heat load also results in fruit flesh disorders and rotting (Humble and Reneby, 2014). Harvesting fruits when temperatures are high will also affect effectiveness of the harvesters and likely to cause more losses through mechanical injuries (Kiaya, 2014).

The harvesting method used by the farmer may also result in post-harvest losses (Humble and Reneby, 2014). Harvesting by shaking the tree, causes all fruits to fall irrespective of their maturity index. The fruits that are not horticulturally mature end up rotting rather than ripening. Use of sticks causes mechanical injuries due to bruising. 10-20mm of the stem should not be removed from the fruit when harvesting to prevent sap that is low in PH and high in oils that causes peel damage due to sap-burns (Johnson and Hofman, 2009). Fruits harvested should not fall directly on the ground which may result in more injury and/or getting in touch with soil-borne pathogens (Johnson and Hofman, 2009). This harvesting method results in entry points for pathogens, increased water loss and evolution of wound ethylene, a senescing hormone (Kader, 2002).

2.3.5.2 Poor handling after harvest

Once the mangoes are harvested, proper handling is key to preserve quality (Kader, 2002). Some of the poor handling practices by most farmers include heaping of fruits in the open field causing more sap-burns, fruits left on direct sunlight without pre-cooling under field shades, and rough handling leading to mechanical injuries (internal fractures, bruises and skin injuries). There is need for harvested fruits to be pre-cooled as soon as possible in a shade to remove field heat and avoid warming and heat accumulation (Kitinoja, 2013). The road from the farm to the storage or packhouse should be smooth to avoid mechanical injuries to fruits when on transit. Transportation needs to be done using refrigerated trucks or during cool hours of the day. Mango fruits should be sorted and graded as per their stage of maturity, ripeness and size (Asghar et al., 2012). Overripe or/and bruised commodities produce ethylene that may result in ripening of other commodities in the store (Miller, 2003). Poor packaging can lead to faster weight loss and a general reduction in shelf life (Hailu et al., 2014). Appropriate packaging material should minimize weight loss and maintain fruit quality. Proper packing and packaging of mangoes are also necessary to avoid heat built up as well as easy transportation to extend the shelf life (FAO, 2011). Poor storage conditions such sub-optimal relative humidity, high temperatures in storage and mixing of perishable fruits with other farm produce leads to spread of heat and other storage diseases leading to produce loss (Kitinoja and Al Hassan, 2012).

2.3.5.3 Poor cold chain management

A cold chain is the continuous handling of the produce at a low temperature for perishable products from harvest to the end users (consumers) (Kitinoja, 2013). The author stated that there are five segments of a cold chain which include packing and cooling fresh food products, food processing, cold storage, distribution and marketing. Mahajan and Frías, (2010) described components of the cold chain into seven: on-farm cooling, initial cooling, storage, transportation, distribution, retail and consumer (Figure 2.1) with possible temperature management.

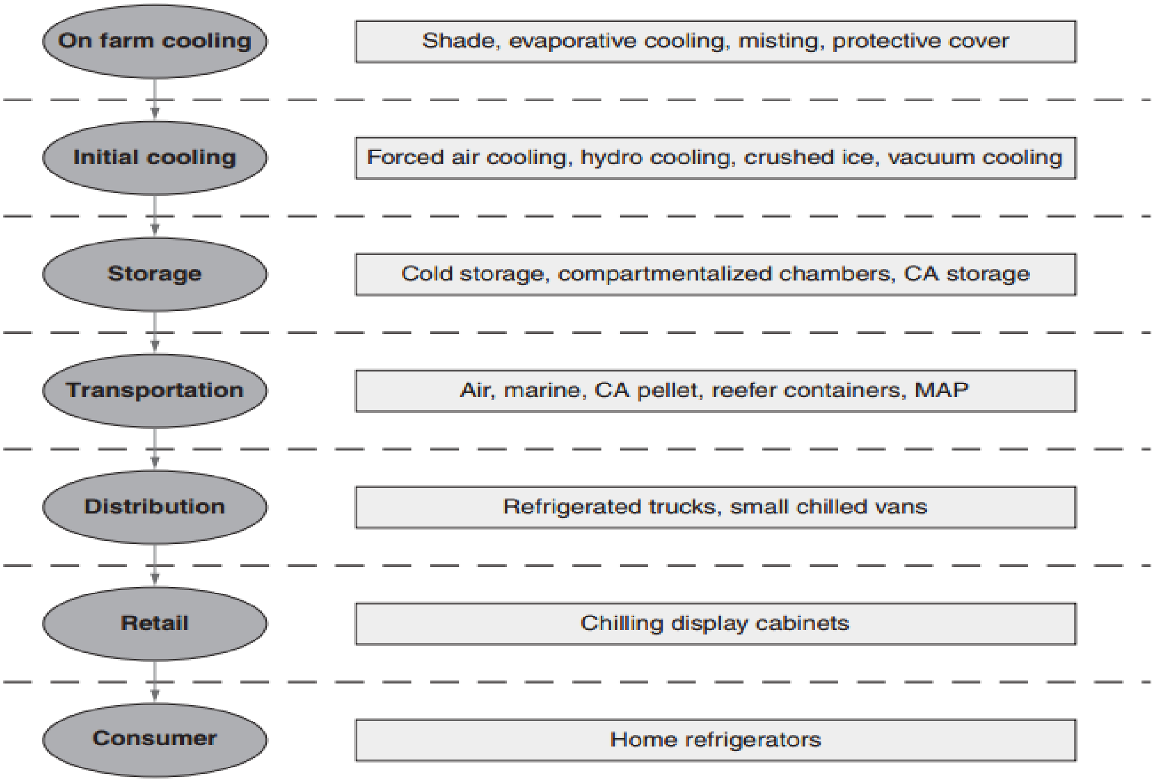


Figure 2.1: Cold chain components with possible temperature maintenance (Source: Mahajan and Frías, 2010).

Most of the farmers' practices have resulted in poor cold chain thus high postharvest losses. Harvesting fruits during hot hours of the day exposes harvested fruits to direct sunlight which leads to high heat load (Kiaya, 2014). Heat load deteriorates quality by increasing metabolic reactions such as respiration & transpiration and shortens shelf life by inducing faster ripening.

Delaying to transport harvested fruits into a cold store or pre-cooling results in loss of quality (Kok et al., 2010; Nunes et al., 1995). Transport of fruits from field to stores or market is done by unrefrigerated trucks during any time of the day while packed in gunny bags or sacs (Humble and Reneby, 2014). This leads to high heat load responsible for quality loss in perishable fruits such as mango. Due to lack of cold storage facilities, most farmers store their harvested fruits under ambient conditions with high temperatures and low relative humidity thus high rate of physiological process that results in faster ripening and deterioration (Ambuko et al., 2018a). Cold storage in conventional cold rooms is one of the solutions in attaining the optimal temperature and relative humidity. However, for most smallholder farmers, conventional cold rooms are out of reach due to the high cost of setting up a conventional cold room, they require technical know-how to operate them and require electrical energy in running, which is lacking in most rural areas (Ambuko et al., 2018a). For those with access to cold storage, the optimal temperature for mango is not observed and general discipline of use of cold rooms, for example keeping the door shut most times. With an open door, the hot air from outside enters raising the temperatures inside the cold room (Ayarmal et al., 2018).

2.3.5.4 Lack of processing capacity

Value addition through the processing of perishable fruits such as mango will result in better and prolonged marketing, goodwill and profitability of products hence increased shelf life and reduction in postharvest loss (Charles Aworh, 2015). Majority of the mango farmers are smallholder farmers who may not have the capacity to purchase machinery and equipment used in mango processing and value addition. Lack of modern processing infrastructure and knowledge/technical know-how in the field of processing is also a limiting factor (Shabani et al., 2015; Shashi et al., 2018). This leads to the selling of fresh mangoes as the only option that farmers have to market their produce. With limited fresh market access, most of the mangoes end up being wasted or sold at a lower price leading to high post-harvest losses and little income.

2.4 Applicable postharvest technologies to reduce postharvest losses in mango

Fruits and vegetables undergo continuous changes from the time of harvest to consumption since they are still living. This results in deterioration as they move along the postharvest handling chain. In developing countries with limited recommended cold storage structures for fresh fruits and vegetables, post-harvest losses can lead to a total economic loss if mitigation measures are not taken (Subrimanian et al., 2017). The quality of freshly harvested fruits and vegetables is dictated by biological variations, environmental conditions, handling methods and sanitation practices. These parameters are further impacted by logistic activities such as the type of packaging, availability of temperature-controlled mode of transport, storage facilities and the types of postharvest treatments that are implemented (Manzini and Accorsi, 2013). Additionally, use of appropriate cultural and harvesting techniques and good post-harvest handling practices such as minimization of physical injury to produce, removal of field heat, sorting, grading and treating with preventing chemicals have proven to reduce post-harvest losses in fresh produce (Chauhan et al., 2006).

2.4.1 Temperature management

Temperature is the major factor affecting the postharvest shelf life of most harvested horticultural crops. It is responsible for most biochemical and metabolic reactions taking place in harvested fruits and vegetables (Yahia, 1999). Low temperatures reduce respiration rates, delays ripening & senescence, reduce water loss, reduce insect and disease activities and thus maintains postharvest quality and extend shelf life. Mango should be handled under cool temperature from the time of harvest till consumption (proper cold chain management). However, optimal temperature range should be observed especially in cold storage to avoid chilling injury, a problem with most tropical fruits (mango being one of them) when subjected to lower temperatures under 10^{o}C. Mango shelf life has been enhanced when stored under cold storage for 23 more days when compared to ambient conditions (Ambuko et al., 2018a; Kitinoja, 2013; Nenguwo, 2000). Proper cold storage requires appropriate infrastructure in place (electricity, technical know-how and capital), which are limiting factors among smallholder farmers. Other cold chain related handling practices include harvesting during cool hours, transport in refrigerated trucks and pre-cooling before storage (Humble and Reneby, 2014).

2.4.2 Modified Atmosphere (MA)

Modified atmosphere involves placing a semi-permeable membrane around the fruit then relying on the fruits’ respiration to modify the atmosphere around the fruit (Johnson and Hofman, 2009). It helps maintain fruit quality by reducing the respiratory rate, ethylene production, reduction in compositional changes associated with ripening and also reduced incidence of physiological disorders and diseases (Kader, 1994). The modified atmosphere has been used in the packaging of tropical fruits such as mango to delay ripening related changes thereby maintaining the quality and extending their shelf life (Githiga et al., 2015). However, MAP can reduce the quality of stored fruits if the fruit cultivar/holding temperature/film permeability/storage time combination is not optimal resulting in anaerobic conditions and offflavours (Githiga et al., 2015; Johnson and Hofman, 2009). Additionally, excess moisture retention inside the bags can increase disease problems such as anthracnose. MAP is effective with proper cold chain. Previous studies have shown that MAP under ambient conditions creates conditions conducive to deterioration thus significantly reducing shelf life (Tefera et al., 2007).

2.4.3 Controlled Atmosphere (CA)

Controlled Atmosphere (CA) storage involves controlling the concentration of oxygen, carbon dioxide and relative humidity in the storage environment (Singh and Zaharah, 2011). This is done by monitoring of gases around the fruit by injecting CO_2 and N_2 into the container as required (Johnson and Hofman, 2009). Use of the controlled atmosphere combined with optimum storage temperature has been effective in prolonging shelf life and fruit quality such as aroma, colour and volatile substances (Singh and Zaharah, 2011). Additional benefits of controlled atmosphere include a reduction in respiration rates in fruits, delayed in the breakdown of chlorophyll hence maintained fruit colour, reduced fruit softening and reduced disease attack (Thompson, 2001). However, use of CA is minimal on tropical fruits such as mango due to high perishability of the fruits as well as the value of the fruit, as it becomes expensive when the cost of CA is factored in (Johnson and Hofman, 2009).

2.4.4 Waxing

Waxing and coating of produce improve their gloss while improving the marketability of the produce (Shih et al., 2001). Edible films and wax create a protective barrier on the surface of mango fruits thus suppressing respiration, minimizing moisture loss and addition of gloss. Edible wax has no noxious effect on human health and considered a biological mechanism of reducing quality loss in perishable produce (Shih et al., 2001). Coating of mangoes with chemicals such as chitosan before harvest and storage has been reported to increase the shelf life and quality of fruits (Jongsri et al., 2016). This is achieved by reducing pest and disease infection that causes injury leading to the formation of entry point for disease pathogens (Jongsri et al., 2016). Maina (2019) also reported successful shelf-life extension and quality preservation in ‘Apple’ mango when applied with different formulations of mango wax and shellac wax. Use of appropriate chemicals maintains fruit firmness and also delays physiological ageing thus maintaining quality (Jongsri et al., 2016). The cost of edible waxes is high and require technical knowledge in formulation and application making it less used among the smallholder farmers. Additionally, waxing of mango is not commonly used mainly because of the risk of off-flavor development (Yahia, 1999).

2.4.5 Ethylene Management

Mango is a climacteric fruit that experiences a series of biochemical changes that are initiated due to autocatalytic production of ethylene and increase in respiration (Yahia, 1999). Managing ethylene production in stored climacteric fruits and entry of external ethylene results in preservation of quality and prolonged shelf life of fruits and vegetables. Various ways can be applied to reduce ethylene synthesis as well as retard effects of already available exogenous ethylene gas, including cold storage, avoidance, use of ethylene synthesis inhibitors, and ethylene absorbers. Excessive ethylene accumulation around ethylene sensitive fruits and vegetables can be achieved by having vents to introduce fresh air inside storage chambers (Blanke, 2014). Harvested fruit and vegetables should be kept away from ethylene producing commodities and combustion engines. They can also be packaged in gas selective packaging films where ethylene is restricted. Ethylene inhibitors act by inhibiting the formation of ACC from SAM via ACC synthase during the ethylene synthesis process (Blanke, 2014). An example of such an inhibitor is aminoethoxyvinylglycine (AVG). Alternatively, ethylene inhibitors can act by competing for ethylene binding sites thus blocking ethylene receptors (Blankenship and Dole, 2003). This is the mechanism used by 1- methylcyclopropene (1-MCP). Ethylene absorbers such as potassium permanganate ($KMnO_4$) are packaged together with the commodity to destroy evolved ethylene (Ishaq et al., 2009). Additionally, continuous cooling is a pre-requisite in the food chain to retard fruit ripening and ethylene synthesis (Blanke, 2014). However, excessive or complete ethylene suppression can result in negative effects such as complete loss of fruit colour, taste and aroma (Blanke, 2014)

2.4.6 Cold storage

Cold storage is important for harvested fruits that are stored for later use or processing due to its optimal temperature management (Jobling, 2000). Cold storage results in low temperatures which lower the rate of metabolic activities, reduce water loss, delay ripening, reduce insect and disease activities and delay senescence in stored horticultural produce thus prolonging shelf life and maintaining quality (Thompson, 2003). To achieve optimal temperature and relative humidity for storage of horticultural produce such as mango, mechanical refrigeration such as the use of conventional cold rooms has been utilized in developed countries and/or in large firms. However, the cost of setting up conventional cold rooms is very high in terms of installation and maintenance costs and need for uninterrupted supplies of electricity which is not readily available (Lal Basediya et al., 2013). A minimum of 10,000 USD is required to set up a conventional cold room (Kitinoja, 2013). Besides, the maintenance cost of variable costs such as fuel/electricity, operational personnel and repairs are also high. This is way beyond reach for smallholder farmers in the developing countries, who dominate the mango production (Ambuko et al., 2018a; Kitinoja, 2013). Thus, there is a need to explore alternative affordable cold storage options.

2.5 Examples of Low-cost cold storage technologies

2.5.1 Coolbot™ cold room

A Coolbot™ cold room is a walk-in cold room that is an inexpensive and less sophisticated build from a standard air conditioner (Kitinoja, 2013). It is made up of 3 main components; the compatible air conditioner, a Coolbot™ controller and insulated room (Ambuko et al., 2018a). The Coolbot™ gadget (Figure 2.2) uses multiple sensors and a programmed microcontroller to direct the air conditioner to operate at the desired temperature (which ranges between 0^{o}C to 18^{o}C) without freezing up (Dubey, 2011). The air conditioner alone, without the Coolbot™ gadget cannot lower temperatures in the storage room lower than 16-18^{o}C. The electronics in the Coolbot™ apply heat to the air conditioner's temperature sensor. When the AC sensor is heated, the compressor turns on while the second Coolbot™ sensor monitors the evaporator and turns the compressor off once the evaporator surface temperature nears the pre-set temperatures (Kumar et al., 2019).

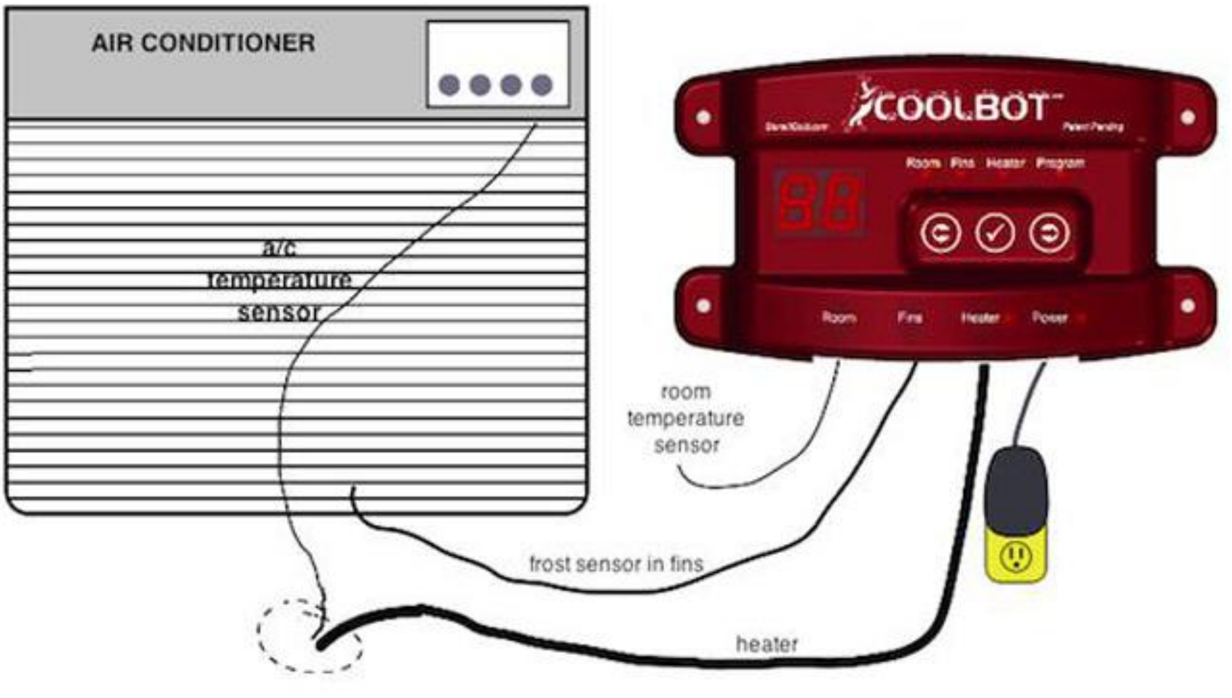


Figure 2.2: The air conditioner and the Coolbot™ gadget (Source: *https://www.engineeringforchange.org/solutions/product/coolbot-walk-cooler/)*

The Coolbot™ is considered relatively low-cost because a standard 4M by 4 M unit whose tonnage depends on the commodity can cost between USD 3,000 to 6,500 USD depending on the level sophistication and availability of materials used in its fabrication (Ambuko et al., 2018a). A conventional cold room of the same size and capacity can cost upwards of 10,000 USD (Karithi, 2016; Kitinoja, 2013). In addition, the Coolbot™ cold room can be constructed from locally available materials and the maintenance costs are low. It is environmentally friendly; uses little energy and has very low carbon emissions. However, access to the Coolbot™ cold room is limited for areas that are off-grid or do not have stable electricity supply. The Coolbot™ cold room has previously been used for shelf-life extension and quality preservation of horticultural produce. For instance, 'Ngowe' and 'Apple' mango varieties stored in the Coolbot™ cold room had its shelf life extended by 16 and 23 days respectively (Ambuko, et al., 2018b). In preserving quality, storing cauliflower and cabbage in the Coolbot™ cold room recorded physiological weight loss by less than 5% and around 6% respectively at the end of the study, making them remain firm, fresh and marketable (Dubey and Raman, 2015). Similar findings were recorded in okra and tomato (Huidrom et al., 2016).

2.5.2 Evaporative cooling

Evaporative cooling technology is a natural and physical phenomenon that operates on the principle of evaporative heat exchange (Ndukwu, 2011). Cool air is provided by evaporative coolers by forcing hot air over a wetted pad or medium that holds water (Sand/charcoal) as seen in figure 2.3 below. When the water in the wetted pad evaporates, it draws heat from the surrounding air while adding moisture thus creating a cooling effect (Lal Basediya et al., 2013). The faster the evaporation, the greater the cooling. The evaporative cooling decreases temperatures while increasing humidity inside the storage chambers; conditions that preserve quality and extend shelf life of perishable horticultural produce (Verploegen et al., 2019). Previous studies have shown that evaporative coolers reduce the temperature by10-15^{o}C below ambient temperatures and increases humidity up to ≥90% (Ambuko et al., 2017). With increased humidity in the chamber due to evaporative cooling, there is minimal water loss from the stored produce to the surrounding air, hence they remain fresh and deterioration (wilting, shriveling and ripening) is reduced (Manyozo et al., 2018). To maintain the cooling effect, water should be added at intervals which may vary depending on storage device material used, the design and the weather conditions (Verploegen et al., 2019). The efficiency of the coolers is determined by the ambient conditions (relative humidity and temperature) that vary depending on the season and agroecological zones (Vala et al., 2014). Evaporative cooling works best with dry weather due to high moisture absorption by the dry air thus high rate of cooling. In areas with air saturated with water, no evaporation takes place hence no cooling effect (Lal Basediya et al., 2013).

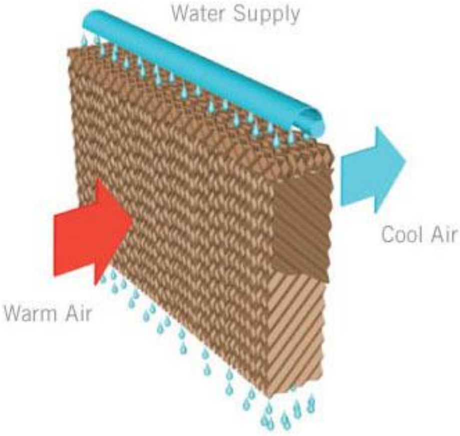


Figure 2.3: Evaporative Cooling (Source: https://www.evapco.com/)

Evaporative cooling is the most economical way of achieving low temperatures and high humidity required by fruits and vegetables by the smallholder farmers especially in developing tropical countries (Kitinoja, 2013). The initial set up cost is low due to use of locally available materials (Liberty et al., 2013), does not require electricity and is environmentally friendly (Getinet et al., 2011; Brian et al., 2013). However, the evaporative coolers have limitations including capacity, ambient humidity levels, and water availability (Brian,2013). Examples of technologies operating on the principle of evaporative cooling include the zero-energy brick cooler, evaporative charcoal cooler and pot-in-pot evaporative cooler.

2.5.2.1 Zero Energy Brick Cooler (ZEBC)

The ZEBC (figure 2.4) is a double-walled structure made of bricks and covered with a moisture absorbing material such as a straw mat. In between the double-walled bricks is sand that retains added water and keeps the inside of ZEBC cool under the principle of evaporative cooling (Verploegen et al., 2018). As water evaporates from the wetted sand (used as a medium to hold water), it reduces the temperature inside the chamber while increasing the humidity level (Rayaguru et al., 2010).When hot and dry air goes via wetted sand, water evaporates taking with it heat from the surrounding of the ZEBC henceforth cools air around the stored commodity itself (Ndukwu and Manuwa, 2014).

ZEBC was built initially in India in the early 1980s by Roy Susanta and D.S. Khuridiya with a quest of helping to preserve perishable horticultural produce in off-grid areas. But has been modified over years and can be built from locally available materials including bricks, sand, wood, dry grass, gunny bags, and twine (Verploegen et al., 2018). The dimensions used for the ZEBC's length and width vary according to the desired size but the height should not be too high for ease of operation. According to Roy (2011), the standard size of a zero-energy brick cooler is 165cm long, 115cm wide, and 67.5cm high with the space between the doubled brick walls to be 7.7cm. A cover made from locally available material that is moisture absorbent can be made based on the length and width of the ZEBC (Chinenye, 2011). The sand in between the brick is wetted before loading the chamber with produce till saturation and then subsequently as the sand dries up depending on the weather and temperatures and humidity required (Roy, 2011).

Figure 2.4: The Zero Energy Brick Cooler (Source: Karurumo Smallholder aggregation and processing center, Embu County)

The unit cost of setting up ZEBC with 100kg capacity is estimated at 53 USD making it affordable to a smallholder farmer in developing county such as Kenya (Roy 2011). Similar costing was reported by Manyozo et al.,(2018) where ZEBC that can store 0.14tons of tomato cost 63.09 USD. However, the cost of setting up ZEBC depend on the complexity of the materials used and their availability. Kitinoja (2013) reports that the unit cost of a ZEBC with a capacity of 200kgs, 1MT and 6MT to be estimated at 200 USD, 1,000 USD and 8,000 USD respectively, which is relatively low compared to the conventional cold room. For instance, they can be made from locally available materials that are cheap and well adapted to the environment. The ZEBC does not require electricity to run, has good water-use efficiency, environmentally friendly, and do not require significant training to operate (Manyozo et al. 2018). The limiting factor with use of ZEBC is that it is small in size thus low capacity, the frequent refilling of sand and use of water especially in dry areas where water is limited and priority of water use is on consumption and farming rather than for cooling. ZEBC is effective in pre-cooling harvested commodities before storage as well as short term storage of fruits and vegetables that deteriorate faster immediately after harvest (Ambuko et al., 2018a). ZEBC has successfully been used for quality preservation and shelf-life extension of tomato and eggplant by 9 and 5 days respectively (Islam and Morimoto, 2012).Manyozo et al.,(2018) reported extension in the shelf life of tomatoes stored in ZEBC by 12 days and its quality preserved, reduced loss of vitamin C by 53.73%. Additionally, storing leafy amaranth in ZEBC resulted in a slowed rate of reduction in physiological weight loss, had only lost 10.5% compared to the fruits under ambient conditions that had lost 47.6% (half) of its initial weight by day 5 of the study (Ambuko et al., 2017). Similar results of extended shelf life and preserved quality of potato, tomato, brinjal, mango, banana and leafy vegetables when stored under ZEBC was has been reported in previous studies (Rayaguru et., 2010).

2.5.2.2 Evaporative Charcoal Cooler (ECC)

Evaporative charcoal cooler (figure 2.5) also operates on the principle of evaporative cooling. Unlike the ZEBC, the ECC is a walk-in structure and the porous medium to hold water (wetted pad) is charcoal that allows free air circulation between produce and the surrounding air (Nenguwo, 2000). Charcoal coolers lower the temperatures by 10-15^{o}C lower than the ambient conditions and raise humidity up to 100% depending on the relative humidity and ambient air (Nenguwo, 2000). ECC is best suited for tropical and subtropical fruits such as mangoes since their optimal storage temperatures can be easily achieved by evaporative coolers (Nenguwo et al., 2000). There exist various designs of the evaporative charcoal cooler in the world but the choice of design will depend on the suitability of the prevailing conditions. The charcoal walls are supported with either metal or wooden frames covered with wire mesh or fibre glass separated by 10cm and the interior filled with charcoal. The 4 charcoal walls are filled almost up to the brim leaving a space of 15-20cm at the top for air circulation. For instance, to construct a 4-5 ton of ECC one needs 4m long x 4m wide x 2.5m high (Ronoh et al., 2020).

Figure 2.5: Evaporative Charcoal cooler (Source: Karurumo Smallholder aggregation and processing center, Embu County).

The unit cost of fabricating and installing a 4 – 5 tons capacity evaporative charcoal cooler is estimated at 7,000 USD when made of aluminium panels fitted with extended wire mesh, an affordable option compared to the cost of setting up a conventional cold room of the same capacity (>10,000 USD) (Kitinoja, 2013). However, this can be more affordable depending on available local materials that can be used in fabrication. Additionally, the evaporative charcoal cooler offers alternatives to farmers who are off-grid and/or those on-grid but with inconsistent supplies of electricity, is environmentally friendly, minimum maintenance costs required and low level of technicality required to operate it. The ECC can be used in pre-cooling of harvested fruits and vegetables before long storage in cold rooms and also for short term storage of fresh produce both at the farm level and market (Lal Basediya et al., 2013). The limiting factors are similar to those of the ZEBC but in addition, the use of charcoal is considered environment unfriendly since it involves cutting down trees. Studies to find alternative inert materials to charcoal are ongoing. Previous studies have shown the effectiveness of ECC for shelf-life extension and quality preservation of harvested horticultural produce. For instance, leafy vegetables stored in ECC had the shelf life extended by 5-6 days and its quality preserved as evidences by a reduced rate of Vitamin C loss, colour changes and weight loss (Ronoh et al., 2018). Also, storing tomatoes and kales in ECC recorded weight loss of less than 10%, thus preserving its quality (Ronoh et al.,2020). Similar findings have been reported in shelf life extension and preservation of quality of eggplant (Balogun and Ariahu, 2020), French beans (Ogumo et al., 2017), tomato (Manyozo et al., 2018) among others (Lal Basediya et al., 2013).

2.5.3 Wakati™ Tent Technology

Wakati™ tent (figure 2.6) is a climate chamber devise for storing fruits and vegetables. The technology can be used on-farm, while on transit and at the market for vendors. The technology is a solar-powered tent-like box that has a ventilator powered by a 10-watt solar panel. Water gradually evaporates to create a humid environment inside the chamber. The amount of water required depend on the size of Wakati™ tent and the quantity of produce stored. For example, to store 200kgs of fruits and vegetables for a week, one requires 1 litre of water (Sefri,2018). The device creates a closed sterile environment, keeping the produce fresh and free of molds (Sefri, 2018). Wakati™ tent does not necessarily lower temperatures but results in increased humidity around stored produce. This keeps the produce fresh for longer due to minimized water loss from the fruits due to vapor water difference (VPD) between the produce and its environment (Gykiere and Pauwels, 2017). The vapor created by the fan is transformed into ozone which eliminates the ethylene produced by oxidizing it into carbon dioxide and water that prevent deterioration (Gykiere and Pauwels, 2017).

Figure 2.6: The WakatiTM tent (Source: *https://www.engineeringforchange.org/solutions/product/wakati-one/)*

The technology is affordable since the unit cost of one Wakati™ tent is 100 USD and its maintenance costs are low. It does not require electricity hence can be used in off-grid areas. Its portability nature gives it the advantage to be moved around across farms or markets for temporal storage of fruits and vegetables. High humidity in the Wakati™ tent can be limiting to commodities that are sensitive to very relative humidity. Solar-powered evaporative coolers have previously been used to extend shelf life of tomato, mango, banana and carrots by 15, 9, 12 and 20 days respectively (Olosunde et al., 2016). To the best of my knowledge Wakati™ tent has not been utilized in Kenya.

2.6 Adoption of postharvest practices and technologies

Despite successful projects in scaling out of postharvest practices and technologies with aim to reducing postharvest losses along mango value chains, there has been reported low adoption rates especially among smallholder farmers (Meena, 2009). Adoption of such practices and technologies is key to ensure returns from agricultural production (Seidu et al. 2012). A maximum adoption rate of 10% over 10 years and a 10% discount rate is reported for the adoption of such technologies (Mujuka et al., 2020). The low adoption rates are attributed to various factors. These include age, sex, marital status, level of education, household size among others (Elamasho et al., 2017).

On farm evaluation of the effectiveness of the applicable practices and low-cost technologies to attain desirable cold chain in mango is critical in the efforts to create awareness and increase adoption.

CHAPTER THREE

3.0 Effectiveness of harvest time, handling practices and cold storage to extend the shelf life of mango fruit

3.1 Abstract

Mango is a highly perishable fruit with a short shelf life. Maintaining a proper cold chain (low but safe handling temperatures) from harvest to the consumption stage is important to extend the shelf life and marketing period of perishable fruits such as mango. Although cold chain management is associated with sophisticated equipment such as conventional cold rooms and refrigerated transport, simple harvest and postharvest handling practices can achieve desirable cold chain for smallholder farmers with limited resources. To evaluate this, an on-farm study was conducted in two experiments repeated within the same season. The study was conducted among smallholder mango farmers attached to Karurumo Smallholder Aggregation and Processing Center in Embu County of Kenya. The objective of the study was to evaluate the effectiveness of simple harvest and postharvest handling practices to attain cold chain and extend the shelf life of mango fruit. The recommended cool/cold chain practices were compared with common farmers' practices. Four mango varieties namely 'Apple', 'Ngowe', 'Kent' and 'Tommy Atkins' harvested at the mature green stage from the farmers' orchards were used in the study. To demonstrate proper cold chain management, fruits were harvested early in the morning (before 8 am) and transported in crates which were lined with dampened newspapers to achieve evaporative cooling during transit. The fruits were delivered to the aggregation centre and precooled remove the field heat. Thereafter, the fruits were transferred to a Coolbot™ cold room with temperature set at 10±2^{o}C (recommended for mango fruit). To demonstrate the common (poor cold chain) harvest and handling practices, the fruits were harvested at midday (12 noon) and transported to the aggregation centre in open crates and then stored at ambient room conditions (Temperature 25±7^{o}C, Relative Humidity of 55±15%). The air and fruit pulp temperatures during handling and storage at the various conditions were monitored regularly using HUATO® data loggers. During the storage period, a random sample of 3 fruits (per variety) was taken from each of the storage options after every 3 days to evaluate ripening-related changes including physiological weight loss, colour, firmness and total soluble solids. Results showed that proper cold chain management practices resulted in low fruit pulp temperature (average 11^{o}C) throughout the storage period compared to 25^{o}C for fruits handled under poor cold chain practices. Consequently, fruits under poor cold chain practices ripened faster as evidenced by lower peel/pulp colour, higher physiological weight loss and higher total soluble solids. Flesh firmness of fruits handled under poor cold chain practices decreased from initial 36.6N, 45.9N, 66.5N and 46.8N to 3.1N, 2.4N, 3.2N and 3.1N for ‘Apple’, ‘Ngowe’, ‘Kent’ and ‘Tommy Atkins’ varieties respectively at the end of storage. The storage duration under poor cold chain varied from 12 days (‘Apple’, ‘Ngowe’ and ‘Tommy Atkins’ varieties) to 15 days (‘Kent’ variety). In comparison, flesh firmness of the fruits handled under proper cold chain was 2.3N, 1.5N, 3.9N and 2.9N respectively for the four varieties at the end of storage on day 30 (‘Apple’, ‘Ngowe’ and ‘Tommy Atkins’ varieties) and day 33 (‘Kent’ variety). Overall, proper cold chain management extended shelf life of mango fruits by an additional 18 days compared to fruits handled under poor cold chain management practices. The results demonstrate that application of simple harvest and handling practices coupled with simple storage technologies can attain and maintain the cold chain required to extend the shelf life. From these results, it is recommended that mango farmers harvest their fruits during cool hours of the day (early morning or late evening) and to precool harvested fruits to remove field before long term storage in cold rooms. Proper cold chain management during harvest, handling and storage is key to the preservation of quality of harvested mango fruit.

3.2 Introduction

Mango (*Mangifera indica L*) is one of the main fruits produced in Kenya mainly for the domestic market and to a small extend for the export market. It is ranked 2nd in both value and in export market after banana and avocado respectively (HCD, 2017). Mango production has increased over the past years as evidenced by area under production increasing by 1,452ha from the year 2016 to 2017, a 3% rise. This increase can be attributed to increased demand for fresh market, fruit processing and health concerns among the consumers (HCD, 2017). However, despite increase in production and growing economic importance of mango in the recent years, its value has not been fully exploited as a result of various factors, including high postharvest harvest losses along the mango value chain. It is reported that at least 40-45% of the mango fruits are lost due to poor harvest and postharvest handling practices (FAO, 2014).

