



**EFFECTS OF POSTHARVEST TREATMENTS, PACKAGING
MATERIALS AND STORAGE PERIOD ON PHYSICOCHEMICAL AND
SENSORY QUALITY OF AVOCADO (*Persea Americana Mill.*), HASS
VARIETY**

M.Sc. THESIS

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**Effects of Postharvest Treatments, Packaging Materials and Storage Period
on Physicochemical and Sensory Quality of Avocado (*Persea Americana*
Mill.): Hass Variety**

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in Food Science and Technology**

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DEDICATION

Having lost my mother in grade six and my father in grade ten, I have reached this academic milestone by navigating immense personal challenges. I dedicate this thesis to all those who accomplish and succeed their goal without the guidance and support of their parents.

STATEMENT OF THE AUTHOR

By signature below, I declare that this thesis is my original work. I have adhered to all ethical and technical standards in the preparation, data collection, analysis, and completion of this thesis. All scholarly material included has been appropriately cited.

This thesis is submitted in partial fulfillment of the requirements for the M.Sc. degree in Food Science and Technology at Haramaya University. It will be deposited in the Haramaya University library, where it will be available to borrowers in accordance with library regulations. I affirm that this thesis has not been submitted to any other institution for any academic degree, diploma, or certificate.

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BIOGRAPHICAL SKETCH

The author, Abdi Adem, was born from his father Adem Abdi and mother Leelloo Abraham on 20 June 1990 EC., in Caffee Banti, West Hararghe, Oromia Region. He completed his elementary education at Guje Primary School in 2003 EC and secondary education at Hades Secondary School in 2005 EC. In 2007 EC, he attended Hirna Preparatory School for his preparatory studies. In 2009 EC, he joined Haramaya University, enrolling in the Food Science and Postharvest Technology department. After completing his studies, he graduated with a Bachelor of Science degree on 20 March 2013 EC. In October 2014 EC, he began his M.Sc. studies in Food Science and Technology at Haramaya University under the “Haramaya University Graduate Students Scholarship.”

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ACRONYMS AND ABBREVIATIONS

AA	Ascorbic Acid
ANOVA	Analysis of Variance
C ₇	Carbon Seven
CAS	Controlled Atmosphere Storage
CRD	Complete Randomized Design
CSA	Central Statistical Agency
DP	Decay Percentage
FAOSTAT	Food and Agricultural Organization Statistics
G _e	Garlic extract
Ha	Hectares
HDPE	High Density Polyethylene
HH	House Hold
H _w	Hot water
LDPE	Low-Density Polyethylene
LLDPE	Linear Low-Density Polyethylene
LSD	Least Significant Difference
MC	Moisture Content
MAP	Modified Atmosphere Packaging
MASHAV	Israel's Agency for International Development
MDPE	Medium Density Polyethylene
MUFA	Monounsaturated Fatty Acids
MT	Madness-Taylor Puncture Test
ND	Number of Decay Fruits
NHANES	National Health and Nutrition Examination Survey
PE	Polyethylene
PER	Peroxide
PHT	Postharvest Treatments
Pp	Polypropylene
PPM	Parts Per Million
PM	Packaging Materials

PPO	Polyphene Oxidize
PUFA	Polyunsaturated Fatty Acid
PS	Plasticized Polystyrene
PVC	Polyvinyl Chloride
PVDC	Polyvinylidene Chloride
Qt	Quintals
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis Software
SFA	Saturated Fatty Acid
SHP	Small Holder Project
TA	Terrible Acid
TNF	Total Number of Fruits
TSS	Total Soluble Solids
TWL	Total Weight Loss
USAID	United States Agency for International Development
EVA	Ethylene Vinyl Acetate
(W _x)	Wax

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Effect of Postharvest Treatments, Packaging Materials and Storage Period on Physicochemical and Sensory Quality of Avocado (*Persea Americana* Mill.), Hass Variety

ABSTRACT

Avocados (Persea Americana Mill.) are classified as climacteric fruits, which are susceptible to rapid physiological deterioration so that requires well-integrated postharvest technologies to maintain its final quality. Thus, the aim of this study were to evaluate the effects of postharvest treatments, packaging materials and storage periods on the physicochemical and sensory quality of the 'Hass' variety avocado fruits. The experiment include of four postharvest treatments (control, hot water, garlic extract and wax), three packaging materials (room storage, carton box, and low-density polyethylene), and 12-days of storage period with four interval of data collection days (day₀, day₄, day₈, and day₁₂) with three replications, that was arranged with a full factorial design. The interaction effects of postharvest treatments, packaging materials and storage period on avocado physicochemical quality of avocado were found to be highly significant ($P < 0.05$) over a 12-days of storage period. Compared to samples stored in carton boxes and room temperature, the interaction effect of postharvest treatments with low density polyethylene (LDPE) significantly ($P < 0.05$) produced the highest physiochemical quality during storage periods. The combination of garlic extract and low density polyethylene bags also maintained better physicochemical qualities than control or hot water treated samples. Generally, after a 12-day of storage period, the avocado treated with a combination of wax and LDPE bags showed the best physiochemical qualities, including highest firmness (2.9N), moisture content (46.2%), pH (5.91), ascorbic acid (13.53mg/100g¹), and lowest weight loss (1.8%), titratable acidity (28.8%), and total soluble solid (34.4°brix), no decay loss, and the best marketability (100%), after 12-days of storage period at 95% confidence of interval ($P < 0.05$). As storage time increases, the final quality of avocado were determined by postharvest treatment and packaging materials used. Therefore, proper postharvest technologies and durations are essential for preserving the avocado quality. In order to further optimize postharvest handling practices and maintain the quality of avocado for extended period of time. The future researcher should examine the long-term effects of different postharvest treatments and packaging options on quality of different variety of avocado fruit.

Keywords: Avocado, Garlic extract, Hot water, low density polyethylene, Wax.

1. INTRODUCTION

Avocado (*Persea Americana Mill.*) belongs to the family Lauraceous. It is an evergreen climacteric fruit, which originated in Mexico, Colombia, Venezuela, Ecuador, and Peru about 1000 years ago (Carabez *et al.*, 2019). Nowadays in Ethiopia, mangoes, citrus fruits, bananas, avocados, papayas, and grapefruits are the main fruits produced. In terms of production, Ethiopia is the second producer in the Africa next to Kenya, and the twelfth-leading producer of avocados in the world (FAO STAT, 2022). In Ethiopia, private orchardists first introduced them into Hirna and Wondo-Genet in 1938. Gradually, fruits have been distributed to other regions where the crop conformed to various agro-ecologies (Bezabih & Hadera, 2016). In Ethiopia, bananas are first in the total production volume, followed by avocados (Awulachew, 2022). Oranges, papayas, avocados, mangos, and bananas accounted for 3.52%, 6.16%, 12.39%, 12.49%, and 63.30% of the fruit produced, in that order. The overall area used for avocado harvesting was 858,152 hectares, and the global fruit production in 2021 was estimated to be 8,685,672 metric tons, according to data from the (Garedew & Tsegaye, 2011). The FAO reports that in 2021, Ethiopia produced 245,336 metric tons of avocados, with 30,585.70 hectares of total harvested area. In 2021, 604.5Qt of avocados were exported from Ethiopia. The United Kingdom (UK), United Arab Emirate, Singapore, France, Saudi Arabia, and Djibouti are Ethiopia's top exporters of avocados.

Avocado being evergreen, its heavy leaf fall may occur during excessive budding flowers and when the tree root is affected by the disease from the soil. Based on varieties and cultivation area, the growth habit of fruits varies from tall and upright to well-shaped and spreading. The size, shape, color, texture, and flavor of the fruit of cultivated species greatly differ. The fruit's edible part is the flesh between the skin and seed. Its color varies from cream to yellowish-green. The flesh of the ripe avocado should have soft butter with a high consistency. The fruit has one seed. The fruit is odd because it is not ripened until detached from the tree. Depending on the variety, some fruit may be left on the tree after reaching maturity. Avocados have high nutritional value, and their taste, versatility of applications, and preparation cost make them one of the most popular tropical fruits consumed worldwide (Jaramillo-Acevedo *et al.*, 2020). Avocados constitute 5 to 40% of oil, depending on the variety, cultivation area, and condition of the season. Only ripe olives contain a higher oil content. The fatty acid composition of avocado determines the therapeutic

value of avocado oil. Avocados are free-cholesterol fruits with many vitamins, particularly the B complex and vitamins A and E, as well as folic acid and iron.

In Ethiopia, the absence of improved varieties of avocado makes the already available varieties the best arena and a common route for seedling dissemination (Bezabih & Hadera, 2016). In Ethiopia, some of the varieties that are introduced and presently available are Hass, Pinkerton, Fuerte, and Ettinger (Bezabih & Hadera, 2016). Bezabih & Hadera, (2016) state that the primary challenges in Ethiopian farmers' markets are that they dominated by a small number of dealers with a little capital and a mass volume of farmers, which provides farmers with less negotiating strength. Furthermore, inadequate information systems, underdeveloped industries, high service costs, and transportation are other challenges of the avocado production. Despite the avocado's significant economic and social role, a variety of restrictions apply to its production, including the fruit deterioration, the disease issue, and the absence of agronomic procedures. There is no value-adding activity at the farmer level in Ethiopia provided that the wholesaler or intermediary level in the supply chains is where the goods are sold raw. When a fruit product achieves significant demand and reaches a marketplace, its value rises. Thus, in order to increase avocado production and demand in Ethiopia, the future researchers ought to focus on adding value actions inside every supply chain.

Avocado is a perishable product. Being a climacteric fruit, an increase in respiration during protein synthesis and physiological disorder combined with oxidation reactions, which happen either enzymatically or through lipid oxidation, limits avocado's shelf life to 2–4 weeks under optimum conditions of storage (temperature, handling, and relative humidity) and from 5 to 7 days at room temperature (Kassim *et al.*, 2013). An increase in respiration rate and spoilage by pathogenic fungi are two main determinant factors that limit avocados' life span. Both qualitative and quantitative loss of avocado fruits may happen throughout the entire distribution network in harvesting. Reneby, (2014) states that in Ethiopia, the greatest avocado losses happen during harvesting, transportation, and storage. The quality of avocados is the overall acceptance of fruit parameters that change at each stage of the maturation process. Henao-Rojas *et al.* (2019) observed that the physical quality parameters complained about by customers are the texture of the avocado and appearance, which is essentially the color and presence of defects. The chemical quality parameters are pH, total soluble solid (TSS), titratable acid (TA), moisture content, and dry matter content

(Hardos and Wakgari, 2016). The degree of change of these parameters depends on the cultivars, maturity, harvest time, postharvest handling and treatment, packaging materials, storage periods, and storage conditions.

Currently, the government and private investors in Ethiopia now acknowledge this crop as a significant prospective crop with numerous advantages, such as being an export crop. As a result, a few small-scale projects are now under way, such as the "Smallholder Horticulture Project (SHP)" that is part of a joint programme between the Ethiopian government, USAID Ethiopia, and MASHAV of Israel. The program's goal is to create a base for Ethiopia's avocado export market while also developing a competitive and sustainable fruit development sector (Jalata, 2021). As a result, the project has been able to promote Ethiopian avocados on the global market for the past three years, and they are starting to show up in marketplaces in Europe and Asia. Additionally, the same project recently supplied the Hass avocado variety from Israel to almost 2000 farmers, and the results were positive and deserving of further expansion so that this paper focuses on the Hass avocado cultivar because of its high yield and resistance to physical and biochemical factors. There also is more demand in the international market for Hass avocados than for the rest of the varieties. Ethiopia exports Hass avocados more than other varieties. It is also characterized as a fruit with variable size, medium oil percentage, 7-11 days of ripening period, small seed size, and medium cold tolerance.

Since the avocado is a climacteric fruit, the ripening process continues after the fruit has been picked from the tree. Therefore, keeping its postharvest quality is not an easy task. The appropriate postharvest technology is required to ensure the postharvest quality of avocados. Some studies show the effect of postharvest treatments and packaging materials on avocados' shelf life, but not in a combined manner. This is a gap that creates research opportunities. In this paper, postharvest technology, such as hot water treatment, waxes and garlic extract were applied to the avocado surface to improve the overall quality and reduce postharvest loss of avocado fruits. Therefore, this study aims to evaluate the effect of the postharvest treatment with respect to each application of packaging materials, such as polyethylene bags and carton boxes, as well as storage period, on the final quality of avocados.

1.1. Statement of Problem

Postharvest losses of avocado fruit happen all the way along the supply chains mainly during handling, storage, processing and transportation (Hodges *et al.*, 2020). As per Reneby's (2014) findings, the primary causes of avocado postharvest losses in Ethiopia, include harvesting, which mostly stems from insufficient harvesting methods employed during transportation; loading, unloading, and storage; and over ripeness. FAO STAT (2022) reported that postharvest losses might vary from 15% to 50% in underdeveloped nations, including Ethiopia. At grower-level, the estimated average post-harvest avocado loss was 24.1%; 5.7% of these losses were attributed to poor harvesting techniques, and 4.9% to lacking proper storage techniques. Therefore, those constraints that increase loss and restrict avocado production should have to be addressed to design an effective strategy. Efficient supply chain management is one strategy to lower post-harvest losses and enhance avocado production. Increased horticultural output and reduced postharvest losses could encourage economic growth in rural areas and create a large number of job possibilities.

At room temperature, the ripening of avocado fruits can take 5-7 days (Aguirre-Joya *et al.* 2017). Traditionally, people use various packaging materials to avoid mechanical damage during transportation and quality deterioration during storage. Those materials are preferable to open air for prolonging the shelf life of fruits but can't halt the problem and extend the shelf life of avocados to the final consumer. Related to this problem, most research has been concentrated on developing variety and postharvest handling practices. Only a few research projects have been focused on avocado postharvest management. So that the considerable quality of avocado fruits is reduced from farm to fork as discussed above. Even if handling practice is one factor in reducing avocado quality deterioration, other factors such as postharvest treatment, packaging materials, and storage period also limit the fruit's quality. Therefore, in this study, the simultaneous effect of packaging material (polyethylene plastic sheet, carton box, and room storage) and postharvest treatments (control, hot water, bee wax and garlic extract) on avocado quality was successfully assessed as the major constraint in reducing quality of Hass avocado fruits. Therefore, this research is focusing on investigating of the interaction effect of postharvest treatments, packaging methods, and storage period on the sensory and physicochemical quality of avocado fruits.

1.2. Objective

1.2.1. General objective

To determine the effect of postharvest treatments, packaging materials and storage period on the physicochemical and sensory quality of avocado fruits.

1.2.2. Specific objectives

The specific objectives of the project were to:

- a) Evaluate the effect of hot water, garlic extract and beeswax on the physicochemical quality of avocado fruits.
- b) Analyze the effect of low density polyethylene and carton box on the physicochemical quality of avocado fruits.
- c) Investigate the effect of various storage durations (day₀, day₄, day₈ and day₁₂) on physicochemical quality of avocado fruits.
- d) Assess the sensory acceptability (color, flavor, texture, appearance and overall acceptability) of the avocado and its juice obtained from treated and untreated fruits over storage periods.
- e) Evaluate the interaction effect of postharvest treatments, packaging materials, and storage period on the physicochemical and sensory quality of avocado fruits.

1.3. Research Questions

- a) What impact do postharvest treatments (hot water, wax, and garlic extract) have on the physicochemical quality of avocados?
- b) How do low density polyethylene and carton affect the quality and shelf life of stored avocados as packaging materials?
- c) How do interaction effect of postharvest treatments, packaging materials and storage periods affect quality of avocado fruits?
- d) In what ways does the duration of storage influence the quality of avocados?
- e) How acceptable is the sensory quality of avocado and its juice produced from treated fruits compared to untreated fruits over storage periods.

1.4. Significance of the Study

This study is significant as it aims to contribute to the existing knowledge on postharvest handling practices for avocados in Ethiopia by identifying effective treatments and packaging techniques, the research offers practical solutions for reducing postharvest losses, enhancing fruit quality, and

improving economic returns for avocado postharvest management. The finding could help strengthen the avocado production sector in Ethiopia, promoting food security while fostering sustainable agricultural practices.