Mango is a highly perishable fruit with a short shelf life after harvest. Ripening and subsequent deterioration of the fruit is attributed to various physiological processes including respiration, softening, colour changes. The rate of ripening and deterioration of the fruit as a result of these physiological processes is affected by environmental factors including temperature and relative humidity (Reid et al., 2010).

In handling perishable commodities such as fruits and vegetables, maintenance of low but safe temperatures during handling of the produce from harvest to the end user (cold chain) is critical for preservation of quality. Cold chain for perishable products is the continuous handling of the produce in cool temperatures during postharvest handling from harvest, collection, transport, storage, processing and marketing until they reach the final consumers (Kitinoja, 2013). Mahajan and Frias (2012) also described components of cold chain into seven: on farm cooling, initial cooling, storage, transportation, distribution, retail and consumer with possible temperature management. An increase in temperature by 10°C above optimum increases rate of deterioration in perishable commodities by 2-3 folds (Kader, 2005). According to Kader (2002), delays between harvesting and cooling or processing can result in quantitative losses (due to water loss and decay) and qualitative losses (losses in flavor and nutritional quality).

Therefore, management of proper cold chain is critical to slow down the rate of metabolic processes and physiological processes such as respiration, transpiration and ethylene production/responses all of which lead to deterioration of harvested produce. Cold storage also slows down activity of micro-organisms and reduces browning and loss of texture, flavor and nutrients (Kitinoja, 2013). Cold chains have been used to maintain post-harvest quality of fruits during shipment, marketing and storage before consumption (Oosthuyse, 1995).

Besides temperature, relative humidity is another environmental factor that contributes to deterioration of harvested perishable produce such as fruits and vegetables. Physiological water loss results in shriveling which contributes significantly to produce deterioration and postharvest losses in perishable commodities. At harvest, the harvested crop may lose water due to several factors including; harvest maturity, environmental conditions and harvest techniques and physical injury (Lufu et al., 2020). Harvesting fruits during hot times of the day will result in high heat load in harvested produce that may lead to high respiration and transpiration, hence higher water loss during prolonged storage (Tyagi et al., 2017). This is due to increased vapour pressure deficit (VPD) within the produce tissue that may cause fruit cracking hence peel permeance allowing increased water loss after harvest (Lufu et al., 2020). Physiological water loss is further aggravated by poor postharvest handling practices (Brosnan and Sun, 2001; Lufu et al., 2020). Low temperature and high relative humidity are key in reducing water loss from the fruit to the surrounding, suppress enzymatic and respiratory activities leading to ripening and senescence and slow pathological activities creating a safe environment for fruit preservation (Katsoulas et al., 2011). On the contrary, high temperatures and low relative humidity at harvest time results in water loss causing fruits to shrivel, lowering quality (Deirdre, 2015).

Most farmers perceive cold chain management as a complex system that requires high cost of infrastructure including conventional cold rooms and refrigerated transport. However, smallholder farmers can achieve the same benefits of the conventional cold chain management practices through application of simple harvest and postharvest handling practices coupled with low-cost storage technologies.

Harvesting produce during cooler times of the day reduces heat load which would otherwise result from high temperatures and exposure to direct sunlight during hotter times of the day (Kiaya, 2014). Harvesting early in the morning when plant cells are turgid minimizes water loss and significantly enhances its shelf life and preserve quality. Studies in French beans showed that the beans harvested during hotter hours of the day lost significantly higher water during storage (Ogumo et al., 2018). Immediately after harvest, use of field shades to keep the produce cool also reduces amount of heat load in the produce. Field shades cool produce thus decreasing metabolic reactions in harvested produce (Ilić et al., 2018). Harvested produce should be transported from the field to storage immediately. Delays in the field may expose the produce to more heat hence high heat load in harvested crops, affecting shelf life and quality (Ogumo et al., 2018). For produce that is destined for cold storage, the longer the duration to cooling the longer the time to attainment of set storage temperature. Past studies show that a delay by one hour between harvest and precooling causes a loss of one day in the shelf life (Arah et al., 2015). Pre-cooling before cold storage is necessary to remove field heat in harvested produce (Kitinoja, 2013). Removal of field heat by precooling reduces post-harvest decay, control the development of physiological disorders, and decreases metabolic activities such as respiration rate and ethylene production thus delays ripening, aging and senescence (Etan et al., 2002). 25-30% postharvest losses are recorded in un-precooled commercial fruits and vegetables while only 5-10% postharvest losses are recorded for precooled produce (Yang et al., 2007). Pre-cooling coupled with other cool chain practices and technologies has been used to extend shelf life and preserve quality of harvested tomatoes (Cherono et al., 2018; Rab et al., 2013).

To complement the harvest and handling practices, there are low-cost cold storage technologies whose efficacy has been shown in various commodities. Examples of low-cost technologies that have been used successfully to preserve quality of perishable produce include the Coolbot™ cold room, solar-powered coolers and evaporative cooling technologies. The Coolbot™ cold room is a low-cost cold storage alternative to conventional cold rooms. The Coolbot™ cold room is composed of the Coolbot™ gadget, a compatible air conditioner (AC) and an insulated room (Ambuko et al., 2018a). The Coolbot™ is an electronic gadget that overrides the thermostat of the AC thereby enabling it to cool the room to lower than set temperatures (usually 18°C) without ice build-up on the evaporator coils (Dubey, 2011). Coolbot™ cold room has been utilized to extend shelf life of mango (Ambuko et al., 2018b) and other produce such as turnips, potatoes, tomatoes and beans. The advantage of the Coolbot™ cold room over conventional cold room is that it is relatively affordable. The cost of a standard size Coolbot™ cold room ranges between USD 3,000 to 6,500 depending on the level of sophistication and availability of constituent components. This cost is a fraction of the cost of conventional cold rooms, especially in developing countries that depend on imports. Past studies also show that the Coolbot™ cold room has better efficiency in electricity consumption and is more environmentally friendly compared to conventional cold rooms (Dubey, 2011). For the smallholder farmers in rural areas without electricity or where electricity is unreliable, evaporative cooling options provides a feasible alternative. Evaporative coolers work on the principle of evaporative cooling whereby when water held in a wetted medium (charcoal or sand) evaporates, it draws heat from the surrounding, creating a cooling effect. Evaporative coolers are considered feasible and appropriate for smallholder rural farmers because they can be made from locally available materials and the costs of running them are low. However, the cooling achieved by evaporative coolers is dependent on the surrounding environment, temperature and relative humidity and the cooling attained is often not low enough to slow down some of the deteriorative processes (Ambuko et al., 2017). Evaporative cooling is effective for pre-cooling and for short term storage of harvested produce (Ambuko et al., 2018a). Different evaporative coolers have been used to extend shelf life and preserve postharvest quality of horticultural crops such as mango (Rayaguru et al., 2010), leafy vegetables (Ambuko et. al., 2017) and tomato (Manyozo et al., 2018).

These low-cost technologies and practices can be applied complementarily to preserve the postharvest quality of perishable produce such as mango fruit and extend their marketing period. This could help the smallholder farmers aggregate their produce and negotiate for better prices from traders and therefore avoid exploitation from traders/middlemen. Ultimately, application of these practices and technologies can contribute to reduction of postharvest losses estimated to be 40-50% in perishable fruits such as mango. However, adoption of these practices and technologies requires evidence of their effectiveness and awareness creation among the potential users, including smallholder farmers.

Therefore, the objective of this study was to evaluate the effectiveness of harvest time, handling practices and cold storage to achieve effective cooling and extend the shelf life of mango fruit.

3.3 Materials and methods

3.3.1 Study site

The study was conducted in Karurumo area (S 0°28'11.6184" E 37°39'47.466"), Runyenjes sub-county, Embu County in Kenya. Embu County is located in a medium potential region, agro-ecological zone (AEZ) III. It receives total annual rainfall of averagely 1067.5mm (received twice in a year), altitude of 700m-6500m above sea level and the temperatures ranges from 26^{o}C-35^{o}C (Jaetzold and Schmidt, 1983).

3.3.2 Test Fruit Samples

Fresh mature green ‘Apple’, ‘Tommy Atkins’, ‘Ngowe’ and 'Kent' mango variety were harvested from 3 selected farms. The farms were from the same ecological zones and the trees selected were of similar vigour and based on their age (6 – 7 years). An objective maturity index based on number of days after fruit set to maturity: 97 days for ‘Ngowe’; 110 days for ‘Apple’ and ‘Tommy’ and 140 days for ‘Kent’ was used to select the mangoes at their mature green stage. Other subjective maturity indices used to complement the objective maturity indices included colour (changing from light yellow to cream from the endocarp towards the rest of the skin) and shoulder orientation (shoulder area swells and rises above the stem end). In addition, stem end sinking and forming a small pit around the stem, the stone becoming hard and observation of the sap density once the mango is detached from the tree were also used to compliment other maturity indices.

3.3.3 Description of the cold storage technologies

The evaporative charcoal cooler was fabricated at the University of Nairobi, Environmental and Bio-system Engineering lab/workshop and assembled on site. The 4m x 4m x 2.5m walls of the evaporative charcoal cooler were fabricated using double aluminium frames. A coated wire mesh was used to cover both sides of the frames leaving 25mm of space between the frames and filled with charcoal. Along the evaporative charcoal walls, ran a water drip line running from a raised water tank of 5,000 litres that kept the charcoal wet throughout the day. On one side of the 4 walled frames, a door made of moisture absorbing materials (polystyrene) was hinged. The roofing was made from iron sheets and the ceiling made of moisture absorbent materials fixed. The whole structure was put under a shaded area to avoid direct sunlight heat.

Figure 3.1: Front and rear view of Evaporative Charcoal Cooler (Source: Karurumo Smallholder aggregation and processing center, Embu County)

The Coolbot™ cold room was constituted from three main components namely; an insulated room, air conditioner (AC) and the Coolbot™ gadget. The 4m x 4m insulated room was assembled utilizing 150 mm thick structural insulated boards made of polyurethane. Polyurethane is an extraordinary dampness, sound, fire, chemical and temperature protection material as well as water proof. The insulation serves to keep low temperatures in the room by easing back move of warmth through radiation and conduction from outside into the room thus lower temperatures inside the cold room are not affected by the external environment. The walls were supported using metal frames. A 24,000 BTU LG air conditioner was installed in the insulated room then connected to the Coolbot™ unit from Store-it-Cold LLC, USA. The Coolbot™ gadget is an electronic device which acts as a control unit (thermostat) that manipulates the air conditioner to work more diligently. The Coolbot™ control unit outperforms the thermostat of the air conditioner and makes it conceivable to achieve desired temperatures. Independently, a standard AC would bring down the temperatures in a room to at least 18°C. Below 18°C, ice expands on the air conditioner's evaporator loops and would require defrosting for the cooling impact to continue. However, with the Coolbot™, the desired cold storage temperatures for the stored produce can be achieved. For this study, optimal temperature for Mango fruits, 10 ± 2^{0}C was pre-set on the Coolbot™. The room was closed most of the times with restricted movements and only pre-cooled fruits were stored as a way of improving insulation.

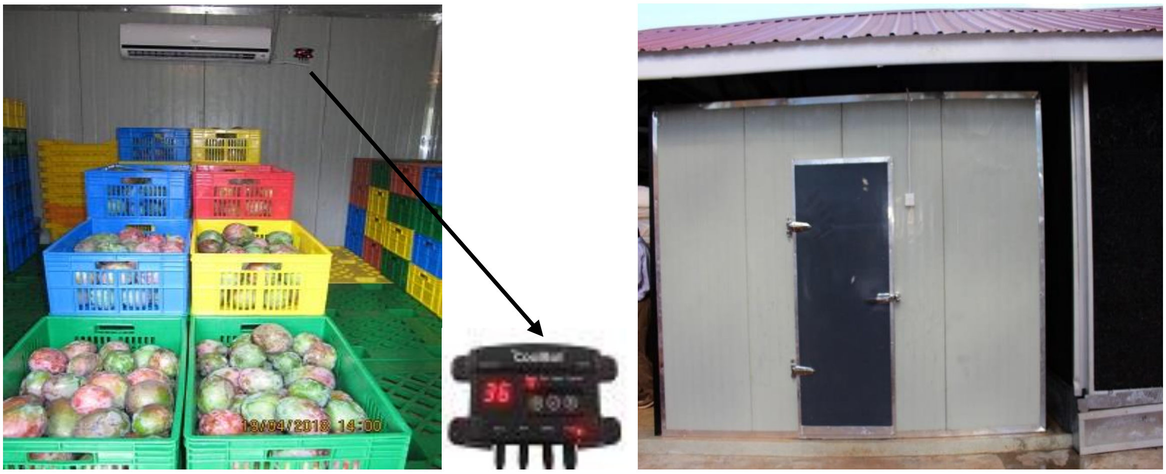


Figure 3.2: The Coolbot™ cold room with crates of mango fruits (Source: Karurumo Smallholder aggregation and processing center, Embu County)

3.3.4 Experimental Design

Uniform mature green mango fruits of ‘Apple’, ‘Ngowe’, ‘Kent’, and ‘Tommy Atkins’ varieties were harvested at two different times of the day from 3 selected farms. The fruits from the 3 farms were mixed to get a more homogenous batch that was then used in the evaluation. To evaluate proper cold chain practices, all the 4 mango varieties were harvested in the morning (before 8am), transported to the experimental site in crates lined with dampened newspapers to simulate evaporative cooling during transit. Upon arrival at the aggregation centre, fruits were sorted for uniformity based on size and freedom from damage. They were then precooled in evaporative charcoal cooler until temperatures stabilized at 22.2°C, 22.03°C, 22.1°C and 22.07°C for ‘Apple’, ‘Ngowe’, ‘Kent’ and ‘Tommy Atkins’ varieties respectively. After precooling, the fruits were stored in open crates in the Coolbot™ cold room at 12 ±2°C). In the second harvest, in order to evaluate poor cold chain management (farmers’ practices), the fruits (same trees/varieties) were harvested the same day at midday (12pm) and transported to the experimental site in open crates. The choice of harvest time (at 12 noon) was to simulate the farmer practices where fruits are harvested and left in the field for a prolonged period before they are dispatched to the target market. At the centre the fruits were sorted for uniformity and then transferred to a storage room under ambient conditions (Temperature 25±7°C, Relative Humidity of 55±15%). The experiment was laid down as a completely randomized design (CRD) with a factorial arrangement of treatments. Factor 1 was cold-chain practices with 2 levels: Cold chain (Treatment 1) and no cold chain (Treatment 2). Factor 2 was variety with 4 levels: ‘Apple’, ‘Ngowe’, ‘Kent’ and ‘Tommy Atkins’. The treatments were replicated 3 times and the experiment repeated consecutively within the same season. The results presented are for one of the experiments because a similar trend was observed on both experiments.

3.3.5 Data Collection

3.3.5.1 Air Temperature and Relative humidity (%)

The air temperature and percentage relative humidity inside the Coolbot™ cold room and ambient room were regularly monitored using HUATO® data loggers (Model HE17x, Huato Electric Co., Ltd, Shenzhen, China) after every one hour. The data from the loggers was retrieved at the end of the experiment by downloading recorded data using HUATO® app.

3.3.5.2 Pulp Temperature

The pulp temperature of the fruits was recorded at harvest time, upon arrival at the centre and after every one hour for precooled fruits till temperatures stabilized, then after every 3 days in both treatments. This was done by plunging tip of the temperature probes into the 3 sample fruits and measurement on the probe taken. The 3 measurements were averaged and presented as the internal pulp temperature.

3.3.5.3 Percentage Cumulative weight loss

In each treatment, 3 fruits per variety numbered 1 to 3 were used to measure cumulative weight loss by use of a computerized gauging scale (Model Libror AEG-220, Shimadzu Corp. Kyoto, Japan). The initial weight of the mango after harvest was noted then there after new weight of the same fruits on each sampling day. Data was collected after every 3 days in both treatments. Percentage cumulative weight loss was calculated using the formula:

% Cumulative weight loss =100 x (Initial weight – Final weight)/Initial weight.

3.3.5.4 Peel and flesh colour

Peel and flesh colour were determined by sampling 3 fruits per treatment and measuring 2 different spots along the equator using a Minolta colour meter (Model CR-200, Osaka, Japan), calibrated with a white standard piece of paper. To access the flesh, the 3 sampled fruits were cut open longitudinally and measurement taken at 2 different spots. Data was collected after every 3 days in both treatments. Colour coordinates (L*, a* and b*) were obtained then hue angles (h°) were calculated by converting a* and b*according to McLellan et al. (1995) as shown:

$$\text{Hue angle } (H^{o}) = \arctan(b/a) \text{ (for +a and +b values)}$$

$$= \arctan(b/a) + 180 \text{ (for -a and +b values)}$$

$$= \arctan(b/a) + 180 \text{ (for -a and -b values)}$$

3.3.5.5 Peel and flesh firmness

Three fruits per treatment were sampled and peel and flesh firmness were measured at 2 different spots of both intact and peeled mango respectively using a penetrometer (Model CR-100D, Sun Scientific Co. Ltd, Japan). The length of the probe was 5mm. For the flesh firmness, the probe penetrated to a depth of 1.5mm and the corresponding force required to penetrate this depth determined. Data was collected after every 3 days in both treatments. Firmness was expressed in Newton (N) (Jiang *et al.,* 1999).

3.3.5.6 Total soluble solids (TSS)

Three fruits per treatment were sampled and total soluble solids determined using an Atago hand refractometer (Model 500, Atago, and Tokyo, Japan). During sampling, 3 ml of the fruit juice was extracted from three different fruits by pressing then set on the hand refractometer to acquire the brix level. Data was collected after every 3 days in both treatments. TSS was then expressed as ^{o}brix. The data presented is on fresh weight basis.

3.3.5.7 Overall shelf-life

Total shelf life of the mango fruits was determined by counting number of days taken to reach the end stage. End stage was based on firmness and visual appearance at which the fruit was saleable.

3.3.6 Data Analysis

The data collected was analyzed using GenStat 15th Edition statistical program. Analysis of Variance (ANOVA) was used to test for significant differences among treatments for each parameter and means separated using Fischer's Protected least significant difference at P=0.05.

3.4 Results

3.4.1 Changes in air temperature and percentage relative humidity in the Coolbot™ cold room and ambient room

The initial temperature in the Coolbot™ cold room 16.9°C was pre-set 10(±2)°C, the recommended cold storage temperature for mango fruits. The pre-set temperature was attained within an hour and remained stable/constant during the 24-hour observation period. In the ambient room, the temperatures vacillated from 24.9°C to 32.8°C. The percentage relative humidity in the Coolbot™ cold room and ambient room ranged between 80.6%-92.6% and 40.4%-71.5% respectively (Figure 3.3).

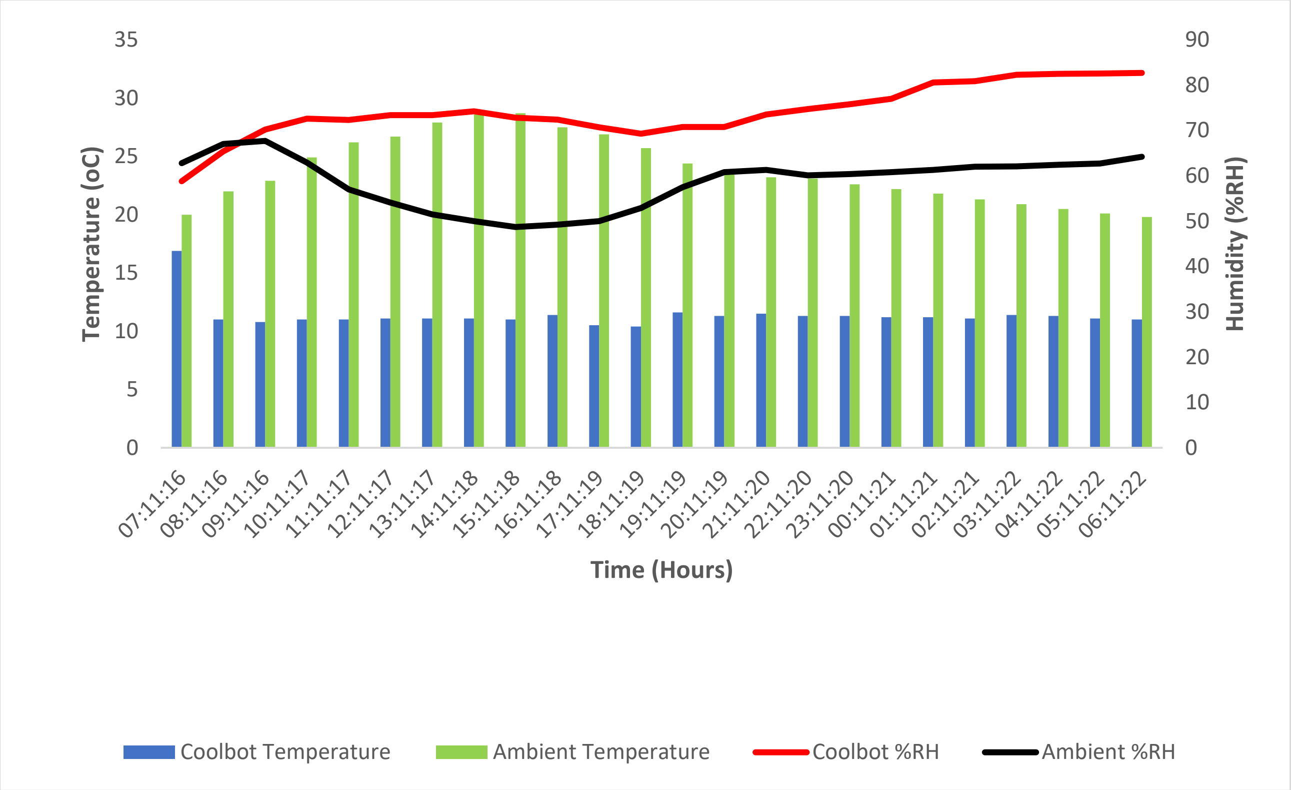


Figure 3.3: Differences in temperature (°C) and Relative Humidity (%) in the Coolbot™ cold room and ambient room during the first 24 hours of storage.

3.4.2 Fruit Pulp Temperature

The average internal pulp temperature was 16.4 °C and 31.4 °C for fruits harvested during the cool morning hours versus hot afternoon respectively. Upon arrival at the aggregation centre, pulp temperature of the fruits harvested in the morning averaged 27.5 °C while that of fruits harvested at midday averaged 33.4°C. After precooling, the pulp temperature stabilized at 22.2°C, 22.03°C, 22.1°C and 22.07°C for 'Apple', 'Ngowe', 'Kent' and 'Tommy Atkins' varieties respectively after 6 hours. There was a significant difference ($p>0.05$) in pulp temperature for fruits under proper cold chain practices and the fruits under poor cold chain management (farmers' practices). However, there was no significant distinction ($p>0.05$) between pulp temperatures of the different mango varieties used in the study (Table 3.1).

Table 3.1: Differences in pulp temperature (^{o}C) of four mango varieties as affected by harvest time, handling practices and cold storage

Variety	**Treatment**	**Days in Storage**												
		T0	**T1**	**3**	**6**	**9**	**12**	**15**	**18**	**21**	**24**	**27**	**30**	**33**
Apple	Cold Chain	16.3^{b}	27.4^{c}	10.9^{a}	10.6^{b}	11.8^{a}	11.5^{a}	11.5^{b}	11.2^{a}	11.4^{a}	11.5^{ab}	11.9^{ab}	12.6^{b}	
	No Cold Chain	31.6^{a}	33.5^{a}	23.5^{b}	24.2^{d}	24.8^{d}	22.3^{c}							
Kent	Cold Chain	16.5^{b}	27.8^{b}	10.8^{a}	10.5^{b}	12^{a}	11.4^{a}	11.5^{b}	11.3^{a}	11.4^{a}	11.7^{bc}	12.1^{b}	12.5^{ab}	12.8
	No cold chain	31.5^{a}	33^{a}	23.5^{b}	22.9^{bc}	23.6^{b}	22.2^{c}	20.7^{e}						
Ngowe	Cold Chain	16.3^{b}	27.5^{c}	11^{a}	11.2^{c}	12^{a}	11.5^{a}	10.6^{a}	11.1^{a}	11.8^{a}	11.9^{c}	11.7^{a}	12.4^{a}	
	No Cold Chain	31.6^{a}	33^{a}	23.5^{b}	24.4^{de}	24.3^{c}	22.8^{d}							
Tommy Atkins	Cold Chain	16.3^{b}	27.3^{c}	11^{a}	9.9^{a}	11.7^{a}	11.2^{a}	11.3^{b}	11.3^{a}	11.8^{a}	11.3^{a}	11.9^{ab}	12.5^{ab}	
	No Cold Chain	31^{a}	34^{a}	23.6^{b}	23.7^{e}	24.1^{c}	25.8^{b}							
Treat x Variety (LSD 0.05)		**0.66**	**0.66**	**0.48**	**0.46**	**0.45**	**0.37**	**0.48**	**0.4**	**0.6**	**0.27**	**0.4**	**0.19**	
%CV		**1.5**	**1.2**	**1.6**	**1.8**	**1.4**	**1.3**	**1.9**	**1.5**	**2.7**	**1.2**	**1.8**	**0.8**	

Means within each column followed by different letters differ significantly at (p>0.05). T0: Pulp Temperature immediately after harvest – in the field, T1: Pulp temperature upon arrival at the aggregation centre.

3.4.3 Percentage physiological weight loss (%PWL)

Physiological weight loss was recorded to be high in fruits under farmer practices (no cold chain). There was a significant difference ($p>0.05$) in percentage cumulative weight loss between fruits under proper cold chain practices and farmer practices. At the end of storage (day 30 – 33), fruits under proper cold chain practices recorded %PWL of 11.59%, 11.15%, 12.72% and 7.79% for ‘Apple’, ‘Ngowe’, ‘Kent’ and ‘Tommy Atkins’ varieties respectively. The fruits under farmer practices recorded significantly high PWL at the end of storage (day 12 – 15) averaging 14.96%, 13.46%, 17.71% and 12.96% for ‘Apple’, ‘Ngowe’, ‘Kent’ and ‘Tommy Atkins’ varieties respectively (Table 3.2).

Table 3.2: Changes in % cumulative weight loss of four mango varieties as affected by harvest time, handling practices and cold storage

Variety	**Treatment**	**Days in storage**											
		0	**3**	**6**	**9**	**12**	**15**	**18**	**21**	**24**	**27**	**30**	**33**
Apple	Cold Chain	0.00	1.66^{a}	2.57^{a}	3.19^{a}	4.51^{a}	5.00^{a}	7.70^{b}	8.47^{b}	9.58^{b}	10.62^{b}	11.59^{b}	
	No Cold Chain	0.00	4.09^{b}	8.35^{c}	11.30^{c}	14.96^{b}							
Kent	Cold Chain	0.00	1.52^{a}	3.10^{a}	3.79^{a}	4.57^{a}	5.63^{a}	7.26^{ab}	7.99^{b}	9.62^{b}	10.57^{b}	11.51^{b}	12.72
	No Cold Chain	0.00	3.45^{b}	7.68^{bc}	10.47^{bc}	13.98^{b}	17.71^{c}						
Ngowe	Cold Chain	0.00	1.75^{a}	2.65^{a}	3.54^{a}	4.77^{a}	5.58^{a}	6.99^{ab}	7.99^{b}	9.22^{b}	10.16^{b}	11.15^{b}	
	No Cold Chain	0.00	3.75^{b}	8.01^{c}	10.85^{bc}	13.46^{b}							
Tommy Atkins	Cold Chain	0.00	1.76^{a}	2.19^{a}	2.58^{a}	3.07^{a}	3.90^{a}	5.10^{a}	5.43^{a}	6.53^{a}	7.19^{a}	7.79^{a}	
	No Cold Chain	0.00	3.62^{b}	6.78^{b}	9.40^{b}	12.95^{b}							
Treat x Variety (LSD 0.05)			**0.97**	**1.38**	**1.79**	**2.31**	**2**	**2.2**	**1.52**	**1.89**	**1.6**	**1.8**	
CV (%)			**20.8**	**15.3**	**14.9**	**14.7**	**13.1**	**11.4**	**10.8**	**13.9**	**8.8**	**9.1**	

Means within each column followed by different letters differ significantly at (p>0.05)

3.4.4 Peel and Flesh Colour

The peel colour of the fruits gradually changed from green to yellow as the fruits ripened while the flesh colour gradually changed from whitish yellow to full yellow. Hue angles for fruits under farmer practices steadily decreased as the fruits ripened faster in comparison to fruits under proper cold chain practices. Peel colour of fruits decreased from the initial hue angle value of 110.33°, 130.72°, 112.28° and 111.12° for ‘Apple’, ‘Kent’, ‘Ngowe’ and ‘Tommy Atkins’ varieties respectively to 73.89°, 101.29°, 77.34° and 85.11° at the end of storage for fruits under proper cold chain management. In comparison, the hue angle of fruits under poor cold chain management was significantly lower; 61.85°, 102.37°, 55.8° and 52.30° respectively at the end of storage, which was much earlier compared to fruits under proper cold chain management (Table 3.3a).

Similarly, flesh colour decreased from initial hue angle value of 87.19°, 89.41°, 91.22° and 89.12° for ‘Apple’, ‘Kent’, ‘Ngowe’ and ‘Tommy Atkins’ varieties respectively to 66.87°, 62.19°, 73.58° and 64.20° at the end of storage for fruits under proper cold chain management. On the other hand, hues of fruits under poor cold chain management decreased to 63.80°, 66.52°, 66.0° and 71.95° respectively at the end of storage, approximately 18 days earlier compared to fruits under proper cold chain practice. (Table 3.3b).

Table 3.3a: Changes in peel hue angles (H^{o})of four mango varieties as affected by harvest time, handling practices and cold storage

Variety	**Treatment**	**Days in storage**											
		0	**3**	**6**	**9**	**12**	**15**	**18**	**21**	**24**	**27**	**30**	**33**
Apple	Cold Chain	110.33^{a}	104.87^{bc}	102.67^{cd}	98.05^{d}	96.66^{b}	96.09^{a}	90.46^{a}	82.29^{a}	81.41^{a}	74.60^{a}	73.89^{a}	
	No Cold Chain	110.33^{a}	96.96^{a}	86.75^{a}	74.20^{b}	61.85^{a}							
Kent	Cold Chain	130.72b	130.53^{e}	128.63^{e}	124.49^{f}	123.83^{c}	122.69^{c}	122.07^{d}	120.28^{b}	119.58^{b}	108.09^{b}	104.22^{c}	101.29
	No Cold Chain	130.72^{b}	130.47^{e}	128.53^{e}	119.04^{f}	108.42^{c}	102.37^{c}						
Ngowe	Cold Chain	112.28^{a}	111.40^{cd}	104.14^{d}	103.07^{de}	98.81^{b}	98.14a^{b}	96.47^{ab}	94.53^{a}	86.30^{a}	81.41^{a}	77.34^{abc}	
	No Cold Chain	112.28^{a}	98.95^{ab}	94.45^{bc}	84.14^{c}	55.80^{a}							
Tommy Atkins	Cold Chain	111.12^{a}	111.01^{d}	105.92^{d}	103.06^{e}	102.08^{b}	98.61a^{b}	97.94^{ab}	96.02^{a}	95.89^{a}	88.74^{a}	85.11^{ab}	
	No Cold Chain	111.12^{a}	97.85^{ab}	72.74^{ab}	70.15^{a}	52.30^{a}							
Treat x Variety (LSD 0.05)		**4.12**	**7.78**	**11.10**	**6.63**	**9.93**	**11.95**	**15.30**	**16.95**	**18.86**	**19.39**	**24.16**	
CV(%)		**2.00**	**4.00**	**6.10**	**3.90**	**6.40**	**6.10**	**8.20**	**9.10**	**10.80**	**11.80**	**16.30**	

Means within each column followed by different letters differ significantly at (p>0.05)

Table 3.3b: Changes in flesh hue angles (H°) of four mango varieties as affected by harvest time, handling practices and cold storage

Variety	**Treatment**	**Days in Storage**											
		0	**3**	**6**	**9**	**12**	**15**	**18**	**21**	**24**	**27**	**30**	**33**
Apple	Cold Chain	87.19^{a}	85.05^{c}	84.24^{c}	83.18^{de}	77.29^{c}	73.96^{bc}	72.05^{ab}	71.88^{a}	70.80^{a}	67.68^{a}	66.87^{a}	
	No Cold Chain	87.19^{a}	71.75^{a}	71.51^{a}	66.98^{a}	63.80^{a}							
Kent	Cold Chain	89.41^{bc}	89.30^{d}	88.99^{e}	88.64^{f}	87.85^{d}	84.56^{e}	84.33^{f}	83.48^{d}	81.12^{c}	78.98^{c}	77.99^{c}	62.19
	No Cold Chain	89.41^{bc}	89.41^{d}	82.04^{d}	81.50^{cd}	71.62^{c}	66.52^{a}						
Ngowe	Cold Chain	91.12^{ab}	88.33^{d}	86.73^{e}	85.94^{ef}	84.66^{d}	84.00^{e}	83.67^{e}	81.99^{c}	81.61^{c}	74.96^{bc}	73.58^{b}	
	No Cold Chain	91.12^{ab}	80.46^{b}	78.39^{b}	75.17^{b}	66.00^{b}							
Tommy Atkins	Cold Chain	89.12^{abc}	87.60^{d}	83.42^{be}	83.20^{f}	80.74^{d}	80.00^{de}	78.94^{de}	76.92^{d}	73.69^{b}	71.22^{b}	64.20^{b}	
	No Cold Chain	89.12^{abc}	81.76^{c}	80.77^{c}	75.66^{c}	71.95^{b}							
Treat x Variety (LSD 0.05)		**10.15**	**3.82**	**2.73**	**3.13**	**3.13**	**3.62**	**3.82**	**2.47**	**3.24**	**3.90**	**6.19**	
CV (%)		**6.20**	**2.50**	**1.90**	**2.20**	**2.30**	**2.50**	**2.70**	**1.60**	**2.20**	**2.70**	**4.50**	

Means within each column followed by different letters differ significantly at ($p>0.05$)

3.4.5 Peel and Flesh Firmness

Peel and flesh firmness decreased gradually as the fruits ripened, regardless of the treatment and variety. Peel firmness of fruits under poor cold chain practices decreased from the initial 110.2N, 153.1N, 118.5N and 115.1N to 22.7N, 18.9N, 30.1N and 29.6N for 'Apple', 'Ngowe', 'Kent' and 'Tommy Atkins' varieties respectively at the end of the storage. Fruit under proper cold chain practices decreased to 7.7N, 6.7N, 15.9N and 9N for 'Apple', 'Ngowe', 'Kent' and 'Tommy Atkins' varieties respectively at the end storage, 18 days earlier compared to fruits under proper cold chain management (Table 3.4a).

Similar trends were recorded in flesh firmness of fruits under the study. Flesh firmness of fruits under poor cold chain practices decreased from initial 36.6N, 45.9N, 66.5N and 46.8N to 3.1N, 2.4N, 3.2N and 3.1N for 'Apple', 'Ngowe', 'Kent' and 'Tommy Atkins' varieties respectively at the end of storage while fruits under proper cold chain practices decreased to 2.3N, 1.5N, 3.9N and 2.9N for 'Apple', 'Ngowe', 'Kent' and 'Tommy Atkins' varieties respectively on the final day of storage (Table 3.4b).

Table 3.4a: Changes in peel firmness (N) of four mango varieties as affected by harvest time, handling practices and cold storage

Variety	**Treatment**	**Days in storage**											
		0	**3**	**6**	**9**	**12**	**15**	**18**	**21**	**24**	**27**	**30**	**33**
Apple	Cold Chain	110.22^{a}	103.08^{bc}	95.73^{bc}	85.42^{d}	65.28^{c}	63.47^{cd}	54.20^{ef}	50.22^{b}	30.48^{b}	15.02^{a}	7.78^{a}	
	No Cold Chain	110.22^{a}	55.47^{b}	45.91^{a}	27.13^{a}	22.68^{a}							
Kent	Cold Chain	153.08^{c}	146.13^{e}	122.47^{e}	117.02^{f}	101.97^{e}	101.33^{e}	86.95^{g}	72.52^{c}	49.93^{c}	40.68^{b}	16.22^{b}	15.92
	No Cold Chain	153.08^{c}	141.43^{e}	116.90^{d}	67.78d	40.15^{b}	30.08^{ab}						
Ngowe	Cold Chain	118.52^{ab}	107.90^{d}	103.22^{c}	64.98^{c}	60.27^{c}	58.22^{bc}	44.75^{de}	42.43^{a}	22.72^{a}	7.93a	6.73^{a}	
	No Cold Chain	118.52^{ab}	34.88^{a}	32.77^{a}	25.28^{a}	18.92^{a}							
Tommy Atkins	Cold Chain	115.08^{ab}	105.93^{cd}	102.42^{c}	95.10^{e}	94.62^{d}	64.32^{d}	61.30^{f}	41.97^{a}	24.45^{ab}	10.93^{a}	9.02^{a}	
	No Cold Chain	115.08^{ab}	113.90^{c}	84.95^{b}	47.10^{b}	39.57^{b}							
Treat x Variety (LSD 0.05)		**16.97**	**13.25**	**14.45**	**12.14**	**14.23**	**12.46**	**12.34**	**6.43**	**7.70**	**15.05**	**4.44**	
CV (%)		**7.40**	**7.30**	**8.90**	**9.70**	**13.80**	**11.50**	**15.70**	**6.70**	**12.80**	**22.60**	**23.00**	

Means within each column followed by different letters differ significantly at (p>0.05)

Table 3.4b: Changes in flesh firmness (N) of four mango varieties as affected by harvest time, handling practices and cold storage

Variety	**Treatment**	**Days in storage**											
		0	**3**	**6**	**9**	**12**	**15**	**18**	**21**	**24**	**27**	**30**	**33**
Apple	Cold Chain	36.55^{a}	32.50^{b}	31.90^{b}	25.13^{c}	22.85^{c}	17.13^{bc}	14.58^{abc}	6.73^{a}	5.96^{a}	4.60^{ab}	2.27^{a}	
	No Cold Chain	36.55^{a}	10.12^{a}	6.92^{a}	3.62^{a}	3.13^{a}							
Kent	Cold Chain	66.47^{b}	49.57^{d}	42.57^{c}	31.07^{d}	20.48^{d}	20.43^{d}	17.50^{c}	10.92^{a}	9.05^{b}	6.13^{b}	5.85^{b}	3.95
	No Cold Chain	66.47^{b}	41.78^{cd}	11.22^{a}	8.05^{ab}	6.80^{ab}	3.20^{ab}						
Ngowe	Cold Chain	45.98^{a}	36.35^{bc}	32.67^{b}	19.13^{bc}	11.88^{b}	9.52^{abc}	8.82^{abc}	7.57^{a}	6.02^{a}	2.78^{a}	1.49^{a}	
	No Cold Chain	45.98^{a}	6.45^{a}	4.82^{a}	4.68^{a}	2.42^{a}							
Tommy Atkins	Cold Chain	46.75^{a}	40.82^{bc}	35.63^{b}	33.02^{c}	25.58^{c}	18.60^{c}	15.25^{bc}	11.27^{a}	6.53^{a}	3.59^{a}	2.95^{a}	
	No Cold Chain	46.75^{a}	38.22^{b}	7.05^{a}	6.48^{a}	3.15^{ab}							
Treat x Variety (LSD 0.05)		**12.78**	**13.47**	**9.87**	**11.58**	**8.38**	**12.9**	**10.88**	**9.31**	**1.8**	**8.3**	**2.16**	
CV(%)		**15**	**22**	**25.3**	**28.1**	**23.2**	**21.6**	**27.6**	**21.3**	**12.6**	**22.5**	**23.3**	

Means within each column followed by different letters differ significantly at (p>0.05)

3.4.6 Total Soluble Solids (TSS)

Total soluble solids increased as the fruits ripened regardless of the treatment and variety. The TSS for fruits under poor cold chain practices increased from the initial 8.47^{o}brix, 6.7 ^{o}brix, 5.63 ^{o}brix and 8.7 ^{o}brix to 22.63 ^{o}brix, 20.23 ^{o}brix, 13.9 ^{o}brix and 18.23 ^{o}brix for ‘Apple’, ‘Ngowe’, ‘Kent’ and ‘Tommy Atkins’ varieties respectively at the end of storage while for fruits under proper cold chain practices increased to 19.43^{o}brix, 20.2 ^{o}brix, 14.03 ^{o}brix and 15.90 ^{o}brix for ‘Apple’, ‘Ngowe’, ‘Kent’ and ‘Tommy Atkins’ varieties respectively at the end of storage (Table 3.5).

Table 3.5: Changes in Total Soluble Solids, TSS (Fresh weight) of four mango varieties on fresh weight basis as affected by harvest time, handling practices and cold storage

Variety	**Treatment**	**Days in storage**											
		0	**3**	**6**	**9**	**12**	**15**	**18**	**21**	**24**	**27**	**30**	**33**
Apple	Cold Chain	8.47^{c}	8.60^{bc}	10.03^{b}	10.10^{b}	10.20^{b}	12.13^{b}	13.13^{bcd}	14.20^{bc}	15.00^{b}	15.10^{b}	19.43^{b}	
	No Cold Chain	8.47^{c}	9.07^{bc}	12.93^{c}	13.37^{d}	22.63^{g}							
Kent	Cold Chain	5.63^{a}	6.63^{a}	6.67^{a}	6.80^{a}	8.97^{a}	9.20^{a}	10.43^{a}	11.17^{a}	11.53^{a}	13.00^{a}	13.33^{a}	14.03
	No Cold Chain	5.63^{a}	7.10^{bc}	9.40^{b}	11.50^{bc}	12.80^{c}	13.90^{cd}						
Ngowe	Cold Chain	6.70^{b}	10.10^{c}	10.93^{b}	11.53^{c}	14.80^{d}	15.90^{e}	16.63^{de}	16.93^{c}	17.83^{c}	18.03^{c}	20.20^{b}	
	No Cold Chain	6.70^{b}	13.67^{e}	17.47^{d}	19.73^{e}	20.23^{f}							
Tommy Atkins	Cold Chain	8.70^{c}	9.00^{b}	9.33^{a}	9.73^{b}	10.40^{a}	11.33^{cd}	12.07^{ab}	13.17^{ab}	13.20^{a}	14.67^{b}	15.90^{a}	
	No Cold Chain	8.70^{c}	11.97^{d}	12.23^{c}	15.20^{d}	18.23^{e}							
Treat x Variety (LSD 0.05)		**0.85**	**1.34**	**1.53**	**1.66**	**1.13**	**1.07**	**2.93**	**3.00**	**1.59**	**1.65**	**3.18**	
CV (%)		**6.70**	**8.00**	**8.30**	**7.60**	**4.50**	**4.50**	**11.90**	**12.00**	**5.90**	**5.60**	**9.80**	

Means within each column followed by different letters differ significantly at (p>0.05)

3.4.7 Overall shelf life

Fruits under poor cold chain practices had a shorter shelf life of 12 days for ‘Apple’, ‘Ngowe’ and ‘Tommy Atkins’ varieties and 15 days for ‘Kent’ variety. On the other hand, fruits under proper cold chain practices had a longer shelf life of 30 days for ‘Apple’, ‘Ngowe’ and ‘Tommy Atkins’ varieties and 33 days for ‘Kent’ variety (Figure 3.4).

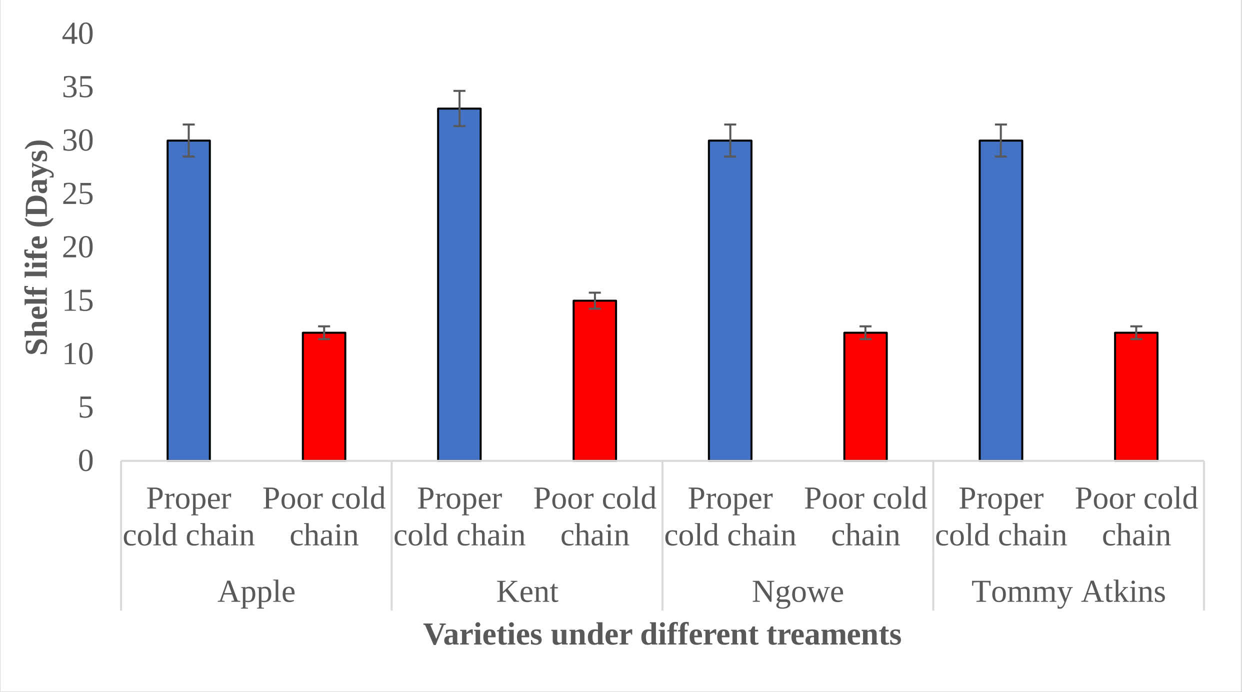


Figure 3.4: Overall shelf life of four mango varieties (‘Apple’, ‘Kent’, ‘Ngowe’ and ‘Tommy Atkins’) as affected by different harvest time, handling practices and cold storage. Top Bars represent S.E of means (P≤0.05)

3.5 Discussion

Temperature management to maintain a proper cold-chain for fresh horticultural produce is key to preservation of quality and reduction of post-harvest losses in perishable commodities (Atanda et al., 2011, Katsoulas et al., 2001; Aung and Chang, 2014; Thompson et al., 2008). For smallholder horticultural farmers with limited resources, simple harvest practices coupled with low-cost cold storage can used to achieve desirable cold chain. In the present study, the effectiveness of these practices and technologies was evaluated in mango fruits. The study evaluated proper cold chain practices or poor cold chain practices (farmer practices) in four mango varieties namely ‘Apple’, ‘Ngowe’, ‘Kent’ and ‘Tommy Atkins’. The effect of the two cold chain options (proper and poor cold chain) on ripening related changes (physiological weight loss, hue angle, firmness and total soluble solids) and the overall shelf life of the fruits was evaluated.

Harvest time greatly affected the pulp temperature with fruits that were harvested during hotter hours of the day recording high pulp temperatures due to high heat load. Horticultural produce accumulate heat during harvesting and postharvest handling and this reduces their storage quality (Venema et al., 2005). High heat load is one of the major causes of deterioration in harvested commodities (Arah et al., 2015). Harvesting and handling perishable produce under cool temperatures is critical for postharvest quality preservation (Arah et al., 2015). Fruits harvested during hot hours of the day should be pre-cooled immediately to remove field heat and slow physiological processes (Kathryn and James, 2004; Johnson and Hofman, 2009). Previous studies have shown that delayed cooling for just one hour can result in one day loss of shelf life (Paull, 1999). Pre-cooled fruits have reduced rate of metabolic activities leading to quality preservation and shelf life extension (Karithi, 2016). Precooling can be done either by hydrocooling, vacuum cooling and/or forced air cooling depending on the commodity and cost benefit associated with it (Jobling, 2001). For smallholder farmers, evaporative coolers can be used to pre-cool fruits and vegetables prior to refrigerated transport and storage (Ambuko et al., 2018a). Precooling also improves cold-resisting ability and minimizes chilling injury on fresh produce (Thompson et al., 1998). Rapid removal of field heat by precooling before storage is critical for efficient running of the cold storage facility (Brosnan and Sun, 2001). Evaporative coolers have been used to achieve cool temperatures necessary for pre-cooling and short term storage of harvested horticultural produce (Islam and Morimoto, 2012; Jahun et al., 2016; Tolesa and Workneh, 2018)

Proper cold chain management significantly reduced the rate of ripening related changes including physiological weight loss, peel and flesh colour, peel and flesh firmness, increase in TSS, ultimately increasing the shelf life of mango fruits by an additional 18 days.

Physiological weight loss (PWL) increased progressively in all the fruits during storage regardless of the treatment. However, the rate of PWL was slower under proper cold chain management. Physiological weight loss in harvested commodities results into shorter shelf life and loss of quality through wilting and shrivelling (Rathore et al., 2007). The higher weight loss in fruits under poor cold chain management practices can be attributed to high temperature and low humidity. The rate of physiological weight loss and shrivelling is dependent on respiration and transpiration and is accelerated with high temperature and low humidity (Abiso et al. 2015). Under proper cold chain management practices, minimal water loss through transpiration and substrate breakdown during respiration was because of low temperatures and high humidity. This condition creates a low vapor pressure deficit (VPD) around the fruit, leading to slowed water loss from the fruits to the surrounding air. Similar results of reduced water loss under low temperatures and high humidity has been reported in mango (Karithi, 2016; Waskar et al., 1997), avocado (Blakey et al., 2011) and guava (Mahajan et al., 2009).

Colour is an important indicator of ripeness and freshness in fruits. In the present study, peel and flesh colour (measured as hue angle) gradually decreased as fruits ripened regardless of the treatment (cold chain practice) and variety. Decrease in hue angles was faster in fruits subjected to poor cold chain management practices hence the shorter shelf life recorded. The slower colour change in fruits under proper cold chain management practices can be attributed to low temperatures leading to reduced metabolic activities. Low temperatures also slow down ethylene biosynthesis and processes triggered by ethylene in ripening fruits such as chlorophyll degradation by chlorophyll oxidase (Beaudry, 2000). Artes et al., (2006) also attributes colour changes to delay in the biosynthesis of anthocyanins and carotenoids resulting from the reduced metabolic processes due to low temperatures in proper cold chain practices. The inhibition of metabolic and enzymatic reactions responsible for ripening due to low temperature has previously been reported in mango (Hafeez et al., 2012; Montalvo et al., 2007), strawberry (Nunes et al., 2003) and indigenous fruits such as Ber (Tembo et al., 2008).

Peel and flesh firmness decreased as fruits ripened regardless of the treatment and variety. At the end stage for fruits under poor cold chain practices, firmness had decreased to less than 50% while the fruits under proper cold chain practices remained firmer till day 30 (‘Apple’, ‘Ngowe’, ‘Tommy Atkinns’) and day 33 (‘Kent’) varieties respectively. Decrease in fruit firmness is attributed to activities of enzymes involved in cell metabolism; depolymerization of cell wall pectin (Cheng et al., 2009; Jarimopas and Kitthawee, 2007). The enzymes include pectin methylesterase (PME), polygalacturonase (PG), endo-B-1,4-glucanase (EGase) and pectatelyase (Lazan et al., 1995). The high firmness retention in fruits under proper cold chain management practices are as a result of low temperatures that could have slowed down the activities of the enzymes involved in cell wall degradation and softening. Reduced transpiration in fruits under proper cold chain due to high humidity and low temperature could also explain high firmness in fruits stored under such conditions since they remained turgid due to minimal moisture loss (Tigist et al., 2013). The finding of the present study are in line with previous studies on the effect of low temperatures on firmness of mango (Ambuko et al., 2018b), avocado (Blakey et al., 2011) and apple fruits (Khorshidi et al., 2010).

Total soluble solids (TSS) increased gradually in all the treatments. Increase in TSS is attributed to breakdown of starch into simple sugar as ripening progresses (Siddiqui et al., 2009). Fruits under poor cold chain practices had faster increase in TSS and over a shorter period time as compared to the fruits under proper cold chain practices. For example, 'Apple' mango under poor cold chain practices had TSS of 22.63^{o}brix on day 12, compared to 19.43^{o}brix on day 30 under proper cold chain management. High increase in TSS of fruits under warmer conditions in poor cold chain management could be attributed to high respiration rate and other enzymatic and metabolic activities (Saranwong et al., 2003). This increase can also be attributed to higher activity by enzymes involved in the breakdown of starch. TSS is variety-dependent hence the observed significant difference among the 4 mango varieties used in the present study (Moraru et al., 2004; Tigist et.al., 2013). The finding of this present study concurs with similar studies previously done on mango (Karithi, 2016), passion fruit (Kishore et al., 2011), apple (Khorshidi et al., 2010), grapefruit (Pailly et al., 2004) and tangerine citrus (Hassan et al., 2014).

3.6 Conclusions

Overall, proper cold chain practices extended shelf life of mango fruits as they remained saleable until day 30 ('Apple', 'Ngowe', 'Tommy Atkinns') and day 33 ('Kent'). The shelf life of the fruits under proper cold chain management was 18 days longer compared to that of fruits under poor cold chain practices. The shelf life of fruits under proper cold chain practices was enhanced by a synergistic effect of proper time of harvest (cooler times of the day), pre-cooling and subsequent storage at low temperature and high humidity. This ultimately resulted in a slowed down rate of ripening and deterioration of the fruits during storage. Harvesting produce such as mango early in the morning (before 8 am) or during cool hours of the day; transport in refrigerated trucks or using dampened newspapers to simulate evaporative cooling; precooling to remove field heat using evaporative coolers and the cold storage in the Coolbot^{TM} cold room can be recommended to actors along the mango value chain.

CHAPTER FOUR

4.0 Evaluation of Effectiveness of Low-Cost Cold Storage Options to Preserve Post-Harvest Quality of Mango Fruit

4.1 Abstract

Mango is a highly perishable fruit that requires optimal storage conditions to preserve postharvest quality. Sub-optimal conditions, especially with regard to temperature contribute to fast deterioration of harvested mango fruits. Proper storage conditions, including cold storage are critical for preservation of quality of perishable produce. There are various low-cost storage technologies that have been shown to preserve quality of perishable produce. However, there is little or no information on their comparative capacity to preserve the postharvest quality of perishable produce such as mango fruit. Therefore, an experiment was carried out in Embu County of Kenya to compare the effectiveness of different low-cost storage technologies to preserve quality and extend the shelf life of mango fruits. Mango fruits, 'Apple' and 'Kent' varieties were harvested at mature green stage from for 6-10 years old trees in selected farms. The fruits were further selected for homogeneity and then divided into 10 batches of 60 fruits each. The batched fruits were subjected to the five treatments (storage conditions) including: Coolbot™ cold room (10±2^{o}C, 75±20%RH), Evaporative Charcoal cooler, ECC (20±5^{o}C, 95±5%RH), Zero energy brick cooler, ZEBC (20±5^{o}C, 90±10%RH), Wakati™ tent (25±5^{o}C, 95±5%RH) and ambient room conditions (25±5^{o}C, 55±15%RH). For each storage option, one batch of the fruits were packaged using Activebag® modified atmosphere packaging (MAP) and the second batch left unpackaged. The experiment was laid out as a completely randomized design with a factorial arrangement of treatments. The air and fruit pulp temperatures during storage were monitored regularly using HUATO® data loggers. Three fruits per treatment were sampled after every 3 days to evaluate ripening-related changes including physiological weight loss, colour, firmness, TSS and TTA. In addition, changes in quality attributes including B-carotene, sugars, and vitamin C were determined. The experiment was repeated in the same season to validate the findings. Storage of mango fruits under the various cold storage technologies significantly increased the fruits' shelf life. The shelf life of 'Kent' mango fruits was extended by 18, 9, 9 and 9 days more in the Coolbot™ cold room, ECC, ZEBC and Wakati™ tent respectively compared to fruits stored at ambient room conditions. Packing the fruits in MAP extended the shelf life by an additional 6 – 9 days under the different storage options. Slow progression of ripening and deterioration was evidenced by changes in colour, firmness (softening) and physiological weight loss which were significantly slowed down by cold storage and MAP. Cool storage and MAP packaging significantly ($p>0.05$) slowed down the rate of Vitamin C loss. In ‘Kent’ variety, vitamin C decreased from initial 105.37mg/100g to 46.85mg/100g (ambient), 51.18mg/100g (ZEBC), 51.75mg/100g (ECC), 50.80mg/100g (Wakati™) and 56.05mg/100g (Coolbot™).

The findings show the effectiveness of the studied storage technologies to extend the shelf life and preserve the postharvest quality of mango fruits. The Coolbot™ cold room can be recommended for mango value chain actors who have access to electricity. On the other hand, the evaporative cooling technologies are ideal in areas without electricity (off-grid). Application of these technologies could therefore extend the marketing period and reduce postharvest losses in the mango value chain.

Keywords: Evaporative cooling, ZEBC, Coolbot™, Charcoal Cooler, Postharvest, Wakati™

4.2 Introduction

The high postharvest losses along the mango value chain are attributed to various factors including pre and postharvest pest and diseases, poor harvesting practices, poor handling and transportation practices, limited and inappropriate cool storage facilities, lack of value addition capacity and overall poor coordination of value chain actors (Yahaya and Mardiyya, 2019).

High postharvest losses in mango (40-45%) are attributed to biological factors (respiration and transpiration) and environmental factors. The rate of deterioration as a result of biological factors is aggravated by environmental (external) factors, including temperature, humidity, air, atmospheric gases composition, and sanitation procedures (Kader, 2005). Of all the environmental factors, temperature plays a central role in commodity deterioration (Kader and Rolle, 2004). An increase in temperature by 10°C increases deterioration rate by 2-3 folds (Q_{10}) in perishable commodity such as mango (Kader, 2005). Temperature lower or higher than the optimal range for fresh produce can result in rapid deterioration due to freezing, chilling injury and heat injury disorders (Kader and Rolle, 2004). Apart from temperature, the relative humidity and gaseous composition in and around the fruit plays a key role in determining the fruit shelf life once harvested. Moisture holding capacity of air increases with temperature. At high temperatures, there is increased relative humidity and precipitation (Ishida et al., 2016). Water loss is directly proportional to vapor pressure deficit (VPD) between the commodity and its environment. On the other hand, VPD is inversely proportional to the relative humidity of the air surrounding the commodity (Kader and Rolle, 2004). The optimal relative humidity range for storage of fruits is 85-95% (Kader and Rolle, 2004). Relative humidity affects the quality preservation of harvested commodity as it influences water loss, decay development, incidence of some physiological disorders and uniformity of ripening (Kader and Rolle, 2004).

Preservation of the quality and extension of the shelf life of harvested fruits requires application of good postharvest handling practices and technologies. Examples of applicable low-cost technologies that have application in fruits and vegetables include coolbot™ cold room, evaporative charcoal cooler, the Zero energy brick cooler and the Wakati™ tent.

The Coolbot™ is an electric powered gadget fitted on the air conditioner and installed in insulated walls to make a cold room that works as a conventional cold room as described in section 3.3.3 above. The Coolbot™ gadget turns an insulated air conditioned room into a cold room that can achieve and maintain cold temperatures by overriding the thermostat of the air conditioner to enable it to cool further (lower than 18^{o}C) without ice developing on the fins (Ambuko et al., 2018a). The initial cost of setting up and operational costs of a Coolbot™ cold room is low compared to a conventional cold room, owing to low electricity consumption. In addition, previous studies have shown that the Coolbot™ cold room does not break down easily requiring frequent repair and maintenance costs (Dubey, 2011). For instance, it would cost as low as 3,500 USD to build a 1 tonne capacity Coolbot™ cold room compared to >10,000 USD for a conventional cold room of the same capacity (Karithi, 2016; Kitinoja, 2013). The Coolbot™ cold room can also be powered using a simple solar powered inverter, making it easy for the farmers to harness the available sunlight in areas where mangoes grow. These makes the Coolbot™ cold room relatively affordable to the smallholder farmer, especially if they are organized in groups. However, the Coolbot™ cold room should be kept closed most times to achieve the set temperatures. In addition, it is not efficient with temperatures under 2^{o}C and may require additional technologies and/or practices such as modified atmospheric packaging (MAP), waxing and humidification to minimize wilting effects caused by forced air movement by fans used in the air conditioner (Karithi, 2016). The Coolbot™ cold room has successfully been used in extension of shelf life and quality preservation of perishable commodities such as mango, flower, potatoes, turnips, tomatoes and beans (Ambuko et al., 2018b; Ambuko et al., 2018c).

Evaporative cooling technology is another efficient and economical means for reducing temperature while increasing the relative humidity in an enclosed structure for storage of perishable harvested horticultural produce with the aim of enhancing their shelf life (Lal Basediya et al., 2013). These technologies work on the principle of evaporative cooling by using induced processes of heat and mass transfer where water and air are working fluids/media (Camargo, 2008). There are various forms of evaporative cooling technologies that include the evaporative charcoal cooler (ECC) and the zero energy Brick cooler (ZEBC) (Ambuko et al., 2018a). Cooling inside the evaporative cooling chambers is achieved by forcing hot air over a wetted pad or medium that holds water (Sand/charcoal). As water in the wetted pad evaporates, it draws heat from the surrounding air while absorbing moisture thus creating a cooling effect (Lal Basediya et al., 2013). The greater the evaporation the greater the cooling effect, because with no net evaporation of water no cooling effect is achieved (Lal Basediya et al., 2013). Evaporative coolers are effective in areas with high temperatures and can lower temperatures by 10-15^{o}C lower than the ambient temperature making it appropriate for short duration storage of fruits and vegetables soon after harvest (Kitinoja, 2013). They also increase the relative humidity (>90%) around the product ensuring they remain fresh longer with minimal water loss thus preserving quality and extending shelf life (Verploegen et al., 2019). Fabrication from locally available materials makes evaporative coolers well adapted and affordable (Ndukwu and Manuwa, 2014). Evaporative coolers are environmentally friendly and do not require any electricity or any other form of energy to run them, making them the most economical means of preserving quality of harvested produce (Getinet et.al., 2011). Evaporative coolers are limited with size hence low capacity of storage especially in the case of ZEBC, ambient relative humidity and water availability (Brian, 2013). Zero energy brick cooler and evaporative charcoal cooler have been evaluated in Malawi and have proved to extent tomato shelf life by 12 days and 10 days respectively (Manyozo et al., 2018). Islam and Morimoto (2012) have also reported use of ZEBC to extend the shelf life of tomato and eggplant by 9 and 5 days respectively. Previous studies also show that shelf life and quality of Coriander leaves, fenugreek leaves, spinach, tomato, green onion, carrot, radish, peas, papaya, sapota, orange, plum and grapes have been enhanced by storage in evaporative coolers (Dadhich et al., 2008).

The Wakati™ is a solar powered tent-like box that can be used to store freshly harvested produce to extend shelf life and preserve quality. Inside the tent, is a ventilator powered by a 3-watt solar panel. The ventilator evaporates water to create a humidified environment to keep the stored produce fresh with minimal water loss and shrivelling and free of moulds (Hardiansyah, 2018). The water vapor in the chamber also creates ozone gas which oxidizes ethylene produced by the fruits into CO_2 and water (Gykiere and Pauwels, 2017). Even though the Wakati™ tent technology does not lower temperature, stored produce remains fresh due to high humid inside the chamber that minimizes water loss from the produce and keeps the produce turgid (Gykiere and Pauwels, 2017). This technology is meant for short term storage since the temperatures are not regulated (Hardiansyah, 2018). Unit cost for the Wakati™ is 100 USD making it affordable to the smallholder farmer. It may be used in the crop field, on transit, at the market by traders or at home by the consumer. However, Wakati™ tents are small in size limiting the capacity of the product that can be stored in the chamber (approximately 100kgs of freshproduce). Wakati™ tent has been used in Haiti, Afghanistan, Tanzania and Uganda to extend shelf-life of fruits and vegetables (Hardiansyah, 2018).

Modified atmospheric packaging (MAP) involves packaging fruits and vegetables in a polymeric film where CO_2 and O_2 are modified. MAP preserves fruit quality and slows down deterioration by inhibiting ethylene production, decreased respiration (Singh and Rao, 2005), reduced water loss and reduced attack from pathogens. MAP helps maintain freshness and therefore quality of the product is prolonged (Valero and Serrano, 2010). There are various products designed specially to achieve MAP for fruits and vegetables. An example of these special MAP products is Activebag® bag which is impregnated with ethylene, CO_2 and O_2 absorbers and anti-microbial compounds resulting in increased freshness and minimal spoilage during storage (Githiga et al., 2015). In forced air cooling the use of MAP in evaporative coolers and cold rooms helps to maintain an environment of low vapor pressure deficit (VPD) around the stored produce thereby preventing water loss and wilting (Ambuko et al., 2018b). Modified atmospheric packaging has been used to extent shelf life fruits and vegetables including mangoes (Githigaet al.,2015). MAP has also been used to enhance the effectiveness of cold storage and/or other technologies. For example, Kelany et al., (2010) reported extended shelf life by 6 more weeks in 'Kent' mangoes when cold storage (temperature at $10^{o}C$) is combined with MAP compared to 2-3 weeks of cold storage alone. In 'Apple' mango when cold storage under Coolbot™ room was complemented with MAP, the shelf life was extended by an additional 5 day compared to fruits that were stored in open crates (Ambuko et al., 2018b).

Past studies in these technologies have been done separately to evaluate the effectiveness of each technology. Comparative studies to compare the effectiveness of the various storage technologies have not been done. Therefore, the objective of this study was to evaluate the effectiveness of selected cold storage technologies (Coolbot™ cold room, ECC, ZEBC) and Wakati™ technology in combination with modified atmosphere packaging to preserve quality and extend the shelf life of 'Apple' and 'Kent' mango fruits.

4.3 Materials and Methods

4.3.1 Study site

As described in section 3.3.1

4.3.2 Test Fruit Samples

The fruits used were ‘Apple’ and ‘Kent’ mango varieties. The maturity indices used are as described in section 3.3.2

4.3.3 Description of Storage facilities

Five storage technologies namely; Coolbot™ cold room, Evaporative Charcoal Cooler, Zero Energy Brick Cooler and Wakati™ were used in the study. Each of the storage technologies was complemented with modified atmosphere packaging (Activebag®). The various technologies are described below.

4.3.3.1 Coolbot™ cold room

As described in section 3.3.3

4.3.3.2 Evaporative Charcoal Cooler

As described in section 3.3.3

4.3.3.3 Zero Energy Brick Cooler (ZEBC)

The Zero Energy Brick Cooler (figure 4.1) was constructed onsite in Karurumo-Embu County. ZEBC is an on farm rural oriented storage structure which operates on the principal of evaporative cooling. A 3m x 2m double walled bricks were raised with baked bricks and riverbed sand used to fill the space between. The bricks overlaid on each other and were not interconnected using cement for free air circulation. On top of the filled riverbed sand, ran a dripline connected to a raised overhead tank for keeping the sand wet. Watering was done by opening little amounts of water in form of droplets that kept the sand wet without flooding/overflowing. During hot hours of the day when ambient temperatures are high, hot air from outside the chamber flows in heating water in wet sand which evaporates as vapor and latent heat leaving a cooling effect (low temperature and high humidity) inside the chamber. The top cover was made from polyvinyl materials (moisture absorbent and allows free air movement) hinged to an aluminium frame. The whole structure is covered by a roof to provide a shade against direct sunlight.

Figure 4.1: Side-view of the Zero Energy Brick Cooler (Source: Karurumo Smallholder aggregation and processing center, Embu County)

4.3.3.4 Wakati™ Tent Technology

The Wakati™ tent technology (figure 4.2) is solar-powered tent-like storage structure that contains a ventilator that runs the fans which gradually creates vapor from water to keep the chamber humidified. The Wakati™ tent was sourced from Wakati BVBA (a Belgian company) and was installed onsite in Karurumo, Embu County. The vaporization process also converts O_2 in water into ozone gas that oxidizes ethylene gas produced by the fruit into CO_2 and water, therefore keeping the produce fresh. The tent is 2M X 1M and can hold up to 150kgs of produce. The water in the ventilator is re-filled after every 3 – 4 days. The Wakati™ tent is kept under a shade to avoid direct sunlight while the 3-watt solar panel is positioned on top of the roof for maximize harnessing of the solar energy.

Figure 4.2: Wakati™ Tent (Source: Karurumo Smallholder aggregation and processing center, Embu County)

4.3.4 Modified Atmospheric Bags

Activebag® modified atmospheric bags were used as complementary technology for the four storage technologies. Activebag® (A45), sourced from Amiran Kenya is a polymeric film package that modifies atmospheric gaseous composition (by lowering O_2 and elevating CO_2 levels) within the package. The effectiveness of modified atmosphere packaging depends on the type, permeability, thickness of the film, and the amount of fruit contained.

4.3.5 Experimental Design

Mature green 'Apple' and 'Kent' mango fruits were harvested from selected farms, mixed then sorted for uniformity and divided into 10 batches of 60 fruits each. The fruits were subjected to various storage conditions including: Coolbot™ cold room (10±2^{o}C, 75±20%RH), Evaporative Charcoal cooler (20±5^{o}C, 95±5%RH), Zero energy brick cooler (20±5^{o}C, 90±10%RH), Wakati™ tent (25±5^{o}C, 95±5%RH) and ambient room conditions (25±5^{o}C, 55±15%RH). For each storage option, one batch of the fruits was packaged using Activebag® modified atmosphere packaging (MAP) and the second batch left unpackaged. The experiment was laid out as a completely randomized design with a factorial arrangement of treatments. For each storage option HUATO® data loggers (Model HE17x, Huato Electric Co., Ltd, Shenzhen, China) were fitted to monitor air and fruit pulp temperatures during the storage period. The results presented are for one of the experiments because a similar trend was observed in the two experiments.

4.3.6 Data Collection

Three fruits were randomly sampled after every 3 days and used to determine ripening-related physiochemical and nutritional analysis. The experiment was repeated consecutively within the same season and the results are for one of the experiments since the results from the repeated experiments were similar.

4.3.6.1 Changes in physical parameters

4.3.6.1.1 Temperature and relative humidity

This was determined as described in section 3.3.5.1

4.3.6.1.2 Pulp Temperature

This was determined as described in section 3.3.5.2

4.3.6.1.3 Cumulative weight loss

This was determined as described in section 3.3.5.3

4.3.6.1.4 Peel and flesh colour

This was determined as described in section 3.3.5.4

4.3.6.1.5 Peel and flesh firmness

This was determined as described in section 3.3.5.5

4.3.6.2 Changes in biochemical fruit quality attributes

4.3.6.2.1 Total soluble solids (TSS)

This was determined as described in section 3.3.5.6

4.3.6.2.2 Titratable acidity

Titration was done to determine the total titratable acidity of the fruits as they ripened. 5ml of the extracted juice was diluted with 25ml of distilled water. 10ml of the diluted juice was titrated with 0.1N Sodium Hydroxide using phenolphthalein as an indicator. The TTA expressed as % citric acid using the equation;

% Citric acid equivalent = Sample reading (ml)*Dilution factor/sample weight (ml)*Citric acid factor (0.0064)*100

The data presented is on fresh weight basis.