1.5. Limitation and Scope of the Study

1.5.1. Limitation

The research is limited to the Hass avocado variety and is conducted within specific geographic regions of Ethiopia. Factor such as climatic variations, potential pest and disease pressures, and difference in local handling practices may impact the generalizability of the findings. Additionally, the study focuses on short-term storage effects, which may not fully capture long-term quality changes.

1.5.2. Scope

The scope of the research includes an examination of postharvest practices, such as treatments and packaging materials, and their effect on physicochemical and sensory attributes of avocados throughout various storage durations. The study aims to provide insights into effective postharvest strategies that could be applied broadly across similar agricultural contexts.

1.6. Organization of the Thesis

The thesis is organized into the following chapters:

- a) Chapter 1: Introduction- Outlines the research problem, objectives, significance, limitations, and organization.
- b) Chapter 2: Literature review- Review existing research related to avocado postharvest handling, postharvest loss and quality management.
- c) Chapter 3: Materials and methods- Details the experimental design, materials used and methodologies applied to the study.
- d) Chapter 4: Results and discussions- Presents and analyzes the finding related to the research objective and questions.
- e) Chapter 5: Conclusions and recommendations-Summarizes the main finding and offers recommendations for future research and practical applications.

2. LITERATURE REVIEW

2.1. Global Production of Avocado Fruit

According to latest the data FAOSTAT (2022), avocados are cultivated on 858, 152 hectares worldwide, yielding a production of 8,685,672 million tons, or roughly 7 tons per hectare. Aside from this, data collected over the past 10 years indicates that avocado output and coverage area globally are growing linearly. Latin American nations account for around 70% of production, with Africa (12%), Asia (14%), Europe (1.7%), and Oceania (1.4%) (FAOSTAT, 2022). This suggests that avocado production is rising internationally.

Furthermore, according to FAOSTAT (2022) research, Mexico is among the top 10 producers of avocados worldwide, followed by Colombia, Peru, Indonesia, Kenya, the Dominican Republic, Brazil, Haiti, Vietnam, and Chile (Table 1). Mexico exceeds the other producing nations in terms of both geographical coverage and production.

Table 1: Top ten Avocado producing countries in the world

Country	Harvested area(Ha)	Proportion of global planted area (%)	Production (Tons)	Proportion of world production (%)	Rank
Mexico	226,534	26%	2,442,945	28%	1
Columbia	94,111	11%	979,618	11%	2
Peru	51,800	6%	777,096	9%	3
Indonesia	50,510	6%	669,260	8%	4
Dominica republic	37,468	4%	634,368	7%	5
Kenya	26,000	3%	416,803	5%	6
Brazil	18,106	2%	300,894	3%	7
Hait	42,723	5%	248,135	3%	8
Vietnam	16,538	2%	212,977	2%	9
Chile	32,363	4%	169,031	2%	10

Source: FAOSTAT (2022).

2.2. Ethiopia's Avocado Production Status

Due to low farm gate prices and a lack of technical production expertise, Ethiopian avocado production is primarily restricted to the domestic market, which has hindered investments in seedling and fruit development. The area coverage and total output of avocados during the previous five years are displayed in (Table 2) as an increasing trend, based on CSA, 2021 meher season statistics. 649,821 quintals of avocado were produced in the country in the 2016–2017 production year, while 2,453,356.30 quintals were produced in the 2020–2021 production year.

Table 2: Avocado area coverage, production (Qt), yield (Qt/Ha), HH consumption (Qt), domestic sale (Qt), and export (Qt) in Ethiopia.

Year	Area coverage (Ha)	Production (Qt)	Yield (Qt/Ha)	HH Consumption (Qt)	Sale (Qt)	Export (Qt)
2016/17	17,834.60	649,821.00	36.4	347,004.40	285,401.4	940
2017/18	18,021.13	814,318.00	45.2	434,438.70	362,127.20	513
2018/19	19,758.75	847,936.48	42.9	457,885.70	373,092.10	200
2019/20	20,875.80	1,044,919.20	50.1	475,542.70	529,251.60	840
2020/21	30,587.70	2,453,356.30	80.2	1,118,485.10	1,211,958.00	604.5

Source: CSA, 2016/17 to 2020/21, (FAOSTAT, 2022).

Where Ha, Qt and HH represent hectare, quintals and house hold, respectively.

In Ethiopia, the rates of avocado production were 20%, 25.3%, 4.12%, 23.2%, and 134% for the years 2016/17, 2017/18, 2018/19, 2019/20, and 2020/21, respectively, as reported by FAO in 2022. This organization also indicates that Ethiopia harvested 245,336 metric tons of avocados from about 30,587.70 hectares, achieving a yield of 80.2 Qt/ha in 2020/21. As a result, as compared to the country's current production potential, avocado acreage, productivity, and production status are all extremely low. The data indicates that there is a significant yield gap when compared to the world average, demanding improvements in all areas. The landrace cultivars being grown in Ethiopia are of low quality, have limited yield potential, and do not satisfy local and international customer demand. This necessitates substituting enhanced landrace types with high production and quality potential for the landraces.

The fruit farming sector has a lot of potential, but it is also known for its low yields and farmer income. Compared to other agricultural products, Ethiopia's fruit farming sector produces high-value goods and offers large returns on comparatively small investments (Bezabih & Hadera, 2016). Bezabih & Hadera (2016) claim that the production of horticulture is dependent on tradition, which is not well-supported by suggestions from science. The supply is clearly impacted by insufficient farmer skills and knowledge of production and product management, even though institutional issues can be linked to this constraint. Farmers make an effort to choose cultivars and employ conventional crop management techniques. The traditional methods used by farmers for product sorting, grading, packing, and transportation have a negative impact on the quality of horticultural items that are sold. As Alemu & Megerssa (2016) state, obstacles impeding the production of avocados can be identified during every step of the production process. At the level of the farm, farmers are forced to employ poor and low-producing varieties due to a lack of clean disease-free seedlings and grafted seedlings.

There are few storage facilities across the chain, and because farmers do not have collective bargaining strength, they are obliged to accept unfair contracts. Shumeta (2016) states that these are the main production constraints: Vegetative growth: According to the majority of farmers, their avocado trees only produce vegetative rather than when they are ready to deliver fruit. Fruits that fall before they are fully ripe have an issue with pests. Improved agronomic practices do not exist. Longevity: The extended time it takes for avocados to bear fruit and the inadequate extension efforts made with them have left farmers extremely unsatisfied. Garedew & Tsegaye (2011) also mentioned that avocado production has a variety of challenges, including fruit deterioration, disease problems, and a lack of effective agronomic practices, despite the fruit's significant economic and social function.

2.3. Postharvest Losses of Avocado

The goal of post-harvest activities should be to control the ripening of fruit that is harvested either unripe or at a mature stage, as well as to extend the range of fruit storage by slowing down the process of senescence. Harvesting, handling, transporting to packing facilities, and all other processes must be done properly to ensure that there is no possibility of mechanical loss. Injuries or damage can hasten the ripening process of fruit and adversely impact its appearance, resulting in browning and defects both during and before storage.

In general, avocados should be carried carefully to be displayed in marketplaces because they are highly sensitive to spoiling when tenderized (Getinet *et al.*, 2011). Softening can potentially drop quality of avocado if not inspected periodically. Any harvested fruit that was ripped or about to ripe should, if possible, be kept 1- 6°C colder to prevent rot. FAO (2022) states that post-harvest losses in underdeveloped nations might vary from 15% to 50%. At the producer level, the average post-harvest loss of avocados was assessed to be 24.1%; 5.7% of this loss was attributed to improper harvesting techniques, and 4.9% to improper storage techniques. Mangoes and avocados generate more losses than perennial crops because they are perishable and sensitive. All post-harvest operations, including handling, storing, processing, packing, shipping, and marketing, result in waste. Lack of infrastructure, expertise, and access to post-harvest technologies causes losses across the supply chain. Managing the supply chain well can help cut down on losses after harvest. Quantitative and qualitative losses are two ways to quantify postharvest losses. According to Hodges *et al.* (2020), losses can happen at any point in the supply chain during operations, including harvesting, transportation, packaging, and marketing. The biggest avocado losses in Ethiopia, according to Reneby (2014) happen during the following stages:- Harvesting, mostly as a result of improper harvesting practices throughout transport; primarily as a result of loading, unloading, and storage; mostly as a result of over ripeness.

2.4. Health Benefits of Avocado Fruits

Avocados are beneficial to health, industry, and nutrition. In addition to having significant quantities of protein, potassium, and unsaturated fatty acids, it is regarded as one of the principal tropical fruits because it contains fat soluble vitamins, which are less common in other fruits. Avocado fruit has long been known to provide health benefits, particularly because of the compounds such as omega fatty acids, phytosterols, tocopherols, and squalene found in its lipidic component. Research has demonstrated the advantages of avocados in relation to a healthy diet, particularly in terms of lowering cholesterol and preventing heart problems. Pulp is frequently utilized in pulp processing, the pharmaceutical and cosmetics sectors, and the creation of commercial oils that resemble olive oil (Duarte & Mark, 2016). A nutrient-and phytochemically dense food that contains significant amounts of dietary fiber, potassium, magnesium, vitamin A, vitamin C, vitamin E, vitamin K1, folate, vitamin B-6, niacin, pantothenic acid, riboflavin, choline, lutein/zeaxanthin, phytosterols, and MUFA-rich oil at 1.7 kcal/g is provided by avocados, which

are consumed half the time on average, according to NHANES data. Avocados have a medium-low calorie density due to their high water content (72%) and low dietary fiber content (6.8%).

Avocados include a wide range of additional nutrients and phytochemicals that may have health advantages beyond the reduction of cholesterol-related vascular disease. When consumed with avocados or other naturally low-fat fruits and vegetables, avocado oil's composition of 71% monounsaturated fatty acids (MUFA), 13% polyunsaturated fatty acids (PUFA), and 16% saturated fatty acids (SFA) contributes to the maintenance of healthy blood lipid profiles and improves the bioavailability of fat-soluble vitamins and phytochemicals (Duarte & Mark, 2016). Additionally, studies revealed that an estimated five million Ethiopians are deficient in vitamins and other vital minerals, accounting for 60 to 80 percent of the country's health issues related to nutritional issues and communicable diseases (Adugnaw & Habtamu, 2016). Avocados are therefore a good solution to enhance the food security of the country.

2.5. Ripening and Maturity of Avocado

The two most obvious signs that an avocado is ripening are a change in skin colour and a softening of the flesh in some cultivars. These modifications come about as a result of two additional phenomena: the respiratory and the ethylene climacteric (London & Sierra, 2019).

If avocados are harvested before they reach their ideal maturation stage, they may not soften without shrivelling, soften unevenly, or provide unpleasant eating quality. In order to maximize the benefits of early season prices, it is crucial from a commercial standpoint to identify the maturity standard that guarantees the appropriate quality when ripe (Gundewadi *et al.*, 2018).

2.6. Factors Influencing Avocado Quality

The pre- and post-harvest variables are the main factors that affect avocado quality and shelf life. The avocados' quality aspects that are affected by these factors include chemical, physical, and sensory quality which are necessary to assess avocado quality at every point of maturity level. In order to maintain the avocado quality after harvest, pre-harvest factors like the avocados' exposure to ambient temperature and water stress as well as the harvesting process have to be controlled. The characteristics of avocado quality that are affected by the combination of postharvest treatments, packing, and storage time will be identified. Ultimately, the optimal avocado treatment and packaging materials, as well as the duration and state of storage during postharvest handling, will be examined and suggested for additional research.

2.6.1. Harvesting and pre-harvest factors

The important pre-harvest variables that have an impact on avocados' post-harvest requirements:- ambient temperature, water stress, and mechanism of harvesting are discussed in this chapter.

2.6.1.1. Ambient temperature

The most important pre-harvest factor influencing the post-harvest quality of avocados throughout growth is ambient temperature (Costa, 2010). Vincent (2019) examined the effects of postharvest treatment on the avocados on each side that was exposed to sunlight while still attached to the tree. The results indicate that the avocados that were directly exposed to sunlight were able to withstand higher temperatures during treatment than the avocados that were shaded. Avocados exposed to high field temperatures can withstand low postharvest temperatures without suffering chilling harm, according to research by Lurie & Pedreschi (2015). According to Undurraga *et al.* (2007), avocados that were kept at 0°C for three to six weeks showed a higher tolerance to chilling harm and were firmer when they were exposed to sunshine. Fruit exposed to the light had an ethylene peak for two to five days when it was ripening at 20°C.

2.6.1.2. Water stress

Water stressed “Hass” avocado trees were found to bear more elongated fruit (Kassim *et al.*, 2013). It is uncertain why this is happening, and more research is necessary. Water stress lowers the internal quality of avocados because it increases polyphenol oxidase activity, which browns the flesh. The concentration of calcium present in avocados that are water-stressed raises the possibility of physiological issues. Avocado quality pre- and post-harvest is impacted by water stress. Pre-harvest water stress causes an increase in ethylene production and early fruit abscission. Water stress affects avocados' typical ripening period and shelf life, which raises the risk of physiological diseases (Tejada *et al.*, 202). Water stress may also have an impact on avocado temperature. When a plant experiences water stress, the temperature of the avocado rises because the water moves through the fruit stalks, providing cooling (Dladla, 2020). This cooling action ends once the avocado is harvested, and sun exposure frequently speeds up the fruit's temperature rise.

2.6.1.3. Harvesting mechanism

Avocados are ripe and mature only once they are harvested, in contrast to other fruits. The maturation and required shelf life of avocados are impacted by the moment of harvest. According

to Mohapatra *et al.* (2013), harvesting fruit too early in the season results in lower pulp dry matter from premature ripening, flavorless fruit with a watery texture, and shriveled and charred fruit. Harvesting prematurely softens the fruit, makes it taste bad, and makes the fruit more susceptible to damage (Blakey, 2011). Avocado with inconsistent harvesting times have lower quality and shorter shelf life (Kassim *et al.*, (2013).

Harvesting wet avocados raises the risk of cold injury, pulp spot, and lenticel damage (Magwaza (2015). Fruit collected early in the morning or late in the afternoon is noted to have less field heat. In general, the best indicators to determine when to harvest fruits are their colour, size, or oil content (El Riachy *et al.*, 2022). The two most common manual harvesting procedures are clipping and snapping. According to Mohammed *et al.* (2018), these two approaches have no effect on the avocados' postharvest ripening or rate of weight loss. Clipping can delay the onset of stem end rot and lessen bruising and puncturing of neighboring fruit while in containers (Hailu, 2017). However, compared to snapped avocados, clipped avocados ripened more slowly. Consequently, more researches has to be done to demonstrate how avocado quality is impacted by clipping and snapping.

2.6.2. Handling practice

The avocado should always be kept in a shaded area after harvesting. If the fruits are exposed to too much heat, they will become sunburned, become dehydrated, and lose quality. Covering field fruits with leaves instead of space blankets, papers, or bins left uncovered was found to be more beneficial in reducing flesh discoloration and disease after storage (Burdon *et al.* (2022). Fruit should be brought home within two hours of being collected (Alkan & Kumar, 2018).

2.6.3. Treatments after harvest

When paired with appropriate packaging materials and storage parameters, treatments have increased avocado quality and extended shelf life before packaging and storage (Kassim *et al.*, 2013). Here are a few post-harvest treatments that are frequently used on avocados.

2.6.3.1. Heat treatments

Biosci *et al.* (2014) found that heating avocados for 24, 48, and 72 hours at 38°C improves their appearance and lessens the effects of chilling injury. This is demonstrated by the delayed evolution of ethylene while the respiration rate stays constant. Moreover, the weight loss decreased with an increase in heating days, resulting in a longer shelf life. Regarding the risk of insect pests in

avocados, Vincent (2019) frequently discussed the process of cold disinfestation. Fruit that is kept at 1°C for 16 days will get chilling damage. Avocados are heated under different circumstances to minimize the onset of damage (Table 3). Water is the most recommended medium for thermal applications because it transfers heat more effectively than air (Sivankalyani *et al.*, 2015). Heat treatment with air takes longer to heat up than heat treatment with water. The time and temperature needed to treat fruits might vary depending on the cultivar and pre-harvest environmental factors like sun exposure. According to Eletreby & Shaaban (2017), heat treatments have an impact on the heat shock proteins that protect fruit from heat damage.