4.3.6.2.3 Vitamin C content

Vitamin C content was determined according to AOAC method (Hernández et al., 2006). 5mls of the extracted juice was topped up with 10% trichloroacetic acid (TCA) in 100ml volumetric flask. The indicator (2,6-dichlophenolindophenol-DCPIP) was added into 10ml of the fruit juice extracted. Ascorbic acid content determined as follows:

$$\text{Ascorbic acid (mg/100ml)} = (A-B) \times C \times 100/S \times (50/5)$$

Where,

A = volume in ml of indophenol solution used in the sample.

B = Volume (in ml) of indophenol solution used for the blank.

C = Mass (in mg) of ascorbic acid equivalent to 1 ml of standard indophenol solution.

S = Weight of the sample taken (in ml)

50/5 = total extraction volume/volume of titrated sample

The data presented is on fresh weight basis.

4.3.6.2.4 Beta-carotene

Beta-carotene content was determined using a modified chromatographic procedure. 5ml of extracted juice was mixed with 50ml of acetone to extract the carotenoids then filtered using a glass funnel. In a separating funnel, 25ml of petroleum ether was used for partitioning to obtain the upper layer which is wealthy in beta-carotene. Washing was done three times using distilled water to eliminate acetone residues while keeping the upper phase. Anhydrous sodium sulphate was then added to remove water on the upper phase stored in sample bottles. The β-carotene content was determined using High Performance Liquid Chromatography (HPLC) (Model LC-10AS, Shimadzu Corp, Kyoto, Japan) and samples read at 450nm. B-carotene content was determined as follows:

$$\beta\text{−carotene (mg/100ml)} = A*\text{Volume (ml)}*104$$

$$A^{1\%}_{1cm}\ *\text{sample weight (ml)}$$

Where,

A= Absorbance

Volume = Total volume of extract (25 ml)

$A^{1\%}_{1cm}$ = Absorption coefficient of β−carotene in Petroleum ether (2592).

The data presented is on fresh weight basis.

4.3.6.2.5 Major soluble Sugars (Fructose, Glucose and Sucrose)

AOAC method was used to examine sugars (fructose, sucrose and glucose) in the sampled mango fruits. 5ml of extracted juice was mixed with 50ml distilled water. 2ml of lead acetate was added to the diluted juice and mixed thoroughly. The solution was filtered in 5% anhydrous oxalate and then micro-filtered. Individual sugars were analyzed using a high-performance liquid chromatography (HPLC) (Model LC-10AS, Shimadzu Corp, Kyoto, Japan) fitted with a refractive index (RI) detector and running under the following conditions: Oven temperature: 30^{o}C, Flow rate: 0.5-1.0 ml/min, Injection volume: 20 µL and mobile phase: Acetonitrile: water (75:25). Sugars present were distinguished and their individual concentration calculated using the standards. The data presented is on fresh weight basis.

4.3.6.3 Overall shelf-life

This was determined as described in section 3.3.5.7

4.3.7 Data Analysis

The data collected was analyzed using GenStat 15th Edition statistical program. Analysis of Variance (ANOVA) was used to test for significant differences among treatments for each parameter and means separated using Fischer’s Protected least significant difference at P=0.05.

4.4 Results

4.4.1 Changes in physiological parameters

4.4.1.1 Changes in air temperature and percentage relative humidity

Prior to the experimental set up, the Coolbot™ Cold room was set to optimal storage conditions for mango, temperature (10±2°C) and percentage relative humidity (75±20%RH). The other storage options had the following conditions: Evaporative Charcoal cooler (20±5°C, 95±5%RH); Zero energy brick cooler (20±5°C, 90±10%RH); Wakati™ tent (25±5°C, 95±5%RH) and ambient room conditions (25±5°C, 55±15%RH) as shown in figure 4.3.

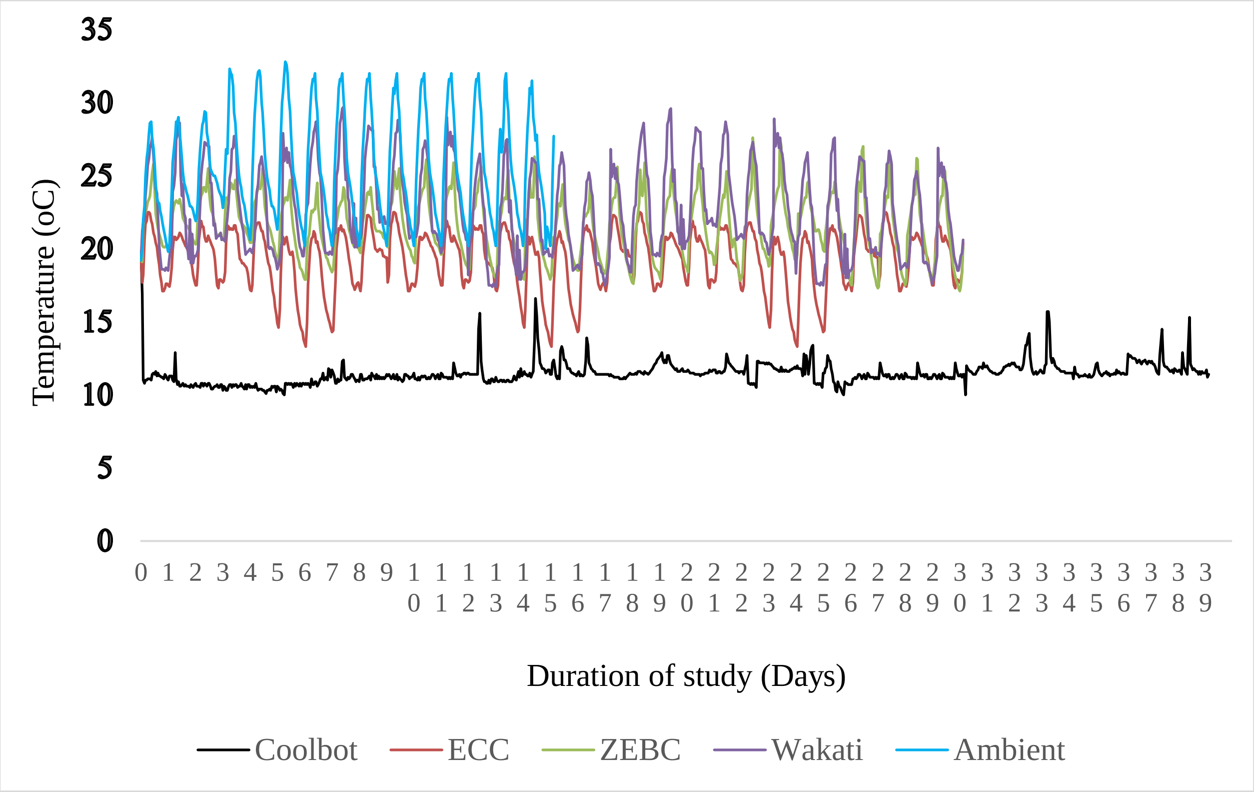


Figure 4.3: Differences in temperature (°C) in the different storage options (Coolbot™ cold room, ECC, ZEBC, Wakati™ tent and ambient room) during the storage period.

4.4.1.2 Internal Pulp Temperatures

The fruit internal temperatures of both mango varieties, whether packaged or unpackaged fluctuated as per the prevailing conditions of the respective storage option. There was significant difference ($p>0.05$) in internal pulp temperatures of mangoes in Coolbot™ Cold room as compared to the rest of the storage option. However, there was no significant difference ($p>0.05$) in internal pulp temperature amongst the 'Apple' and 'Kent' mango varieties as well fruits packaged and fruits in open crates (Table 4.1a and 4.1b).

Table 4.1a: Changes in Internal Pulp Temperature (^{o}C) in ‘Apple’ mango fruits harvested at mature green maturity stages and stored under different storage options with or without Activebag® modified atmosphere packaging.

Storage Option	**Packaging**	**Days in Storage**											
		0	**3**	**6**	**9**	**12**	**15**	**18**	**21**	**24**	**27**	**30**	**33**
Ambient	Packaged	25.6^{e}	25.0^{e}	23.8^{g}	25.1^{e}	24.2^{f}	21.3^{e}						
Ambient	Unpackaged	25.4^{e}	25.4^{e}	24.7^{h}	25.9^{ef}	23.5^{e}							
ZEBC	Packaged	23.4^{d}	24.4^{d}	20.7^{d}	23.1^{d}	21.8^{d}	19.8^{c}	22.4^{d}	21.1^{h}				
ZEBC	Unpackaged	23.7^{d}	24.1^{d}	20.8^{d}	22.9^{d}	20.8^{c}	20.5^{d}	21.9^{d}					
ECC	Packaged	19.8^{b}	20.2^{c}	18.0^{c}	21.3^{c}	18.9^{b}	18.4^{b}	18.3^{b}	19.3^{f}				
ECC	Unpackaged	20.7^{c}	20.8^{c}	18.3^{c}	21.0^{c}	18.4^{b}	18.7^{b}	18.4^{b}					
Coolbot™	Packaged	11.4^{a}	11.1^{b}	9.3^{a}	13.2^{b}	12.2^{a}	10.9^{a}	11.8^{a}	12.2^{b}	12.2^{b}	11.8^{a}	12.7^{a}	13.1
Coolbot™	Unpackaged	10.8^{a}	10.4^{a}	10.5^{b}	11.3^{a}	11.6^{a}	11.2^{a}	11.3^{a}	11.9^{a}	11.4^{a}	11.3^{a}	12.6^{a}	
Wakati™	Packaged	25.2^{e}	25.6^{e}	22.8^{f}	26.5^{f}	25.1^{g}	24.2^{f}	24.3^{e}	22.6^{i}				
Wakati™	Unpackaged	25.5^{e}	25.2^{e}	21.7^{e}	26.7^{f}	22.3^{d}	23.9^{f}	24.6^{e}					
Storage x Packaging (LSD 0.05)		**0.63**	**0.58**	**0.29**	**0.92**	**0.59**	**0.45**	**0.58**	**0.33**	**0.69**	**0.54**	**0.35**	
CV (%)		**1.7**	**1.6**	**0.9**	**2.5**	**1.7**	**1.4**	**1.7**	**1.0**	**2.6**	**2.1**	**1.2**	

Means within each column followed by different letters differ significantly at ($p>0.05$)

Table 4.1b: Changes in Internal Pulp Temperature (^{o}C) in ‘Kent’ mango fruits harvested at mature green maturity stages and stored under different storage options with or without Activebag® modified atmosphere packaging.

Storage Option	**Packaging**	**Days in Storage**													
		0	**3**	**6**	**9**	**12**	**15**	**18**	**21**	**24**	**27**	**30**	**33**	**36**	**39**
Ambient	Packaged	25.5^{ef}	26.0^{h}	23.1^{g}	24.6^{e}	23.5^{de}	22.6^{e}								
Ambient	Unpackaged	25.1^{de}	23.1^{e}	24.1^{h}	25.1^{f}	23.1^{de}									
ZEBC	Packaged	23.5^{c}	24.8^{g}	20.1^{e}	23.0^{d}	18.5^{bc}	20.4^{d}	20.8h	21.3^{e}	20.8^{f}	20.7^{h}	19.2^{f}			
ZEBC	Unpackaged	23.7^{c}	24.2^{f}	20.3^{e}	22.8^{d}	21.0^{cd}	20.6^{d}	21.4^{g}	21.5^{e}						
ECC	Packaged	20.0^{b}	20.3^{c}	17.6^{c}	20.8^{c}	18.5^{bc}	18.5^{c}	18.0^{c}	19.0^{cd}	17.9c	19.1^{f}	19.4^{f}			
ECC	Unpackaged	19.8^{b}	21.1^{d}	18.8^{d}	20.9^{c}	18.0^{b}	18.8^{c}	18.3^{cd}	19.3^{d}						
Coolbot™	Packaged	10.9^{a}	10.7^{a}	12.4^{b}	12.4^{b}	11.7^{a}	11.6^{a}	11.8^{b}	11.6^{a}	11.6^{a}	11.8^{b}	12.6^{a}	13.3^{a}	12.8	13.0
Coolbot™	Unpackaged	10.8^{a}	12.0^{b}	11.3^{a}	11.5^{a}	11.3^{a}	12.3^{b}	10.9^{a}	11.6^{a}	11.7^{a}	10.9^{a}	12.4^{a}	12.3^{a}		
Wakati™	Packaged	25.1^{d}	24.9^{g}	22.9^{g}	25.5^{f}	25.4^{e}	24.3^{f}	24.6^{i}	22.3^{f}	21.3^{g}	25.0^{j}	18.3^{e}			
Wakati™	Unpackaged	25.6^{f}	24.5^{fg}	21.6^{f}	26.5^{g}	24.5^{e}	23.8^{f}	23.7^{h}	22.4^{f}						
Storage x Packaging (LSD 0.05))		**0.37**	**0.43**	**0.45**	**0.39**	**2.86**	**0.50**	**0.52**	**0.36**	**0.35**	**0.54**	**0.59**	**0.29**		
CV (%)		**1.0**	**1.2**	**1.4**	**1.1**	**8.6**	**1.5**	**1.6**	**1.1**	**1.1**	**1.7**	**1.9**	**1.0**		

Means within each column followed by different letters differ significantly at (p>0.05)

4.4.1.3 Percentage Cumulative Weight loss

Percentage cumulative weight loss increased as all fruits ripened. Storage in Coolbot™ cold room significantly (p>0.05) aided the fruits to retain their initial weight (9.27% for ‘Apple’ and 11.44% for ‘Kent)’ followed by evaporative coolers. Fruits on open crates under ambient room temperature lost most of their initial weight (15.10% for ‘Apple’ variety and 18.44% for ‘Kent’ variety) by the end of marketable stage (Day 12) compared to 2.43% and 0.95% for ‘Apple’ and ‘Kent’ varieties respectively stored in the Coolbot™ cold room on the same day. ‘Apple’ mango stored in evaporative charcoal cooler, zero energy brick cooler and Wakati™ tent lost 9.27%, 9.01% and 13.21% respectively while the ‘Kent’ mango stored in the same storage options lost 11.44%, 8.74%, and 14.56% respectively by the end of their shelf life. Combination of cool storage and MAP significantly (p>0.05) reduced percentage cumulative weight loss. All fruits in cool storage and packaged in MAP retained fruit weight by the end of their shelf life. Packaged ‘Apple’ mango recorded %CWL of 1.55%, 2.65%, 2.37%, 3.15% and 3.88% for Coolbot™, charcoal cooler, brick cooler, Wakati™ tent and ambient conditions respectively by the end of their shelf life (Table 4.2a). Likewise, ‘Kent’mango recorded 1.46%, 1.38%, 1.97%, 2.43% and 1.07% respectively at the end of their shelf life (Table 4.2b).

Table 4.2a: Changes in Cumulative weight loss (%) in ‘Apple’ mango fruits harvested at mature green maturity stages and stored under different storage options with or without Activebag® modified atmosphere packaging.

Storage Option	**Packaging**	**Days in Storage**											
		0	**3**	**6**	**9**	**12**	**15**	**18**	**21**	**24**	**27**	**30**	**33**
Ambient	Packaged	0.00	0.49^{a}	1.40^{b}	1.58^{b}	2.43^{b}	3.88^{c}						
Ambient	Unpackaged	0.00	3.78^{d}	7.89^{f}	11.33^{f}	15.10^{f}							
ZEBC	Packaged	0.00	0.30^{a}	0.59^{a}	0.96^{ab}	1.33^{ab}	1.63^{ab}	2.07^{bc}	2.37^{b}				
ZEBC	Unpackaged	0.00	1.74^{bc}	4.57^{e}	6.31^{e}	8.89^{e}	11.05^{e}	13.21^{f}					
ECC	Packaged	0.00	0.48^{a}	0.56a	0.88^{ab}	1.28^{ab}	1.44^{ab}	2.09^{bc}	2.65^{bc}				
ECC	Unpackaged	0.00	$1.75b^{c}$	3.28^{d}	4.75^{d}	6.64^{d}	7.90^{d}	9.01^{e}					
Coolbot™	Packaged	0.00	0.09^{a}	0.26^{a}	0.26^{a}	0.52^{a}	0.77^{a}	0.77^{ab}	0.95^{a}	1.12^{a}	1.29^{a}	1.38^{a}	1.55
Coolbot™	Unpackaged	0.00	1.33^{b}	2.53^{c}	3.16^{c}	4.07^{c}	5.20^{c}	6.46^{d}	7.16^{f}	8.08^{b}	8.99^{b}	9.27^{b}	
Wakati™	Packaged	0.00	0.20^{a}	0.67^{a}	1.67^{b}	2.01^{ab}	2.35^{b}	2.75^{c}	3.15^{c}				
Wakati™	Unpackaged	0.00	1.94^{c}	3.87^{de}	6.64^{e}	9.04^{e}	11.16^{e}	13.38^{f}					
Storage x Packaging (LSD 0.05)			**0.45**	**0.73**	**1.10**	**1.55**	**1.54**	**1.78**	**0.83**	**1.95**	**2.13**	**2.01**	
CV (%)			**21.6**	**16.6**	**17.2**	**17.7**	**16.3**	**16.6**	**14.0**	**18.6**	**18.2**	**16.6**	

Means within each column followed by different letters differ significantly at (p>0.05)

Table 4.2b: Changes in Cumulative weight loss (%) in ‘Kent’ mango fruits harvested at mature green maturity stages and stored under different storage options with or without Activebag® modified atmosphere packaging.

Storage Option	**Packaging**	**Days in Storage**													
		0	**3**	**6**	**9**	**12**	**15**	**18**	**21**	**24**	**27**	**30**	**33**	**36**	**39**
Ambient	Packaged	0.00	0.39^{a}	0.56^{a}	0.62^{a}	0.95^{a}	1.07^{a}								
Ambient	Unpackaged	0.00	4.57^{d}	9.28^{d}	13.29^{d}	18.14^{e}									
ZEBC	Packaged	0.00	0.13^{a}	0.26^{a}	0.33^{a}	0.52^{a}	0.79^{a}	1.05^{a}	1.31^{a}	$1.51b^{c}$	1.77^{bc}	1.97^{bc}			
ZEBC	Unpackaged	0.00	2.39^{c}	3.98^{c}	5.9^{7c}	8.02^{d}	10.69^{d}	12.74^{d}	14.56^{d}						
ECC	Packaged	0.00	0.14^{a}	0.21^{a}	0.21^{a}	0.41^{a}	0.48^{a}	0.62^{a}	0.76^{a}	0.97^{ab}	1.17^{ab}	1.38^{ab}			
ECC	Unpackaged	0.00	1.49^{b}	2.37^{b}	3.42^{b}	4.96^{bc}	6.17^{bc}	7.60^{b}	8.71^{b}						
Coolbot™	Packaged	0.00	0.24^{a}	0.30^{a}	0.43^{a}	0.49^{a}	0.49^{a}	0.55^{a}	0.67^{a}	0.73^{a}	0.91^{a}	1.03^{a}	1.16^{a}	1.28	1.46
Coolbot™	Unpackaged	0.00	1.50^{b}	2.36^{b}	3.33^{b}	4.35^{b}	5.70^{b}	6.72^{b}	7.68^{b}	8.97^{d}	10.26^{d}	10.59^{d}	11.44^{c}		
Wakati™	Packaged	0.00	0.12^{a}	0.18^{a}	0.42^{a}	0.59^{a}	0.77^{a}	1.13^{a}	1.31^{a}	1.66^{c}	2.02^{c}	2.43^{c}			
Wakati™	Unpackaged	0.00	1.51^{b}	2.84^{b}	4.46^{b}	5.85^{c}	7.47^{c}	9.96^{c}	12.10^{c}						
Storage x Packaging (LSD 0.05)			**0.42**	**0.91**	**1.45**	**1.49**	**1.50**	**1.78**	**1.50**	**0.88**	**1.02**	**0.93**	**2.27**		
CV (%)			**19.9**	**23.8**	**20.8**	**19.8**	**21.3**	**20.4**	**17.3**	**15.7**	**15.6**	**13.2**	**15.8**		

Means within each column followed by different letters differ significantly at (p>0.05)

4.4.1.4 Peel Colour

Peel colour, expressed as hue angle, decreased in all fruits as they ripened. Cool storage reduced the rate of peel colour turning from green to yellow. Complimenting cool storage with MAP significantly ($p>0.05$) enhanced the green colour retention in ‘Apple’ mango varieties. ‘Apple’ mangoes stored on open crates in ambient conditions recorded lower hue angle reducing from 110.33^o to 59.53^o on day 12. The fruits in charcoal cooler, brick Cooler and Wakati™ tent had their hue angle reduced to 60.65^o, 56.57^o and 54.82^o respectively on day 18 while the Coolbot™ cold room recording 64.14^o on day 30. The ‘Apple’mango packaged in MAP bags recorded hue angles of 72.53^o, 55.33^o, 59.14^o, 58.18^o and 64.86^o in Coolbot™, charcoal cooler, brick cooler, Wakati™ tent and ambient conditions respectively at the end of their shelf life (Table 4.3a).

In ‘Kent’mangoes stored on open crates had the highest hue angle with most fruits retaining the green colour as they ripened, a morphological characteristic of the variety. The hue angle reduced from 130.72^o to 109.34^o, 117.40^o, 106.39^o, 105.06^o and 105.62^o in Coolbot™, charcoal Cooler, brick Cooler, Wakati™ tent and ambient conditions respectively at the end of their shelf life. Fruits packaged in MAP bags on other hand reduced to 53.46^o, 58.73^o, 57.06^o, 57.93^o and 58.02^o in Coolbot™, charcoal cooler, brick cooler, Wakati™ tent and ambient conditions respectively at the end of their shelf life (Table 4.3b).

Table 4.3a: Changes in Peel colour (H^{o}) in ‘Apple’ mango fruits harvested at mature green maturity stages and stored under different storage options with or without Activebag® modified atmosphere packaging.

Storage Option	**Packaging**	**Days in Storage**											
		0	**3**	**6**	**9**	**12**	**15**	**18**	**21**	**24**	**27**	**30**	**33**
Ambient	Packaged	110.33^{a}	100.79^{b}	93.70^{abc}	86.43^{cd}	75.35^{b}	64.86^{abc}						
Ambient	Unpackaged	110.33^{a}	94.85^{a}	88.01^{ab}	63.80^{a}	59.53^{a}							
ZEBC	Packaged	110.33^{a}	102.98^{b}	99.00^{c}	85.51^{def}	84.87^{bc}	77.44^{cd}	69.49^{cd}	59.14^{ab}				
ZEBC	Unpackaged	110.33^{a}	94.95^{a}	87.19^{abc}	76.96^{bc}	62.76^{a}	61.84^{a}	56.57^{ab}					
ECC	Packaged	110.33^{a}	98.52^{ab}	96.06^{bc}	88.75^{cde}	85.01^{cd}	72.18^{bc}d	69.11^{bcd}	55.33^{ab}				
ECC	Unpackaged	110.33^{a}	99.20^{ab}	93.14^{abc}	71.72^{ab}	62.95^{a}	61.65^{ab}	60.65^{abc}					
Coolbot™	Packaged	110.33^{a}	102.26^{b}	97.19^{c}	94.15^{ef}	93.22^{de}	87.05^{de}	86.78^{ef}	82.73^{c}	77.85^{a}	76.76^{a}	74.88^{a}	72.53
Coolbot™	Unpackaged	110.33^{a}	101.87^{b}	99.94^{c}	99.53^{f}	96.03^{e}	94.80^{e}	87.39^{f}	83.80^{c}	77.54^{a}	73.34^{a}	64.14^{a}	
Wakati™	Packaged	110.33^{a}	96.16^{ab}	93.96^{bc}	89.49^{def}	86.11^{cd}	79.39^{d}	64.48^{abcd}	58.18^{ab}				
Wakati™	Unpackaged	110.33^{a}	101.14^{b}	84.90^{a}	65.76^{ab}	65.21^{a}	60.08^{a}	54.82^{a}					
Storage x Packaging (LSD 0.05)		**4.83**	**5.56**	**12.02**	**10.72**	**8.73**	**13.12**	**11.60**	**15.87**	**12.99**	**11.61**	**15.71**	
CV (%)		**2.6**	**3.2**	**7.5**	**7.5**	**6.7**	**10.8**	**9.9**	**13.7**	**7.6**	**6.9**	**10.1**	

Means within each column followed by different letters differ significantly at (p>0.05)

Table 4.3b: Changes in Peel colour (H^{o}) in ‘Kent’ mango fruits harvested at mature green maturity stages and stored under different storage options with or without Activebag® modified atmosphere packaging.

Storage Option	**Packaging**	**Days in Storage**													
		0	**3**	**6**	**9**	**12**	**15**	**18**	**21**	**24**	**27**	**30**	**33**	**36**	**39**
Ambient	Packaged	130.72^{a}	105.26^{a}	93.27^{ab}	85.21^{a}	64.27^{ab}	58.02^{a}								
Ambient	Unpackaged	130.72^{a}	126.45^{a}	126.11^{bc}	112.46^{bc}	105.62^{abc}									
ZEBC	Packaged	130.72^{a}	126.13^{a}	118.79^{bc}	111.66^{bc}	108.40^{abc}	103.69^{ab}	97.30^{a}	85.12^{a}	75.07^{a}	64.32^{a}	57.06^{a}			
ZEBC	Unpackaged	130.72^{a}	128.63^{a}	126.96^{bc}	124.36^{bc}	124.14^{bc}	116.87^{ab}	109.35^{ab}	106.39^{ab}						
ECC	Packaged	130.72^{a}	126.27^{a}	125.70^{bc}	121.79^{bc}	119.62^{bc}	111.53^{ab}	102.25^{ab}	86.46^{a}	75.68^{ab}	61.83^{a}	58.73^{a}			
ECC	Unpackaged	130.72^{a}	127.26^{a}	126.51^{bc}	124.12^{bc}	123.27^{bc}	121.47^{abc}	120.87^{ab}	117.40^{ab}						
Coolbot™	Packaged	130.72^{a}	126.47^{a}	126.16^{bc}	123.17^{bc}	121.87^{bc}	121.60^{abc}	119.46^{bc}	112.58^{ab}	94.09^{bcd}	91.98^{abc}	88.14^{ab}	75.32^{a}	64.27	53.46
Coolbot™	Unpackaged	130.72^{a}	128.90^{a}	128.26^{c}	128.01^{c}	127.97^{c}	127.25^{c}	126.93^{c}	126.21^{b}	125.57^{e}	119.87^{d}	119.79^{b}	109.34^{c}		
Wakati™	Packaged	130.72^{a}	123.21^{a}	120.75^{bc}	118.49^{bc}	113.89^{bc}	106.65^{ab}	94.37^{a}	93.30^{a}	81.89^{ab}	74.31^{abc}	57.93^{a}			
Wakati™	Unpackaged	130.72^{a}	126.86^{a}	123.77bc	118.66^{bc}	114.10^{bc}	110.03^{ab}	107.04^{ab}	105.06^{ab}						
Storage x Packaging (LSD 0.05)		**8.53**	**9.52**	**8.78**	**10.11**	**12.50**	**12.73**	**12.95**	**22.44**	**8.76**	**15.28**	**31.63**	**10.47**		
CV (%)		**3.8**	**4.4**	**4.1**	**4.9**	**6.2**	**6.6**	**6.7**	**12.5**	**4.5**	**8.4**	**21.6**	**4.8**		

Means within each column followed by different letters differ significantly at ($p>0.05$)

4.4.1.5 Flesh Colour

Flesh colour of stored mango fruits reduced as fruits ripened. Cool storage reduced significantly ($p>0.05$) the rate at which the hue angle reduced as they ripened. Use of MAP bags with these cool storage options further slowed the lowering of the hue angle as fruits ripened. In ‘Apple’ mangoes on open crates, the hue angle reduced from initial 87.19^o to 68.43^o, 63.76^o, 64.97^o, 65.65^o and 62.86^o in Coolbot™ cold room, charcoal cooler, brick cooler, Wakati™ tent and ambient conditions respectively at the end of their shelf life. Packaged fruits recorded hue angles of 62.55^o, 63.48^o, 64.61^o, 62.55^o and 65.72^o in Coolbot™ cold room, charcoal cooler, brick cooler, Wakati™ tent and ambient conditions respectively at the end of their shelf life (Table 4.4a).

In ‘Kent’mangoes, the hue angle of unpackaged fruits reduced from the initial 89.41^o to 59.87^o, 63.92^o, 61.95^o, 63.12^o and 62.00^o in Coolbot™ cold room, charcoal cooler, brick cooler, Wakati™ tent and ambient conditions respectively at the end of their shelf life. MAP packaged fruits reduced to 62.8^o, 61.7^o, 62.89^o, 63.98^o and 59.35^o in Coolbot™ cold room, charcoal cooler, brick cooler, Wakati™ tent and ambient conditions respectively at the end of their shelf life (Table 4.4b).

Table 4.4a: Changes in Flesh Colour (H^{o}) in ‘Apple’ mango fruits harvested at mature green maturity stages and stored under different storage options with or without Activebag® modified atmosphere packaging.

Storage Option	**Packaging**	**Days in Storage**											
		0	**3**	**6**	**9**	**12**	**15**	**18**	**21**	**24**	**27**	**30**	**33**
Ambient	Packaged	87.19^{a}	79.96^{a}	79.21^{ab}	75.99^{ab}	68.82^{a}	65.72a						
Ambient	Unpackaged	87.19^{a}	79.31^{a}	71.60^{a}	67.82^{a}	62.86^{a}							
ZEBC	Packaged	87.19^{a}	85.15^{a}	81.24^{ab}	80.68^{b}	74.96^{ab}	70.57^{ab}	65.92^{d}	64.61^{ab}				
ZEBC	Unpackaged	87.19^{a}	81.92^{a}	78.58^{ab}	76.53^{ab}	67.06^{a}	66.38^{a}	64.97^{a}					
ECC	Packaged	87.19^{a}	86.45^{a}	80.80^{ab}	69.48^{a}	69.04^{a}	67.29^{a}	66.78^{d}	63.48^{ab}				
ECC	Unpackaged	87.19^{a}	78.49^{a}	75.86^{a}	67.63^{a}	65.80^{a}	65.44^{a}	63.76^{a}					
Coolbot™	Packaged	87.19^{a}	84.59^{a}	83.18^{b}	80.25^{b}	79.87^{b}	79.73^{bc}	76.85^{bc}	75.09^{cd}	74.07^{c}	71.98^{a}	67.44^{a}	62.55
Coolbot™	Unpackaged	87.19^{a}	86.86^{a}	85.16^{b}	83.81^{c}	77.37^{bc}	73.34^{b}	70.43^{ab}	70.32^{ab}	69.46^{a}	68.79^{a}	68.43^{a}	
Wakati™	Packaged	87.19^{a}	77.98^{a}	75.82^{a}	73.31^{ab}	71.08^{ab}	70.53^{ab}	65.36^{bc}	62.55^{a}				
Wakati™	Unpackaged	87.19^{a}	86.98^{a}	72.94^{a}	71.43^{ab}	68.95^{a}	66.68^{a}	65.65^{b}					
Storage x Packaging (LSD 0.05)		**1.74**	**13.24**	**11.12**	**6.24**	**8.22**	**7.57**	**6.59**	**7.48**	**3.52**	**8.81**	**11.60**	
CV (%)		**1.2**	**9.2**	**8.5**	**5.1**	**6.6**	**6.1**	**5.2**	**5.8**	**2.1**	**5.9**	**7.3**	

Means within each column followed by different letters differ significantly at (p>0.05)

Table 4.4b: Changes in Flesh Colour (H^{o}) in ‘Kent’ mango fruits harvested at mature green maturity stages and stored under different storage options with or without Activebag® modified atmosphere packaging.

Storage Option	**Packaging**	**Days in Storage**													
		0	**3**	**6**	**9**	**12**	**15**	**18**	**21**	**24**	**27**	**30**	**33**	**36**	**39**
Ambient	Packaged	89.41^{a}	87.33^{ab}	84.41^{b}	77.85^{ab}	61.71^{a}	59.35^{a}								
Ambient	Unpackaged	89.41^{a}	84.42^{a}	78.90^{ab}	69.60^{a}	62.00^{a}									
ZEBC	Packaged	89.41^{a}	88.78^{b}	86.17^{b}	84.79^{c}	81.58^{b}	79.16^{bc}	75.49^{abc}	75.40^{bcd}	71.61^{abc}	67.62^{a}	62.89^{a}			
ZEBC	Unpackaged	89.41^{a}	84.89^{a}	79.98^{ab}	77.27^{a}b	75.73^{b}	71.19^{ab}	69.62^{ab}	61.95^{a}						
ECC	Packaged	89.41^{a}	86.16^{ab}	84.00^{b}	82.73^{bc}	81.71^{b}	81.18^{bc}	79.64^{bc}	75.92^{cd}	69.10^{ab}	67.57^{a}	61.70^{a}			
ECC	Unpackaged	89.41^{a}	89.24^{ab}	87.49^{b}	85.42^{c}	80.54^{b}	72.72^{ab}	70.00^{ab}	63.92^{ab}						
Coolbot™	Packaged	89.41^{a}	87.81^{ab}	87.45^{b}	86.88^{c}	85.27^{b}	83.34^{bc}	80.26^{c}	78.49^{d}	77.53^{bc}	74.49^{b}	72.80^{c}	66.71^{a}	63.54	62.80
Coolbot™	Unpackaged	89.41^{a}	88.64^{ab}	87.26^{b}	84.31^{c}	81.91^{b}	79.97^{bc}	77.61^{c}	72.91^{bc}	70.14^{abc}	65.88^{a}	60.54^{a}	59.87^{a}		
Wakati™	Packaged	89.41^{a}	87.66^{ab}	86.28^{b}	80.11^{bc}	79.83^{ab}	79.36^{bc}	73.95^{bc}	71.48^{bc}	70.33^{abc}	68.81^{a}	63.98^{ab}			
Wakati™	Unpackaged	89.41^{a}	88.23^{ab}	86.83^{b}	85.49^{bc}	82.67^{b}	76.06^{ab}	70.88^{ab}	63.12^{a}						
Storage x Packaging (LSD 0.05)		**1.12**	**16.29**	**11.16**	**9.17**	**5.10**	**22.44**	**7.60**	**6.05**	**7.86**	**23.87**	**6.31**	**5.15**		
CV (%)		**0.7**	**10.1**	**7.1**	**6.2**	**3.4**	**15.6**	**5.0**	**4.2**	**5.3**	**18.5**	**4.3**	**2.7**		

Means within each column followed by different letters differ significantly at (p<0.05)

4.4.1.6 Peel Firmness

Peel firmness of all fruits decreased as ripening progressed. Fruits under cool storage experienced lower rate of fruit softening as compared to the fruits under ambient conditions. Combination of cool storage with MAP bags had significant effect ($p>0.05$) on the fruits hence taking long to soften and therefore minimum force needed to prick its peel. ‘Apple’ mangoes in open crates reduced in peel firmness from initial 110.2N to 7.25N, 7.45N, 6.3N, 5.0N and 26.85N in Coolbot™ cold room, charcoal cooler, brick cooler, Wakati™ tent and ambient conditions respectively at the end of their shelf life. Packaged ones reduced peel firmness to 4.8N, 3.4N, 3.65N, 7.6N and 18.60N in Coolbot™ cold room, charcoal cooler, brick cooler, Wakati™ tent and ambient conditions respectively at the end of their shelf life (Table 4.5a).

In ‘Kent’ mangoes, peel firmness for unpackaged fruits reduced from initial 153.0N to 14.70N, 6.7N, 5.7N 12.4N and 67.0N in Coolbot™ cold room, charcoal cooler, brick cooler, Wakati™ tent and ambient conditions respectively at the end of their shelf life. On other hand, packaged fruits reduced to 9.7N, 9.8N, 10.45N, 7.4N and 34.0N in Coolbot™ cold room, charcoal cooler, brick cooler, Wakati™ tent and ambient conditions respectively at the end of their shelf life (Table 4.5b).

Table 4.5a: Changes in Peel Firmness (N) in ‘Apple’ mango fruits harvested at mature green maturity stages and stored under different storage options with or without Activebag® modified atmosphere packaging.

Storage Option	**Packaging**	**Days in Storage**											
		0	**3**	**6**	**9**	**12**	**15**	**18**	**21**	**24**	**27**	**30**	**33**
Ambient	Packaged	110.22^{a}	76.38^{ab}	53.00^{a}	30.93^{a}	23.22^{ab}	18.60^{a}						
Ambient	Unpackaged	110.22^{a}	81.32^{ab}	43.92^{a}	27.87^{a}	26.85^{bc}							
ZEBC	Packaged	110.22^{a}	80.88^{ab}	72.90^{ab}	44.02^{bc}	37.97^{c}	11.98^{a}	4.16^{ab}	3.65^{ab}				
ZEBC	Unpackaged	110.22^{a}	93.13^{ab}	67.70^{ab}	38.00^{ab}	23.48^{ab}	7.50^{a}	6.33^{bcd}					
ECC	Packaged	110.22^{a}	89.17^{ab}	43.97^{a}	31.33^{ab}	25.03^{abc}	12.57^{a}	12.40^{c}	3.42^{ab}				
ECC	Unpackaged	110.22^{a}	71.23^{a}	41.78^{a}	40.18^{bc}	33.27^{c}	24.03^{a}	7.45^{bcd}					
Coolbot™	Packaged	110.22^{a}	103.43^{ab}	100.33^{c}	89.28^{d}	60.97^{d}	60.53^{b}	29.43^{d}	28.20^{cd}	23.40^{a}	18.56^{a}	14.83^{a}	4.83
Coolbot™	Unpackaged	110.22^{a}	107.88^{b}	102.97^{c}	101.43^{e}	101.03^{e}	59.47^{b}	41.63^{e}	38.35^{d}	29.75^{ab}	15.87^{a}	7.25^{a}	
Wakati™	Packaged	110.22^{a}	95.02^{ab}	52.70^{a}	33.94^{ab}	33.57^{c}	17.87^{a}	12.20^{c}	7.63^{ab}				
Wakati™	Unpackaged	110.22^{a}	95.53^{ab}	47.35^{a}	32.70^{ab}	18.65^{ab}	9.68^{a}	5.03^{a}					
Storage x Packaging (LSD 0.05)		**15.46**	**44**	**36.91**	**12.44**	**23.06**	**13.65**	**4**	**2.3**	**17.81**	**10.97**	**15.87**	
CV (%)		**8.2**	**28.7**	**14**	**16.3**	**23.4**	**20.5**	**16**	**9.4**	**17.7**	**7.6**	**21.5**	

Means within each column followed by different letters differ significantly at (p>0.05)

Table 4.5b: Changes in Peel Firmness (N) in ‘Kent’ mango fruits harvested at mature green maturity stages and stored under different storage options with or without Activebag® modified atmosphere packaging.

Storage Option	**Packaging**	**Days in Storage**													
		0	**3**	**6**	**9**	**12**	**15**	**18**	**21**	**24**	**27**	**30**	**33**	**36**	**39**
Ambient	Packaged	153.08^{a}	150.77^{b}	136.63^{bcd}	103.60^{bc}	101.40^{cd}	34.03^{a}								
Ambient	Unpackaged	153.08^{a}	142.82^{ab}	109.03^{a}	80.52^{a}	67.03^{a}									
ZEBC	Packaged	153.08^{a}	147.82^{ab}	131.25^{ab}	106.35^{bc}	56.83^{a}	40.12^{a}	39.02^{ab}	31.00^{bc}	28.20^{a}	12.10^{ab}	10.45^{ab}			
ZEBC	Unpackaged	153.08^{a}	141.47^{ab}	128.53^{ab}	98.04^{bc}	92.70^{a}b	45.55^{ab}	15.92^{a}	5.72^{abc}						
ECC	Packaged	153.08^{a}	142.23^{ab}	122.30^{ab}	112.92^{bc}	107.97^{c}	105.05^{c}	70.73^{cd}	52.90^{cde}	23.65^{a}	18.35^{bc}	9.88^{a}			
ECC	Unpackaged	153.08^{a}	144.93^{ab}	138.58^{bc}	123.72^{bc}	110.98^{d}	105.23^{c}	16.62^{a}	6.72^{abc}						
Coolbot™	Packaged	153.08^{a}	152.45^{b}	144.57^{d}	136.90^{bc}	119.00^{d}	102.78^{c}	76.03^{d}	68.68^{e}	42.65^{a}	35.83^{d}	25.57^{ab}	23.57^{a}	22.60	9.78
Coolbot™	Unpackaged	153.08^{a}	150.97^{ab}	148.82^{d}	143.57^{c}	122.77^{d}	86.95^{b}	67.37^{cd}	55.52^{de}	46.69^{a}	26.45^{c}	22.67^{b}	14.70^{a}		
Wakati™	Packaged	153.08^{a}	139.60^{a}	127.62^{ab}	103.20^{bc}	95.10^{ab}	41.97^{a}	39.10^{ab}	26.63^{abc}	24.07^{a}	16.63^{ab}	7.42^{ab}			
Wakati™	Unpackaged	153.08^{a}	146.00^{ab}	107.82^{a}	97.55^{ab}	57.55^{a}	46.73^{ab}	29.94^{ab}	12.43^{ab}						
Storage x Packaging (LSD 0.05)		**30.74**	**23**	**19.67**	**23.16**	**36.54**	**19.35**	**7.99**	**5.6**	**38.4**	**23.52**	**23.02**	**21.72**		
CV (%)		**11.5**	**8.8**	**7.6**	**12.8**	**23.8**	**17.3**	**25.3**	**18.1**	**19.8**	**19.1**	**18.2**	**18.9**		

Means within each column followed by different letters differ significantly at ($p>0.05$)

4.4.1.7 Flesh Firmness

All fruits reduced flesh firmness gradually as they ripened. Cooler environment had significant effect ($p>0.05$) effect on flesh firmness of the fruits as compared to ambient conditions. The interaction between cool storage and use of MAP further lowered the rate of fruit flesh softening. ‘Apple’ mangoes on open crates reduced in flesh firmness from the initial 36.55N to 3.8N, 3.5N, 1.15N, 1.5N, and 3.8N in Coolbot™ cold room, charcoal cooler, brick cooler, Wakati™ tent and ambient conditions respectively at the end of their shelf life. The packaged ‘Apple’mangoes reduced flesh firmness to 1.9N, 2.15N, 1.3N, 2.75N and 3.4N in Coolbot™ cold room, charcoal cooler, brick cooler, Wakati™ tent and ambient conditions respectively at the end of their shelf life (Table 4.6a).

‘Kent’mangoes stored directly on open crates reduced their flesh firmness from the initial 66.5N to 5.7N,3.1N, 3.55N, 2.05N and 6.3N while packaged fruits reduced to 2.0N, 2.95N, 1.3N, 2.75N and 3.4N in Coolbot™ cold room, charcoal cooler, brick cooler, Wakati™ tent and ambient conditions respectively at the end of their shelf life (Table 4.6b).

Table 4.6a: Changes in Flesh Firmness (N) in ‘Apple’ mango fruits harvested at mature green maturity stages and stored under different storage options with or without Activebag® modified atmosphere packaging.

Storage Option	**Packaging**	**Days in Storage**											
		0	**3**	**6**	**9**	**12**	**15**	**18**	**21**	**24**	**27**	**30**	**33**
Ambient	Packaged	36.55^{a}	14.45^{a}	6.90^{a}	5.87^{a}	5.18^{a}	3.37^{ab}						
Ambient	Unpackaged	36.55^{a}	16.84^{a}	7.42^{a}	4.33^{a}	3.82^{a}							
ZEBC	Packaged	36.55^{a}	18.45^{ab}	12.10^{ab}	5.57^{a}	5.02^{a}	3.67^{ab}	2.68^{ab}	1.35^{a}				
ZEBC	Unpackaged	36.55^{a}	21.85^{abc}	12.12^{ab}	7.08^{a}	4.28^{a}	3.33^{ab}	1.14^{ab}					
ECC	Packaged	36.55^{a}	36.05^{abc}	6.40^{a}	5.52^{a}	4.65^{a}	3.93^{ab}	3.87^{ab}	2.15^{ab}				
ECC	Unpackaged	36.55^{a}	24.22^{abc}	10.00^{ab}	5.53^{a}	4.80^{a}	4.17^{ab}	3.47^{ab}					
Coolbot™	Packaged	36.55^{a}	35.05^{c}	29.28^{c}	22.98^{a}	20.68^{b}	12.17^{cd}	12.07^{c}	7.15^{c}	4.82^{a}	4.63^{a}	3.52^{a}	1.87
Coolbot™	Unpackaged	36.55^{a}	33.70^{bc}	32.00^{c}	25.70^{b}	22.38^{c}	19.20^{d}	15.17^{cd}	6.95^{d}	5.72^{a}	5.07^{a}	3.83^{a}	
Wakati™	Packaged	36.55^{a}	20.48^{abc}	7.89^{a}	6.43^{a}	6.30^{a}	6.08^{ab}	5.15^{cd}	2.75^{ab}				
Wakati™	Unpackaged	36.55^{a}	29.55^{abc}	9.78a^{b}	8.73^{a}	4.77^{a}	4.62^{ab}	1.50^{ab}					
Storage x Packaging (LSD 0.05)		**16.92**	**24.64**	**16.24**	**15.49**	**9.52**	**4.87**	**2.22**	**0.82**	**6.44**	**6.97**	**3.91**	
CV (%)		**27.2**	**23.7**	**25.1**	**22.1**	**24.6**	**25.4**	**16.4**	**10.9**	**20.3**	**15.4**	**15.6**	

Means within each column followed by different letters differ significantly at (p>0.05)

Table 4.6b: Changes in Flesh Firmness (N) in ‘Kent’ mango fruits harvested at mature green maturity stages and stored under different storage options with or without Activebag® modified atmosphere packaging.

Storage Option	**Packaging**	**Days in Storage**													
		0	**3**	**6**	**9**	**12**	**15**	**18**	**21**	**24**	**27**	**30**	**33**	**36**	**39**
Ambient	Packaged	66.47^{a}	62.35^{ab}	60.42^{b}	40.88^{bc}	34.90^{cd}	11.37^{ab}								
Ambient	Unpackaged	66.47^{a}	56.07^{a}	38.67^{a}	8.58^{a}	6.27^{a}									
ZEBC	Packaged	66.47^{a}	64.82^{ab}	55.47^{ab}	46.42^{bc}	15.80^{ab}	14.44^{bc}	10.37^{abc}	4.88^{cd}	4.35^{a}	3.65^{a}	3.43^{ab}			
ZEBC	Unpackaged	66.47^{a}	58.47^{a}	55.42^{ab}	36.80^{b}	29.05^{bc}	16.51^{bc}	5.20^{ab}	3.55^{bcd}						
ECC	Packaged	66.47^{a}	66.05^{ab}	63.28^{b}	57.47^{c}	18.10^{ab}	17.73^{bc}	9.22^{ab}	7.62^{f}	6.28^{cde}	4.25^{a}	2.95^{ab}			
ECC	Unpackaged	66.47^{a}	61.02^{ab}	51.35^{ab}	50.12^{bc}	46.87^{de}	6.63^{a}	3.53^{ab}	3.10^{b}						
Coolbot™	Packaged	66.47^{a}	65.37^{ab}	58.33^{b}	56.53^{c}	48.07^{f}	21.85^{c}	20.22^{c}	13.73^{g}	10.90^{e}	9.73^{a}	8.37^{abc}	6.33^{a}	4.13	2.17
Coolbot™	Unpackaged	66.47^{a}	64.32^{ab}	61.95^{b}	58.47^{c}	56.22^{fg}	20.52^{c}	10.35^{c}	9.15^{g}	8.90^{de}	8.25^{a}	6.82^{ab}	5.77^{a}		
Wakati™	Packaged	66.47^{a}	62.52^{ab}	59.60^{b}	46.98^{bc}	14.83^{ab}	7.12^{a}	5.63^{ab}	5.38^{def}	5.07^{a}	3.23^{a}	1.24^{a}			
Wakati™	Unpackaged	66.47^{a}	60.60^{ab}	57.80^{ab}	20.68^{a}	10.66^{ab}	8.83^{a}	4.22^{ab}	2.05^{a}						
Storage x Packaging (LSD 0.05)		**19.20**	**14.45**	**21.22**	**17.75**	**16.31**	**5.43**	**2.08**	**1.02**	**3.27**	**3.50**	**3.12**	**3.58**		
CV (%)		**17.0**	**13.3**	**22.3**	**21.8**	**27.1**	**28.3**	**21.2**	**10.7**	**22.8**	**25.4**	**22.6**	**19.1**		

Means within each column followed by different letters differ significantly at (p>0.05)

4.4.2 Changes in fruit quality attributes

4.4.2.1 Total Soluble Solids

As fruits ripened, there was a progressive increase in Titratable soluble solids (TSS), measured in ^{o}brix on fresh weight basis. The rate was slower in fruits under cool storage as compared to fruits under ambient conditions. Combination of cold storage with MAP had significant effect ($p>0.05$) on the TSS by lowering its rate. In ‘Apple’ mangoes stored in open crates, the ^{o}brix increased from the initial 8.47^{o}brix to 19.6^{o}brix, 17.10^{o}brix, 15.2^{o}brix, 17.9^{o}brix and 16.3^{o}brix while fruits packaged in MAP bags increased to 20.5^{o}brix, 16.1^{o}brix, 16.2^{o}brix, 15.4^{o}brix, and 16.7^{o}brix in Coolbot™ cold room, charcoal cooler, brick cooler, Wakati™ tent and ambient conditions respectively at the end of their shelf life (Table 4.7a).

Brix content in ‘Kent’ mangoes stored in open crates increased from the initial 5.6^{o}brix to 18.1^{o}brix, 16.5^{o}brix, 13.9^{o}brix, 14.8^{o}brix, and 15.2^{o}brix while the brix content of fruits packaged in MAP bags increased to 16.80^{o}brix, 17.3^{o}brix, 15.2^{o}brix, 15.2^{o}brix and 14.9^{o}brix in Coolbot™ cold room, charcoal cooler, brick cooler, Wakati™ tent and ambient conditions respectively at the end of their shelf life (Table 4.7b).

Table 4.7a: Changes in Total Soluble solids (^{o}Brix) in ‘Apple’ mango fruits harvested at mature green maturity stages and stored under different storage options with or without Activebag® modified atmosphere packaging.

Storage Option	**Packaging**	**Days in Storage**											
		0	**3**	**6**	**9**	**12**	**15**	**18**	**21**	**24**	**27**	**30**	**33**
Ambient	Packaged	8.47^{a}	11.00^{c}	11.73^{abc}	12.23^{bc}	14.43^{abc}	16.70c						
Ambient	Unpackaged	8.47^{a}	14.13^{d}	14.33^{c}	16.00^{d}	16.33^{c}							
ZEBC	Packaged	8.47^{a}	10.23^{bc}	11.80^{ab}	12.23^{bc}	14.47^{abc}	14.93^{abc}	16.00^{a}	16.27^{a}				
ZEBC	Unpackaged	8.47^{a}	10.20^{bc}	13.10^{ab}	13.60^{cd}	13.70^{bc}	14.23^{ab}	15.27^{a}					
ECC	Packaged	8.47^{a}	9.20^{a}	12.43^{ab}	12.93^{bcd}	13.77^{abc}	14.27^{ab}	15.00^{a}	16.13^{a}				
ECC	Unpackaged	8.47^{a}	12.60c^{d}	12.80^{ab}	13.20^{bc}	13.60^{abc}	14.47^{ab}	17.10^{b}					
Coolbot™	Packaged	8.47^{a}	9.10^{a}	9.23^{a}	11.83^{a}	11.93^{a}	12.43^{a}	13.47^{a}	13.50^{a}	13.50^{a}	13.87^{a}	17.63^{a}	20.50
Coolbot™	Unpackaged	8.47^{a}	9.70^{ab}	10.07^{ab}	12.47^{ab}	13.47^{bc}	14.40^{ab}	15.00^{a}	15.43^{a}	16.20^{a}	17.73^{a}	19.63^{c}	
Wakati™	Packaged	8.47^{a}	9.23^{a}	10.33^{ab}	13.30^{cd}	13.63^{ab}	14.37^{abc}	14.43^{a}	15.43^{a}				
Wakati™	Unpackaged	8.47^{a}	9.60^{ab}	13.20^{ab}	14.23^{cd}	14.83^{c}	16.47^{c}	17.90b					
Storage x Packaging (LSD 0.05)		**0.35**	**3.85**	**4.03**	**3.16**	**3.03**	**3.19**	**3.10**	**3.49**	**1.93**	**3.47**	**1.94**	
CV (%)		**2.5**	**16.7**	**22.7**	**14.7**	**12.3**	**12.2**	**12.4**	**13.1**	**6.2**	**7.6**	**5.8**	

Means within each column followed by different letters differ significantly at (p>0.05).

Table 4.7b: Changes in Total Soluble solids (^{o}Brix) in ‘Kent’ mango fruits harvested at mature green maturity stages and stored under different storage options with or without Activebag® modified atmosphere packaging**.**

Storage Option	**Packaging**	**Days in Storage**													
		0	**3**	**6**	**9**	**12**	**15**	**18**	**21**	**24**	**27**	**30**	**33**	**36**	**39**
Ambient	Packaged	5.63^{a}	7.27^{b}	8.67^{ab}	10.20^{bc}	12.80^{abc}	14.90^{ab}								
Ambient	Unpackaged	5.63^{a}	8.27^{c}	9.87^{b}	12.67^{bc}	15.20^{de}									
ZEBC	Packaged	5.63^{a}	7.57^{b}	8.33^{ab}	8.40^{a}	8.73^{ab}	9.23^{a}	9.97^{a}	10.30^{a}	11.37^{a}	14.40^{bc}	15.23^{c}			
ZEBC	Unpackaged	5.63^{a}	7.10^{ab}	9.27^{b}	10.77^{bc}	11.00 ^{bc}	12.27^{abc}	13.80^{c}	13.97^{cd}						
ECC	Packaged	5.63^{a}	6.93^{ab}	9.43^{b}	9.67^{ab}	10.10^{bcd}	10.43^{bc}	10.60^{a}	11.10^{ab}	11.67^{a}	13.13d^{bc}	17.33^{ad}			
ECC	Unpackaged	5.63^{a}	8.87^{cd}	10.10^{ab}	10.67^{bc}	11.47^{bc}	12.50^{bcd}	13.30^{c}	16.57^{e}						
Coolbot™	Packaged	5.63^{a}	7.07^{ab}	7.23^{a}	7.70^{a}	8.60^{ab}	9.23^{a}	10.43^{a}	10.73^{a}	10.80^{a}	11.43^{ab}	11.53^{a}	13.20^{a}	15.63	16.80
Coolbot™	Unpackaged	5.63^{a}	6.63^{ab}	7.33^{a}	7.43^{a}	7.73^{a}	10.70^{bcd}	11.20^{bc}	12.33^{bc}	12.47^{a}	12.80^{b}	12.90^{b}	18.13^{a}		
Wakati™	Packaged	5.63^{a}	8.20^{c}	8.90^{b}	9.27^{ab}	9.27^{ab}	10.03^{cd}	11.50^{c}	13.40^{c}	13.47^{a}	14.50^{bc}	15.27^{c}			
Wakati™	Unpackaged	5.63^{a}	8.27^{c}	9.80^{bc}	10.00^{bc}	11.03^{cde}	11.93^{d}	12.03^{bc}	14.83^{d}						
Storage x Packaging (LSD 0.05)		**0.43**	**3.17**	**3.02**	**1.83**	**2.63**	**2.90**	**2.06**	**1.70**	**1.46**	**2.05**	**1.81**	**3.66**		
CV (%)		**4.5**	**17.5**	**21.1**	**12.5**	**14.7**	**14.4**	**9.0**	**9.2**	**7.4**	**7.1**	**8.5**	**13.9**		

Means within each column followed by different letters differ significantly at ($p>0.05$).

4.4.2.2 Titratable acidity

TTA decreased in all fruits as ripening progressed. However, the rate of decrease in TTA was slower in fruits stored in cool storage options. Combination of cool storage and MAP significantly ($p>0.05$) fruits' TTA content. TTA content of 'Apple' mangoes in open crates decreased from the initial 0.92% citric acid equivalent to 0.19, 0.18, 0.17, 0.15 and 0.10 for the Coolbot™ cold room, charcoal cooler, brick cooler, Wakati™ tent and ambient conditions respectively at the end of their shelf life. Similarly, the TTA content of 'Apple' mangoes packaged in MAP decreased to 0.12, 0.19, 0.18, 0.14 and 0.11% citric acid equivalent for the Coolbot™ cold room, charcoal cooler, brick cooler, Wakati™ tent and ambient conditions respectively at the end of their shelf life. Decrease in TTA of 'Kent' fruits followed the same trend as seen in tables 4.8a and 4.8b.

Table 4.8a: Changes in Titratable Acidity (% citric acid equivalent) in 'Apple' mango fruits harvested at mature green maturity stages and stored under different storage options with or without Activebag® modified atmosphere packaging.

Storage Option	**Packaging**	**Time in storage (Days)**						
		0	**6**	**12**	**18**	**24**	**30**	**33**
Ambient	Packaged	0.92^{a}	0.58^{ef}	0.30^{b}				
Ambient	Unpackaged	0.92^{a}	0.40^{a}	0.10^{a}				
ZEBC	Packaged	0.92^{a}	0.54^{de}	0.54^{c}	0.31^{bc}			
ZEBC	Unpackaged	0.92^{a}	0.47^{abcd}	0.36^{b}	0.17^{a}			
ECC	Packaged	0.92^{a}	0.54^{bcde}	0.39^{b}	0.22^{ab}			
ECC	Unpackaged	0.92^{a}	0.48^{abc}	0.31^{b}	0.18^{ab}			
Wakati^{TM}	Packaged	0.92^{a}	0.52^{cde}	0.33^{b}	0.16^{a}			
Wakati^{TM}	Unpackaged	0.92^{a}	0.47^{ab}	0.29^{b}	0.15^{a}			
Coolbot^{TM}	Packaged	0.92^{a}	0.72^{f}	0.62^{c}	0.47^{d}	0.34^{a}	0.21^{a}	0.12
Coolbot^{TM}	Unpackaged	0.92^{a}	0.65^{de}	0.60^{c}	0.47^{cd}	0.30^{a}	0.19^{a}	
Storage x Packaging (LSD 0.05)			**0.14**	**0.14**	**0.15**	**0.30**	**0.17**	
CV (%)			**11.8**	**15**	**21.2**	**22.1**	**21.8**	

Means within each column followed by different letters differ significantly at ($p>0.05$)

Table 4.8b: Changes in Titratable Acidity (% citric acid equivalent) in ‘Kent’ mango fruits harvested at mature green maturity stages and stored under different storage options with or without Activebag® modified atmosphere packaging.

Storage Option	Packaging	Time in storage (Days)							
		0	6	12	18	24	30	36	39
Ambient	Packaged	0.70^{a}	0.46^{abc}	0.22^{a}	0.14^{a}				
Ambient	Unpackaged	0.70^{a}	0.40^{a}	0.30^{ab}					
ZEBC	Packaged	0.70^{a}	0.58^{e}	0.46^{cd}	0.38^{e}	0.25^{ab}	0.17^{bc}		
ZEBC	Unpackaged	0.70^{a}	0.44^{ab}	0.34^{ab}	0.29^{cd}				
ECC	Packaged	0.70^{a}	0.51^{de}	0.46^{cd}	0.38^{de}	0.24^{ab}	0.16^{bc}		
ECC	Unpackaged	0.70^{a}	0.52^{abcd}	0.37^{b}	0.26^{bc}				
Wakati™	Packaged	0.70^{a}	0.56^{de}	0.51^{d}	0.37^{de}	0.21^{a}	0.15^{ab}		
Wakati™	Unpackaged	0.70^{a}	0.55^{de}	0.30^{b}	0.17^{ab}				
Coolbot™	Packaged	0.70^{a}	0.59^{bcde}	0.53^{cd}	0.39^{de}	0.32^{b}	0.25^{d}	0.17	0.12
Coolbot™	Unpackaged	0.70^{a}	0.60^{cde}	0.48^{c}	0.38^{e}	0.32^{ab}	0.14^{a}		
Storage x Packaging (LSD 0.05)			**0.15**	**0.09**	**0.09**	**0.11**	**0.04**		
CV (%)			**13.1**	**10.1**	**15.2**	**15.4**	**3.3**		

Means within each column followed by different letters differ significantly at ($p>0.05$)

4.4.2.3 Beta-carotene

Gradual increase in beta-carotene was recorded in all in fruits as they ripened. Cool storage and MAP packaging had a significant effect ($p>0.05$) effect on the amount of beta-carotene on each sampling day. Fruits in cool storage reported lowest amounts of beta-carotene. ‘Apple’ mango had high amounts of beta carotene compared to ‘Kent’. For instance, on the final day of each shelf life, unpackaged ‘Apple’ mangoes under ambient conditions recorded 9.45mg/100g of beta-carotene on day 12 as compared to 2.86mg/100g on day 33 for fruits packaged and stored in the Coolbot™

cold room (Table 4.9a). Similarly, packaged ‘Kent’ mango recorded low beta-carotene of 2.73mg/100g in the Coolbot™ cold room on day 39 as compared to fruits unpackaged and under ambient conditions which recorded 9.35mg/100g (Table 4.9b).

Table 4.9a: Changes in Beta-Carotene (mg/100g fresh weight) in ‘Apple’ mango fruits harvested at mature green maturity stages and stored under different storage options with or without Activebag® modified atmosphere packaging.

Storage Option	**Packaging**	**Time in storage (Days)**						
		0	**6**	**12**	**18**	**24**	**30**	**33**
Ambient	Packaged	0.42^{a}	3.44^{f}	4.19^{e}				
Ambient	Unpackaged	0.42^{a}	5.43^{g}	9.45^{g}				
ZEBC	Packaged	0.42^{a}	1.68^{c}	3.67^{cd}	4.68^{e}			
ZEBC	Unpackaged	0.42^{a}	1.93^{cd}	3.57^{c}	4.89^{f}			
ECC	Packaged	0.42^{a}	2.31^{e}	3.74^{d}	5.01^{f}			
ECC	Unpackaged	0.42^{a}	1.67^{c}	3.74^{d}	4.61^{de}			
Wakati™	Packaged	0.42^{a}	1.57^{c}	2.66^{b}	3.87^{c}			
Wakati™	Unpackaged	0.42^{a}	2.44^{e}	4.54^{f}	6.10^{g}			
Coolbot™	Packaged	0.42^{a}	0.65^{a}	1.32^{a}	1.77^{a}	2.08^{a}	2.51^{a}	2.86
Coolbot™	Unpackaged	0.42^{a}	0.84^{b}	1.46^{a}	1.88^{a}	2.64^{c}	3.20^{c}	
Storage x Packaging (LSD 0.05)			**0.16**	**0.16**	**0.16**	**0.30**	**0.30**	
CV (%)			**3.1**	**1.8**	**1.7**	**2.9**	**2.4**	

Means within each column followed by different letters differ significantly at (p>0.05)

Table 4.9b: Changes in Beta-Carotene (mg/100g fresh weight) in ‘Kent’ mango fruits harvested at mature green maturity stages and stored under different storage options with or without Activebag® modified atmosphere packaging.

Storage Option	**Packaging**	**Time in storage (Days)**							
		0	**6**	**12**	**18**	**24**	**30**	**36**	**39**
Ambient	Packaged	0.26^{a}	1.99^{f}	4.13^{h}	6.28^{h}				
Ambient	Unpackaged	0.26^{a}	3.17^{g}	6.03^{i}					
ZEBC	Packaged	0.26^{a}	0.60^{a}	1.43^{b}	2.02^{b}	3.35^{de}	4.27^{efg}		
ZEBC	Unpackaged	0.26^{a}	1.31^{d}	3.17^{g}	4.49^{g}				
ECC	Packaged	0.26^{a}	0.63^{a}	1.56^{c}	2.43^{c}	3.64^{ef}	4.03^{def}		
ECC	Unpackaged	0.26^{a}	1.19^{c}	2.22^{d}	3.60^{e}				
Wakati™	Packaged	0.26^{a}	1.10^{c}	2.45^{e}	3.25^{d}	3.94^{f}	4.54^{g}		
Wakati™	Unpackaged	0.26^{a}	1.55^{e}	2.83^{f}	4.10^{f}				
Coolbot™	Packaged	0.26^{a}	0.56^{a}	1.45^{a}	1.63^{a}	1.80^{a}	2.05^{a}	2.29	2.73
Coolbot™	Unpackaged	0.26^{a}	0.88^{b}	1.05^{b}	2.03^{b}	2.47^{b}	2.85^{b}		
Storage x Packaging (LSD 0.05)			**0.13**	**0.16**	**0.16**	**0.38**	**0.35**		
CV (%)			**4.5**	**2.7**	**1.9**	**4.7**	**3.7**		

Means within each column followed by different letters differ significantly at ($p>0.05$)

4.4.2.4 Vitamin C

Vitamin C gradually decreased in all fruits as ripening progressed regardless of the variety, storage and packaging. However, there was a reduced rate of loss of vitamin C in packaged fruits under cool storage. Cool storage and MAP packaging significantly ($p>0.05$) affected the rate of Vitamin C loss. Unpackaged ‘Apple’ mango under ambient conditions had lowest amount (49.45mg/100g) of Vitamin C by day 9 as compared to 51.73mg/100g, 53.01mg/100g and 50.36mg/100g on day 18 in the ZEBC, ECC and Wakati™ tent respectively and 64.60mg/100g in the Coolbot™ cold room on day 30. Similar trends were reported in packaged ‘Apple’ fruits (Table 4.10a). In ‘Kent’ variety, lower vitamin C content was recorded in unpackaged fruits under ambient conditions by day 15 (44.01mg/100g) while vitamin C were retained more in the packaged ‘Kent’ mango in the Coolbot™ cold room (56.05mg/100g) on day 39. Wakati™ tent, ZEBC and ECC recorded similar results of reduced Vitamin C loss as compared to fruits under ambient conditions (Table 4.10b).

Table 4.10a: Changes in Vitamin C (mg/100g fresh weight) in ‘Apple’ mango fruits harvested at mature green maturity stages and stored under different storage options with or without Activebag® modified atmosphere packaging.

Storage Option	**Packaging**	**Time in storage (Days)**						
		0	**6**	**12**	**18**	**24**	**30**	**33**
Ambient	Packaged	109.28^{a}	82.97^{b}	61.30^{b}				
Ambient	Unpackaged	109.28^{a}	80.89^{a}	49.45^{a}				
ZEBC	Packaged	109.28^{a}	95.48^{d}	79.63^{d}	66.45^{e}			
ZEBC	Unpackaged	109.28^{a}	93.50^{c}	71.47^{c}	51.73^{ab}			
ECC	Packaged	109.28^{a}	95.90^{d}	82.42^{e}	62.61^{d}			
ECC	Unpackaged	109.28^{a}	91.91^{c}	70.87^{c}	53.01^{bc}			
Wakati™	Packaged	109.28^{a}	97.01^{e}	78.27^{d}	63.47^{d}			
Wakati™	Unpackaged	109.28^{a}	90.48^{c}	72.71^{c}	50.36^{a}			
Coolbot™	Packaged	109.28^{a}	103.49^{g}	87.10^{f}	76.39^{g}	67.59^{a}	60.26^{a}	58.32
Coolbot™	Unpackaged	109.28^{a}	99.79^{f}	86.73^{f}	73.05^{g}	61.15^{a}	54.60^{a}	
Storage x Packaging (LSD 0.05)			**1.87**	**2.13**	**2.11**	**11.59**	**7.79**	
CV (%)			**0.9**	**1.3**	**1.5**	**4.1**	**3.1**	

Means within each column followed by different letters differ significantly at ($p>0.05$)

Table 4.10b: Changes in Vitamin C (mg/100g fresh weight) in ‘Kent’ mango fruits harvested at mature green maturity stages and stored under different storage options with or without Activebag® modified atmosphere packaging.

Storage Option	**Packaging**	**Time in storage (Days)**							
		0	**6**	**12**	**18**	**24**	**30**	**36**	**39**
Ambient	Packaged	105.37^{a}	81.55^{a}	62.61^{bc}	46.85^{b}				
Ambient	Unpackaged	105.37^{a}	85.68^{ab}	61.43^{ab}					
ZEBC	Packaged	105.37^{a}	94.49^{de}	80.30^{e}	73.64^{h}	60.95^{c}	51.18^{a}		
ZEBC	Unpackaged	105.37^{a}	94.05^{e}	63.04^{c}	53.39^{d}				
ECC	Packaged	105.37^{a}	99.08^{f}	78.14^{d}	64.21^{e}	57.55^{ab}	51.75^{ab}		
ECC	Unpackaged	105.37^{a}	86.58^{b}	63.87^{c}	51.39^{d}				
Wakati™	Packaged	105.37^{a}	91.97^{d}	85.33^{f}	68.16^{f}	57.39^{a}	50.80^{ab}		
Wakati™	Unpackaged	105.37^{a}	87.76^{c}	61.79^{a}	49.29^{c}				
Coolbot™	Packaged	105.37^{a}	97.90^{f}	82.73^{e}	71.17^{g}	65.56^{d}	61.30^{e}	58.27	56.05
Coolbot™	Unpackaged	105.37^{a}	97.00^{f}	84.07^{f}	74.49^{h}	61.19^{bc}	55.49^{d}		
Storage x Packaging (LSD 0.05)			**1.97**	**1.74**	**1.51**	**2.70**	**1.42**		
CV (%)			**1.0**	**1.1**	**1.1**	**1.7**	**1.0**		

Means within each column followed by different letters differ significantly at (p>0.05)

4.4.2.5 Changes in major sugars

4.4.2.5.1 Fructose

Fructose amount increased gradually as fruits ripened. Cool storage and packaging had a significant effect (p>0.05) on fructose. At the end of their shelf life, packaged ‘Apple’ mangoes recorded fructose amount of 10.44g/100g, 8.92g/100g, 8.51g/100g, 8.84g/100g and 8.47g/100g when stored in the Coolbot™ cold room, ZEBC, ECC, Wakati™ tent and ambient conditions respectively (Table 4.11A). While the packaged ‘Kent’ variety recorded lower fructose amounts of 8.19g/100g, 6.86g/100g, 6.81g/100g, 6.75g/100g and 6.94g/100g when stored in the Coolbot™

cold room, ZEBC, ECC, Wakati™ tent and ambient conditions respectively at the end of their shelf life (Table 4.11B).

Table 4.11a: Changes in Fructose (g/100g fresh weight) in ‘Apple’ mango fruits harvested at mature green maturity stages and stored under different storage options with or without Activebag® modified atmosphere packaging.

Storage Option	**Packaging**	**Time in storage (Days)**						
		0	**6**	**12**	**18**	**24**	**30**	**33**
Ambient	Packaged	1.95^{a}	4.18^{c}	6.66^{d}				
Ambient	Unpackaged	1.95^{a}	4.72^{d}	9.17^{e}				
ZEBC	Packaged	1.95^{a}	3.70^{b}	5.03^{a}	7.57^{d}			
ZEBC	Unpackaged	1.95^{a}	3.47^{b}	6.64^{d}	9.26^{g}			
ECC	Packaged	1.95^{a}	3.43^{b}	5.53^{bc}	7.86^{e}			
ECC	Unpackaged	1.95^{a}	3.41^{b}	5.72^{c}	8.95^{f}			
Wakati™	Packaged	1.95^{a}	3.63^{ab}	5.43^{b}	7.02^{a}			
Wakati™	Unpackaged	1.95^{a}	3.66^{b}	6.53^{d}	8.95^{f}			
Coolbot™	Packaged	1.95^{a}	3.51^{ab}	5.38^{b}	7.48^{cd}	8.80^{a}	9.02^{a}	10.44
Coolbot™	Unpackaged	1.95^{a}	3.37^{a}	5.62^{c}	7.35^{bc}	9.59^{c}	10.76^{d}	
Storage x Packaging (LSD 0.05)			**0.33**	**0.23**	**0.19**	**0.30**	**0.30**	
CV (%)			**3.9**	**1.6**	**1.0**	**0.8**	**0.7**	

Means within each column followed by different letters differ significantly at ($p>0.05$)

Table 4.11b: Changes in Fructose (g/100g fresh weight) in ‘Kent’ mango fruits harvested at mature green maturity stages and stored under different storage options with or without Activebag® modified atmosphere packaging.