Table 3: Heat treatment regime of avocados

Temp. (°C)	Heating media	Exposure Time	Effects	Reference
37 – 38	Air	17-18 h	Reduced chilling injury	Nduku (2022)
38	Air	6-12 h	Reduced chilling injury and reduction in ripening time and flesh injury after ripening	Kassim <i>et al.</i> , (2013)
38	Water	2 h	Reduced chilling injury	Biosci <i>et al.</i> , (2014)
40 and 41	Water	30 min	Reduced body rots and decreased vascular browning	Z. Zhang <i>et al.</i> , (2017)
38	Water	30 min	Good appearance and internal quality	Sivankalyani <i>et al.</i> , (2015)
38	Air	6 h	Reduced chilling injury	Eletreby and Shaaban, (2017)

2.6.3.2. Conditioning at low temperatures

Conditioning fruits at low temperatures involves maintaining avocados at slightly higher temperatures than those that could result in low temperatures (Sunić and Ilić, (2017). According to Bill *et al.* (2014), low-temperature conditioning for four days, between 4 and 8°C, is advised to preserve fruits against chilling damage. Carvalho & Rooyen (2014) reported similar outcomes, with temperatures of 6 to 8°C for three to five days. Damage to the skin and internal quality was repaired; hard skin, tissue disintegration, and rot triggers were reduced, if not completely

eliminated (Carvalho & Rooyen, 2014). Zhang *et al.* (2017) confirmed that hot water treatments are not as effective in preventing exterior chilling injury and enhancing avocado quality overall as low-temperature conditioning is. In order to lessen chilling harm, heat shock proteins can also be produced by temperatures that are almost below freezing (Zhang *et al.*, 2017). The reason for this is that heat shock proteins inhibit the rate at which ethylene is produced, which is linked to higher degrees of chilling injury.

2.6.3.3. Wax treatments and surface coatings

Avocados suffer greatly from postharvest water loss, which causes a greater degree of physiological abnormalities and accelerates ripening (Jin *et al.*, 2015). Because of their impermeability, waxes have been shown to reduce the possibility of water loss. This allows the fruit to retain its weight for longer periods of time, improving turgidity and water retention capacity. According to Olaeta *et al.* (2016), waxes provide a surface barrier, which prevents the gas from moving. As a result, the internal environment is altered, which slows down respiration and delays ripening. An 11% percentage of PE-based wax was found to significantly improve the outer shine and reduce mass loss (Joyce, 2021). Waxes can enhance avocados' physiological characteristics as well as their exterior cosmetic appeal by giving the fruit's surface a shine and luster. Hailu (2017) discovered that using pectin-based waxes produced better results in lowering the rate of respiration than their previous work applying coatings with methyl cellulose.

2.6.4. Packaging materials

Food packaging's primary benefits include extended food storage, preservation, and protection (Eletreby & Shaaban, 2017). This lesson provides an overview of previous and present avocado packaging and storage trends. For avocados, the two most used techniques are modified atmosphere packing (MAP) and controlled atmosphere storage (CAS). These methods have been shown to preserve the quality of fresh fruit, including avocados, and extend their shelf life (Rensburg, 2021). Fruit needs to be thoroughly dried before being packaged. Fruits that are packed moist have a higher risk of disease and suffer physiological damage while being stored (Kassim, 2013). Modern packing houses include quick air-drying equipment to dry fruit before packing. A sufficient amount of ventilation is needed for the carton to enable effective and quick cooling, and handling and transportation will require the mechanical string. About 9% free-flow area, that is,

the area of the holes compared to the overall area of the carton is needed to obtain adequate cooling in the carton.

Table 4: Packaging film permeability (Hernandez-Brenes *et al.*, 2011).

Film type	Oxygen*	Transmission rate	
		Carbon dioxide*	Water vapour**
Low density polyethylene (LDPE)	3900-13000	7700 – 77000	6 - 23.2
Linear low density polyethylene (LLDPE)	7000 – 9300	-	16 – 31
Medium density polyethylene(MDPE)	2600 - 8293	7700 – 38750	8 – 15
High density polyethylene (HDPE)	52 - 4000	3900 – 10000	4 – 10
Polypropylene (PP)	1300 - 6400	7700 – 21000	4 - 10.8
Polyvinyl Chloride (PVC)	620 – 2248	4263 – 8138	> 8
Polyvinyl Chloride (PVC), plasticized	77 - 7750	770 – 55000	> 8
Polystyrene (PS)	2000 – 7700	10000 - 26000	108.5 - 155
Ethylene vinyl acetate copolymer (12% VA)	8000 – 13000	35000 - 53000	60
Ionomer	3500 - 7500	9700 - 17800	22 – 30
Rubber hydrochloride (Pliofilm)	130 - 1300	520 – 5200	>8
Polyvinylidene chloride (PVDC)	8 - 26	59	1.5 – 5

* Measured in units of $\text{cm}^3 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ at 1 atmosphere. **Measured in units of $\text{g} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ at 37.8°C and 90% relative humidity

Packaging film

High-density polyethylene (HDPE), low-density polyethylene (LDPE), polyvinylchloride (PVC), polypropylene (PP), ethylene vinyl acetate (VA), polystyrene (PS), ionomer, polyvinylidene chloride (PVDC), and rubber hydrochloride (pliofilm) are the main plastic packaging materials used for modified atmosphere packaging (MAP) of whole fruit and vegetables (Blakey, 2011)

(Table 4). According to Soltani (2017), storing avocados in PE bags lessens the impacts of chilling injury. According to Hernández *et al.* (2016) "Fuerte" that was individually packaged in PE bags with a thickness of 0.025 mm and left for 23 days at 14 to 17°C ripened normally after being taken out of the bags. Following storage, it was discovered that there was 5% oxygen and 8% carbon dioxide in the bags' environment. Similarly, "Hass" that was individually packed and kept at 10°C had a longer shelf life (Mahmood and Sultan, 2019)

Subsequent research showed that the effect on the storage life of unwrapped avocados and perforated bags is identical. Low-density polyethylene (LDPE) films demonstrated more favorable MAP conditions of high carbon dioxide and low oxygen in preserving avocado, papaya, and mango freshness when compared to oriented PS and PP films (Pesis *et al.*, 2000). Due to their ease of reuse, biodegradable films and coatings are becoming more environmentally friendly when compared to plastic films (Gupta *et al.*, 2020). Both the operation of the packaging itself and the postharvest behavior of avocados depend on the use of biodegradable film formulations. Avocados can benefit from gelatin-starch coatings and films, which can limit weight loss, retain the colour of the skin, and result in firmer fruit pulps (Bocaega *et al.*, 2021).

2.7. The Effect of Storage Condition on Quality of Avocado

Avocado (*Persea Americana*), is a fruit that is high in water-soluble vitamins, particularly A and C, and unsaturated fatty acids. Furthermore, it has a low sugar level and is suggested for those who have diabetes. It can be either raw or cooked and added to salads. Freshly cut avocados with minimal processing go through several stages, including raw material selection, cleaning, washing, peeling, cutting, drying, and packaging. After processing, a 100% usable, handy, fresh product with excellent nutritional value is produced. Avocados are considered fresh fruit, and they should be stored at cooler temperatures to prevent microbial contamination and preserve their sensory and organoleptic qualities. Darkening and pulp softening are the primary limiting elements that customers take into account during the commercialization of fresh-cut fruit and vegetables. The food's appearance is the primary determinant of its acceptance or rejection. Furthermore, the most important and challenging goal for processors is to maintain the original colour during processing and storage.

The primary concern that arises during the avocado's shelf life is the pulp's discoloration. The change results from the oxidation of phenols and quines, which causes tissue browning, being

catalyzed by peroxides (PER) and polyphenol oxidase (PPO) enzymes generated in the presence of oxygen. The most practical and successful ways to prevent avocados from darkening are to prepare and store the fruits at lower temperatures and to use chemical additives in conjunction with low temperatures.

Avocados come from tropical and subtropical regions, so they cannot be kept at low temperatures for long period. Thus, it is generally recommended to store items between 3 and 7°C. Typical indications of avocado fruit chilling injury include skin pitting, blackening, and discoloration of the inside flesh (spots, pulp, grey pulp, and vascular browning) (Kumar *et al.*, 2021). Most avocado cultivars, such as Hass avocados, ripen in 2 to 10 days after harvest; ripe avocados have a 1- to 2-day shelf life. Hass avocados are susceptible to bruising and illness, but they can have a four-week shelf life if cared for and kept correctly (Gonzalez *et al.*, 2020). Under refrigeration storage the ideal temperature of fruits are: 5 to 13°C for unripe fruits, depending on the kind of fruits and harvest time; 2 to 4°C for mature avocados; and 90–95% relative humidity are recommended.

Therefore, conditions found in storage medium play a crucial role in maintaining the quality of avocado fruits. Below is a discussion of the necessary storage conditions and how they affect avocado quality.

2.7.1. Temperature

Temperature is one of the most crucial aspects that taken into account when storing fruit because it affects biological activities fruits (Shah *et al.*, 2016). Fruit that is stored at low temperatures has a longer shelf life and a slowed metabolic rate because it produces less ethylene and respire more slowly (El-ramady *et al.*, 2015). According to theory, for every 10°C increase in temperature, the respiration rate doubles (Zhang *et al.*, 2017). Depending on the variety, such as Hass avocados, the ideal storage temperature range for unripe avocados is 5 to 13°C, while for ripe avocados it is 2 to 4°C. This means that avocados can last anywhere from two to four weeks.

2.7.2. Relative humidity

For the majority of fresh commodities, high relative humidity conditions are necessary during storage (Sivanappan, 2017). Water loss decreases as relative humidity rises because there is less of a vapour pressure deficit (Mahajan *et al.*, 2017). Low relative humidity can cause water loss in avocados, which can severely impact their texture and appearance. Avocados held at low relative

humidity lost water more quickly than those stored at high relative humidity, according to (Al 2020). Additionally, the ripening process was expedited by three and a half days. On the other hand, compared to avocados held at 98% relative humidity, those kept at 60% relative humidity or less for four days produce a 1.5% increase in dry mass and shorter ripening days (Getinet *et al.*, 2011). The optimal storage conditions for 'Hass' avocados involve temperatures between 5 and 7 for early- season fruit and 4 to 5.5 for late season fruit, with high relative humidity of 95%, allowing for a shelf life of up to 6 weeks (Gonzalez *et al.*, 2020).

2.7.3. Concentration of gas

Gases have a big impact on how fresh goods are stored, especially nitrogen, ethylene, carbon dioxide, and oxygen (Gonzalez *et al.*, 2020). The avocado cultivar and intended usage determine the combination of gas concentrations.

Avocado ripening is inhibited by increases in carbon dioxide and decreases in oxygen. Marketable fruit could be stored for nine weeks at 5°C without suffering chilling harm when a combination of an oxygen concentration and a carbon dioxide concentration of 3 and 8%, respectively, was used (Olivares *et al.*, 2020). Avocados can sustain foliar and mesocarp damage when exposed to low oxygen concentrations and very high carbon dioxide levels (Bill *et al.*, 2014). Anaerobic respiration is anticipated to occur at oxygen concentrations below 1% (Munhuweyi *et al.*, 2020). Long-term exposure to oxygen levels below 3% is not advised (Pandey & Paul, 2011). Avocados stored in 12.6% oxygen and 40% carbon dioxide have a higher rate of respiration than avocados preserved in 16.8% oxygen and 20% carbon dioxide (Rensburg, 2021). Avocados are soften more slowly at greater carbon dioxide levels and suffer peel damage at lower concentrations of oxygen (Bill *et al.*, 2014),.

2.7.4. The avocado cold chain

Transporting avocados from their growing region to stores in Ethiopia requires careful planning and sensible management. Avocados impacted by the cold chain at any point are of low quality (Blakey *et al.* (2015). In order to encourage transportation regimens, the avocado was stored at 10°C for 28 days, which slowed down the rate of mass loss and softening. An example of an avocado cold chain is illustrated in Figure 2, where TX represents the temperature at each stage X in °C (for example, TH is the temperature at harvest).

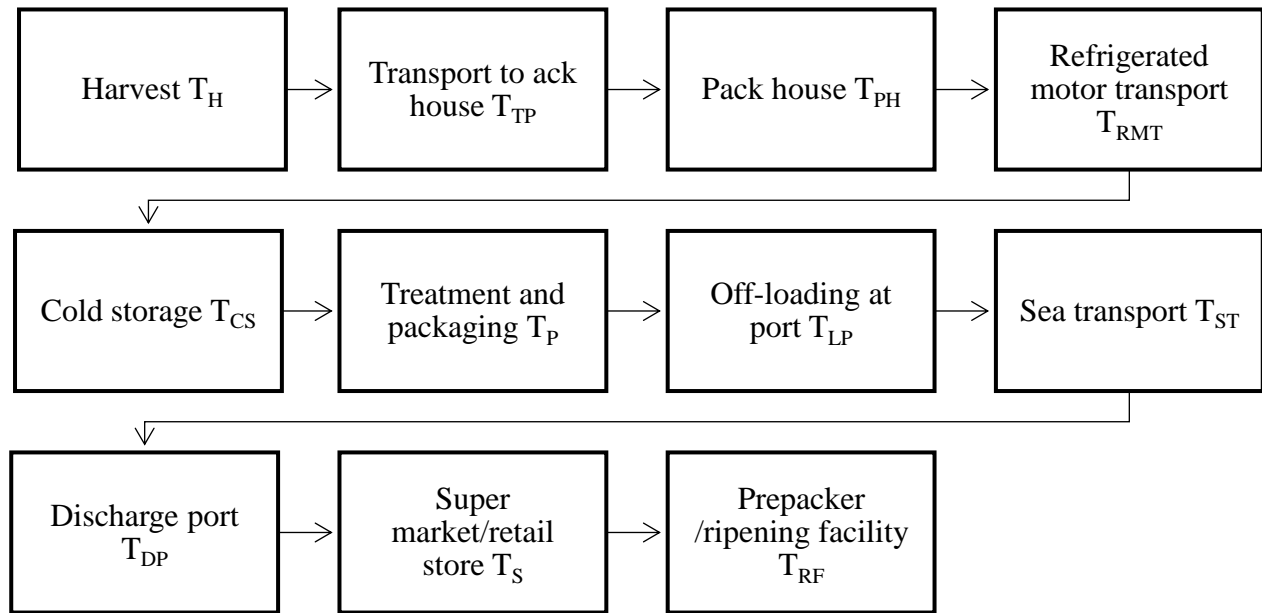


Figure 1: The cold chain of avocados (Ashinie, 2019)

2.8. Changes to Avocado Quality Following Harvest

Colour, texture, flavor, and aroma are the primary attributes that consumers look for when making a purchase and are considered crucial parameters for avocado quality (Cañete, 2018). In this session, the majority of avocado quality parameters are covered in summary form.

2.8.1. Physical attributes

Avocados' look and visual appeal are the primary physical quality characteristics that buyers take into account when making a buying decision. Some of the physical quality parameters of avocados are texture, skin colour, firmness, physiological abnormalities of whole avocados, and the colour and viscosity of pureed avocados.

2.8.1.1. Skin colour

Avocado skin colour is a crucial indicator of the fruit's ripening stage for both the industry and consumers (Pathare *et al.* (2013). Skin colour can be determined objectively or subjectively by means of an eye colour rating made by skilled sensory panelists or by utilizing a Chroma meter or colorimeter. It has been discovered that avocado cultivars differ in terms of skin tone. For instance, the "Hass" cultivar exhibits a colour shift from green to black (Fal & Ferreira, 2022). However, Hailu (2017) asserted that the 'Sharwil' variety's skin tone does not darken with age. Consequently, in order to distinguish between the different stages of maturity, alternative systems must be used.