Storage Option	**Packaging**	**Time in storage (Days)**							
		0	**6**	**12**	**18**	**24**	**30**	**36**	**39**
Ambient	Packaged	1.57^{a}	2.54^{cd}	4.18^{d}	6.94^{f}				
Ambient	Unpackaged	1.57^{a}	3.83^{g}	6.42^{h}					
ZEBC	Packaged	1.57^{a}	2.05^{a}	3.09^{a}	4.19^{a}	5.02^{a}	6.86^{bc}		
ZEBC	Unpackaged	1.57^{a}	3.60^{f}	5.57^{g}	6.41^{d}				
ECC	Packaged	1.57^{a}	2.42^{bc}	3.50^{c}	4.82^{b}	5.33^{bc}	6.81^{ab}		
ECC	Unpackaged	1.57^{a}	3.45^{e}	5.46^{fg}	6.58^{e}				
Wakati™	Packaged	1.57^{a}	2.48^{b}	3.65^{c}	4.85^{b}	5.96^{d}	6.75^{ab}		
Wakati™	Unpackaged	1.57^{a}	3.66^{f}	5.31^{f}	6.78^{f}				
Coolbot™	Packaged	1.57^{a}	2.47^{bc}	3.33^{b}	4.89^{b}	5.11^{a}	6.68^{a}	7.40	8.19
Coolbot™	Unpackaged	1.57^{a}	2.68^{d}	4.55^{e}	5.33^{c}	6.85^{g}	7.81^{f}		
Storage x Packaging (LSD 0.05)			**0.14**	**0.07**	**0.15**	**0.26**	**0.18**		
CV (%)			**2.1**	**1.6**	**1.1**	**1.7**	**1.0**		

Means within each column followed by different letters differ significantly at ($p>0.05$)

4.4.2.5.2 Glucose

Glucose increased gradually as fruits ripened in all storage options. Cool storage and packaging had a significant effect ($p>0.05$) on amount of glucose. Slow increase in glucose was recorded in packaged fruits under cool storage. Unpackaged ‘Apple’ mangoes recorded glucose amounts of 5.05g/100g on day 12 while ZEBC, ECC, Wakati™ Tent and Coolbot™ cold room had 3.93g/100g, 3.86g/100g, 3.53g/100g and 3.25g/100g respectively on same day. Similar trend was recorded in packaged ‘Apple’ mango fruits (Table 4.12a). The unpackaged ‘Kent’ mango fruits recorded glucose levels of 4.30g/100g, 4.47g/100g, 4.36g/100g, 4.38g/100g and 4.79g/100g under ambient conditions, ZEBC, ECC, Wakati™ tent and Coolbot™ cold room respectively at the end of each storage shelf life. Packaged 'Kent' mangoes had similar trend in glucose amounts (Table 4.12b).

Table 4.12a: Changes in Glucose (g/100g fresh weight) in 'Apple' mango fruits harvested at mature green maturity stages and stored under different storage options with or without Activebag® modified atmosphere packaging.

Storage Option	**Packaging**	**Time in storage (Days)**						
		0	**6**	**12**	**18**	**24**	**30**	**33**
Ambient	Packaged	1.79^{a}	2.91^{f}	3.94^{d}				
Ambient	Unpackaged	1.79^{a}	3.11^{g}	5.05^{e}				
ZEBC	Packaged	1.79^{a}	2.19^{ab}	3.21^{b}	3.92^{c}			
ZEBC	Unpackaged	1.79^{a}	2.61^{de}	3.93^{d}	4.95^{e}			
ECC	Packaged	1.79^{a}	2.12^{a}	3.20^{bc}	3.85^{c}			
ECC	Unpackaged	1.79^{a}	2.76^{ef}	3.86^{d}	4.94^{e}			
Wakati™	Packaged	1.79^{a}	2.26^{a}	3.33^{b}	4.36^{d}			
Wakati™	Unpackaged	1.79^{a}	2.50^{bc}	3.53^{c}	4.91^{e}			
Coolbot™	Packaged	1.79^{a}	2.43^{cd}	2.94^{a}	3.24^{a}	3.67^{a}	4.17^{a}	4.68
Coolbot™	Unpackaged	1.79^{a}	2.11^{a}	3.25^{b}	3.96^{c}	4.62^{c}	5.20^{c}	
Storage x Packaging (LSD 0.05)			**0.18**	**0.22**	**0.24**	**0.48**	**0.48**	
CV (%)			**3.2**	**2.7**	**2.4**	**2.7**	**2.4**	

Means within each column followed by different letters differ significantly at (p>0.05)

Table 4.12b: Changes in Glucose (g/100g fresh weight) in 'Kent' mango fruits harvested at mature green maturity stages and stored under different storage options with or without Activebag® modified atmosphere packaging.

Storage Option	**Packaging**	**Time in storage (Days)**							
		0	**6**	**12**	**18**	**24**	**30**	**36**	**39**
Ambient	Packaged	1.41^{a}	0.37^{a}	0.30^{a}	4.45^{e}				
Ambient	Unpackaged	1.41^{a}	2.63^{de}	3.89^{f}					
ZEBC	Packaged	1.41^{a}	1.59^{b}	2.68^{c}	3.22^{a}	3.87^{a}	4.21^{a}		
ZEBC	Unpackaged	1.41^{a}	2.29^{c}	2.84^{cd}	3.86^{d}				
ECC	Packaged	1.41^{a}	2.30^{cde}	2.91^{cd}	3.57^{cd}	3.98^{a}	4.12^{a}		
ECC	Unpackaged	1.41^{a}	2.34^{cd}	3.41^{e}	3.86^{de}				
Wakati™	Packaged	1.41^{a}	2.37^{cd}	2.98^{cd}	3.49^{bc}	3.97^{a}	4.14^{a}		
Wakati™	Unpackaged	1.41^{a}	2.50^{e}	3.60^{f}	4.18^{f}				
Coolbot™	Packaged	1.41^{a}	2.36^{cde}	2.90^{d}	3.49^{bc}	3.91^{a}	4.18^{a}	4.31	4.54
Coolbot™	Unpackaged	1.41^{a}	1.48^{b}	2.31^{b}	3.36^{b}	3.97^{a}	4.45^{a}		
Storage x Packaging (LSD 0.05)			**0.22**	**0.21**	**0.20**	**0.18**	**0.16**		
CV (%)			**4.8**	**3.4**	**2.4**	**1.8**	**1.5**		

Means within each column followed by different letters differ significantly at (p>0.05)

4.4.2.5.3 Sucrose

Sucrose content increased as fruits ripened. Cool storage had a significant effect (p>0.05) on the sucrose content. Combination of cool storage and MAP further delayed the increase in sucrose content when compared to unpacked fruits under ambient conditions. On their last day of the shelf life, unpackaged 'Apple' mango had sucrose content of 8.00g/100g, 8.28g/100g, 8.03g/100g, 8.59g/100g and 7.61g/100g when stored in the ZEBC, ECC, Wakati™ tent, Coolbot™ cold room and ambient conditions respectively. Similar trend of sucrose content recorded in packaged ‘Apple’ mangoes (Table 4.13a). In unpackaged ‘Kent’ mangoes, sucrose content was 6.82g/100g, 6.67g/100g, 6.91g/100g, 6.85g/100g and 6.85g/100g for ZEBC, ECC, Wakati™ tent, Coolbot™ cold room and ambient conditions respectively at the end of the storage. Packaged ‘Kent’ mangoes had similar trend in sucrose content (Table 4.13b).

Table 4.13a: Changes in Sucrose (g/100g fresh weight) in ‘Apple’ mango fruits harvested at mature green maturity stages and stored under different storage options with or without Activebag® modified atmosphere packaging.

Storage Option	**Packaging**	**Time in storage (Days)**						
		0	**6**	**12**	**18**	**24**	**30**	**33**
Ambient	Packaged	1.72^{a}	3.36^{d}	6.30^{f}				
Ambient	Unpackaged	1.72^{a}	4.45^{g}	7.61^{g}				
ZEBC	Packaged	1.72^{a}	3.01^{c}	5.59^{d}	7.34^{d}			
ZEBC	Unpackaged	1.72^{a}	3.99^{f}	5.49^{d}	8.00^{e}			
ECC	Packaged	1.72^{a}	3.37^{de}	5.10^{c}	6.47^{c}			
ECC	Unpackaged	1.72^{a}	3.24^{d}	5.08^{c}	8.28^{f}			
Wakati™	Packaged	1.72^{a}	2.95^{b}	4.96^{b}	7.33^{d}			
Wakati™	Unpackaged	1.72^{a}	3.60^{e}	5.99^{e}	8.03^{e}			
Coolbot™	Packaged	1.72^{a}	2.77^{ab}	4.27^{a}	5.70^{a}	6.99^{a}	8.16^{a}	8.88
Coolbot™	Unpackaged	1.72^{a}	2.56^{a}	4.85^{b}	6.19^{b}	7.32^{b}	8.59^{b}	
Storage x Packaging (LSD 0.05)			**0.17**	**0.18**	**0.16**	**0.30**	**0.30**	
CV (%)			**2.3**	**1.5**	**1.0**	**1.0**	**0.8**	

Means within each column followed by different letters differ significantly at ($p>0.05$)

Table 4.13b: Changes in Sucrose (g/100g fresh weight) in 'Kent' mango fruits harvested at mature green maturity stages and stored under different storage options with or without Activebag® modified atmosphere packaging.

Storage Option	**Packaging**	**Time in storage (Days)**							
		0	**6**	**12**	**18**	**24**	**30**	**36**	**39**
Ambient	Packaged	1.33^{a}	2.94^{cd}	4.41^{c}	6.42e				
Ambient	Unpackaged	1.33^{a}	3.02^{d}	5.56^{f}					
ZEBC	Packaged	1.33^{a}	2.83^{c}	4.02^{b}	4.96^{c}	5.84^{abc}	6.57^{cd}		
ZEBC	Unpackaged	1.33^{a}	3.19^{e}	4.94^{e}	5.99^{d}				
ECC	Packaged	1.33^{a}	2.59^{b}	4.09^{b}	4.95^{c}	6.45^{c}	6.61^{bc}		
ECC	Unpackaged	1.33^{a}	2.23^{a}	4.12^{b}	5.81^{d}				
Wakati™	Packaged	1.33^{a}	2.35^{a}	3.15^{a}	4.28^{a}	5.04^{ab}	6.59^{d}		
Wakati™	Unpackaged	1.33^{a}	3.43^{f}	4.49^{d}	5.94^{d}				
Coolbot™	Packaged	1.33^{a}	2.12^{a}	3.32^{a}	4.65^{b}	5.03^{a}	5.81^{a}	6.93	7.21
Coolbot™	Unpackaged	1.33^{a}	2.57^{b}	3.23^{a}	4.43^{b}	5.31^{a}	6.12^{b}		
Storage x Packaging (LSD 0.05)			**0.15**	**0.15**	**0.19**	**0.76**	**0.25**		
CV (%)			**2.4**	**1.6**	**1.5**	**5.2**	**1.4**		

Means within each column followed by different letters differ significantly at (p>0.05)

4.4.3 Overall shelf life

The shelf life of 'Apple' mango fruits was extended by 18 days in the Coolbot™ cold room and by 9 days in the ECC, ZEBC and Wakati™ tent. Packaging the fruits in MAP further extended the shelf life by an additional 3 days in all storage options.

The shelf life of 'Kent' mango fruits was extended by 24 days in the Coolbot™ cold room and by 6 days in the ECC, ZEBC and Wakati™ tent. Packaging the fruits in MAP further extended the shelf life by an additional 9 days (Coolbot™ cold room, ECC, ZEBC and Wakati™ tent) and 3 days (ambient).

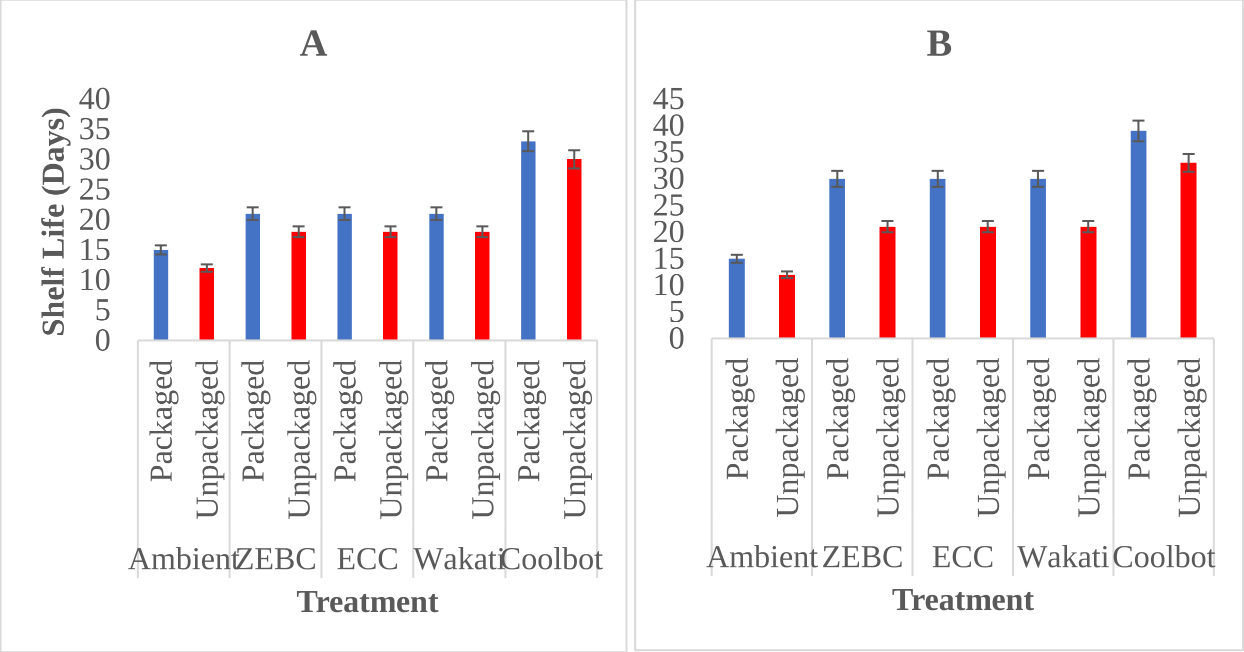


Figure 4.4: Overall shelf life (days in storage) of 'Apple' (A) and 'Kent' (B) harvested at mature green maturity stages and stored under different storage options with or without Activebag® modified atmosphere packaging. Top Bars represent S.E of means ($P \leq 0.05$).

4.5 Discussion

Mango is a climacteric fruit and is considered still living after harvest. Therefore, metabolic and physiological processes including respiration, transpiration and other compositional changes continue until senescence and death. High temperatures increases the rate of these processes leading to reduced shelf life thus high post-harvest losses estimated at 40-50% in perishable commodities such as mango fruit (Shitanda and Wanjala, 2006). An increase in temperature by 10^{o}C increases deteriorative process by 2-3-fold (Kader, 2005). Therefore, handling and storage of perishable produce at low but safe temperatures is important for postharvest quality preservation. Conventional cold storage facilities require massive investment for installation and maintenance making them inaccessible for majority of smallholder farmers in rural areas with unreliable electricity (Alexiades et al.,2014). Research into low-cost and appropriate alternative to conventional cold storage infrastructure have resulted in simple technologies that have applicability among smallholder farmers. These include the Coolbot™ cold room, evaporative cooling technologies and Wakati™ tent.

In the present study, effectiveness of Coolbot™ cold room to achieve and maintain the set storage temperature throughout to the storage period was demonstrated. The set temperature for cold storage of mango fruits (10±2°C) was attained within an hour of produce loading and maintained throughout the storage period of 39 days. In addition, a high relative humidity of 75±20%was attained and maintained during the storage period.

In the case of evaporative cooling technologies, the evaporative charcoal cooler (ECC) and the Zero energy brick cooler (ZEBC), cooling is passive as water evaporates from the wetted medium (charcoal or sand). In the present study 20±5^{o}C temperature was attained and maintained in the ECC and ZEBC over a period of 30 days. The lowest temperature attained in the ECC and ZEBC was 14.6^{o}C and 17.1^{o}C respectively. During the same period, the ambient air temperature ranged from 19.1^{o}C to 32.2^{o}C. In addition to the cooling effect, high relative humidity (RH) was attained in the ECC and ZEBC. The highest RH attained in the ECC and ZEBC was 99.9% and 99.2% respectively. In comparison, the ambient RH ranged from 40.4% to 71.5% during the study period. In the case of Wakati™ tent, an average temperature of 22.5^{o}C was attained with a minimum of 18.5^{o}C and maximum of 28.5^{o}C. In addition, a higher humidity average (96.2%) was attained inside the tent.

Previous studies on the various technologies evaluated in this current study showed effectiveness to attain cold temperatures and high relative humidity. For instance, Ambuko et al (2018b) reported that the Coolbot™ cold room attained pre-set temperatures of 10±1°C from 18°C within 6 hours and was maintained within the storage period. In the case of evaporative coolers, Shitanda et al., (2011) reported an increased relatively humidity by 38%in the evaporative charcoal cooler compared to ambient conditions. Manyozo et al., (2018) recorded a temperature reduction of 2°C to 16°C and an increase of 24% and 42.59% RH in the ECC. Chinenye (2011) also recorded a 10^{o}C decrease in temperature and increase of RH from 40.3% to 92% in evaporative coolers. In addition, temperature difference of 5-6°C and the RH of 87-92% between the room conditions and earthen pot cool chamber was also recorded in an experiment with same design of ZEBC (Murugan et al., 2011). The demonstrated cooling effectiveness of the technologies was reflected in produce cooling and preservation of quality of the stored mango fruits.

Internal pulp temperatures of the fruits fluctuated with the air temperatures inside the storage chamber with an average of 11.3^{o}C, 22.1^{o}C, 19.5^{o}C, 24.3^{o}C, and 25.0^{o}C for the Coolbot™ cold room, ZEBC, ECC, Wakati™ tent, and ambient conditions respectively. Lower pulp temperature is key in reducing the rate of metabolic reactions in harvested fruits, since they are still living (Ayele and Bayleyegn, 2017). At low temperature, most of the metabolic and physiological processes associated with senescence and ultimate deterioration proceed at a lower rate. These include respiration, transpiration, softening, ethylene evolution and pathological breakdown.

Previous studies on optimal storage temperatures and relative humidity of different commodities showed that storing mango under the optimal storage conditions extend its shelf life by 14-21 days (Camelo, 2004). In this study, the Coolbot™ cold room extended shelf life by 18 and 21 days for ‘Apple’ and ‘Kent’ mangoes respectively while the shelf life was extended by 12 days for both varieties when stored in the ECC, ZEBC and Wakati™ tent. Previous studies on ‘Apple’ mango stored in the Coolbot™ cold room reported extended shelf life by 23 days more when compared with the fruits under ambient conditions. This shelf life was extended further by 5 days under MAP (Ambuko et al., 2018b).

Weight loss due to respiration and transpiration is a major factor in the deterioration of harvested fruits and vegetables. In the current study, weight loss was reported in all fruits irrespective of the storage option and packaging. Fruits under the Coolbot™ cold room recorded less cumulative weight loss (9.27% and 11.44% ‘Apple’ and ‘Kent’ respectively) by the end of the study. This could be attributed to low temperatures and high relative humidity (Abiso et al., 2015). Combination of cool storage and MAP further recorded much lower weight loss compared to the fruits that were not packaged and/or stored under ambient conditions. MAP provides a microclimate around the fruit with high humidity and reduced water vapor pressure deficit which minimizes amount of water lost (transpired) from the fruit (Gitari et al., 2018). In addition, low oxygen levels in MAP slows down respiration rate hence a slower rate of breakdown of carbohydrates (Martínez-Romero et al., 2006). The efficiency of MAP bags is reduced under high temperatures since the film turns more water permeable resulting to water loss from packaged produce (Irtwange, 2006), a scenario that might have resulted to poor MAP performance under ambient and Wakati™ tent. Effectiveness of MAP also varied based on variety, where packaging ‘Kent’ mango was more significant than ‘Apple’ mango as evidenced by extended shelf life of ‘Kent’ mango. This is attributed to difference in compositional properties of the film and commodity variation in the varieties used in the study. Previous findings of reduced weight loss in fruits under MAP have been reported including; on mango (Bartolomeu et al., 2012; Githiga et al.,2015; Maina et al., 2019; Ouma et al., 2014)**,**banana (Maqbool et al., 2011) and passion fruit (Yumbya et al., 2014).

One of the notable changes in ripening and deteriorating fruits in loss of firmness and subsequent softening which contributes significantly to postharvest losses in fruits. In the present study, firmness (Peel and flesh) decreased as fruits ripened across all treatments. Fruits under cool environment retained higher firmness for longer compared to fruits under ambient conditions. For instance, in 'Apple' and 'Kent' mangoes stored in open crates in the Coolbot™ cold room, the peel firmness decreased from the initial 110.2N and 153N to 7.25N on day 30 and 14.7N on day 33 respectively. Softening in harvested fruits is mediated by cell wall metabolism which is catalyzed by enzymes such as polygalacturonase (PG), pectin methylesterase (PME), pectatelyase and endo-β-1,4-glucanase (EGase) activities). Higher firmness observed in fruits under cold storage could be attributed to low activity of these enzymes at low temperature (Cheng et al.,2009; Jarimopas and Kitthawee, 2007). The synergistic effect of cold storage and MAP leading to slower softening could be attributed to the modified conditions (low O_2 and high CO_2) that lead to reduced metabolism (Ullah et al.,2012). The present study results concur with the study conducted on mango where 'Apple' mango flesh firmness was retained more by end of the storage period (30.5N on day 40) when packaged in MAP and stored under cold storage (Ambuko et al., 2018b), and that firmness signficantly decreased with increaasing storage period of mango (Ezz and Awad, 2011). Similar trends were observed in studies with other commodities; banana (Ahmad et al., 2001; Maqbool et al., 2011), apple (Khorshidi et al., 2010), and tomato (Manyozo et al., 2018).

Colour change is among the visual changes observed in ripening climacteric fruits such as mango. As mango fruit ripen, the peel color changes from green to yellow/orange while the flesh colour changes from whitish yellow to orange or yellow. The intensity of the color reported as the hue angle increases with ripening. In the present study, the peel and flesh colour (measured as hue angle) decreased gradually with time, regardless of the storage conditions. Color change in mango fruits that were stored under cold storage conditions was less rapid compared to the fruits that were stored under ambient conditions. The flesh hue angle of 'Apple 'and 'Kent' mango fruits stored in the Coolbot™ cold room decreased from the initial 87.19^o and 89.41^o to 68.43^o on day 30 and 59.87^o on day 33 respectively. Flesh hue angles observed under ECC, ZEBC and Wakati^{TM}

decreased to 63.76°, 64.97° and 65.65° respectively on day 18 (‘Apple’) and to 63.92°, 61.95° and 63.12° respectively on day 21 (‘Kent’) compared to 62.86° and 62.00° for ‘Apple’ and ‘Kent’ respectively on day 12 under ambient conditions.

Packaging in MAP further delayed the colour changes in the peel and flesh which was reported as 62.55° on day 33 and 62.8° on day 39 for ‘Apple’ and ‘Kent’ varieties respectively in the coolbot cold room while ECC, ZEBC and Wakati recorded 63.48°, 64.61° and 62.55° respectively on day 21 (‘Apple’) and 61.70°, 62.89° and 63.98° respectively on day 30 (‘Kent’) compared to 65.72° and 59.35° for ‘Apple’ and ‘Kent’ on respectively on day 15 under ambient conditions. Colour change is attributed to chlorophyll degradation by chlorophyllase enzyme and synthesis of colour pigments such as anthocyanins and carotenoids during ripening (Islam and Morimoto, 2014; Medlicott et al., 1986). The observed delay in colour changes under cold storage and/or MAP conditions could be attributed to decreased metabolic reactions responsible for the synthesis of the colour inducing pigments (Blankenship and Dole, 2003). Delayed colour change in packaged fruits under cold storage has previously been reported in mango; from 91.5° to 58.53°on day 12 for fruits under ambient conditions and to 79.57° 23 days later in the Coolbot^{TM} cold room (Ambuko et al., 2018b) and other commodities namely; passion (Yumbya et al., 2014) , loquats (Amors et al., 2008) and pomegranates (Selcuk and Erkan, 2014).

The goal of postharvest management practices and technologies is to extend the shelf life of perishable produce while preserving quality attributes, including nutritional quality. In the present study changes in various quality attributes of the mango fruit were observed including total soluble solids (TSS), total titratable acidity (TTA), beta-carotene, Vitamin C and soluble sugars. TSS increased gradually as the fruits ripened across all treatments. Increase in TSS is attributed to the breakdown of stored carbohydrates during respiration into simple sugars (Saranwong et al., 2003). The rate of increase in TSS was slowed down by cold storage and MAP. For example in ‘Apple’ and ‘Kent’mango fruits which were stored in the Coolbot^{TM} cold room, the TSS increased from the initial 8.47°brix and 5.63°brix to 19.63°brix on day 30 and 18.13°brix on day 33 respectively while ECC, ZEBC and Wakati recorded 17.10°brix, 15.27°brix and 17.90°brix respectively on day 18 (‘Apple’) and 16.57°brix, 13.97°brix and 14.83°brix respectively on day 21 (‘Kent’) compared to 16.33°brix and 15.20°brix for ‘Apple’ and ‘Kent’ on respectively on day 12 under ambient conditions. Packaging in MAP bags further slowed the increase in TSS; with fruits under

Coolbot™ cold room increasing to 20.50^{o}brix on day 33 (‘Apple’) and 16.80^{o}brix on day 39 (‘Kent’) while ECC, ZEBC and Wakati recorded 16.13^{o}brix, 16.27^{o}brix and 15.43^{o}brix respectively on day 21 (‘Apple’) and 17.33^{o}brix, 15.23^{o}brix and 15.27^{o}brixrespectively on day 30 (‘Kent’) compared to 16.70^{o}brix and 14.90^{o}brix for ‘Apple’ and ‘Kent’ on respectively on day 15 under ambient conditions. Slow increase in TSS in packaged fruits under cool storage can be attributed to slowed activities of enzymes sucrose synthase, invertase and amylase (Kumar et al., 1994) at the low temperatures. In addition, low TSS levels could be due to low respiration due to low O_2 and high CO_2 under the MAP (Singh et al.,2012). Previous studies on mango showed slowed increase in ^{o}brix level in fruits stored under cold storage (21.43^{o}brix on day 21) as compared to 20.03^{o}brix on day 7 under ambient conditions (Maina et al., 2019). A similar trend in TSS has been reported in other commodities such as; passion (Yumbya et al., 2014), avocado (Gonzalez et al., 1990) and papaya (Azene et al., 2014).The observed changes in TSS were mirrored in the simple sugars (Fructose, Glucose and Sucrose) which increased as the fruits ripened despite the storage conditions and packaging. Fruits under cool storage and packaged in MAP had relatively low sugars compared to unpackaged fruits under ambient conditions. This is attributed to slow rate of respiration at low temperature and modified atmosphere that retards the hydrolysis of starch into simple sugars (Girardi et al., 2005; Siddiqui and Dhua, 2010). The activity of the enzymes such as Sucrose synthase, invertase and amylase are also reduced causing the slow breakdown of starch in cool stored (Kishore et al., 2011) and packaged fruits (Saranwong et al., 2003). On the contrary, TTA decreased as the fruit ripened. There was slowed reduction in TTA for fruits under cool storage and MAP. This is attributed to slow metabolism as a result of controlled gaseous composition of the fruit leading to slow catabolism of organic acids (Girardi et al.,2005). Previous studies showed decrease in TTA as fruit ripens, with slower rate in cold stored fruits. Maina et al. (2019) reported that TTA decreased from initial 0.775 % citric acid equivalent to 0.205 % citric acid equivalent on day 22 compared to 0.103 % citric acid equivalent on day 7 in fruits under ambient conditions. Similar trends in TTA changes have been reported in other commodities; tomato (Mathooko, 2003), plum (Díaz-Mula et al., 2011), and passion fruit (Yumbyaet al., 2014).

Beta-carotene increased as the fruits ripened. This was evidenced by the turning of flesh colour from cream yellow to yellow over storage time. There was a steady increase in beta-carotene in fruits under ambient conditions as compared to fruits under the cool storage. Gradual increase in beta carotene was also reported in packaged fruits. The slow rate increase of beta carotene in fruits under cool storage and packaged in MAP bags is attributed to delayed synthesis and accumulation of carotenoids (Marty et al., 2005). The slowed carotenoid synthesis and accumulation is due to reduced enzymatic reactions caused by low temperatures in cool storage options(Jarimopas and Kitthawee, 2007) and due to low O_2 and high CO_2in packaged fruits (Artes et al., 2006).

Vitamin C (ascorbic acid) decreased in all fruits as ripening progressed. Fruits under cool storage and fruits packaged in MAP had delayed decrease in Vitamin C due to its low oxidative degradation during respiration and/or transformation into sugars as a result of low temperature and altered gaseous composition in MAP bags (low O_2 and high $CO_{2)}$ respectively (Appiah et al., 2011). Low transpiration in cool storage and packaged fruits could also be the cause for gradual decease in ascorbic acid in fruits stored in such conditions due to the water-soluble nature of Vitamin C (Valero and Serrano, 2010). Previous studies on mango as reported by Ambuko et al., (2018b) showed that cold stored packaged fruits retained 59.8mg/100g of vitamin C on day 40 compared to cold stored unpackaged fruits (51.8mg/100g on day 35) and unpackaged fruits under ambient conditions (51.53mg/100g on day 12). Other commodities such as papaya (Singh and Rao, 2005), and passion fruits (Yumbyaet al.,2014) have also reported high vitamin C retention in cold stored fruits.

Overall, significant changes were observed in ‘Kent’ variety compared to ‘Apple’ variety as evidenced by longer shelf life (3-6 more days) and better fruit quality. Different mango cultivars respond differently to various postharvest technologies, for example faster colour change under unpackaged fruits and/or high storage temperatures (Ayele et al., 2012). Some fruit varieties are also genetically firmer than the others. Packaging positively affects the fruit cultivars based on their plant genetic, physiological and morphological characteristics (Jiang and Joyce, 2000). Similar findings of varied response to different postharvest treatments by different varieties has been reported in ‘Apple’ and ‘Kent’ mango varieties (Ayele et al., 2012) and other horticultural commodities (Watkins, 2000).

4.6 Conclusions

Storage of mango fruits in cool environments (Coolbot™ cold room, ECC, ZEBC and Wakati™ tent) extended their shelf life. Combining cool storage with MAP has a significant on extending shelf as well as maintaining quality of the stored fruits. This was achieved by minimizing effects of forced air in most cold rooms that may result in wilting and shrivelling. Cold storage extended shelf life by 9 – 18 days while MAP further extended it by 3-9 days. Cool storage of using the Coolbot^{TM} technology can therefore be recommended as a low-cost cold storage option to smallholder farmers who have access to electricity. However, for farmers who are off-grid the use of evaporative cooling technologies evaluated in this study is recommended.

CHAPTER 5

5.0 General Discussion, Conclusions and Recommendations

5.1 Discussion

Reducing food loss and waste (FLW) is broadly seen as an important way to reduce production costs and increase the efficiency of the food system, improve food security and nutrition, and contribute towards ecological sustainability (FAO, 2019). There can be no sustainable food systems when 30% of the food meant for human consumption is lost or wasted in the food production networks. The percentage losses are even higher (40-50%) in perishable commodities including fruits and vegetables.

Reduction of FLW in food supply chains requires a multifaceted approach to address the drivers along the supply chain and especially at the critical loss points. The critical loss points in mango span across the entire value chain, from the time of harvest to the retail and consumption stage. The drivers of losses at the various stages are interconnected such that actions (or lack of action) at one stage contribute to FLW at other stages of the supply chain (FAO, 2014).

One of the key drivers of FLW in perishable commodities including fruits and vegetables is poor cold chain management. Although cold chain management is misconceived as high-tech cold storage infrastructure, the present study sought to demonstrate that simple harvest practices and low-cost cold storage technologies can be applied to attain desirable cold storage for mango fruit.

The first specific objective evaluated the effectiveness of selected harvest time, handling practices and cold storage to extend shelf life of mango fruits. Harvesting fruits during cool hours of the day (early morning before 8am and/or evening) when temperatures are low and humidity is high is the first step of maintaining a cool chain for harvested fruits. At this time, there is minimal water loss from the fruits due to balanced water vapor pressure deficit (Kiaya, 2014). Simulation of evaporative cooling in transit using wetted newspapers showed that cold chain can be maintained in transit, even without refrigerated tracks. Precooling before storage is necessary to remove field heat and reduce the energy required by the cooling facility (Samtani and Kushad, 2015). This can be achieved in evaporative coolers with lower temperature (18^{o}C) and high humidity (>95%) in readiness for long-time storage in a cold room (12^{o}C). Proper cold chain management reduced rate of metabolic activities within the harvested mango fruits as evidenced by reduced physiological weight loss, retained peel and flesh colour for long and reduced softening of fruits under such conditions. Maintaining a proper cold chain management for harvested 'Apple', 'Ngowe', 'Kent', and 'Tommy Atkins' mangoes extended their shelf life by 18 days when compared to fruits under poor cold chain management.

The second specific objective compared the effectiveness of different storage technologies (Coolbot™, Zero Energy Brick Cooler, Charcoal Cooler and Wakati™) to preserve post-harvest quality of mango fruits. The Coolbot™ cold room had a significant effect on mango shelf life due to the pre-set optimal storage conditions for mango. The Coolbot™ cold room is an alternative to conventional cold rooms where the coolbot™ gadget connected to a split air conditioner overrides its thermostat making it to cool further below the 16 or 18°C obtained without developing ice on its fins. It is relatively cheap to set up and maintain as compared to conventional cold room (costs 3,000USD to 6,500 USD depending on level of sophistication and availability of constituent components, compared to a conventional cold room of the same capacity that will cost >10,000 USD) and is environmentally friendly. The evaporative coolers (ZEBC and ECC) also extended mango shelf life compared to the ambient room conditions. The temperature in evaporative coolers is passively controlled and is dependent on ambient conditions (temperature and relative humidity). Although the evaporative coolers did not attain significant cold storage in comparison to the Coolbot™ cold room, the lower temperature and high relative humidity preserved the quality better than the ambient room conditions. The ECC and ZEBC do not need electricity, are easy to operate and can be built using locally available materials. These factors make evaporative cooling technologies suited for rural areas where most of the horticultural production occurs.

Although cold storage is critical for quality preservation of perishables, there are other innovative storage technologies that have proved beneficial for perishable produce. In the present study, the effectiveness of Wakati™ tent was evaluated and shown to preserve quality and extent the shelf life of mango fruits compared to ambient room conditions due to increased humidity and oxidation of ethylene in the tent. The Wakati™ tent is portable and can therefore be used for storage at various stages of the supply chain.

Modified atmospheric packaging (MAP) is a simple postharvest technology that has application in various products including fruits and vegetables. However, the use MAP can be restricted due to unavailability of appropriate films that provide safe modified atmospheres, especially under abusive temperature conditions that can occur in the handling chain. Packages that provide safe atmospheres at one temperature may result in anaerobic conditions at higher temperature (Clarke and DeMoor, 1997). To realize the benefits of MAP, produce characteristics must be matched with the film characteristics. Recent studies in MAP have yielded suitable films for specific products whereby the film characteristics are matched with the produce characteristics. The Activebag® which was used in the present study is one such tailor-made films.

Mango fruits that were stored under cold storage or either of the three storage options had a longer shelf life as evidenced by reduced shriveling from water loss, retention of water-soluble nutrients like vitamin C, slower change in colour (peel and pulp), retained firmness of the peel and pulp among other ripening changes. Additionally, combining cold storage and MAP reduced the rate of starch breakdown as evidenced by low TSS, glucose, fructose and sucrose in fruits under such conditions. Modified atmospheric packaging was shown to compliment cold storage by minimizing water loss and subsequent shriveling that is typical of forced air-cooling systems. Despite these benefits, it was noted that fruits that were packaged with Activebag® had poor color development and developed off-flavors towards the end of storage. Additionally, the packaged fruits had higher manifestation of postharvest diseases such as anthracnose. This is attributed to the conducive environment of high humidity under MAP.

5.2 Conclusion

The results from this study shows that proper cold chain management can be achieved through proper harvest practices and simple storage technologies. Harvesting mangoes in the morning when both internal pulp and outside temperatures are low, precooling in the evaporative chambers and storage under low but safe temperatures can significantly extend the shelf life of mango fruit.

Mango storage using simple storage technologies (Coolbot™ cold room, ECC, ZEBC and Wakati™ tent) can be used to extend the shelf life and hence marketing period of mango fruits. Combining cool storage with MAP significantly extended shelf life and maintained quality of mango fruits. MAP compliments cold storage by minimizing effects of forced air in most cold rooms that may result in wilting and shrivelling.

Overall, this study concludes that cool chain management is key in maintaining fresh harvested crops and that the low-cost alternative storage options (Coolbot™ cold room, ZEBC, ECC and

Wakati™ tent) coupled with modified atmospheric packaging can be adopted by smallholder farmers prolong mango shelf life, preserve quality and extend the fruits' marketing period.

5.3 Recommendations

- Fruits and vegetable harvesting during cool hours of the day (before 8am and in the evening after sunset), transport of commodity in crates lined with wetted/damp newspapers to simulate evaporative cooling can be adopted as a good practice in cold chain management.
- Precooling of harvested produce using evaporative cooling prior to long-term storage in the cold rooms can enhance the produce shelf life by removing the field heat.
- Besides serving the purpose of produce precooling prior to cold storage, evaporative coolers (ZEBC and ECC) can be adopted by smallholder farmers who are off-grid. The fact that they are made from locally available materials, makes them affordable and well adapted to local conditions.
- The Coolbot™ cold room achieved and maintained comparable temperatures as a conventional cold room. It therefore be recommended for adoption as a low-cost alternative to conventional cold rooms. Use of water buckets in the cold room can be used to increase humidity in the cold room to reduce the water vapor pressure deficit and therefore minimize water loss and shriveling.
- The Wakati™ tent can be adopted by retail traders and farmers due to their portability nature for temporal storage of fruits and vegetables.
- The use of Activebag® bags in modified atmospheric packaging achieves best results when complemented with cold storage. Use of MAP without cold storage negates the beneficial effects as evidenced by off-flavors and increased deterioration from postharvest diseases.
- A cost benefit analysis is recommended before adoption of the various technologies. Some of the success factors that could influence adoption of the technologies include; the effectiveness, the cost (initial set up, running and repairs), local availability of materials required to fabricate the technology, required infrastructure in place such as power supply (for the Coolbot™ cold room), weather patterns (evaporative coolers will require dryer areas).

REFERENCES

Abad, E., Palacio, F., Nuin, M., De Zarate, A. G., Juarros, A., Gómez, J. M., & Marco, S. (2009). RFID smart tag for traceability and cold chain monitoring of foods: Demonstration in an intercontinental fresh fish logistic chain. *Journal of food engineering*, *93*(4), 394-399.

Abdul Rahaman, A., Al Hassan, N. & Halidu, H. (2014). Charcoal evaporative cooling technology for storage of dwarf ger marglobe tomato fruits. International Journal of Technical Research and Applications 2, 6:149-151

Abiso, E, N Atheesh*, and H Addisalem. (2015). Effect of storage methods and ripening stages on postharvest quality of tomato (Lycopersicom Esculentum mill) cv. Chali effect of storage methods and ripening stages on postharvest Tomato (Lycopersicom Esculentum L.) Is Botanically Classified as a Fr. Annals. Food Science and Technology 16(1): 127–37.

(AFA)Website, Agriculture and Food Authority. (2020). Accessed online at http://horticulture.agricultureauthority.go.ke/images/docs/AFA%20Strategic%20Plan-min(1).pdf

Ahmad, Saeed, A K Thompson, Ahmad Hafiz, and Ali Asghar Asi. (2001). Effect of Temperature on the Ripening Behavior and Quality of Banana Fruit. International Journal of Agriculture & Biology 3(2): 224–27. http://www.fspublishers.org/published_papers/87164_.pdf.

Alexiades, A., Sánchez, J. I., Lekashman, K., & Muse, W. (2014). Cost and commercialization analysis for cold storage technology in Kenya. UC Davies.

Ambuko, J., Wanjiru, F., Karithi, E., Hutchinson, M., Chemining'wa, G., Mwachoni, E., … Nenguwo, N. (2018a). Cold chain management in horticultural crops value chains: Options for smallholder farmers in Africa. Acta Horticulturae. https://doi.org/10.17660/ActaHortic.2018.1225.9

Ambuko, J., Karithi, E., Hutchinson, M., Wasilwa, L., Hansen, B., & Owino, W. (2018b). Postharvest shelf life of mango fruits stored in a CoolbotTM cold room. *Acta*

Horticulturae, (1225), 193-197.

Ambuko, Jane, Esther Karithi, Margaret Hutchinson, and Willis Owino. (2018c). Modified Atmosphere Packaging Enhances the Effectiveness of Coolbot^{TM} Cold Storage to Preserve Postharvest Quality of Mango Fruits. Journal of Food Research 7(5): 7.

Ambuko Jane, F. Wanjiru, G. N. Chemining'wa, W.O. Owino and Eliakim Mwachoni (2017). Preservation of Postharvest Quality of Leafy Amaranth (*Amaranthus spp*) Vegetables Using Evaporative Cooling. Journal of Food Quality. Article ID 5303156, https://doi.org/10.1155/2017/5303156

Ambuko, J. (2016). The plight of small-holder mango farmers in Kenya during the peak season. Hortfresh Journal, May-June, 2016 Issue

Amoros, A., Pretel, M. T., Zapata, P. J., Botella, M. A., Romojaro, F., & Serrano, M. (2008). Use of modified atmosphere packaging with microperforated polypropylene films to maintain postharvest loquat fruit quality. *Food Science and Technology International*, *14*(1), 95-103.

Ara, R., Motalab, M., Uddin, M. N., Fakhruddin, A. N. M., & Saha, B. K. (2014). Nutritional evaluation of different mango varieties available in Bangladesh. *International Food Research Journal*, *21*(6).

Arah, Isaac Kojo, Harrison Amaglo, Ernest Kodzo Kumah, and Hayford Ofori. (2015). Preharvest and Postharvest Factors Affecting the Quality and Shelf Life of Harvested Tomatoes: A Mini Review. *International Journal of Agronomy* 2015.

Artés, F., Gómez, P. A., & Artés-Hernández, F. (2006). Modified atmosphere packaging of fruits and vegetables. *Stewart Postharvest Review*, *2*(5), 1-13.

Asghar M. B., Parviz, A.M., Asaad, M.M. and Hamed D. (2012). Sorting and grading of cherries on the basis of ripeness, size and defects by using Image Processing Techniques. International Journal of Agriculture and Crop Science, 4(16):11441149

Atanda, S.A., Pessu P. O., Agoda S., Isong I. U. and Ikotun, K. (2011). The concepts and problems of postharvest food losses in perishable crops. African Journal of Food Science 5 (11), 603-613.

Aung, M.M., Chang, Y.S., (2014). Temperature management for the quality assurance of a perishable food supply chain. Food Control 40, 198–207.

Ayarmal, A., O.Melhus, and A.Chaudhuri. (2018). The Effects Of Fan And Door Opening On A Cold Storage Room: A Numerical Study. *Proceedings of The 59th Conference on Simulation and Modelling* (September): 201–9. http://www.ep.liu.se/ecp/article.asp?issue=153&article=028&volume=.

Ayele, L, and A Bayleyegn. (2017). Effect of Low Temperature Storage on Ripening and Quality of Mango. Mangifera indica L.). Acad. Res. J. Agri. Sci. Res 5(7): 570–76. https://www.researchgate.net/publication/322715184.

Ayele, L., Abegaz, K., & Yetneberk, S. (2012). Postharvest Ripening and Shelf Life of Mango (Mangifera indica L.) Fruit as Influenced by 1-Methylcyclopropene and Polyethylene Packaging. *Ethiopian Journal of Agricultural Sciences*, *22*(1), 26-44.

Azene, Mulualem, Tilahun Seyoum Workneh, and Kebede Woldetsadik. (2014). Effect of Packaging Materials and Storage Environment on Postharvest Quality of Papaya Fruit. Journal of Food Science and Technology 51(6): 1041–55.

Baldwin, E. A., Burns, J. K., Kazokas, W., Brecht, J. K., Hagenmaier, R. D., Bender, R. J., & Pesis, E. D. N. A. (1999). Effect of two edible coatings with different permeability characteristics on mango (Mangifera indica L.) ripening during storage. *Postharvest Biology and Technology*, *17*(3), 215-226.

Balogun, A. A., and C. C. Ariahu. (2020). Quality Evaluation of Fresh Fluted Pumpkin Leaves Stored in Evaporative Coolers. *Asian Food Science Journal* 18(3): 12–23.

Bartolomeu, Bartolomeu G., Ana C. Pinheiro, Maria G. Carneiro-Da-Cunha, and António A. Vicente. (2012). Development and Characterization of a Nanomultilayer Coating of Pectin and Chitosan - Evaluation of Its Gas Barrier Properties and Application on ‘Tommy Atkins’ Mangoes. Journal of Food Engineering 110(3): 457–64. http://dx.doi.org/10.1016/j.jfoodeng.2011.12.021.

Beaudry, R. M. (2000). Responses of horticultural commodities to low oxygen: limits to the expanded use of modified atmosphere packaging. *HortTechnology*, *10*(3), 491-500.

Blakey, R J, I Bertling, and J P Bower. (2011). Importance of Cold Chain Maintenance and Storage Temperature to Avocado Ripening and Quality [Electronic Resource]. *Acta horticulturae* (911): 555–64.

Blanke, Michael M. (2014). Reducing Ethylene Levels along the Food Supply Chain: A Key to Reducing Food Waste? *Journal of the Science of Food and Agriculture* 94(12): 2357–61.

Blankenship, Sylvia M., and John M. Dole. (2003). 1-Methylcyclopropene: A Review. Postharvest Biology and Technology 28(1): 1–25.

Brian lipinski, Craig Hanson, James Lomax, Lisa Kitinoja, Richard Waite and Tim Searchinger. (2013). Reducing Food Loss and Waste. (May): 1–40

Brosnan, Tadhg, and Da Wen Sun. (2001). Precooling Techniques and Applications for Horticultural Products - a Review. *International Journal of Refrigeration* 24(2): 154–70.

Camargo, J. R. (2008). Evaporative cooling: water for thermal comfort. *Ambiente e Agua-An Interdisciplinary Journal of Applied Science, 3*(2), 51-61.

Camelo, A. F. L. (2004). *Manual for the preparation and sale of fruits and vegetables: from field to market* (Vol. 151). Food & Agriculture Org.

Chang, Lan Yen, and Jeffrey K. Brecht. (2020). Variation among Strawberry Cultivars in Bruising Susceptibility Related to Wound Ethylene Production and Sensitivity. *HortScience* 55(4): 444–48.

Charles Aworh, O. (2015). Promoting Food Security and Enhancing Nigeria’s Small Farmers’ Income through Value-Added Processing of Lesser-Known and under-Utilized Indigenous Fruits and Vegetables. *Food Research International* 76(P4): 986–91. http://dx.doi.org/10.1016/j.foodres.2015.06.003.

Chauhan, O. P., Raju, P. S., Dasgupta, D. K., & Bawa, A. S. (2006). Instrumental textural changes in banana (var. Pachbale) during ripening under active and passive modified atmosphere. International journal of food properties, 9(2), 237-253.

Cheng, G., Yang, E., Lu, W., Jia, Y., Jiang, Y., & Duan, X. (2009). Effect of nitric oxide on ethylene synthesis and softening of banana fruit slice during ripening. *Journal of agricultural and food chemistry, 57*(13), 5799-5804.

Cherono, Kipchumba, Milindi Sibomana, and Tilahun Seyoum Workneh. (2018). Effect of Infield Handling Conditions and Time to Pre-Cooling on the Shelf-Life and Quality of Tomatoes. *Brazilian Journal of Food Technology* 21.

Chinenye, Ndukwu Macmanus. (2011). Development of Clay Evaporative Cooler for Fruits and Vegetables Preservation. Agricultural Engineering International: CIGR Journal 13(1).

Chomchalow, Narong, and Prem Na Songkhla. (2008). Thai Mango Export : A Slow-but-Sustainable Development. *Agriculture* 12(1): 1–8.

Chopra S., Baboo B., Kudo S.K. and Oberoi H.S. (2003). An effective on farm storage structure for tomatoes. Acta Horticulturae. 682: 591-598 In Proceedings of the International Seminar on Downsizing Technology for Rural Development, Orissa, India, 9/10/ 2003.

Clarke, R. and C.P. De Moor. (1997). The future in film technology: A tunable packaging system for fresh produce, p. 68–75. In: J. Gorney (ed.). CA'97 Proceedings. vol. 5. Fresh-cut fruits and vegetables and MAP. Univ. Calif. Postharvest Hort. Ser. 19.

Crane, J.H., Salazar-Garcia, S., Lin, T.S., de Queiroz Pinto, A.C. & Shu, Z. H., (2009). Crop Production: Management (432- 483) in Litz, R. E. (eds). The mango: botany, production and uses, 2nd edition. CABI, Oxfordshire.

Dadhich, Sushmita Mukherjee, Hemant Dadhich, and Radha Charan Verma. (2008). Comparative Study on Storage of Fruits and Vegetables in Evaporative Cool Chamber and in Ambient. *International Journal of Food Engineering* 4(1).

De, Almacenamiento, De Mangifera, and L Van Dyke. (2005). Using Modified Atmosphere Packaging for Storing 'Van Dyke' Mango (Mangifera Indica L.) Fruit. Agronomia Colombiana 23(2): 269–75.

Deirdre, H. (2015). Water relations in harvested fresh produce. PEF white paper No. 15-01

Díaz-Mula, H. M., Zapata, P. J., Guillén, F., Valverde, J. M., Valero, D., & Serrano, M. (2011). Modified atmosphere packaging of yellow and purple plum cultivars. 2. Effect on bioactive compounds and antioxidant activity. *Postharvest biology and technology*, *61*(2-3), 110-116.

Do Nascimento Nunes, M. C., Nicometo, M., Emond, J. P., Melis, R. B., & Uysal, I. (2014). Improvement in fresh fruit and vegetable logistics quality: berry logistics field studies. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *372*(2017), 20130307.

Dubey, N.and Raman, M.N. (2013). Effect of Coolbot Cool room on shelf-life of Cabbage and Cauliflower.American International Journal of Research in Formal, Applied and Natural Sciences13 (1):66-69

Dubey, Neeru. (2011). Use of Coolbot Technology for Construction of Low Cost-Low-Capacity Cold Storages on Farms.: 112–16.

Elemasho, M. K., Alfred, S. D. Y., Aneke, C. C., Chugali, A. J. C., & Ajiboye, O. (2017). Factors affecting adoption of post-harvest technologies of selected food crops in Rivers State, Nigeria. *International journal of agricultural economics and extension*, *5*(5), 295-301.

Elias. A, (2007): Technical Assessment on Viability of Integrated Fruits Processing in Ethiopia; Master of sciences Thesis, Addis Ababa, Ethiopia

EO, Ogumo, Kunyanga CN, Kimenju JW, and Okoth MW. (2018). Effects of Harvest Time and Duration before Cooling on the Post-Harvest Quality and Shelf-Life Stability of French Bean (Phaseolus Vulgaris L.). *Journal of Nutrition & Food Sciences* 08(05).

Export Zones Promotion Council (EZPC) (2017). Horticulture Industry in Kenya: History and challenges. EZPC Nairobi Kenya

Ezz, Thanaa M., and Rehab M. Awad. (2011). Effect of Some Post Harvest Treatments under Different Low Temperature on Two Mango Cultivars. Australian Journal of Basic and Applied Sciences 5(10): 1164–74.

FAO, (2011). Global food losses and food waste- extent, causes and prevention, by

Gustavsson, C.C., U. Sonesson, R. Van Otterdjik and A. Meybeck. Rome. Accessed on 15th June 2014 on http://www.fao.org.docrep/014/mb060e00.pdf

FAO, (2014). Food losses and waste in the context of sustainable food systems. High Level Panel of Experts (HLPE), Report 8.

FAO, (2019). The State of Food and Agriculture 2019. Moving forward on food loss and waste reduction. Rome.

Getinet, H., T. S. Workneh, and K. Woldetsadik. (2011). Effect of Maturity Stages, Variety and Storage Environment on Sugar Content of Tomato Stored in Multiple Pads Evaporative Cooler. *African Journal of Biotechnology* 10(80): 18481–92.

Girardi, C. L., Corrent, A. R., Lucchetta, L., Zanuzo, M. R., da Costa, T. S., Brackmann, A., ... & Rombaldi, C. V. (2005). Effect of ethylene, intermittent warming and controlled atmosphere on postharvest quality and the occurrence of woolliness in peach (Prunus persica cv. Chiripá) during cold storage. *Postharvest Biology and Technology*, *38*(1), 25-33.

Gitari, Harun, Nancy Karanja, Charles Gachene, and Solomon Kamau. (2018). Increasing Potato Equivalent Yield Increases Returns to Investment under Potato- Legume Intercropping Systems. (August): 1–7.

Githiga, R, J Ambuko, M Hutchnison, and W Owino. (2015). Effect of Activebag® Modified Atmosphere Packaging on the Postharvest Characteristics of Mango Fruits, Mangifera Indica L, Cultivar Tommy Atkins. Journal of Applied Biosciences 83(1): 7535.

Gonzalez, G., Elhadi M. Yahia, and I. Higuera. (1990). Modified Atmosphere Packaging (Map) of Mango and Avocado Fruit. Acta Horticulturae (269): 335–44.

Gor, C., Agong, S., Acheng, L., Akuno, W. and Andika, D. (2012). The interface between mango value chain analysis and the socioeconomic determinants, African journal of horticulture science. 6(1): 1-16

Griesbach, J. (2003). Mango Growing in Kenya. International Center for Research in Agroforestry, Nairobi, Kenya.

Gykiere and Pauwels. (2017). Low Power Ozone Generator in Moisture Rich Climate for the Preservation of Fruits and Vegetables. 1.

Hafeez, O., Malik, A. U., Khan, A. S., Rehman, A., & Javaid, Q. A. (2012). Impact of different packaging types and low temperature shipping durations on fruit quality and marketability of Pakistani mangoes. *International Journal of Agriculture and Biology*, *14*(1), 47-54.

Hernández, Y., Lobo, M. G., & González, M. (2006). Determination of vitamin C in tropical fruits: A comparative evaluation of methods. *Food chemistry*, *96*(4), 654-664.

Hailu, M., Workneh, T. S., & Belew, D. (2014). Effect of packaging materials on shelf life and quality of banana cultivars (Musa spp.). Journal of food science and technology, 51(11), 2947-2963.

Hassan, Z. H., S. Lesmayati, R. Qomariah, and A. Hasbianto. (2014). Effects of Wax Coating Applications and Storage Temperatures on the Quality of Tangerine Citrus (Citrus Reticulata) Var. Siam Banjar. *International Food Research Journal* 21(2): 641–48.

Hodges, R.J., Bernard, M., Knipschild, H. & Rembold, F. (2010). African Postharvest Losses Information System – a network for the estimation of cereal weight losses.

Holcroft, D. (2015). Water relations in harvested fresh produce. PEF White Paper, (15-01), 16.

Horticultural Crops Directorate (HCD). (2017). Validated Report 2016-2017.

Huidrom, Deepak, Neeru Dubey, Manju Rawat, and Thangjam Rishikanta. (2016). Low Cost Storage Technology for Farmers ' Cooperative Groups and Retail Mandi. 3(2): 79–82.

Humble, Susanna, and Amanda Reneby. (2014). Post-Harvest Losses in Fruit Supply Chains – A Case Study of Mango and Avocado in Ethiopia. *Unpublished Masters of Agricultureal Economics and Management, Swedish University of Agricultural Sciences.* (899): 74.

Humphrey, J., McCulloch, N., and Ota, M. (2004). The impact of European market changes on employment in the Kenyan horticulture sector. Journal of International

Development, 16(1), 6 3-80.

Ilić, Zoran S., Lidija Milenković, Ljubomir Šunić, and Maja Manojlović. (2018). Color Shade Nets Improve Vegetables Quality at Harvest and Maintain Quality During Storage. *Contemporary Agriculture* 67(1): 9–19.

Ingle, M., D‟Souza, M.C. and Townsend, E.C. (2000). Fruit characteristics of York apples during development and after storage. Horticulturae Scientia, 35(1): 95-98

Irtwange, S V. (2006). Application of Modified Atmosphere Packaging and Related Technology in Postharvest Handling of Fresh Fruits and Vegetables. Agricultural Engineering International: the CIGR Ejournal VIII (4): 1–13.

Irungu, J. (2011). Contribution of horticulture to food security in Kenya. Acta Horticulture 911, 27-32

Ishaq, Saira, Habib Ahmed Rathore, Tariq Masud, and Sartaj Ali. (2009). Influence of Post Harvest Calcium Chloride Application, Ethylene Absorbent and Modified Atmosphere on Quality Characteristics and Shelf Life of Apricot (Prunus Armeniaca L.) Fruit during Storage. *Pakistan Journal of Nutrition* 8(6): 861–65.

Ishida, K., Ohara, N., Kavvas, M. L., Chen, Z. Q., & Anderson, M. L. (2018). Impact of air temperature on physically-based maximum precipitation estimation through change in moisture holding capacity of air. *Journal of Hydrology, 556*, 1050-1063.

Islam, Md Parvez, and Tetsuo Morimoto. (2012). Zero Energy Cool Chamber for Extending the Shelf-Life of Tomato and Eggplant. *Japan Agricultural Research Quarterly* 46(3): 257–67.

Islam, Md Parvez, and Tetsuo Morimoto. (2014). A New Zero Energy Cool Chamber with a Solar-Driven Adsorption Refrigerator. Renewable Energy 72: 367–76. http://dx.doi.org/10.1016/j.renene.2014.07.038.

Jaetzold R. and Schmidt H. (1983); Farm management handbook of Kenya, vols. IIC Eastern Province

Jahun, B G, S A Abdulkadir, S M Musa, and Huzaifa Umar. (2016). Assessment of

Evaporative Cooling System for Storage of Vegetables. *International Journal of Science and Research (IJSR)* 5(1): 1197–1203.

James, S. J., C. James, and J. A. Evans. (2006). Modelling of Food Transportation Systems - a Review.” *International Journal of Refrigeration* 29(6): 947–57.

Jarimopas, Bundit, and Udomsak Kitthawee. (2007). Firmness Properties of Mangoes. International Journal of Food Properties 10(4): 899–909.

Jiang, Y., & Joyce, D. C. (2000). Effects of 1-methylcyclopropene alone and in combination with polyethylene bags on the postharvest life of mango fruit. *Annals of Applied Biology*, *137*(3), 321-327.

Jiang, P., Bertone, J. F., Hwang, K. S., & Colvin, V. L. (1999). Single-crystal colloidal multilayers of controlled thickness. *Chemistry of Materials*, *11*(8), 2132-2140.

Jobling, By Jenny. (2001). Correct Cool Chain Management Is Essential for All Fruit and Vegetables. *Sydney Postharvest Laboratory*: 1–4.

Jobling, Jenny. (2000). Temperature Management Is Essential for Maintaining Produce Quality. *Good Fruit and Vegetables magazine*: 30–31. http://www.postharvest.com.au/Temperature_article1.PDF.

Johnson, G.I., Hofman, P.J., (2009). Postharvest technology and quarantine treatments. In: Litz, R.E. (Ed.), The Mango: Botany, Production and Uses, second ed. CABI, Wallingford UK, pp. 529605.

Jongsri, P., Wangsomboondee, T., Rojsitthisak, P., & Seraypheap, K. (2016). Effect of molecular weights of chitosan coating on postharvest quality and physicochemical characteristics of mango fruit. LWT-Food Science and Technology, 73, 28-36.

Kader, A. A. (2010). Flavor vs marketability of fresh-cut fruits. *Italus Hortus, 17*(3), 7-10.

Kader, A. A. (2009, April). Handling of horticultural perishables in developing vs. developed countries. In *VI International Postharvest Symposium 877* (pp. 121-126).

Kader, A. A. (2008). Flavor quality of fruits and vegetables. *Journal of the Science of Food and Agriculture, 88*(11), 1863-1868.

Kader, A. A. (2005). Increasing Food Availability by Reducing Postharvest Losses of Fresh Produce. Acta Horticulturae 682: 2169–76.

Kader, A.A. (2005). Post harvest handling.379-407, In Preace, J.E. and P.E. Reed. The Biology of Horticulture, 2nd Ed, John Wiley and Sons.

Kader, A. A. (2002). Postharvest Technology of Horticultural Crops, Third Ed. University of Carlifonia. Agriculture and Natural Resources, 3311: 533-535.

Kader, A. A. (1994). Regulation of fruit physiology by controlled/modified atmospheres. *Postharvest Physiology of Fruits 398*, 59-70.

Kader, A.A. and Rolle S.R. (2004). The role of post harvest management in assuring quality and safety of horticultural produce. FAO Agricultural Support Systems Division 152:1010-1365.

Karithi, M. S. (2016). Evaluation of the efficacy of Coolbot™ cold storage technology to preserve quality and extend shelf life of mango fruits, Master's Thesis, University of Nairobi.

Kassa, Mesay. (2017). Strategic Analysis of Mango (Mangifera Indica) Value Chain in Dilla Zuriya District, Dilla Ethiopia. *International Journal of Plant & Soil Science* 16(1): 1–12.

Kassahun, T. (2014). Review of bamboo value chain in Ethiopia. *International Journal of African Society Culture and Traditions*, *2*(3), 52-67.

Kathryn C.T. and James W.R. (2004). Harvesting and handling peaches. Accessed online at http://www.ent.uga.edu/peach/peachhbk/harvest/harvestandhandle.pdf

Katsoulas, N., Baille, A., & Kittas, C. (2001). Effect of misting on transpiration and Conductance of a greenhouse rose canopy. Agricultural and Forest Meteorology, 106, 233-247.

Kelany, A.E., Abdel-Wahab, S.M., Abdel-Hafeez, A.A. and Osman, M.T. (2010). Using Modified Atmosphere and different Temperatures for Storing "Kent" Mango Fruit. Journal of Horticultural Science and OrnamentalPlants2(1):46-56

Kemunto, N. O. (2013). Effects of agro-ecological zones on the postharvest shelf life and quality of “apple” mango (Mangifera indica L.) and their response to 1Methylcyclopropene(1-MCP). Master of Science, Thesis. University of Nairobi, Kenya.

Khorshidi, Jalal, Mohammad Fakr Tabatabaei, and Fazel Mir Ahmadi. (2010). Storage Temperature Effects on the Postharvest Quality of Apple (Malus Domestica Borkh. Cv. Red Delicious). New York Science Journal 3(3): 3–6.

Khorshidi, Jalal, Mohammad Fakr Tabatabaei, and Fazel Mir Ahmadi. (2010). Storage Temperature Effects on the Postharvest Quality of Apple (Malus Domestica Borkh. Cv. Red Delicious). *New York Science Journal* 3(3): 3–6.

Kiaya, Victor. (2014). Post-Harvest Losses and Strategies To. *The Journal of Agricultural Science* 149(3–4): 49–57.

Kishore, Kundan, K. A. Pathak, Rohit Shukla, and Rinku Bharali. (2011). Effect of Storage Temperature on Physico-Chemical and Sensory Attributes of Purple Passion Fruit (Passiflora Edulis Sims). Journal of Food Science and Technology 48(4): 484–88.

Kitinoja, L. (2013). Use of cold chains for reducing food losses in developing countries, (13), 1–16. PEF White Paper No. 13-03

Kitinoja, Lisa, and Adel A Kader. (2015). Measuring Postharvest Losses of Fresh Fruits and Vegetables in Developing Countries. *The Postharvest Education Foundation* (February): 1–26. http://www.postharvest.org/PEF_White_Paper_15-02_PHFVmeasurement.pdf%0Ahttps://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=12&cad=rja&uact=8&ved=2ahUKEwiH8-P2gvbjAhVTi1wKHd3gDBUQFjALegQIAhAC&url=http%3A%2F%2Fpostharvest.org%2FPEF_White_Paper_15-.

Kitinoja, L. and Alhassan, H.Y. (2012). Identification of appropriate post-harvest technologies for small scale horticultural farmers and marketers in Sub-Saharan Africa and South Asia. Acta Horticulturae, 934:31-40.

Kitinoja, L. and Kader, A.A. (2002). Small-Scale post harvest handling Practices: A manual for Horticultural Crops. 4th Edition, University of California, Post harvest research and Information Centre, Davis

Kitinoja, Lisa, Sunil Saran, Susanta K. Roy, and Adel A. Kader. 2011. “Postharvest Technology for Developing Countries: Challenges and Opportunities in Research, Outreach and Advocacy.” *Journal of the Science of Food and Agriculture* 91(4): 597–603.

Kitinoja, L. (2010). Identification of appropriate postharvest technologies for improving market access and incomes for small horticultural farmers in Sub-Saharan Africa and South Asia. WFLO Grant Final Report, 323.

Kok, R D, J P Bower, and I Bertling. (2010). Low Temperature Shipping and Cold Chain Management of ‘Hass’ Avocados: An Opportunity to Reduce Shipping Costs RD. *South African Avocado Growers’ Association* 33: 33–37.

Korir, J. K., Affognon, H. D., Ritho, C. N., Kingori, W. S., Irungu, P., Mohamed, S. A., & Ekesi, S. (2015). Grower adoption of an integrated pest management package for management of mango-infesting fruit flies (Diptera: Tephritidae) in Embu, Kenya. *International Journal of Tropical Insect Science*, *35*(2), 80-89.

Kumah, Patrick, and Francis Appiah. (2011). Effect of Hot Water Treatment on Quality and Shelf-Life of Keitt Mango. Agriculture and Biology Journal of North America 2(5): 806–17.

Kumar, S., Kumar, A., & Kumar, S. (2019). Development of a cold storage facility for agricultural produce using air conditioner. *Journal of Postharvest Technology*, *7*(1), 93-100.

Lal Basediya, Amrat, D. V.K. Samuel, and Vimala Beera. (2013a). Evaporative Cooling System for Storage of Fruits and Vegetables - A Review. *Journal of Food Science and Technology* 50(3): 429–42.

Lazan, Hamid, Mohd Kasim Selamat, and Zainon Mohd Ali. (1995). B-Galactosidase, Polygalacturonase and Pectinesterase in Differential Softening and Cell Wall Modification during Papaya Fruit Ripening. *Physiologia Plantarum* 95(1): 106–12.

Liberty, J. T, B. O. Ugwuishiwu, S. a. Pukuma, and C. E. Odo. (2013). Principles and Application of Evaporative Cooling Systems for Fruits and Vegetables Preservation. *International Journal of Current Engineering and Technology* 3(3): 1000–1006.

Lufu, Robert, Alemayehu Ambaw, and Umezuruike Linus Opara. (2020). Water Loss of Fresh Fruit: Influencing Pre-Harvest, Harvest and Postharvest Factors. *Scientia Horticulturae* 272(May).

M, Okoth E, and Onyango C A. (2013). Evaluation of Chemical and Nutritional Quality Attributes of Selected Mango Varieties at Three Stages of Ripeness, Grown in Lower Eastern Province of Kenya – Part 2. *Journal of Animal &Plant Sciences* 17(3): 2619–30. http://www.m.elewa.org/JAPS;

Mahajan, B. V.C., S. R. Sharma, and R. K. Dhall. (2009). Optimization of Storage Temperature for Maintaining Quality of Guava. *Journal of Food Science and Technology* 46(6): 604–5.

Mahajan, P. V., & Frías, J. (2012). Cold chain. Decontamination of Fresh and Minimally Processed Produce, 269-484.

Mahajan, Pramod V., and Jesus Frías. (2010). Cold Chain. In *Decontamination of Fresh and Minimally Processed Produce*, ed. Vicente M. Gómez-López. , 469–82.

Maina, Benson. (2019). Efficacy Of Waxing Innovations To Extend Shelf Life And Preserve Postharvest Quality Of Mango Fruits By A Thesis Submitted in Partial Fulfilment of the Requirement for the Degree of Master of Science Horticulture of the University of Nairobi Department of Plant Science and Crop Protection Faculty of Agriculture.

Maina, Benson, Eric Verploegen, and Grace Burleson. (2019). Assessment of the Use and Barriers of Evaporative Cooling Technologies by Small Holder Farmers in Kenya.

Maina, Benson, Jane Ambuko, Margaret J. Hutchinson, and Willis O. Owino. (2019). The Effect of Waxing Options on Shelf Life and Postharvest Quality of ‘Ngowe’ Mango Fruits under Different Storage Conditions. Advances in Agriculture 2019: 1–9.

Maina, B., Ambuko, J., Hutchinson, M., & Owino, W. (2018). The Effect of Different Waxing Technologies on Shelf Life of ‘Apple’Mango Fruits Stored Under Different Storage

Conditions.

Maloba, S., Ambuko, J., Hutchinson, M., & Owino, W. (2017). Offseason flower induction in mango fruits using ethephon and potassium nitrate. Journal of Agricultural Science, 9(9), 158.

Maneepun, Saipin, and Monthatip Yunchalad. (2004). Developing Processed Mango Products for International Markets. *Acta Horticulturae* 645: 93–105.

Manyozo, Fred N., Jane Ambuko, Margaret J. Hutchinson, and J. F. Kamanula. (2018). Effectiveness of Evaporative Cooling Technologies to Preserve the Postharvest Quality of Tomato. *International Journal of Agronomy and Agricultural Research* 13(2): 114–27.

Manzini, Riccardo, and Riccardo Accorsi. (2013). The New Conceptual Framework for Food Supply Chain Assessment. *Journal of Food Engineering* 115(2): 251–63. http://dx.doi.org/10.1016/j.jfoodeng.2012.10.026.

Maqbool, M., Ali, A., Alderson, P. G., Mohamed, M. T. M., Siddiqui, Y., & Zahid, N. (2011). Postharvest application of gum arabic and essential oils for controlling anthracnose and quality of banana and papaya during cold storage. *Postharvest biology and technology*, *62*(1), 71-76.

Martínez-Romero, D., Alburquerque, N., Valverde, J. M., Guillén, F., Castillo, S., Valero, D., & Serrano, M. (2006). Postharvest sweet cherry quality and safety maintenance by Aloe vera treatment: a new edible coating. *Postharvest Biology and Technology*, *39*(1), 93-100.

Marty, I., Bureau, S., Sarkissian, G., Gouble, B., Audergon, J. M., & Albagnac, G. (2005). Ethylene regulation of carotenoid accumulation and carotenogenic gene expression in colour-contrasted apricot varieties (Prunus armeniaca). *Journal of Experimental Botany*, *56*(417), 1877-1886.