The following are the parameters related to colour measuring: L = Lightness or brightness, a^* = redness or greenness, and b^* = yellowness or blueness, as per (Setagane 2020)

2.8.1.2. Firmness

In order to determine the avocado's ripening stage, its firmness is crucial (Lu *et al.*, 2015). One way to define firmness is the resistance to penetrating, using invasive techniques, such as physical hand approaches. Firmness is assessed using non-destructive techniques like impulse response and ultrasonic techniques, or destructive techniques like the Madness-Taylor puncture test (MT). Destructive methods are better suited for laboratory analysis than they are for commercial control advancement. Ultrasonic techniques were employed by Salem *et al.*, (2013) to evaluate firmness in a non-destructive manner, yielding results that were comparable to those of destructive approaches.

Impulse response techniques can determine fruit firmness and shelf life instead of using destructive testing procedures, and they were found to be more effective than MT tests in this regard (Landahl & Terry, 2020). A strong link was found in earlier research by Uarrota *et al.* (2021) between fruit firmness, maturity stage, and anticipated storage duration. Avocados that are stored at low temperatures have a slower rate of softening, making storage temperature a critical element in determining firmness. The hardness of avocados decreased from about 130.51 N to 54.62 N, 19.92 N, and 7.37 N when they were held at 15°C during storage days 0, 4, 8, and 12, in that order (Hailu, 2017). The avocado firmness decreased from 75.43 to 2.63 N in 12 days at 20°C temperature and 75% relative humidity (Arzate-vázquez *et al.* 2011).

2.8.1.3. Texture

Texture is an essential determinant of avocado quality that the consumer might consider when evaluating the fruit's resistance to external force (Joyce (2015). One of the key elements determining the texture of an avocado is its oil content and the link that exists between the two (Tan (2017). Blakey *et al.* (2015) also observed that there was no discernible alteration in texture with an increase in oil content over the harvest season. Texture is directly impacted by wounding, storage temperature, and carbon dioxide and oxygen concentrations (Blakey *et al.* 2015).

2.8.1.4. Size

Avocados tend to be modest in size, hence size is an important quality indicator (Cañete, 2018). As noted by Moreno-ortega *et al.* (2019), the size of fruit distribution can also be affected by the production season.

2.8.2. Disorders of the physiology

Under certain conditions, all biological systems function at their best. Physiological diseases are likely to occur if these interval periods are modified in a significant way. The shelf life of fresh goods is frequently increased by low-temperature storage. Ali *et al.* (2020) state that this results in avocado chilling injury. Chilling injury is primarily characterized by black patches on the peel or a grey or dark-brown discoloration of the monocarpic tissue (Rojas *et al.*, 2021). The best way to prolong avocado shelf life was to treat them with hot water prior to storage in order to lessen the impacts of chilling injury Ma *et al.* (2014). Chilling injury can be minimized by storing avocados at a low temperature slightly above the point at which damage from chilling is most likely to occur (Kassim *et al.*, 2013). It was discovered that 6 to 8°C was the ideal low temperature to preserve avocados for three to five days. However, the minimum storage temperature was reported to be 4°C by Kassim *et al.* (2013). Physiological abnormalities worsen with storage time and temperature, according to an experiment conducted on the 'Hass' variety by Shah *et al.* (2016).

Other postharvest conditions that reduce avocado quality are sunburn and environments with controlled or altered conditions. Avocados that have been sunburned experience symptoms such as yellowing, bleaching, or roughened skin (Ferguson & Woolf, 2000). They can also develop problems if they are exposed to an unstable atmosphere, low oxygen levels, or excessive carbon dioxide concentrations (Burdon *et al.*, 2007). It was also discovered that the administration of exogenous ethylene caused discoloration of the monocarp (Pesis *et al.*, 2002).

2.8.3. Chemical attributes

Since charges related to external appearance are not always easily resolved, identifying the fruit ripeness of avocados is frequently difficult. Consequently, the need arises for further methods of maturity determination that make use of chemical properties. Dry matter content, total soluble sugar, and total terrible acid are the chemical parameters of avocados that are covered in this topic.

2.8.3.1. Total titratable acidity

The sourness and sweetness of fruit are correlated with its acidity. One way to determine acidity is titratable acidity. The concentration of free hydrogen ions that are actively bound is known as pH, while the amount of hydrogen ions that are weakly bound is known as terrible acidity. When avocados with pectin bases were stored at higher temperatures, severe acidity was noticed in both coated and uncoated avocados (Tan, 2021).

2.8.3.2. Dry mater content

The cost of increased dry matter content and oil accumulation is made possible by prolonging the avocado's maturation stage. Nonetheless, there has been a recorded rise in the disease's occurrence. An avocado-producing country adopts maturity guidelines to prevent the marketing of poor-quality immature avocados. The maturity standard that was received is the California minimum dry matter content of 20.8% for "Hass" or a slightly higher minimum dry matter content of approximately 25% to decrease disorders during storage (Gupta *et al.*, 2020).

2.8.3.3. Total soluble solid

One of the primary components of avocados is carbohydrates. Total soluble solid is a crucial source energy for development, growth, and maintenance (Gamble *et al.*, 2010). The common disaccharide sucrose and its constituent hexodes, fructose and glucose, the uncommon seven carbon (C7) reducing sugar mannoheptulose and its reduced polio form, perseitol, are among the five primary soluble sugars found in avocados (Olawejaju, 2014). 98% of these soluble sugars are total soluble sugars (TSS). Avocado flesh and peel TSS, particularly the C7 sugars, significantly decrease while ripening at 20°C. An increase in the oil content coincided with a decrease in the TSS (Liu *et al.*, 1999). Although it happened more slowly, the TSS decreased during storage at 1 and 5°C. Similarly, during ripening, Hernández *et al.*, (2016) found lower levels of C7 sugars. Carbohydrates are stored during the growth of avocados, however enzymatic systems that metabolise the C7 sugars utilize these carbohydrates for postharvest physiological functions, including respiration (Manovski *et al.*, 2015). This implies that the C7 sugars are crucial to the ripening process of the avocado's respiration.

2.8.3.4. pH

The pH range of avocados is 6-6.5 (Kassim *et al.*, 2013). Over time, storage causes the avocado's pH to drop. Avocados coated with pectin-based coatings show a slower rate of pH drop when

compared to untreated fruit and fruit subjected to higher temperatures. Pre-treatments involving brief exposure to high carbon dioxide or low oxygen levels have been utilized to minimize physiological problems and improve storage conditions. Additionally, these circumstances may lower intracellular pH, which may alter physiological processes dependent on pH (Ke *et al.*, 1995). Avocados can lower their pH from 6.9 to 6.7, 6.3, and 6.3, respectively, at 20°C by exposing them to (a) 0.25% oxygen, (b) 20% oxygen combined with 80% carbon dioxide, or (c) 0.25% oxygen and 80% carbon dioxide (Rojas *et al.*, 2022).

2.8.4. Sensory characteristics

The product's flavor, hand feel, and mouth feel are examples of its sensory attributes (Zhang *et al.*, 2021). One of the primary sensory characteristics of avocados is flavor. It is an essential component of the fruit-eating quality and consists of both aroma and taste. Taste is the result of the temperature dependent ratio of sugar to acid to (Kassim *et al.*, 2013). When grapefruit is stored at 8°C, it may be observed that the acidity decreases more than when grapefruit is stored at 12°C (Hernandez-Brenes *et al.*, 2011). During the ripening process, fruits retain a higher concentration of volatiles (Obenland *et al.*, 2012). Premature fruit harvesting may result in an undesirable flavor (Lovatt, 2020). Elevated acetaldehyde and ethanol levels are the cause of the off-flavor (Taiti *et al.*, 2015). Acetaldehyde and ethanol levels rise when avocados are treated with 80% carbon dioxide and 0.25% oxygen (Botondi *et al.*, 2018).

Elevated quantities of acetaldehyde and ethanol were observed when 'Hass avocado' was exposed to carbon dioxide and oxygen concentrations of less than 20% and up to 0.5%, respectively (Kassim *et al.*, 2013). Depending on the variety, avocados with an oil content rating of 10–30% have a taste that is satisfactory and a smooth, soft texture.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The avocado sample came from Melkasa Agricultural Research Centre, which is located 429 km from Haramaya University and 117 km from Addis Ababa in the East Shewa zone of Oromia Regional State. The Centre is located at 8°24' N latitude, 39°21' E longitude, and 1550 meters above sea level. The Andosol of volcanic soil, which has a pH of 7 to 8.2, is the most common form. The minimum and maximum annual temperatures are 14 °C and 28.4 °C, respectively, and the average annual rainfall is 763 mm (Dessye and Melkamu, 2021).

The experiment was conducted in 2024 from October to November in the Food Science and Postharvest Technology Laboratory of Oda Bultum University, at room temperature of about 24°C and humidity. Oda Bultum University is located in the West Hararghe Zone of Oromia Regional State, Ethiopia. The area is located at 40°52' E longitude, 9°05' N latitude, and altitude of 1826 m.a.s.l at a distance of about 326 km east of Addis Ababa on a way to Harar City. The mean annual rainfall is 750 mm to 1200 mm and the minimum and maximum annual temperatures are 13.9°C and 28°C, respectively.

3.2. Sample Collection and Preparation

Green mature 'Hass' avocados were manually harvested by expert harvesters early in the morning to reduce field heat and minimize mechanical injury. Avocados within a mass range of 281–327 g were selected and packed into single layer standard count 12 corrugated cardboard boxes (12 avocados per box) with ventilation. A total of 144 avocados, amounting to approximately 70 kg, were selected for this experiment based on their uniformity of weight, shape, colour, size and whether they were bruised and blemish-free to be used in the experiment (Mohammed et al., 1999; Maftoonazad and Ramaswamy, 2008; Getinet et al., 2011; Hassan and Dann, 2019). The selected samples were immediately transported and stored at room temperature in Oda Bultum University's Food Science Laboratory, where sample preparation, treatment, and storage trials were carried out.

The avocado samples were visually inspected at the laboratory to ensure that they were not subjected to any damage during transportation and, if they were damaged avocados were excluded from the samples (Getinet *et al.*, 2011.) All work surfaces, tools, and utensils were cleaned and disinfected. Avocados were treated and tested at room temperature over 12-days of storage periods.

3.3. Material Preparation

The packaging materials needed for the experiment, such as cardboard (carton) and plastic polyethylene bag as well as the garlic clove used for preparation of garlic extract were collected from Oda Bultum University's local market, Chiro. Finally, the bee wax that used for postharvest treatment was obtained from Oda Bultum University's bee farm.

3.4. Experimental Design

An experimental design consisting of four postharvest treatments (control, wax (%), hot water immersion (38°C), and garlic extract (%), three packaging materials (polyethylene bags, cartons, and room storage) and 12 days of storage period with three replications was arranged with a full factorial design under ambient temperature. The experiment had four data collection points starting from the initial day and repeated within every four day's intervals. The experimental design layout was shown in Table 5 below.

Table 5: Experimental design layout

Factor A	Factor B	Factor C			
		Storage period (days)			
Postharvest treatment's	Packaging materials	D ₀	D ₄	D ₈	D ₁₂
Control	B	D ₀ B	D ₄ B	D ₈ B	D ₁₂ B
	B ₁	D ₀ B ₁	D ₄ B ₁	D ₈ B ₁	D ₁₂ B ₁
	B ₂	D ₀ B ₂	D ₄ B ₂	D ₈ B ₂	D ₁₂ B ₂
Hot water	B	H _w D ₀ B	H _w D ₄ B	H _w D ₈ B	H _w D ₁₂ B
	B ₁	H _w D ₀ B ₁	H _w D ₄ B ₁	H _w D ₈ B ₁	H _w D ₁₂ B ₁
	B ₂	H _w D ₀ B ₂	H _w D ₄ B ₂	H _w D ₈ B ₂	H _w D ₁₂ B ₂
Wax	B	W _x D ₀ B	W _x D ₄ B	W _x D ₈ B	W _x D ₁₂ B
	B ₁	W _x D ₀ B ₁	W _x D ₄ B ₁	W _x D ₈ B ₁	W _x D ₁₂ B ₁
	B ₂	W _x D ₀ B ₂	W _x D ₄ B ₂	W _x D ₈ B ₂	W _x D ₁₂ B ₂
Garlic extract	B	G _e D ₀ B	G _e D ₄ B	G _e D ₈ B	G _e D ₁₂ B
	B ₁	G _e D ₀ B ₁	G _e D ₄ B ₁	G _e D ₈ B ₁	G _e D ₁₂ B ₁
	B ₂	G _e D ₀ B ₂	G _e D ₄ B ₂	G _e D ₈ B ₂	G _e D ₁₂ B ₂

Where; H_w = Hot water, W_x = wax, and G_e = Garlic extract represent postharvest treatments; B = Room storage, B_1 = Low density polyethylene and B_2 = Carton box represent packaging materials while D_0 , D_4 , D_8 , and D_{12} are represent storage periods

3.5. Postharvest Treatments

Control: 36 representative fruits from complete samples were immersed in distilled water for 30 minutes, then taken out and left to dry at room temperature (Persea, 2017).

Hot water treatment: After first heating to 80°C, the water bath's temperature was lowered to 38°C to cool down to optimum temperature that not affect quality of avocado. After five minutes in hot water at 38°C, the avocado samples were taken out of water and allowed to dry at room temperature (Setagane, 2020).

Coating: Beeswax gained from Oda Bultum University bee products. It was slowly cooked until it became a liquid. A sponge was dipped into it once it had cooled. All of the designated sample fruits were then covered with a thin layer of beeswax. One kilogram of avocado fruits required about 1.6 milliliters of wax (Blakey, 2012). The fruits were dipped in wax and then allowed to dry at room temperature for half an hour on paper towels (Persea, 2017). Following treatment, the fruits were placed in their respective packaging materials and kept at room temperature.

Garlic extracts: The cloves of fresh garlic (*Allium sativum* L.) were bought from a store local market. The clove of garlic was peeled, and ethanol was used to sterilize the cleansed surface. The 1.5 kg of garlic cloves were crushed after being weighed. In the first round, crushed cloves were then used to extract pure juice using a juice extractor. After that, 1250 mL of ethanol and the remaining clove juice were extracted. Following that, the mixture was put in a glass jar and left to extract at room temperature for the entire night. Next, a Buchner funnel and Whatman qualitative filter paper (No. 4) were used to filter the extract. Following filtration, the filtrate was placed in a vacuum rotary evaporator set to 60 to 80°C in order to eliminate the ethanol, leaving behind only a semisolid extract solution. This extract was regarded as the extract's 100% concentration. The detail procedure of garlic extract preparation was expressed in flow chart below (Figure 3). After five minutes of immersion in the extracted solution, the avocado fruits were left to dry. Lastly, each packing material was used to pack the treated fruits (Y.Li et al., 2024)

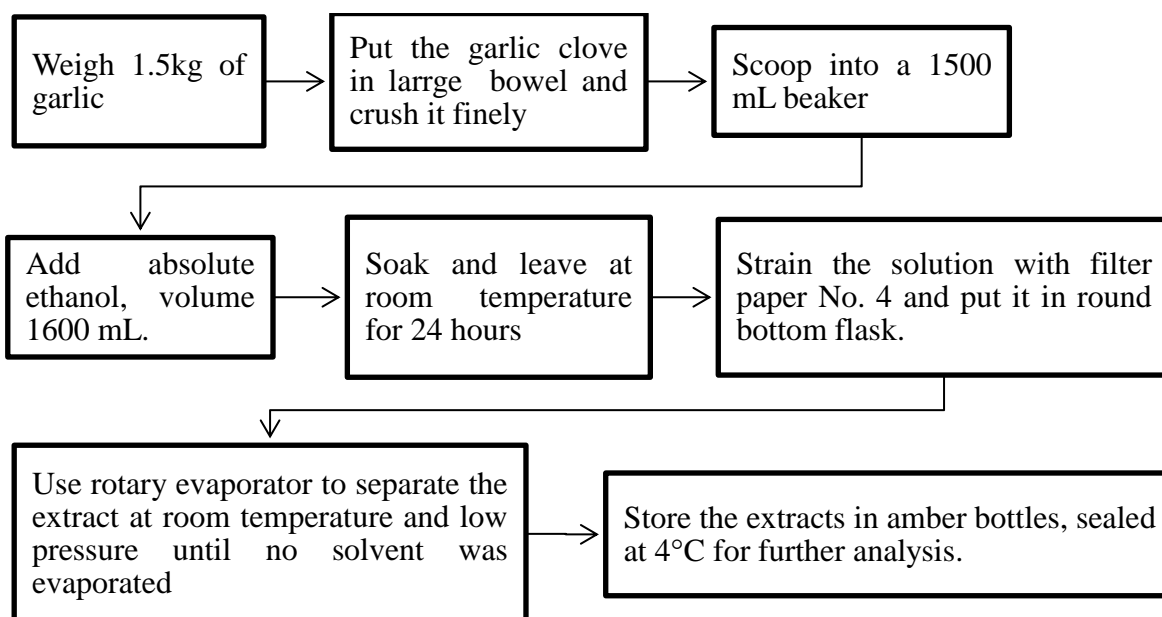


Figure 2: Flow chart of garlic extract preparation (Bar, Binduga, & Szychowski, 2022).