Mathooko, F.M. (2003). A comparison of Modified atmosphere packaging under ambient conditions and low temperature storage on quality of tomato fruit. African Journal of Food Agriculture Nutrition and Development. 3: 2-9

Mbogo, GP, EB Mubofu, and CC Othman. (2010). Post Harvest Changes in Physico-Chemical Properties and Levels of Some Inorganic Elements in off Vine Ripened Orange (Citrus Sinensis) Fruits Cv (Navel and Valencia). *African Journal of Biotechnology* 9(12): 1809–15. http://www.ajol.info/index.php/ajb/article/view/78369.

Medlicott, A P, Mohinder Bhogal, and S B Reynolds. (1986). Changes in Peel Pigmentation during Ripening of Mango Fruit. Ann. appl. Biol 109: 651–56.

Meena MS, Prasad M, Singh R (2009). Constraints Perceived by Rural-Processors in Adopting Modern Post – Harvest Technologies Indian Res. J Ext-Edu 9 (1).

Mercier, Samuel, Sebastien Villeneuve, Martin Mondor, and Ismail Uysal. (2017). Time–Temperature Management Along the Food Cold Chain: A Review of Recent Developments. *Comprehensive Reviews in Food Science and Food Safety* 16(4): 647–67

Miller A.R. (2003). Harvest and handling injury: physiology, biochemistry and detection in: postharvest physiology and pathology of vegetables, 2nd Edition J.A. Bartz and J. K. Brecht (Eds.). Marcel Dekker, New York 2003: 177-208.

Montalvo, Efigenia, Hugo S. García, Beatriz Tovar, and Miguel Mata. (2007). Application of Exogenous Ethylene on Postharvest Ripening of Refrigerated 'Ataulfo' Mangoes. *LWT - Food Science and Technology* 40(8): 1466–72.

Moraru, Catalin, Logan Logendra, Tung Ching Lee, and Harry Janes. (2004). Characteristics of 10 Processing Tomato Cultivars Grown Hydroponically for the NASA Advanced Life Support (ALS) Program. *Journal of Food Composition and Analysis* 17(2): 141–54.

Msogoya, T., and E. Kimaro. (2011). Assessment and Management of Post Harvest Losses of Fresh Mango under Small-Scale Business in Morogoro, Tanzania. 11(1): 1358–63.

Mujuka, E., Mburu, J., Ogutu, A., & Ambuko, J. (2020). Returns to investment in postharvest loss reduction technologies among mango farmers in Embu County, Kenya. *Food and Energy Security*, *9*(1), e195.

Muriithi, B. W., Affognon, H. D., Diiro, G. M., Kingori, S. W., Tanga, C. M., Nderitu, P. W.,

... & Ekesi, S. (2016). Impact assessment of Integrated Pest Management (IPM) strategy for suppression of mango-infesting fruit flies in Kenya. *Crop Protection*, *81*, 20-29.

Murugan, Am, Singh A.J.A. Ranjith, and S. Vidhya. (2011). Evaluation of Self-Life and Organoleptic Aspects of Fruits Stored in a Modified Traditional Earthen Pot Cool Chamber. Indian Journal of Traditional Knowledge 10(2): 375–79.

Muthoka M.M. and Ogutu M. (2014). Response Strategies to Challenges Faced by the Horticultural Firms in Nairobi County of Kenya. Journal of Economics and Sustainable Development; Vol.5, No.5, 2014

Mututo, D., (2011). Mango Farming Changing Livelihood of Farmers in Makueni County. Department of Information and Public communications, Kenya.

Ndukwu, M C, and S I Manuwa. (2014). Review of Research and Application of Evaporative Cooling In. 7(October): 85–102.

Nenguwo, N. (2000). Appropriate technology cold store construction and review pf post-harvest transport and handling practices for export fresh produce from Rwanda. Chenomics International

Nunes, M. C.N., J. K. Brecht, A. M.M.B. Morais, and S. A. Sargent. (1995.) Physical and Chemical Quality Characteristics of Strawberries after Storage Are Reduced by a Short Delay to Cooling. *Postharvest Biology and Technology* 6(1–2): 17–28.

Nunes, M. C.N., J. P. Emond, and J. K. Brecht. (2003). Quality of Strawberries as Affected by Temperature Abuse during Ground, in-Flight and Retail Handling Operations." *Acta Horticulturae* 604: 239–46.

Obura, J. M., N. Banadda, J. Wanyama, and N. Kiggundu. (2015). A Critical Review of Selected Appropriate Traditional Evaporative Cooling as Postharvest Technologies in Eastern Africa. *Agricultural Engineering International: CIGR Journal* 17(4): 345–54.

Odero, D. O., Mburu, J., Ackello-Ogutu, C., & Nderitu, J. H. (2013). Value chain analysis of smallholder snap-bean production in Kirinyaga County, Kenya, African Association of Agricultural Economists (AAAE) fourth international conference, September 22-

25.

Ogumo, E. O., C. N. Kunyanga, M. W. Okoth, and J. Kimenju. (2017). Current Knowledge and Performance of Existing Charcoal Coolers in Improving the Overall Quality and Shelf-Life of French Beans. *African Journal of Agricultural Research* 12(49): 3399–3409.

Oosthuyse, S. A., & Jacobs, G. (1995). Relationship between branching frequency, and growth, cropping and structural strength of 2-year-old mango trees. Scientia Horticulturae, 64(1-2), 85-93.

Ouma, L, J Ambuko, S Shibairo, and W O Owino. (2014). Comparison of Quality Attributes of Mango Fruits Produced from Two Contrasting Agro-Ecological Zones of Kenya. RUFORUM Fourth Biennial Conference, Maputo, Mozambique, 19-25 July 2014 (July): 235–40. https://www.cabdirect.org/cabdirect/abstract/20173009500.

Pailly, Olivier, Gilles Tison, and Audric Amouroux. (2004). Harvest Time and Storage Conditions of ‘Star Ruby’ Grapefruit (Citrus Paradisi Macf.) for Short Distance Summer Consumption. *Postharvest Biology and Technology* 34(1): 65–73.

Pathak, N., Caleb, O. J., Wegner, G., Rolleczek, C., Rauh, C., & Mahajan, P. V. (2017). Impacts of mixed fruit loading on postharvest physiological responses and quality of horticultural produce. *Food Packaging and Shelf Life*, *14*, 66-73.

Paull, Robert E. (1999). Effect of Temperature and Relative Humidity on Fresh Commodity Quality. *Postharvest Biology and Technology* 15(3): 263–77.

Perkins-Veazie, P. (2007). Carotenoids in Watermelon and Mango. *Acta Horticulturae* 746: 259–64.

Pesis, E., Aharoni, D., Aharon, Z., Ben-Arie, R., Aharoni, N., & Fuchs, Y. (2000). Modified atmosphere and modified humidity packaging alleviates chilling injury symptoms in mango fruit. *Postharvest biology and technology*, *19*(1), 93-101.

Pressman, Etan, Mary M. Peet, and D. Mason Pharr. (2002). The Effect of Heat Stress on Tomato Pollen Characteristics is Associated with Changes in Carbohydrate Concentration in the Developing Anthers. *Annals of Botany* 90(5): 631–36.

Rab, A., Rehman, H., Haq, I., Sajid, M., Nawab, K., & Ali, K. (2013). Harvest stages and pre-cooling influence the quality and storage life of tomato fruit. *Journal of Animal and Plant Sciences*, *23*(5), 1347-1352.

Rajwana, I. A., Malik, A. U., Khan, A. S., Saleem, B. A., & Malik, S. A. (2010). A new mango hybrid shows better shelf life and fruit quality. *Pak. J. Bot*, *42*(4), 2503-2512.

Rathore, H. A., Masud, T., Sammi, S., Soomro, H. A. (2007). Effects of storage on physico-chemical composition and sensory properties of mango (Mangifera indica L.) var. Dosehari. Pakistan Journal of Nutrition, 6: 143-148.

Rayaguru, Kalpana, Md K. Khan, and N. R. Sahoo. (2010). Water Use Optimization in Zero Energy Cool Chambers for Short Term Storage of Fruits and Vegetables in Coastal Area. Journal of Food Science and Technology 47(4): 437–41.

Reid, M., Thompson, J., and Chih-Ham, C. (2010). Small-scale coolrooms and cool transport for limited resource farmers.

Rolle, R.S. (2006). Improving postharvest management and marketing in the Asia-Pacific region: issues and challenges. From: Postharvest management of fruit and vegetables in the Asia-Pacific region, APO, ISBN: 92-833-7051-1.

Ronoh, Erick K., Christopher L. Kanali, and Samuel N. Ndirangu. (2020). Effectiveness of an Evaporative Charcoal Cooler for the Postharvest Preservation of Tomatoes and Kales. *Research in Agricultural Engineering* 66(No. 2): 66–71.

Ronoh, E. K., Kanali, C. L., Ndirangu, S. N., Mang'oka, S. M., & John, A. W. (2018). Performance evaluation of an evaporative charcoal cooler and its effects on quality of leafy vegetables. *Journal of Postharvest Technology*, *6*(3), 60-69.

Roy, Susanta K. (2011). On-Farm Storage Technology Can Save Energy and Raise Farm Income. *Amity Science, Technology & Innovation Foundation*: 234–2143. http/files/datastore/234-2143.pdf.

Samtani J.B. and Kushad M.M. (2015). A longer marketing life for Blackberry and Raspberry. Virginia Cooperative extension, Publication 432-701.

Saranwong, Sirinnapa, Jinda Sornsrivichai, and Sumio Kawano. (2003). Performance of a Portable near Infrared Instrument for Brix Value Determination of Intact Mango Fruit. *Journal of Near Infrared Spectroscopy* 11(3): 175–81.

Sefri Hardiansyah, Eldawaty. (2018). Nigeria: Spoilage and Waste. *Jurnal Abdimas Dewantara* 53(9): 1689–99.

Seidu JM, Issah A, George E, Mahama AA (2012). Processing plantain into high quality flour using solar dryers. International Journal of Agricultural economics and Extension, vol. 4 : 11.

Selcuk, Nurten, and Mustafa Erkan. (2014). Changes in Antioxidant Activity and Postharvest Quality of Sweet Pomegranates Cv. Hicrannar under Modified Atmosphere Packaging. Postharvest Biology and Technology 92: 29–36. http://dx.doi.org/10.1016/j.postharvbio.2014.01.007.

Shabani, Amir, Seyed Mohammad Reza Torabipour, and Reza Farzipoor Saen. (2015). A New Super-Efficiency Dual-Role FDH Procedure: An Application in Dairy Cold Chain for Vehicle Selection. *International Journal of Shipping and Transport Logistics* 7(4): 426–56.

Shashi, S., Cerchione, R., Singh, R., Centobelli, P., & Shabani, A. (2018). Food cold chain management: From a structured literature review to a conceptual framework and research agenda. *The International Journal of Logistics Management*.

Shih, F. F, Daigle K.W. &Champagne E.T. (2001). Effect of rice wax on water vapour permeability and sorption properties of edible pullan films. Food Chemistry 127,118-121.

Shitanda, D., and N. V. Wanjala. (2006). Effect of Different Drying Methods on the Quality of Jute (Corchorus Olitorius L.). Drying Technology 24(1): 95–98.

Shitanda, D., O. K. Oluoch, and A. M. Pascall. (2011). Performance Evaluation of a Medium Size Charcoal Cooler Installed in the Field for Temporary Storage of Horticultural Produce. Agricultural Engineering International: CIGR Journal 13(1): 1–12.

Shukla, Manish, and Sanjay Jharkharia. (2013). Agri-Fresh Produce Supply Chain

Management: A State-of-the-Art Literature Review. *International Journal of Operations and Production Management* 33(2): 114–58.

Siddiqui, M.W., &, and Dhua, R.S. (2009). Standardization of Ethrel Treatment for Inducing Ripening of Mango Var. Himsagar. *International Conference on Horticulture*: 1641–48.

Siddiqui, Md Wasim, and R. S. Dhua. (2010). Eating Artificially Ripened Fruits Is Harmful. Current Science 99(12): 1664–68.

Singh, P., Singh, M. K., Kumar, V., Kumar, M., & Malik, S. (2012). Effect of physico-chemical treatments on ripening behavior and post-harvest quality of Amrapali mango (Mangifera indica L.) during storage. *Journal of Environmental Biology*, *33*(2), 227.

Singh, S. P., and D. V. Sudhakar Rao. (2005). Effect of Modified Atmosphere Packaging (MAP) on the Alleviation of Chilling Injury and Dietary Antioxidants Levels in 'Solo' Papaya during Low Temperature Storage. European Journal of Horticultural Science 70(5): 246–52.

Singh, Z., & Zaharah, S. S. (2011, June). Controlled Atmosphere Storage of Mango Fruit: Challenges and Thrusts and Its Implications in International Mango Trade. In Global Conference on Augmenting Production and Utilization of Mango: Biotic and Abiotic Stresses 1066 (pp. 179-191).

Singh, Z., Singh, R. K., Sane, V. A., & Nath, P. (2013). Mango-postharvest biology and biotechnology. *Critical Reviews in Plant Sciences*, *32*(4), 217-236.

Sivakumar, Dharini, Yuming Jiang, and Elhadi M. Yahia. (2011). Maintaining Mango (Mangifera Indica L.) Fruit Quality during the Export Chain. *Food Research International* 44(5): 1254–63. http://dx.doi.org/10.1016/j.foodres.2010.11.022.

Subramanian, K. S., Sekar, C., Meneka, S. S., & Prakash, L. V. (2018). Reducing postharvest losses in mango in South Asia.

SW, Kebede, and Bokelmann W. (2017). African Indigenous Vegetables and Their Production Practices: Evidence from the HORTINLEA Survey in Kenya. *Agrotechnology* 06(03).

Tefera, A., T. Seyoum, and K. Woldetsadik. (2007). Effect of Disinfection, Packaging, and Storage Environment on the Shelf Life of Mango. *Biosystems Engineering* 96(2): 201–12.

Tembo, L., Chiteka, Z. A., Kadzere, I., Akinnifesi, F. K., & Tagwira, F. (2008). Storage temperature affects fruit quality attributes of Ber (Ziziphus mauritiana Lamk.) in Zimbabwe. *African journal of Biotechnology*, *7*(17).

Thompson, A. K. (2008). *Fruit and vegetables: harvesting, handling and storage*. John Wiley & Sons.

Thompson, A.K. (2003). Fruits and vegetables harvesting, handling and storage by Blackwell publishers limited.

Thompson, A.K. (2001). Controlled Atmosphere Storage of Fruits and Vegetables. CABI

Thompson, A.K. (1998). Controlled Atmosphere Storage of Fruits and Vegetables. CAB International, Oxon. New York, NY.

Tigist, M., Tilahun Seyoum Workneh, and Kebede Woldetsadik. (2013). Effects of Variety on the Quality of Tomato Stored under Ambient Conditions. *Journal of Food Science and Technology* 50(3): 477–86.

Toivonen, P. (2007). Fruit maturation and ripening and their relationship to quality. Stewart Postharvest Review 2:7.

Tolesa, G. N., and T. S. Workneh. (2018). Effects of Evaporative Cooling and CoolBot Air Conditioning on Changes in the Environmental Conditions inside the Cooling Chamber. Acta Horticulturae 1201: 281–88.

Trienekens, Jacques H. (2011). Agricultural Value Chains in Developing Countries a Framework for Analysis. *International Food and Agribusiness Management Review* 14(2): 51–82.

Tyagi, S., Sahay, S., Imran, M., Rashmi, K., & Mahesh, S. S. (2017). Pre-harvest factors influencing the postharvest quality of fruits: A review. *Curr. J. Appl. Sci. Technol*, *23*(1), 12.

Ullah, Hameed, Saeed Ahmad, Muhammad Amjad, and Muhammad Azam Khan. (2012). “Response of Mango Cultivars to Modified Atmosphere Storage at an Ambient Temperature Cv. Alphanso and Chounsa.” Pakistan Journal of Agricultural Sciences 49(3): 293–99.

Vala, K V, F Saiyed, and D C Joshi. (2014). Evaporative Cooled Storage Structures: An Indian Scenario. Trends in Post Harvest Technology 2(3): 22–32.

Valero, D., & Serrano, M. (2010). Postharvest biology and technology for preserving fruit quality. CRC press.

Van Der Waal, J. W.H., and A. Zongo. (2011). Developing a Fresh Mango Export Value Chain with West-African Smallholder Mango Farmers. *Acta Horticulturae* 895: 283–91.

Venema, J. H., Linger, P., Van Heusden, A. W., Van Hasselt, P. R., & Brüggemann, W. (2005). The inheritance of chilling tolerance in tomato (Lycopersicon spp.). *Plant Biology*, *7*(02), 118-130.

Verploegen, Eric, Ousmane Sanogo, and Takemore Chagomoka. (2019). Evaluation of Low-Cost Evaporative Cooling Technologies for Improved Vegetable Storage in Mali. *GHTC 2018 - IEEE Global Humanitarian Technology Conference, Proceedings*: 5–12.

Verploegen, Eric, Peter Rinker, and Kukom Ognakossan. (2018). Evaporating Cooling Best Practices: Producing and Using Evaporative Cooling Chambers and Clay Pot Coolers. (June). http://www.scopus.com/inward/record.url?eid=2-s2.0-34548264203&partnerID=40&md5=85ca2971a59fa761c2443677f0cfa1e7.

Wahome, S. W., Kimani P. M., Muthomi, J. W., & Narla, R. D. (2013). Quality and yield of snap bean lines locally developed in Kenya. International Journal of Agronomy and Agricultural Research, 3(7), 1-10.

Waskar DP, Masalkar SD. (1997). Effect of hydrocooling and bavistin dip on the shelf and quality of mango during storage under various environments. Acta Hortic 455:687–695.

Watkins, C. B. (2000). Responses of horticultural commodities to high carbon dioxide as related to modified atmosphere packaging. *HortTechnology*, *10*(3), 501-506.

Wayua, Francis O., Michael W. Okoth, and John Wangoh. (2012). Design and Performance Assessment of a Low Cost Evaporative Cooler for Storage of Camel Milk in Arid Pastoral Areas of Kenya. *International Journal of Food Engineering* 8(1).

Yahaya, S. M., Kamalu, A. B., Ali, M. U., Lawan, M., Ajingi, Y. S., Haruna, M., & Mardiyya, A. Y. (2019). A Study of Pathogenic Fungi Causing Post Harvest Losses of Pineapple Sold at Wudil and Yan Lemo Markets of Kano State. *Journal of Experimental Agriculture International*, 1-6.

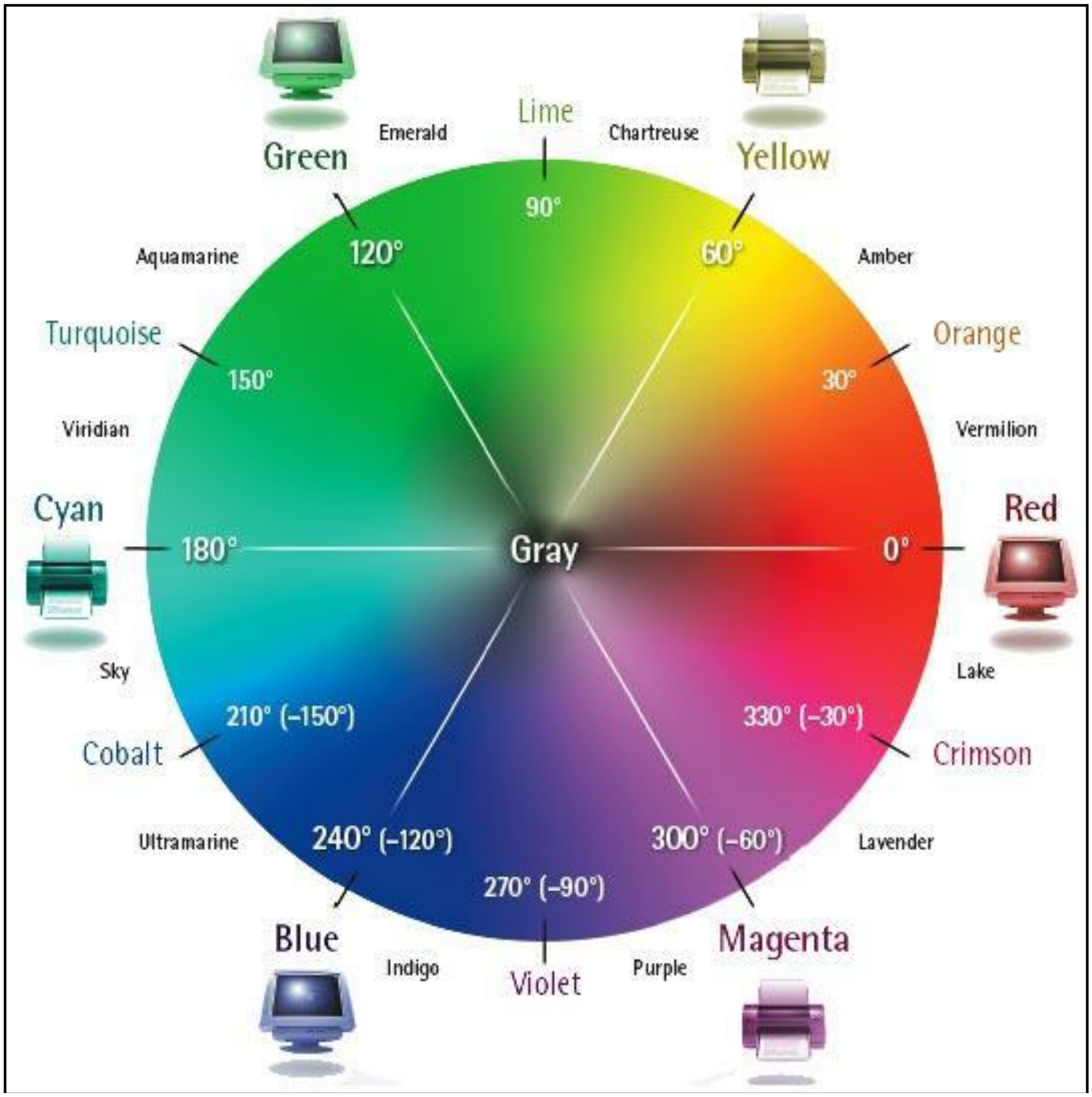
Yahia, E. H. M. (1999). Postharvest handling of mango. *ATUT/RONCO technical staff, Egypt. Accessed*, *4*, 2000.

Yang, Z., Ma, Z., Zhao, C., & Chen, Y. (2007). Study on Forced-air Pre-cooling of Longan. In 2007 ASAE Annual Meeting (p. 1). American Society of Agricultural and Biological Engineers.

Yumbya, P. Ambuko J., Shibairo S. and Owino.W.O. (2014). Effect of Modified Atmosphere Packaging on the Shelf Life and Postharvest Quality of Purple Passion Fruit (Passiflora edulis Sims). Journal of Postharvest Technology. 02 (01): 025-036.

APPENDICES

Appendix 1: The colour wheel.



Appendix 2: Analysis of Variance (ANOVA) table for effect of proper cold chain management practice and farmers' practice on pulp temperature for 'Apple', 'Ngowe', 'Kent' and 'Tommy Atkinns' mango varieties under storage.

Change	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
+ Treatment	1	5588.407	5588.407	1944.43	<.001
+ Variety	3	18.434	6.145	2.14	0.097
+ Treatment.Variety	3	51.067	17.022	5.92	<.001
Residual	192	551.818	2.874		
Total	199	6209.726	31.205		

Appendix 3: Analysis of Variance (ANOVA) table for effect of proper cold chain management practice and farmers' practice on percentage cumulative weight loss for 'Apple', 'Ngowe', 'Kent' and 'Tommy Atkinns' mango varieties under storage.

Change	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
+ Treatment	1	365818.	365818.	127.74	<.001
+ Variety	3	1126124.	375375.	131.08	<.001
+ Treatment.Variety	3	40234.	13411.	4.68	0.004
Residual	192	549844.	2864.		
Total	199	2082020.	10462.		

Appendix 4: Analysis of Variance (ANOVA) table for effect of proper cold chain management practice and farmers' practice on peel colour for 'Apple', 'Ngowe', 'Kent' and 'Tommy Atkinns' mango varieties under storage.

Change	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
+ Treatment	1	452.3	452.3	1.92	0.168
+ Variety	3	36895.2	12298.4	52.12	<.001
+ Treatment.Variety	3	4445.6	1481.9	6.28	<.001
Residual	192	45306.0	236.0		
Total	199	87099.1	437.7		

Appendix 5: Analysis of Variance (ANOVA) table for effect of proper cold chain management practice and farmers' practice on flesh colour for 'Apple', 'Ngowe', 'Kent' and 'Tommy Atkinns' mango varieties under storage.

Change	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
+ Treatment	1	272.0	272.0	2.72	0.101
+ Variety	3	2811.7	937.2	9.37	<.001
+ Treatment.Variety	3	249.7	83.2	0.83	0.478
Residual	192	19208.5	100.0		
Total	199	22541.9	113.3		

Appendix 6: Analysis of Variance (ANOVA) table for effect of proper cold chain management practice and farmers' practice on Peel firmness for 'Apple', 'Ngowe', 'Kent' and 'Tommy Atkinns' mango varieties under storage.

Change	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
+ Treatment	1	71.	71.	0.04	0.845
+ Variety	3	43045.	14348.	7.70	<.001
+ Treatment.Variety	3	3871.	1290.	0.69	0.558
Residual	192	357986.	1865.		
Total	199	404973.	2035.		

Appendix 7: Analysis of Variance (ANOVA) table for effect of proper cold chain management practice and farmers' practice on flesh firmness for 'Apple', 'Ngowe', 'Kent' and 'Tommy Atkinns' mango varieties under storage.

Change	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
+ Treatment	1	1492.5	1492.5	3.41	0.066
+ Variety	3	10160.7	3386.9	7.75	<.001
+ Treatment.Variety	3	285.3	95.1	0.22	0.884
Residual	192	83942.3	437.2		
Total	199	95880.8	481.8		

Appendix 8: Analysis of Variance (ANOVA) table for effect of proper cold chain management practice and farmers' practice on Total Soluble Solids (TSS) for 'Apple', 'Ngowe', 'Kent' and 'Tommy Atkinns' mango varieties under storage.

Change	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
+ Treatment	1	55.92	55.92	3.98	0.047
+ Variety	3	594.09	198.03	14.09	<.001
+ Treatment.Variety	3	9.31	3.10	0.22	0.882
Residual	192	2697.86	14.05		
Total	199	3357.19	16.87		

Appendix 9: Analysis of Variance (ANOVA) table for effect of storage option and modified atmospheric packaging on pulp temperature for 'Apple' and 'Kent' mango varieties under storage.

Change	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
+ Variety	1	2.725	2.725	1.47	0.226
+ Storage	4	13099.938	3274.985	1768.20	<.001
+ Package	1	0.186	0.186	0.10	0.752
+ Variety.Storage	4	17.311	4.328	2.34	0.054
+ Variety.Package	1	0.876	0.876	0.47	0.492
+ Storage.Package	4	14.462	3.615	1.95	0.101
+ Variety.Storage. Package	4	14.988	3.747	2.02	0.090
Residual	502	929.785	1.852		
Total	521	14080.271	27.025		

Appendix 10: Analysis of Variance (ANOVA) table for effect of storage option and modified atmospheric packaging on percentage cumulative weight loss for 'Apple' and 'Kent' mango varieties under storage.

Change	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
+ Variety	1	1821057.	1821057.	6.49	0.011
+ Storage	4	386207.	96552.	0.34	0.848
+ Package	1	13322.	13322.	0.05	0.828
+ Variety.Storage	4	56857.	14214.	0.05	0.995
+ Variety.Package	1	142780.	142780.	0.51	0.476
+ Storage.Package	4	373733.	93433.	0.33	0.856
+ Variety.Storage. Package	4	139058.	34764.	0.12	0.974
Residual	502	140759867.	280398.		
Total	521	143692881.	275802.		

Appendix 11: Analysis of Variance (ANOVA) table for effect of storage option and modified atmospheric packaging on peel colour for 'Apple' and 'Kent' mango varieties under storage.

Change	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
+ Variety	1	168002.0	168002.0	445.32	<.001
+ Storage	4	1108.0	277.0	0.73	0.569
+ Package	1	821.0	821.0	2.18	0.141
+ Variety.Storage	4	2639.2	659.8	1.75	0.138
+ Variety.Package	1	3688.7	3688.7	9.78	0.002
+ Storage.Package	4	3706.8	926.7	2.46	0.045
+ Variety.Storage. Package	4	3430.5	857.6	2.27	0.060
Residual	502	189386.0	377.3		
Total	521	372782.2	715.5		

Appendix 12: Analysis of Variance (ANOVA) table for effect of storage option and modified atmospheric packaging on flesh colour for 'Apple' and 'Kent' mango varieties under storage.

Change	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
+ Variety	1	14368.87	14368.87	164.18	<.001
+ Storage	4	279.45	69.86	0.80	0.527
+ Package	1	28.17	28.17	0.32	0.571
+ Variety.Storage	4	576.90	144.23	1.65	0.161
+ Variety.Package	1	114.68	114.68	1.31	0.253
+ Storage.Package	4	343.63	85.91	0.98	0.417
+ Variety.Storage. Package	4	408.35	102.09	1.17	0.325
Residual	502	43934.54	87.52		
Total	521	60054.60	115.27		

Appendix 13: Analysis of Variance (ANOVA) table for effect of storage option and modified atmospheric packaging on peel firmness for 'Apple' and 'Kent' mango varieties under storage.

Change	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
+ Variety	1	182638.	182638.	74.61	<.001
+ Storage	4	29176.	7294.	2.98	0.019
+ Package	1	12244.	12244.	5.00	0.026
+ Variety.Storage	4	20093.	5023.	2.05	0.086
+ Variety.Package	1	1412.	1412.	0.58	0.448
+ Storage.Package	4	2728.	682.	0.28	0.892
+ Variety.Storage. Package	4	4738.	1185.	0.48	0.748
Residual	502	1228884.	2448.		
Total	521	1481914.	2844.		

Appendix 14: Analysis of Variance (ANOVA) table for effect of storage option and modified atmospheric packaging on flesh firmness for 'Apple' and 'Kent' mango varieties under storage.

Change	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
+ Variety	1	45664.	45664.	29.69	<.001
+ Storage	4	2058.	515.	0.33	0.855
+ Package	1	30.	30.	0.02	0.889
+ Variety.Storage	4	4132.	1033.	0.67	0.612
+ Variety.Package	1	387.	387.	0.25	0.616
+ Storage.Package	4	3396.	849.	0.55	0.698
+ Variety.Storage. Package	4	3082.	770.	0.50	0.735
Residual	502	771979.	1538.		
Total	521	830729.	1594.		

Appendix 15: Analysis of Variance (ANOVA) table for effect of storage option and modified atmospheric packaging on total soluble solids (TSS) for 'Apple' and 'Kent' mango varieties under storage.

Change	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
+ Variety	1	907.16	907.16	87.18	<.001
+ Storage	4	26.43	6.61	0.63	0.638
+ Package	1	45.18	45.18	4.34	0.038
+ Variety.Storage	4	32.82	8.21	0.79	0.533
+ Variety.Package	1	3.15	3.15	0.30	0.582
+ Storage.Package	4	38.90	9.72	0.93	0.444
+ Variety.Storage. Package	4	37.98	9.49	0.91	0.456
Residual	502	5223.78	10.41		
Total	521	6315.40	12.12		

Appendix 16: Analysis of Variance (ANOVA) table for effect of storage option and modified atmospheric packaging on TTA for 'Apple' and 'Kent' mango varieties under storage.

Change	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
+ Variety	1	0.16032	0.16032	11.50	0.001
+ Storage	4	4.29594	1.07398	77.06	<.001
+ Packaging	1	0.11366	0.11366	8.16	0.005
+ Variety.Storage	4	0.10568	0.02642	1.90	0.119
+ Variety.Packaging	1	0.03199	0.03199	2.30	0.134
+ Storage.Packaging	4	0.02920	0.00730	0.52	0.718
+ Variety.Storage.Packaging	4	0.12739	0.03185	2.29	0.067
Residual	83	1.15670	0.01394		
Total	102	6.02087	0.05903		

Appendix 17: Analysis of Variance (ANOVA) table for effect of storage option and modified atmospheric packaging on Beta-carotene for 'Apple' and 'Kent' mango varieties under storage.

Change	d.f.	s.s.	m.s.	v.r.	F pr.
+ Variety	1	4.068	4.068	1.04	0.310
+ Storage	4	56.213	14.053	3.60	0.009
+ Packaging	1	3.011	3.011	0.77	0.382
+ Variety.Storage	4	2.599	0.650	0.17	0.955
+ Variety. Packaging	1	1.300	1.300	0.33	0.565
+ Storage.Packaging	4	7.320	1.830	0.47	0.758
+ Variety.Storage.Packaging	4	3.448	0.862	0.22	0.926
Residual	83	323.755	3.901		
Total	102	401.715	3.938		

Appendix 18: Analysis of Variance (ANOVA) table for effect of storage option and modified atmospheric packaging on Vitamin C for 'Apple' and 'Kent' mango varieties under storage.

Change	d.f.	s.s.	m.s.	v.r.	F pr.
+ Variety	1	909.2	909.2	1.73	0.192
+ Storage	4	60.5	15.1	0.03	0.998
+ Packaging	1	41.2	41.2	0.08	0.780
+ Variety.Storage	4	47.7	11.9	0.02	0.999
+ Variety.Packaging	1	86.9	86.9	0.17	0.685
+ Storage.Packaging	4	107.0	26.8	0.05	0.995
+ Variety.Storage.Packaging	4	44.9	11.2	0.02	0.999
Residual	83	43633.1	525.7		
Total	102	44930.5	440.5		

Appendix 19: Analysis of Variance (ANOVA) table for effect of storage option and modified atmospheric packaging on Fructose for 'Apple' and 'Kent' mango varieties under storage.

Change	d.f.	s.s.	m.s.	v.r.	F pr.
+ Variety	1	29.497	29.497	4.15	0.045
+ Storage	4	19.521	4.880	0.69	0.604
+ Packaging	1	2.549	2.549	0.36	0.551
+ Variety.Storage	4	1.478	0.370	0.05	0.995
+ Variety.Packaging	1	5.431	5.431	0.76	0.385
+ Storage.Packaging	4	0.738	0.184	0.03	0.999
+ Variety.Storage.Packaging	4	0.370	0.092	0.01	1.000
Residual	83	590.300	7.112		
Total	102	649.884	6.371		

Appendix 20: Analysis of Variance (ANOVA) table for effect of storage option and modified atmospheric packaging on Glucose for 'Apple' and 'Kent' mango varieties under storage.

Change	d.f.	s.s.	m.s.	v.r.	F pr.
+ Variety	1	2.293	2.293	1.43	0.235
+ Storage	4	2.605	0.651	0.41	0.803
+ Packaging	1	0.560	0.560	0.35	0.556
+ Variety.Storage	4	2.406	0.602	0.38	0.825
+ Variety.Packaging	1	0.079	0.079	0.05	0.825
+ Storage.Packaging	4	1.838	0.460	0.29	0.886
+ Variety.Storage.Packaging	4	2.685	0.671	0.42	0.794
Residual	83	132.833	1.600		
Total	102	145.299	1.425		

Appendix 21: Analysis of Variance (ANOVA) table for effect of storage option and modified atmospheric packaging on Sucrose for 'Apple' and 'Kent' mango varieties under storage.

Change	d.f.	s.s.	m.s.	v.r.	F pr.
+ Variety	1	14.732	14.732	2.60	0.110
+ Storage	4	4.246	1.061	0.19	0.944
+ Packaging	1	0.048	0.048	0.01	0.927
+ Variety.Storage	4	0.462	0.115	0.02	0.999
+ Variety.Packaging	1	0.757	0.757	0.13	0.715
+ Storage.Packaging	4	1.384	0.346	0.06	0.993
+ Variety.Storage.Packaging	4	0.464	0.116	0.02	0.999
Residual	83	469.562	5.657		
Total	102	491.654	4.820		