3.6. Packaging Materials

Based on earlier research demonstrating their positive effects on avocado quality, polyethylene bags and cartons were chosen as the packaging materials for this study (Kassim & Workneh, 2020).

3.7. Physicochemical Analysis of Avocado Fruits

3.7.1. Weight loss

At the beginning of the experiment and at the designated intervals, each green mature preserved avocado from each treatment was weighed separately using a sensitive balance (Hertog *et al.*, 2003). For each sample in every period, the differential weight loss was computed and expressed as a percentage. The sum of the individual physiological weight reductions was used to calculate the cumulative weight loss (%).

$$\text{Weight loss} = \frac{\text{initial weight} - \text{final weight}}{\text{initial weight}} \times 100 \quad (1)$$

3.7.2. Fruit firmness

The firmness of the fruits at different ripening stages was measured randomly. A penetrometer was positioned at the center of the fruit, allowing it to penetrate and the force required for penetration was recorded in Newton's (N). Fruit firmness was measured using a pressure meter or N, as described by Mazhar *et al.*, (2016).

3.7.3. Moisture content determination

To determine moisture content, 5 grams of grated avocado puree were placed in a petri dish. The samples were dried in an oven at 105°C for 48 hours, after which they were reweighed until constant weight recorded. The moisture content was then expressed as a percentage of the original weight of the pure (Chen *et al.*, 2009).

$$\text{Moisture \%} = \frac{\text{initial weight} - \text{final weight}}{\text{sample weight}} \times 100 \quad (3)$$

3.7.4. Marketability percentage

The percentage of marketable avocado fruits was determined following the method described by Ashenafi & Tura, (2018). Marketability was assessed based on subjective observations of decay, shriveling, smoothness, shininess, surface defects, and signs of decay. The number of marketable fruits was counted to calculate the percentage of marketable fruit at each observation day during storage. The percentage of marketability was computed using following formula.

$$\text{Marketability (\%)} = \frac{\text{Number of marketable fruit}}{\text{Initial number of fruit}} \times 100 \quad (4)$$

3.7.5. Total soluble solid (TSS)

To measure total soluble solids, the refractometer was calibrated using known °Brix values. During each storage period, 2 to 4 drops of clear avocado juice were placed on the prism of the Abe refractometer, and the TSS was measured at room temperature, expressed in °Brix (Widodo *et al.*, 2021).

3.7.6. Total titratable acidity (TTA)

For TTA determination, 5 grams of avocado puree were mixed with distilled water in a beaker. The mixture was homogenized and frozen at -4°C, then thawed. The homogenate was filtered through muslin to obtain the juice (Maftoonazad & Ramaswamy, 2008). An aliquot of 3 mL of juice was pipetted into a 50 mL beaker, and two drops of phenolphthalein indicator were added. The juice was titrated with 0.1 N Sodium Hydroxide (NaOH) until a stable pink color appeared for five seconds while stirring through a hand shaking. Titratable acidity was calculated as the number of milliliters of 0.1 N sodium hydroxide multiplied by an appropriate conversion factor (Equation 5). A conversion factor of 0.28 was selected, based on linoleic acid, a predominant acid

in avocado, as used by Maftoonazad & Ramaswamy, (2008). The titratable acidity was calculated as follows:

$$\text{TTA} = \frac{0.1 \text{ NaOH} \times 0.28}{S} \times 100 \quad (5)$$

Where:

TTA= Total titratable acidity,

0.1 moles of NaOH [N] = amount of NaOH added [mL],

0.28 = Conversion factor, and

S = Juice sample [mL]

3.7.7. pH

The pH was measured using a calibrated standard pH meter (ME 962P model; Max Electronics, India), utilizing pH 4 and pH 7 buffer solutions. The pH probe was immersed in the avocado juice until the reading stabilized (Hernandez-Brenes *et al.*, 2011).

3.7.8. Ascorbic acid (AA)

The method described by AOAC (2005) was employed to determine ascorbic acid content. A 3 mL sample was weighed, and 150 mL of distilled water was added. The mixture was filtered to yield a clear solution. Next, 10 mL of the transparent solution was placed in a small flask, and 2.5 mL of acetone was added. Titration was conducted by adding indophenol solution (2, 6-dichlorophenolindophenol) until a pink color was achieved, remaining for 15 seconds. The vitamin C content was calculated using the following formula:

$$\text{Vitamin C} \left(\frac{\text{mg}}{100} \right) = \frac{20 \times (V_1 - V_2) \times C}{\text{Weight of sample}} \quad (6)$$

Where: C = mg of vitamin C per milliliter of indophenols

V = indophenol solution in titration (mL)

3.8. Sensory Evaluation

Avocado fruits taken from storage were visually and physically examined for changes such as mold, skin color, flavor, texture, appearance, and overall acceptability during each data collection interval. After 12 days of storage, avocado juice produced from all packaging methods underwent sensory evaluation. To assess the sensory attributes of different avocado juices that pass through different mediums of treatment, 30 untrained panelists have been selected from staff and students

for evaluation by the Hedonic Rating Scale method (Meilgaard, 2006). Therefore, they were presented randomly with a sample of each avocado juice prepared with code from each storage medium after 12 days of storage. Then, they evaluate and rate the sample for each attribute and mark the number that best describes their choice on the accompanying line scale: like very much = 5, like moderately = 4, neither like nor dislike = 3, dislike moderately = 2, dislike very much = 1.

3.9. Ethical Considerations

This study was conducted in accordance with institutional research ethics standards. No endangered species was used, and the collection of sample and materials were followed an environmental guidelines and international standard.

3.10. Statistical Analysis

The experiment utilized a full-factorial design. Three fruit samples from each packaging material were used, with three replications for each data collection day. All variables were analyzed using analysis of variance (ANOVA) via the general linear model's procedure of the statistical analysis system (SAS software package, version 9.0 SAS Institute Inc., 2008). Multiple comparisons among treatment means were conducted using the least significant difference (LSD) at a 5% significance level, and results were presented as mean \pm standard deviation.

4. RESULTS AND DISCUSSION

The effects of postharvest treatments, packaging materials and storage period on the physicochemical and sensory characteristics of avocado fruits were investigated in this study.

4.1. The Effect of Postharvest Treatments, Packaging Materials and Storage Period on Physicochemical Quality of Avocado Fruits

4.1.1. Weight loss

The mean values of weight loss of avocados subjected to various postharvest treatments and packaging materials were presented in Table 6 below. The choice of packaging exhibited significant differences in weight loss at 95% confidence level ($P < 0.05$). Weight loss (WL) of avocado increased as storage time increased, influenced by the type of postharvest treatments and packaging applied (Liamngee *et al.*, 2019). Throughout storage days, avocados packed in low density polyethylene (LDPE) recorded the lowest weight loss of 6% and 18.7% on days 4 and 12, respectively, compared with 7.57% and 28.5% loss recorded for fruits packed in a carton box, while 9.12% and 47.97% weight loss were recorded for fruits stored at room temperature during respective storage periods. The result showed the fruits kept in LDPE and carton boxes had extended storage life till day 12, while avocados stored at room temperature were discarded after day 12, highlighting the effectiveness of packaging in moisture retention (Adjouman *et al.*, 2018).

Moreover, the postharvest treatments also significantly influenced weight loss ($P < 0.05$). The untreated avocados exhibited the highest weight loss of 6.12% and 48.3% on days 4 and 12, respectively. During storage days the lowest weight loss of 1.7% and 2.7% was recorded for avocado treated with wax on days 4 and 12, respectively, compared with garlic extract and hot water treated fruits which recorded WL of 2.4% and 3.2% and 4.1% and 16.4% on respective storage periods. Throughout storage time avocados treated with wax and garlic extract experienced significant lowest weight losses as presented in Table 6 below. This indicates that these treatments effectively minimize moisture loss, functioning as protective barriers (Sapper *et al.*, 2019). The significant differences between the treatments may be attributed to the superior barrier properties of the coatings, which likely enhance their bioactive compound activities (Liamngee *et al.*, 2019).

Table 6: Effect of postharvest treatments, packaging materials and storage period on weight loss of avocado fruits

Postharvest treatments	WL (%)		
	Day4	Days8	Day12
Control	6.12±0.14 ^a	24.13±0.20 ^a	48.30±0.70 ^a
Hot water	4.10±0.26 ^b	12.60±0.62 ^b	16.40±0.12 ^b
Wax	1.72±0.08 ^d	2.30±0.15 ^c	2.70±0.14 ^d
Garlic extract	2.40±0.20 ^c	2.60±0.10 ^c	3.20±0.70 ^c
CV (%)	5.13	3.30	2.13
LSD (0.05)	0.35	0.60	0.71
Packaging materials			
Room storage	9.12± 0.14 ^a	24.13±0.20 ^a	47.97±0.30 ^a
Low density polyethylene	6.00±0.20 ^c	11.60±0.40 ^c	18.70±0.40 ^c
Carton	7.57± 0.55 ^b	19.30±0.10 ^b	28.5±0.20 ^b
CV (%)	4.60	1.50	1.01
LSD (0.05)	0.70	0.50	0.64

Every value displayed is mean ± standard deviation. $P < 0.05$ indicates a substantial difference between the means in a column with a distinct superscript letter. Where: WL = weight loss, LSD = least significant difference, and CV = coefficient of variance.

4.1.2. Firmness

The effects of packaging materials on firmness showed significant differences ($P < 0.05$) on days 8 and 12 compared to day 4, as indicated in Tables 7 below. As storage time progresses the firmness of the avocado significantly ($P < 0.05$) decreases at different rates based on the packaging materials and treatments applied to it. The highest firmness values of 2.84 N and 1.8 N were recorded for avocados that were stored in LDPE on days 4 and 12, respectively, compared to firmness values of fruits that were kept in a carton box (2.53 N and 1.5 N) and at room storage (2.43 N and 0.3 N) during the respective storage periods. The effect of postharvest treatments on firmness showed more significant ($P < 0.05$) difference on days 8 and 12, while a less significant difference observed on day 4. On day 4 there was no significant ($P > 0.05$) difference observed between control and hot water. Throughout storage time the avocado fruits that were treated with wax recorded the highest

firmness values of 3.3 N and 2.5 N when compared to the other treatments. On the other hand, fruits that were treated with garlic extract exhibited better (3 N and 2.3 N) firmness than hot water (2.73N and 1.4N) and control (2.67 N and 0.3 N) fruits, as presented in Table 7 below. As observed from the results, the highest firmness was recorded for wax-treated avocado, while the lowest value was recorded for control fruits, attributed to the coating's ability to inhibit enzymatic activities that lead to tissue softening (Adjouman *et al.*, 2018).

Table 7: Effect of postharvest treatments, packaging materials and storage period on firmness of avocado fruits

Postharvest treatments	Firmness (N)		
	Day4	Days8	Day12
Control	2.67±0.07 ^c	1.80±0.10 ^d	0.30±0.10 ^d
Hot water	2.73±0.04 ^c	2.50±0.03 ^c	1.4.00±0.01 ^c
Wax	3.30±0.03 ^a	3.07±0.03 ^a	2.50±0.01 ^a
Garlic extract	3.00±0.03 ^b	2.71±0.02 ^b	2.30±0.01 ^b
CV (%)	1.54	2.20	3.20
LSD (0.05)	0.10	0.10	0.10
Packaging materials			
Room storage	2.43±0.12 ^b	1.80±0.10 ^b	1.30±0.10 ^c
Low density polyethylene	2.84±0.14 ^a	2.14±0.20 ^a	1.80±0.10 ^a
Carton	2.53± 0.07 ^b	2.10±0.06 ^{ab}	1.50±0.04 ^b
CV (%)	4.32	6.90	5.45
LSD (0.05)	0.20	0.30	0.20

Every value displayed is mean ± standard deviation. P<0.05 indicates a substantial difference between the means in a column with a distinct superscript letter. Where: LSD = least significant difference, and CV = coefficient of variance.

4.1.3. Percentage of marketability

Table 8 below present the influence of packaging materials and postharvest treatments on the percentage of marketability during 12 days of storage periods. As storage time progresses, the marketability percentage decreases depending on postharvest holding practice. The effect of

packaging materials and postharvest treatments on the percentage of marketability of avocado showed no significant ($P>0.05$) difference on day 4 (Table 8). However, the effect of packaging materials and postharvest treatments on the percentage of marketability of avocado exhibited significant ($P<0.05$) difference on days 8 and 12. As observed from Table 8 below, the impact of packaging materials on the percentage of marketability varied with values of 91.6% for non-packaged, 96.8% for LDPE and 95.4% for carton box packaged fruits on day 8. On day 12 the percentage of marketability were decreased to 85.4%, 87%, and 84.3% for carton, LDPE, and room storage-kept avocado fruits, respectively. Notably, the lowest marketability was associated with fruits stored at room temperature, while those packaged in low density polyethylene achieved the highest marketability. This difference can be attributed to the coatings' ability to minimize weight loss, shrinkage, spoilage, and metabolic stress after harvest, all of which enhance avocado marketability (Mutari & Debbie, 2011).

As presented in Table 8 below, the effect of postharvest treatment on percentage of marketability showed a significant ($P<0.05$) difference within all treatments on day 12. The fruits that were treated with garlic extract were 100% marketable up to day 8, while wax-treated samples extended their marketability (100%) till day 12. As showed in Table 8 below, after 12-days of storage periods, the control and hot water-treated fruits showed less marketability compared to wax- and garlic-extract-treated samples (Ahmad & Siddiqui, 2015).

Table 8: Effect of postharvest treatments, packaging materials and storage period on percentage of marketability of avocado fruits

Postharvest treatments	Percentage of marketability (%)		
	Day4	Days	Day12
Control	100.00±0.00 ^a	92.60±1.76 ^c	84.30±1.00 ^d
Hot water	100.00±0.00 ^a	96.30±0.01 ^b	87.30±0.96 ^c
Wax	100.00±0.00 ^a	100.00±0.00 ^a	100.00±0.00 ^a
Garlic extract	100.00±0.00 ^a	100.00±0.00 ^a	94.30±0.99 ^b
CV (%)	-	0.90	7.90
LSD (0.05)	0.00	1.70	1.60
Packaging materials			
Room storage	100.00± 0.00 ^a	91.60±1.04 ^c	84.30±1.01 ^b
Low density polyethylene	100.00± 0.00 ^a	96.98±0.60 ^a	87.00±0.80 ^a
Carton	100.00± 0.00 ^a	95.40±0.60 ^b	85.40±0.60 ^{ab}
CV (%)	-	0.80	0.97
LSD (0.05)	0.00	1.50	1.63

Every value displayed is mean ± standard deviation. P<0.05 indicates a substantial difference between the means in a column with a distinct superscript letter. Where: LSD = least significant difference, and CV = coefficient of variance.

4.1.4. Moisture content

As demonstrated in Table 9 below, the effect of postharvest treatment and packaging materials on the moisture content MC (%) of avocado fruits exhibited significant (P<0.05) difference at varied rates across storage days. As storage time increases the moisture content of avocado showed significant (P<0.05) decreases. On day 4 the effect of both postharvest treatments and packaging materials on MC recorded statistically consistent results apart from control fruits that were kept at room temperature, suggesting that there is no significant difference (P<0.05) between postharvest treatments and packaging materials. The impact of postharvest treatments on MC showed significance (P<0.05) difference on days 8 and 12, as observed from the Table 9 below. Throughout storage periods the untreated fruits were recorded lowest moisture values of 50.5% and 38.97% on days 4 and 12, respectively, compared to the treated fruits. The highest moisture

content of 54.4% and 44.9% was recorded with fruits that were treated with wax on days 4 and 12, respectively, while garlic-extract treated samples also recorded moisture content of 53.5% and 43.42% on the same storage periods. The hot-water treated samples retained more moisture content (53.1% and 41.5%) on days 4 and 12, respectively, compared to control fruits. This suggests that these treatments effectively minimize moisture loss, thereby enhancing fruit quality (Edmarcos, 2020).

The effect of packaging materials on MC (%) also exhibited a significant ($P<0.05$) difference on days 8 and 12. As summarized in Table 9 below the low density polyethylene material demonstrated slightly better (44.9% and 41.9%) moisture retention compared to the carton box (44.4% and 39.8%) and control sample (43.14% and 38.97%) during days 8 and 12, respectively. This indicates the effectiveness of packaging materials and postharvest treatments in maintaining the quality and shelf life of avocado fruits across storage periods (Tyl & Sadler, 2017)

Table 9: Effect of postharvest treatments, packaging materials and storage period on MC (%) of avocado fruits.

Postharvest treatments	Moisture content (%)		
	Day4	Days	Day12
Control	50.50±0.60 ^b	43.14± 0.23 ^c	38.97± 0.20 ^d
Hot water	53.10±0.80 ^a	46.10±0.20 ^b	41.47±1.30 ^c
Wax	54.40±0.97 ^a	47.43±0.50 ^a	44.90±0.30 ^a
Garlic extract	53.50±0.54 ^a	47.41±0.40 ^a	43.42± 0.40 ^b
CV (%)	1.42	0.76	1.60
LSD (0.05)	1.42	0.70	1.30
Packaging materials			
Room storage	50.53±0.6 ^b	43.14±0.23 ^b	38.97±0.2 ^c
Low density polyethylene	52.1±0.3 ^a	44.9±0.76 ^a	41.9±0.4 ^a
Carton	51.93±0.1 ^a	44.4±0.5 ^a	39.8±0.5 ^b
CV (%)	0.80	1.21	0.88
LSD (0.05)	0.80	1.06	0.71

Every value displayed is mean \pm standard deviation. $P < 0.05$ indicates a substantial difference between the means in a column with a distinct superscript letter. Where: LSD = least significant difference, and CV = coefficient of variance.

4.1.5. pH

Table 10 below presented the effect of postharvest treatments and packaging materials on the pH of avocado fruits during 12 days of storage periods. Both postharvest treatments and packaging materials showed the least significant ($P < 0.05$) difference on day 4, while more significant differences ($P < 0.05$) were observed on days 8 and 12. As expressed in Table 10 below, the effect of postharvest treatments on pH showed a significant ($P < 0.05$) difference throughout storage periods. As storage periods increase, the pH value of fruits significantly ($P < 0.05$) decreases at a varied rate based on the treatments applied to them. The highest pH levels of 6.64, 6.54 and 5.67 were recorded for fruits that were treated with wax during days 4, 8 and 12, respectively, while the control group recorded the lowest pH values of 5.8, 5.34 and 4.82 during the same storage periods.

Table 10: The main effects of postharvest treatments, packaging materials and storage period on pH of avocado fruits.

Postharvest treatments	pH		
	Day4	Days	Day12
Control	5.80 \pm 0.10 ^d	5.34 \pm 0.01 ^d	4.82 \pm 0.01 ^c
Hot water	6.30 \pm 0.01 ^c	5.45 \pm 0.01 ^c	5.34 \pm 0.10 ^b
Wax	6.64 \pm 0.01 ^a	6.54 \pm 0.01 ^a	5.67 \pm 0.01 ^a
Garlic extract	6.49 \pm 0.01 ^b	6.32 \pm 0.01 ^b	5.4 \pm 0.10 ^b
CV (%)	0.80	0.20	0.96
LSD (0.05)	0.10	0.02	0.10
Packaging materials			
Room storage	5.80 \pm 0.10 ^b	5.34 \pm 0.01 ^b	4.82 \pm 0.01 ^c
Low density polyethylene	6.32 \pm 0.01 ^a	5.41 \pm 0.01 ^a	5.22 \pm 0.01 ^a
Carton	6.24 \pm 0.01 ^a	5.34 \pm 0.01 ^b	4.91 \pm 0.01 ^b
CV (%)	0.96	0.20	0.20
LSD (0.05)	0.12	0.02	0.02

Every value displayed is mean \pm standard deviation. $P < 0.05$ indicates a substantial difference between the means in a column with a distinct superscript letter. Where: LSD = least significant difference, and CV = coefficient of variance.

This trend indicates that postharvest treatments, particularly the application of wax, can effectively preserve the acidity of fruits over storage time. Consequently, these findings suggest that choosing appropriate treatments can enhance the quality and shelf life of stored avocado fruits. The garlic extract (6.49 and 5.4) and hot water (6.3 and 5.34) also maintained pH at a higher level than the control groups during days 4 and 12, respectively. The control sample had the lowest pH, indicating higher acidity, which is associated with a shorter shelf life (García *et al.*, 2014). Conversely, the higher pH values in the wax and garlic extract treatments suggest that these treatments effectively retard acid reduction, thereby prolonging shelf life by modifying the internal atmosphere of the fruit (García *et al.*, 2014). The effects of packaging materials on pH were less pronounced, with no significant ($P > 0.05$) differences observed between polyethylene (6.32) and cardboard (6.24) samples on day 4, while fruits that were stored at room temperature recorded the lowest (5.8) pH value during the same storage time. This indicates that the choice of packaging has a significant impact on the pH levels of avocados (Tyl & Sadler, 2017).

4.1.6. Total soluble solid

Total soluble solid (TSS) is the amount of sugar and soluble minerals present in fruits and vegetables. Table 11 below demonstrated the effect of postharvest treatments and packaging materials on the TSS values of avocado fruits during the 12-day storage period. The TSS values of avocado were significantly ($P < 0.05$) increased as storage time increased. The influence of postharvest treatments on TSS showed the least significant difference on day 4, while more significant differences were observed on days 8 and 12. Throughout storage periods the wax-treated avocado recorded the lowest TSS values of 32.1°Brix and 37.1°Brix on days 4 and 12, respectively, compared to the control, hot water and garlic extract-treated samples on the same storage periods. The garlic extract and hot water retard the increase in TSS values, while the highest (37.1°Brix and 41°Brix) TSS values during the corresponding storage time was recorded by untreated avocado sample. The control samples had a significantly ($P < 0.05$) higher TSS value compared to treated samples, indicating that the treatments could reduce loss of moisture and sugar content through metabolic changes (Ashenafi & Tura, 2018). On the other hand, in terms of

packaging, TSS values were shown to be significantly consistent on days 4 and 8. There were no significant differences among these groups ($P>0.05$), suggesting that packaging materials do not significantly affect TSS value compared to postharvest treatments (Table 11) (Hellen,2020).

Table 11: Effect of postharvest treatments, packaging materials and storage period on TSS of avocado fruits.

Postharvest treatments	TSS (°Brix)		
	Day4	Days	Day12
Control	34.20±0.50 ^a	37.00± 1.0 ^a	41.00± 1.00 ^a
Hot water	33.60±0.10 ^a	35.60±0.36 ^b	40.60±0.50 ^a
Wax	32.10±0.32 ^b	33.10±0.32 ^c	37.10±0.50 ^b
Garlic extract	32.50±0.50 ^b	33.60±0.50 ^c	38.30± 0.30 ^c
CV (%)	1.21	1.75	1.60
LSD (0.05)	0.75	1.20	1.20
Packaging materials			
Room storage	34.50±0.50 ^a	36.70±0.60 ^a	41.12±0.50 ^a
Low density polyethylene	33.30±0.30 ^a	36.40± 0.40 ^a	38.6±0.65 ^c
Carton	34.30±1.30 ^a	36.90±0.45 ^a	39.70±0.40 ^b
CV (%)	2.40	1.32	0.93
LSD (0.05)	1.60	0.96	0.70

Every value displayed is mean ± standard deviation. $P<0.05$ indicates a substantial difference between the means in a column with a distinct superscript letter. Where: TSS = total soluble solid, LSD = least significant difference, and CV = coefficient of variance.

However, after day 8 of storage periods, all packaging materials showed a significant ($P<0.050$) difference. After 12 days of storage, the highest TSS value of 41.12°brix was recorded for fruits that were stored at ambient temperature, while LDPE maintained a TSS value at a lower (38.6°brix) level than carton-packed fruits, which recorded a TSS value of 39.7°brix in the same storage period (Table 11). In this study, the increase in the TSS value of avocado fruits could be due to the slowing down of respiration and metabolic activities due to packaging materials, hence retarding the ripening process. The results of this study were aligned with the statement of García

et al. (2014), who reported that the packaged fruits during storage time lead to a change in polysaccharides, consequently changing the TSS value of fruits.

4.1.7. Titratable acidity

Titrateable acidity (TA) is a measure of total acidity in the fruits (Tyl & Sadler, 2017). The influence of postharvest treatment and packaging materials on TA was demonstrated in Table 12 below during 12 of days of storage period. Analysis results of titrateable acidity revealed the presence of high significance ($P < 0.05$) differences within postharvest treatments on days 8 and 12. Data presented on the Table 12 below showed that as storage days continue the TA of avocado fruits were also significantly increased. However, the postharvest treatments retard the increasing rate of TA throughout storage time. The wax-treated avocados recorded the lowest TA value of 24.9% and 32.7% on days 4 and 12, respectively, while the control group had recorded the highest TA value of 36.4% and 60.67% on the same storage periods.

The hot water and garlic extract also slow down the increasing rate of TA value across storage periods compared to control samples. This retardation of acidity in treated samples is beneficial for extending shelf life (Getaneh, 2019). The effect of packaging materials on TA exhibited a significant ($P < 0.05$) difference with all packaging mediums on days 8 and 12, while only fruits kept in low density polyethylene (LDPE) bags showed a significant difference from other storage mediums on day 4. Across storage periods, avocado fruits that were packaged in LDPE bags showed the lowest TA value of 32.4% and 49.5% on days 4 and 12, respectively, compared to cartons and room storage medium (Table 12).

Table 12: Effect of postharvest treatments, packaging materials and storage period on TA of avocado fruits.

Postharvest treatments	TA (%)		
	Day ₄	Day ₈	Day ₁₂
Control	36.40±0.10 ^a	43.80±1.06 ^a	60.67±0.01 ^a
Hot water	30.80±0.10 ^b	39.20±0.10 ^b	46.70±0.10 ^b
Wax	24.90±0.60 ^c	29.40±0.10 ^d	32.70±0.10 ^d
Garlic extract	25.20±0.10 ^c	32.20±0.10 ^c	35.00±0.20 ^c
CV (%)	0.98	1.50	0.30
LSD (0.05)	0.54	1.02	0.23
Packaging materials			
Room storage	36.70±0.70 ^a	43.80±1.06 ^a	60.70±0.01 ^a
Low density polyethylene	32.40±1.30 ^b	39.10±0.40 ^c	49.50±0.10 ^c
Carton	35.80±1.04 ^a	42.00±0.10 ^b	50.30±0.10 ^b
CV (%)	2.90	1.60	0.15
LSD (0.05)	2.04	1.30	0.20

Every value displayed is mean \pm standard deviation. $P < 0.05$ indicates a substantial difference between the means in a column with a distinct superscript letter. Where: TA = titratable acidity, LSD = least significant difference, and CV = coefficient of variance.

4.1.8. Ascorbic acid

As demonstrated in Table 13 below, the effect of postharvest treatments and packaging materials on ascorbic acid (AA) showed a significant ($P < 0.05$) difference throughout storage periods. As storage time increased, the AA value of avocado were significantly decreased. However, the decreasing rate might vary depending on postharvest treatments and packaging materials applied to fruits. The avocado fruits that were treated with wax and garlic extract retarded the AA decreasing rate at a higher level than the hot water and control samples across storage time. The wax-treated avocado fruits were recorded with the highest AA value, which decreased from 14.1 mg/100g to 13 mg/100g from day 4 to 12, respectively, while the lowest AA value was recorded with untreated avocado, which decreased from 12.8 mg/100g to 5.10 mg/100g on the same storage days. The other treatments, hot water and garlic extract, showed better AA value which decreased

from 13.2 mg/100g to 10.75 mg/100g and 13.5 mg/100g to 12.25 mg/100g from day 4 to 12, respectively. The higher AA content in treated fruits suggests that the coatings may inhibit respiration and oxidation processes (Ashenafi & Tura, 2018).

The influence of packaging materials on AA content showed significance differences ($P < 0.05$) across storage time as presented in Table 13 below. The AA content of avocado fruits that were stored in LDPE bags decreased from 12.9 mg/100g to 10 mg/100g at a slower rate than fruits that were kept in cartons and at room temperature during the day 4 to 12 storage periods. The AA content of samples that were packaged in cartons decreased from 12.81 mg/100g to 8.01 mg/100g, while that of non-packaged samples also dropped from 12.8 mg/100g to 5.10 mg/100g during storage time, which range from day 4 to 12, respectively. All the statistical results observed from.

Table 13: Effects of postharvest treatments, packaging materials and storage period on AA of avocado fruits.

Postharvest treatments	AA (mg100g ⁻¹)		
	Day4	Days	Day12
Control	12.80±0.01 ^d	9.50±0.01 ^c	5.10±0.01 ^d
Hot water	13.20±0.30 ^c	12.50±0.02 ^b	10.76±0.60 ^c
Wax	14.10±0.10 ^a	13.50±0.01 ^a	13.00±0.01 ^a
Garlic extract	13.50±0.02 ^b	12.70±0.02 ^b	12.20±0.02 ^b
CV (%)	1.20	0.13	2.90
LSD (0.05)	0.30	0.03	0.60
Packaging materials			
Room storage	12.80±0.01 ^b	9.51±0.01 ^c	5.1±0.01 ^c
Low density polyethylene	12.90±0.01 ^a	12.60±0.99 ^a	10.01±0.01 ^a
Carton	12.81±0.02 ^b	10.97± 0.60 ^b	8.01±0.02 ^b
CV (%)	0.11	6.01	0.20
LSD (0.05)	0.03	1.30	0.03

Every value displayed is mean ± standard deviation $P < 0.05$ indicates a substantial difference between the means in a column with a distinct superscript letter. Where: AA = ascorbic acid, LSD = least significant difference, and CV = coefficient of variance.

Table 13 above highlight that packaged fruits retained more AA content than the non-packaged samples, promoting the effectiveness of packaging materials in maintaining the nutritional content of fruit across storage time (Hellen, 2020).

Generally, the fruit samples that were treated with postharvest treatments maintained higher AA content than control fruits. Similarly, fruit kept in LDPE packaging material had higher AA content than those stored in the open environment. This result agrees with the similar results that were reported with the nectarine, avocado, and Graviolas fruits by Getaneh (2019), Hellen (2020), and Edmarcos (2020), respectively. The result of the higher vitamin C content in the treated avocado fruit compared to untreated fruit could be due to an oxidative breakdown of organic acids like ascorbic acid (Hellen, 2020).

4.2. Effect of Storage Period on the Weight Loss, Firmness and Percentage of Marketability of Avocado Fruits

Data in Table 14 below showed the effect of storage periods on the physical quality of avocado fruits. As observed from the results, the effect of storage periods on weight loss (WL) of stored avocado fruits showed a significant ($P < 0.05$) difference. As the storage period increased, the WL (%) of avocados also increased significantly ($P < 0.05$), with variations attributed to different storage durations. Notably, the minimum WL of 9.12% was recorded on day 4, while the maximum value of 48.6% was recorded on day 12. This weight loss is primarily caused by moisture loss during metabolic processes, including respiration and transpiration (Kabir *et al.*, 2020). Consistent with these findings, the highest weight loss percentage was observed at the end of the storage period, corroborating previous research (Ghoshal & Chopra, 2022). The ability to reduce weight loss can be linked to effective coatings and packaging that provide semi-barrier properties against moisture loss and gaseous exchanges as discussed in section 4.5.

The firmness data of stored avocado fruits were also shown in Table 14 below, indicating a decline in firmness as the storage period continued. Significant differences ($P < 0.05$) were found between samples stored for varied storage durations. The firmness recorded on the initial day was highest (4.23 N), while the lowest value of 0.3 N was noted on day 12. This loss in firmness is attributed to the activity of cell wall-degrading enzymes that compromise the fruit's skin integrity, leading to increased cell permeability and accelerated moisture loss (Tigist & Workneh, 2013).

Data presented in Table 14 below showed the effect of storage periods on the percentage of marketability of stored avocado fruits. As presented in Table 14 below, there is no observed significant ($P>0.05$) difference between percentage of marketability due to storage duration on days 0 and 4, revealing that all fruits were marketable until day 4. Significant differences ($P<0.05$) were noted on days 8 and 12, attributed to the effects of various storage durations on percentage of marketability. As storage periods of avocado fruits increased, the percentage of marketability was significantly decreased. The minimum marketability percentage value of 83.9% was recorded on day 12, while the maximum value of 100% marketability was maintained until day 4. The primary factors contributing to marketability loss include weight loss, decay loss, and firmness reduction, as these directly impact the marketable volume of the fruits (Mutari & Debbie, 2011). The most substantial marketability loss was observed at the end of the storage period (day 12), highlighting the importance of treatments and packaging materials that minimize weight loss and spoilage, which ultimately enhance fruit marketability (Mutari & Debbie, 2011).

Table 14: Effect of storage period on the weight loss, firmness and percentage of marketability of avocado fruits

Factors	Quality parameters		
	Storage period (days)	Weight loss (%)	Firmness (N)
0	0.00± 0.00 ^d	4.23±0.10 ^a	100±0.00 ^a
4	9.12±0.14 ^c	2.74±0.05 ^b	100±0.00 ^a
8	24.13±0.20 ^b	1.80±0.10 ^c	90.8±0.76 ^b
12	48.60±0.40 ^a	0.30±0.10 ^d	83.95±0.56 ^c
CV (%)	1.20	3.70	0.50
LSD (0.05)	0.45	0.16	0.90

Every value displayed is mean ± standard deviation. $P<0.05$ indicates a substantial difference between the means in a column with a distinct superscript letter. Where: N = Newton, LSD = least significant difference, and CV= coefficient of variance.

4.3. Effect of Storage Period on moisture content, Total Soluble Solid, Titratable Acidity, pH, and Ascorbic Acid of Avocado Fruits

Data in Table 15 below showed the effects of storage periods on the moisture content (MC), total soluble solids (TSS), pH, titratable acidity (TA), and ascorbic acid (AA) of avocado fruits. Significant differences ($P < 0.05$) in moisture content were observed due to varying storage periods. As the storage period progressed, moisture content gradually decreased. The highest moisture content of avocados subjected to the storage period was recorded 56% on the initial day of storage, while the lowest recorded value was 38.97% on day 12. This decrease in MC was closely associated with increased weight loss and decay percentages observed in the avocados as storage time progressed.

Significant differences ($P < 0.05$) in pH and TSS were also noted due to the storage duration. Data indicated in Table 13 presented that an increase in storage period led to a decrease in pH and an increase in TSS. Specifically, TSS values increased from 34.7°Brix to 41.1°Brix from day 4 to 12, respectively, while pH values decreased from 5.8 to 4.82 in the same storage periods. The maximum TSS value of 41.1°Brix and the lowest pH value of 4.82 were noted on day 12, suggesting that storage periods significantly affect both TSS and pH value. These changes can be reduced with application of packaging materials and postharvest treatments on avocado fruits during storage time, which act as barriers to transpiration losses while creating a modified atmosphere conducive to maintaining fruit quality (Tsague Donjio *et al.*, 2023); (Miah, 2021).

Table 15: Effects of storage period on moisture content, total soluble solid, titratable acidity, pH, and ascorbic acid of avocado fruits

Factors	Parameters				
	Storage period (days)	pH	TSS (°brix)	TA (%)	AA (mg100g ⁻¹)
0	6.67±0.00 ^a	31.00±0.00 ^d	15.87±0.00 ^d	15.20±0.00 ^a	56.00±0.20 ^a
4	5.80±0.10 ^b	34.70±0.30 ^c	36.40±0.10 ^c	12.80±0.01 ^b	50.50±0.63 ^b
8	5.34±0.01 ^c	37.10±0.40 ^b	51.80±0.10 ^b	9.51±0.01 ^c	43.14±0.23 ^c
12	4.82±0.01 ^d	41.10±0.40 ^a	60.67±0.01 ^a	5.10±0.01 ^d	38.97±0.20 ^d
CV (%)	0.89	0.85	0.17	0.08	0.77
LSD (0.05)	0.10	0.60	0.13	0.02	0.70

Every value displayed is mean ± standard deviation. $P < 0.05$ indicates a substantial difference between the means in a column with a distinct superscript letter. Where: TSS = total soluble solid,

TA = titratable acidity, AA = ascorbic acid, MC = moisture content, N = Newton, LSD = least significant difference, and CV= coefficient of variance.

Changes in TA and AA also reflect the main effects of storage periods on the quality of avocado fruits, as shown in Table 15 above. Significant differences ($P < 0.05$) were observed in TA and AA as the storage period increased. The TA values significantly increased, while AA values also decreased significantly due to internal physiological changes that convert organic acids into other compounds, including sugars. The increase in acidity may be attributed to the use of acids as an energy source during ripening (Hosea *et al.*, 2018). The lowest TA (36.4%) of avocado fruits was recorded on day 4, while the highest TA (60.67%) was noted on day 12, revealing an increase in TA as storage time extended to day 12. However, the AA ($\text{mg}100\text{g}^{-1}$) value of avocado decreased from 12.5 mg/100 g on day 4 to 5.1 mg/100 g on day 12 (Table 15). These differences and higher decreasing rate of AA ($\text{mg}100\text{g}^{-1}$) value across storage periods can be tackled with the application of packaging and treatments on the fruits, which slow down respiration and reduce metabolic activities, thereby delaying changes in organic acids (Vishwasrao & Ananthanarayan, 2017)

4.4. Interaction Effects of Postharvest Treatments, Packaging Materials and Storage Period on Physicochemical Quality of Avocado Fruits

4.4.1. Weight loss

The data presented in Table 16 below elucidates the interaction effect of postharvest treatments, packaging materials, and storage periods on the weight loss (%) of stored avocado fruits. The analysis reveals presence significance differences ($P < 0.05$) among the treatment's combination. After day 4 all avocado samples subjected to treatments combination exhibited lower weight loss compared to control samples, indicating the efficacy of the treatments in maintaining fruit quality. Notably, the weight loss of avocado samples was negligible on the first day of storage, with no significant differences ($P > 0.05$) observed among the treatments.

As the storage period progressed, the highest rates of weight loss (%), ranging from 9.12% to 48.3%, were recorded in control fruit samples, while the lowest values, between 0.6% and 1.8%, were observed in samples treated with wax and stored in low-density polyethylene (LDPE) bags as the storage duration extended from day 4 to 12, respectively. Untreated fruits stored at room temperature exhibited the highest weight loss compared to treated avocado kept at the same storage medium. The combination of postharvest treatments with LDPE bags consistently resulted in the

lowest weight loss, while treatments with carton boxes also showed reduced weight loss compared to room temperature storage. This finding aligns with research indicating that optimal storage conditions significantly influence the physiological processes of fruits (ktenioudaki *et al.*, 2019). The primary driver of weight loss in avocados is moisture evaporation during metabolic processes such as transpiration and respiration (Mohammed & Afework, 2018). The application of edible coatings, such as wax and garlic extract, effectively retards physiological weight loss by slowing down the process of respiration and reducing loss of water. The difference in weight loss responses of treated versus untreated fruits can be attributed to varying atmospheric conditions and the inherent characteristics of the treatments employed (Kabir *et al.*, 2020).

Table 16: Interaction effect of postharvest treatments, packaging materials, and storage period on weight loss (%) of avocado fruits stored under ambient conditions.

Factors		Storage period (days)			
		0	4	8	12
C	B	0.00±0.00 ^a	9.12±0.14 ^a	24.10±0.20 ^a	48.30±0.70 ^a
	B ₁	0.00±0.00 ^a	6.00±0.20 ^c	11.56±0.40 ^d	18.70±0.42 ^c
	B ₂	0.00±0.00 ^a	7.60±0.55 ^a	19.30±0.10 ^b	28.50±0.24 ^b
H_w	B	0.00±0.00 ^a	6.10±0.30 ^c	12.60±0.60 ^c	16.40±0.12 ^d
	B ₁	0.00±0.00 ^a	5.80±0.20 ^c	6.90±0.15 ^e	9.80±0.15 ^f
	B ₂	0.00±0.00 ^a	6.03±0.25 ^c	7.20±0.20 ^e	12.40±0.14 ^e
W_x	B	0.00±0.00 ^a	1.72±0.086 ^e	1.74±0.09 ^g	2.75±0.14 ^{gh}
	B ₁	0.00±0.00 ^a	0.60±0.02 ^g	1.30±0.20 ^h	1.80±1.65 ^h
	B ₂	0.00±0.00 ^a	1.10±0.30 ^f	1.63±0.24 ^g	2.60±0.25 ^{gh}
G_e	B	0.00±0.00 ^a	2.40±0.20 ^d	2.71±0.20 ^f	3.10±0.25 ^g
	B ₁	0.00±0.00 ^a	0.80±0.20 ^{fg}	1.4±0.40 ^g	1.90±0.25 ^h
	B ₂	0.00±0.00 ^a	1.70±0.50 ^e	2.3±0.30 ^f	2.53±0.15 ^{gh}
CV (%)		-	6.95	3.87	4.40
LSD (0.05)		0.00	0.48	0.50	0.94

Every value displayed is mean ± standard deviation. P<0.05 indicates a substantial difference between the means in a column with a distinct superscript letter. Where: PHT = postharvest treatments, PM = packaging materials, C = untreated avocado, H_w= hot water, W_x= wax, Ge =

garlic extract, B = unpacked avocado, B₁ = polyethylene, and B₂ = carton, LSD = least significant difference, and CV = coefficient of variance.

4.3.2. Percentage of marketability

The percentage of marketable fruits showed no significant differences ($P>0.05$) on days 0 and 4 due to the interaction effects of postharvest treatments and packaging materials. However, by day 8, marketability declined at varying rates, significantly differing among samples. For control samples stored at ambient temperature, marketability decreased from 90.8% on day 8 to 83.3% on day 12. In contrast, the same samples packaged in polyethylene and carton boxes showed a decrease from 97.3% to 87% and from 95.4% to 85% on the same days, respectively. Samples treated with hot water, wax, and garlic extract-maintained marketability until day 8 (Table 17). However, the marketability of hot water-treated samples stored at ambient temperature decreased to 96.3% on day 8 and further to 87.3% on day 12, while fruits treated with hot water and packaged in LDPE or carton boxes retained their marketability until day 8, showing decreases to 90.4% with LDPE and 90.41% with cartons on day 12, respectively.

The combination of wax and garlic extract packaged in LDPE showed 100% marketability until day 12 (Table 17). However, as demonstrated in Table 17 below, fruits that treated with wax and garlic extract and then kept at room storage showed significantly decreased marketability to 97.2% and 94.3% on day 12, respectively. On the other hand, fruits treated with garlic extract and stored in cartons exhibited marketability losses of 96.9% on day 12, while those treated with wax-maintained marketability throughout storage periods. These results highlight the importance of postharvest treatments and packaging in preserving fruit quality, as reported by Mutari & Debbie, (2011).

Table 17: Interaction effect of postharvest treatments, packaging materials and storage period on percentage of marketability (%) of avocado fruits stored under ambient condition.

Factors		Storage period (days)			
PHT+PM		0	4	8	12
C	B	100.00±0.00 ^a	100.00±0.00 ^a	90.80±0.76 ^c	83.90± 0.56 ^g
	B ₁	100.00±0.00 ^a	100.00±0.00 ^a	97.30±1.01 ^b	87.00±0.80 ^e
	B ₂	100.00±0.00 ^a	100.00±0.00 ^a	95.40±0.56 ^d	85.00±0.60 ^f
H_w	B	100.00±0.00 ^a	100.00±0.00 ^a	96.30±0.01 ^c	87.30±0.97 ^e
	B ₁	100.00±0.00 ^a	100.00±0.00 ^a	100.00±0.00 ^a	90.40±0.01 ^d
	B ₂	100.00±0.00 ^a	100.00±0.00 ^a	100.00±0.00 ^a	90.41± 0.85 ^d
W_x	B	100.00±0.00 ^a	100.00±0.00 ^a	100.00±0.00 ^a	97.20±0.30 ^b
	B ₁	100.00±0.00 ^a	100.00±0.00 ^a	100.00±0.00 ^a	100.00±0.00 ^a
	B ₂	100.00±0.00 ^a	100.00±0.00 ^a	100.00±0.00 ^a	100.00±0.00 ^a
Ge	B	100.00±0.00 ^a	100.00±0.00 ^a	100.00±0.00 ^a	94.30±0.99 ^c
	B ₁	100.00±0.00 ^a	100.00±0.00 ^a	100.00±0.00 ^a	100.00±0.00 ^a
	B ₂	100.00±0.00 ^a	100.00±0.00 ^a	100.00±0.00 ^a	96.98±0.57 ^b
CV (%)		–	–	0.40	0.60
LSD (0.05)		0.00	0.00	0.70	1.01

Every value displayed is mean ± standard deviation. P<0.05 indicates a substantial difference between the means in a column with a distinct superscript letter. Where: PHT = postharvest treatments, PM = packaging materials, C = untreated avocado, H_w= hot water, W_x= wax, Ge = garlic extract, B = unpacked avocado, B₁ = polyethylene, and B₂ = carton, LSD = least significant difference, and CV = coefficient of variance.

4.3.3. Firmness

Table 18 below presented the interaction effect of postharvest treatments, packaging materials, and storage periods on the firmness of avocado fruits. During 12-day storage periods, the firmness of fruit showed a highly significance (P<0.05) difference due to postharvest treatments, packaging materials, and storage period. As the storage period increased, the firmness showed a significant decreasing pattern. The decreasing rate is faster and earlier for untreated fruit than any other

treatment due to enhanced ripening that led to softening. Softening of fruit is related to solubilization of pectic substances, which accelerates breakdown of starch to soluble sugars and loss of water from the peel (Mebratie *et al.*, 2015).

At the beginning of the experiment (day 0), almost all fruit have the same firmness. Starting from day 4 to 12, the fruit sample treated with a combination of wax and polyethylene showed the highest firmness values of 4.04, 3.50, and 2.9 N on days 4, 8, and 12, respectively, followed by the fruit sample treated with a combination of garlic extract and LDPE that retained firmness of 3.45, 2.9, and 2.7 N on the same storage days. Fruit samples that received a combination of wax and a carton box also revealed better firmness of 3.5, 3.1, and 2.8 N, on days 4 to 12, respectively. Compared to control fruits, the hot-water-treated fruit with a carton box and LDPE maintained good firmness. The hot water treated sample with a combination of LDPE showed more preferable firmness quality of 3.1, 2.5, and 2.1 N on days 4, 8, and 12, respectively, than control samples, which recorded 2.9, 2.2, and 1.53 N firmness with the same storage medium and period.

Moreover, after 12 days of storage time, the lowest firmness of 1.3 N was recorded for control samples at ambient temperature, while the highest firmness of 2.9 N was recorded for fruits treated with wax and packaged in LDPE bags. The deterioration rate of the control sample is faster than the remaining samples. Generally, the findings suggest that applying edible coatings, particularly combining wax with LDPE, significantly maintains the firmness of avocado fruits compared to other treatments. The gradual decrease in firmness aligns with the natural ripening process of avocados, which is influenced by increased ethylene concentrations that stimulate the production of polygalacturonase, an enzyme responsible for softening (Sucharitha *et al.*, 2018).

Table 18: Interaction effect of postharvest treatments, packaging materials, and storage period on firmness of avocado fruits stored under ambient conditions.

Factors		Storage period (days)			
PHT+PM		0	4	8	12
C	B	4.23±0.07 ^a	2.47±0.06 ^k	1.84±0.05 ⁱ	1.30±0.10 ^j
	B ₁	4.23±0.07 ^a	2.90±0.05 ^g	2.20±0.10 ^g	1.53±0.04 ^h
	B ₂	4.23±0.07 ^a	2.58±0.04 ^j	2.10±0.06 ^h	1.50±0.01 ^h
H_w	B	4.23±0.07 ^a	2.70±0.02 ⁱ	2.20±0.01 ^g	1.40±0.02 ⁱ
	B ₁	4.23±0.07 ^a	3.10±0.02 ^f	2.60±0.01 ^e	2.20±0.01 ^f
	B ₂	4.23±0.07 ^a	2.80±0.03 ^h	2.30±0.03 ^g	1.80±0.10 ^g
W_x	B	4.23±0.07 ^a	3.30±0.03 ^d	3.00±0.02 ^{bc}	1.50±0.01 ^d
	B ₁	4.23±0.07 ^a	4.04±0.05 ^a	3.50±0.01 ^a	2.90±0.01 ^a
	B ₂	4.23±0.07 ^a	3.50±0.02 ^b	3.10±0.02 ^b	2.80±0.01 ^b
G_e	B	4.23±0.07 ^a	3.00±0.03 ^g	2.50±0.02 ^f	2.30±0.01 ^e
	B ₁	4.23±0.07 ^a	3.45±0.04 ^c	2.90±0.04 ^c	2.70±0.01 ^c
	B ₂	4.23±0.07 ^a	3.22±0.02 ^e	2.80±0.2 ^d	2.50±0.01 ^d
CV (%)		1.70	1.20	2.30	2.03
LSD (0.05)		0.13	0.06	0.10	0.07

Every value displayed is mean ± standard deviation. P<0.05 indicates a substantial difference between the means in a column with a distinct superscript letter. Where: PHT = postharvest treatments, PM = packaging materials, C = untreated avocado, H_w= hot water, W_x= wax, Ge = garlic extract, B = unpacked avocado, B₁ = polyethylene, and B₂ = carton, LSD = least significant difference, and CV = coefficient of variance.

4.3.4. Moisture content

Table 19 below presents avocado moisture content from different treatments and packaging materials during different storage periods. The results obtained from analysis indicate that the moisture content of avocado showed a significant difference (P<0.05) due to postharvest treatments and packaging materials. The moisture content of avocados generally decreased

significantly over time, as observed from day 0 to day 12. This trend is consistent with findings that indicate moisture loss is a critical factor affecting the shelf life of avocado (Workneh, 2020).

The interaction effect of postharvest treatments, packaging materials, and storage periods significantly affects the moisture content of avocado fruits. During storage periods the control avocado that had not been pretreated nor packaged or subjected to ambient conditions showed the greatest loss in MC of 50.5% and 29.97% on days 4 and 12, respectively, while the samples that had been pretreated with wax and packed in polyethylene bags showed the lowest reduction in MC of 55.1% and 46.2% on days 4 and 12, respectively. The control avocado exhibited the lowest moisture retention, highlighting the challenges of unprotected fruit. After day 12, untreated fruits that were packaged in LDPE showed better (34.13%) moisture retention than those packed in a carton and at ambient temperature. The hot water-treated samples with a combination of LDPE bags showed good moisture retention of 53.64% on day 4 and 36.3% on day 12 compared to control fruits (Table 18). The garlic extract demonstrated potential for better moisture retention of 42.1% with LDPE bags on day 12 due to its antifungal properties, while wax effectively reduced moisture loss throughout storage periods. The effect of packaging materials significantly affects the moisture content of avocado. Throughout storage time the LDPE consistently showed higher moisture retention across treatments, likely due to its barrier properties, while carton didn't retain moisture as well as polyethylene, indicating a need for careful selection based on storage periods (Kassim & Workneh, 2020).

Therefore, the interaction effect of postharvest treatments, packaging materials, and storage periods significantly influences the moisture retention of avocados during storage time. Selecting appropriate treatments and packaging is essential for minimizing moisture loss and maintaining the quality of avocados, which is crucial for both consumer satisfaction and marketability.

Table 19: Interaction effect of postharvest treatments, packaging materials and storage period on moisture content of avocado fruits stored under ambient condition.

Factors		Storage period (days)			
PHT+PM		0	4	8	12
C	B	56.00±0.20 ^a	50.50±0.63 ^f	43.14± 0.23 ^h	29.97±0.80 ⁱ
	B ₁	56.00±0.20 ^a	51.59±1.40 ^{fe}	44.87±0.76 ^g	34.13±0.70 ^g
	B ₂	56.00±0.20 ^a	51.40±1.30 ^{fe}	44.50 ±0.47 ^g	31.14±0.20 ⁱ
H _w	B	56.00±0.20 ^a	52.40±0.40 ^{de}	46.10±0.16 ^f	32.90±0.35 ^h
	B ₁	56.00±0.20 ^a	53.64±0.40 ^{cdb}	47.10±0.97 ^{ed}	36.30±0.60 ^f
	B ₂	56.00±0.20 ^a	53.05±0.20 ^{cd}	46.50±0.15 ^{ef}	34.60±0.60 ^g
W _x	B	56.00±0.20 ^a	54.05±0.60 ^{cab}	47.50±0.49 ^{cd}	38.70±0.40 ^e
	B ₁	56.00±0.20 ^a	55.10±0.80 ^a	49.60±1.10 ^a	46.20±0.80 ^a
	B ₂	56.00±0.20 ^a	54.40±1.30 ^{cab}	49.12±0.60 ^{ab}	43.64± 0.40 ^b
G _e	B	56.00±0.20 ^a	53.50±0.50 ^{cd}	47.10±0.41 ^{ed}	37.10±0.50 ^f
	B ₁	56.00±0.20 ^a	54.90±0.10 ^{ab}	48.80±0.60 ^{ab}	42.10±0.06 ^c
	B ₂	56.00±0.20 ^a	54.20±0.70 ^{cab}	48.40±0.43 ^{cb}	40.20±0.50 ^d
CV (%)		0.40	1.60	1.20	1.50
LSD (0.05)		0.34	1.40	0.94	0.92

Every value displayed is mean ± standard deviation. P<0.05 indicates a substantial difference between the means in a column with a distinct superscript letter. Where: PHT = postharvest treatments, PM = packaging materials, C = untreated avocado, H_w= hot water, W_x= wax, Ge = garlic extract, B = unpacked avocado, B₁ = polyethylene, and B₂ = carton, LSD = least significant difference, and CV = coefficient of variance.

4.3.5. Total soluble solid

Table 20 below illustrated the interaction effect of postharvest treatments, packaging materials, and storage period on the total soluble solids (TSS) of avocados, which exhibited significant (P<0.05) differences except on day 0. Initially, on day 0, all samples exhibited almost equal TSS value, indicating no significant (P>0.05) differences at the outset. However, variations in TSS

emerged throughout the storage periods, primarily due to the influence of postharvest treatments and packaging materials.

Notably, from day 4 to 12, the interaction impact of packaging materials and postharvest treatments on TSS was found to be more significant ($P < 0.05$) across storage time. This suggests that the choice of packaging and treatments plays a crucial role in maintaining the quality of avocados over time. Generally, as storage duration increased, TSS value also significantly rose gradually. Untreated avocado fruits that were stored at room temperature recorded the highest TSS values of 34.5°brix and 41°brix on days 4 and 12, respectively. However, all fruits that were subjected to postharvest treatments and packaging materials reduced the increasing rate of TSS throughout storage periods. Specifically, fruits that subjected to a combination of treatments with LDPE bags effectively maintain the quality of avocado better than carton box. For instance, avocados that were treated with wax and stored in LDPE bags effectively retarded the increasing rate of TSS values than any other treatments discussed in this section. As presented in Table 20 below, fruits that were treated with wax and kept in LDPE recorded the lowest TSS value of 31.3°brix on day 4 and 33.4°brix on day 12, followed by the sample that treated with garlic extract, which recorded 31.6°brix and 34.9°brix with the same packaging materials and storage period. However, the garlic extract-treated sample that was stored in a carton box recorded TSS values of 31.9°brix and 35.8°brix on days 4 and 12, respectively. In contrast to untreated samples, the hot-water-treated fruits that were packaged in LDPE bags and cartons also recorded the TSS values of 37.2°brix and 37.9°brix, respectively, on day 12, indicating the bactericidal and fungicidal properties of hot water in maintaining fruit quality. The indicated data in Table 20 below highlights that, extended storage periods correlated with increased TSS levels across all treatments. However, avocados treated with a combination of wax and LDPE demonstrated the lowest TSS value throughout the storage duration, followed by those treated with garlic extract and packaged in LDPE (Workneh *et al.*, 2011). This finding also aligns with the research of Sarmin *et al.* (2018), who noted that a slower respiration rate can lead to reduced metabolite production, thereby resulting in lower TSS as carbohydrates are converted into sugars more slowly.

Moreover, the effectiveness of LDPE bags in reducing the rise of TSS when combined with wax and garlic extract highlights its role in maintaining optimal moisture levels. LDPE bags create a low vapor pressure deficit, while wax layers help prevent excessive moisture loss, which is crucial

since excess moisture can lead to higher TSS levels. The control group exhibited the highest (41°brix) TSS value, likely due to rapid ripening processes that promote the hydrolysis of carbohydrates into simpler sugars, corroborating findings by Anim *et al.* (2017), who demonstrated that natural wax treatments can delay changes in TSS value. Further supporting this, Zewdie *et al.* (2022) reported that treatments with neem extract effectively slowed TSS increases, underscoring the importance of plant extract as postharvest treatments in preserving fruit quality. Tabassum *et al.* (2018), also found similar results, indicating that treatments with guava leaf and lemon extracts significantly helped in retaining TSS levels.

Table 20: Interaction effect of postharvest treatments, packaging materials, and storage periods on TSS of avocado fruits stored under ambient conditions.

Factors		Storage period (days)			
PHT+PM		0	4	8	12
C	B	31.00±0.01 ^a	34.50±0.50 ^a	37.80±0.30 ^a	41.00±1.00 ^a
	B ₁	31.00±0.01 ^a	33.3±0.30 ^{cd}	35.80±0.25 ^{bc}	38.70±0.90 ^{cd}
	B ₂	31.00±0.01 ^a	34.30±1.30 ^{cb}	37.30±0.30 ^a	40.20±1.00 ^{ab}
H _w	B	31.00±0.01 ^a	33.50±0.20 ^{cb}	36.40±0.40 ^b	39.50±0.70 ^{cb}
	B ₁	31.00±0.01 ^a	32.60±0.51 ^{efd}	34.40±0.40 ^d	37.20±0.30 ^e
	B ₂	31.00±0.01 ^a	32.80±0.26 ^{ecd}	35.30±0.30 ^c	37.97±0.50 ^{ed}
W _x	B	31.00±0.01 ^a	32.30±0.30 ^{efg}	32.50±0.30 ^{ef}	35.80±0.20 ^f
	B ₁	31.00±0.01 ^a	31.30±0.10 ^h	31.70±0.12 ^g	33.40±0.60 ^h
	B ₂	31.00±0.01 ^a	31.60±0.10 ^{hg}	31.90±0.60 ^{gf}	34.20±0.76 ^{dhg}
G _e	B	31.00±0.01 ^a	32.50±0.50 ^{efd}	32.70±0.90 ^e	38.30±0.25 ^{ed}
	B ₁	31.00±0.01 ^a	31.60±0.53 ^{hg}	32.10±0.40 ^{gef}	34.90±0.70 ^{fg}
	B ₂	31.00±0.01 ^a	31.90±0.51 ^{hfg}	32.40±0.40 ^{ef}	35.80±0.60 ^f
CV (%)		0.00	1.60	1.30	1.80
LSD (0.05)		0.00	0.87	0.73	1.13

Every value displayed is mean ± standard deviation. P<0.05 indicates a substantial difference between the means in a column with a distinct superscript letter. Where: PHT = postharvest treatments, PM = packaging materials, C = untreated avocado, H_w= hot water, W_x= wax, Ge =

garlic extract, B = unpacked avocado, B₁ = polyethylene, and B₂ = carton, LSD = least significant difference, and CV = coefficient of variance.

The data presented in Table 20 above detail the interaction effects of postharvest treatments, packaging materials, and storage period on TSS value. For each treatment combination with packaging materials, TSS values increased consistently from day 0 to day 12, providing a clear indication that both treatments and packaging influence the quality of avocados during storage time. Therefore, these findings highlight the importance of selecting appropriate postharvest treatments and packaging materials to effectively manage TSS in avocados, ultimately contributing to better preservation of fruit quality during storage time.

4.3.6. Titratable acidity

The interaction between postharvest treatments, packaging materials, and storage period significantly affected the titratable acidity (TA) of avocados, with a notable significance ($P < 0.05$) difference observed (Table 21). Over the storage period, TA increased significantly, influenced by the specific treatments and packaging materials applied. Notably, untreated avocados packaged in low-density polyethylene (LDPE) bags exhibited the highest TA than those kept at room temperature and in carton box, rising from 28% on day 4 to 49.5% on day 12. These trends indicated that storage medium and treatment method play crucial roles in the fruit's acidity levels (Ali *et al.*, 2010).

The combination of LDPE with wax and garlic extract retained an increase in TA of fruits at a higher level than any other treatments discussed in this section. The lowest TA values of 22.4% and 28.8% were recorded for the fruit sample treated with a combination of wax with LDPE on days 4 and day 12, respectively, while the fruit sample that received the same treatment and was kept in a carton recorded TA values of 23.7% and 30.8% on the respective storage periods. The TA value of fruit treated with the interaction of garlic extract with LDPE recorded 23.8% and 33.03% on days 4 and 12, respectively, while it recorded 25.2% and 34.4% with a carton on the respective storage days. Hot-water-treated fruit also retains more TA value of 30.8% and 46.7%, 26.4% and 38.6%, 26.6% and 42% with room storage, LDPE bags, and carton boxes on days 4 and 12, respectively. The highest TA value was recorded for control fruits kept at ambient temperature (Table 21). The TA value of control fruits kept at ambient temperature was raised from 28% to

49.5% with LDPE, 34.2% to 50.3% with a carton, and 36.4% to 60.67% at room temperature storage from days 4 to 12, respectively.

Generally, the TA of avocado fruits significantly increases as storage time continues. TA is related to maturity and determines the storage quality of fruits. Ali *et al.* (2010) reported that a faster increase in TA value causes senescence that shortens the shelf life of fruits. Increasing or decreasing rate of TA is due to the respiration and metabolic activity of fruits (Hassan *et al.*, 2014). The postharvest treatments that involved interaction with packaging materials retard the increasing rate of TA during storage periods. Slow increases in TA indicate that these treatments effectively slow down respiration rate. Thus, the postharvest treatments of wax with LDPE packaging materials effectively reduce the raise in TA value of fruits more than any other treatments discussed in this paper during storage time (Akhtar and Getaneh *et al.*, 2019).

Table 21: Interaction effect of postharvest treatments, packaging materials and storage periods on TA of avocado fruits stored under ambient conditions.

Factors		Storage period (days)				
		0	4	8	12	
PHT+PM	B	15.87±0.02 ^a	36.40±0.10 ^a	51.80±0.10 ^a	60.67±0.01 ^a	
	C	B ₁	15.87±0.02 ^a	28.00±0.10 ^d	40.20±0.95 ^{bc}	49.50±0.10 ^c
		B ₂	15.87±0.02 ^a	34.20±0.60 ^b	40.50±1.80 ^b	50.30±0.10 ^b
H _w	B	15.87±0.02 ^a	30.80±0.10 ^c	39.20±0.10 ^c	46.70±0.10 ^d	
	B ₁	B ₁	15.87±0.02 ^a	26.40±0.60 ^e	32.20±0.10 ^e	38.60±0.70 ^f
		B ₂	15.87±0.02 ^a	26.60±0.10 ^e	36.40±0.10 ^d	42.00±0.10 ^e
W _x	B	15.87±0.02 ^a	25.20±0.10 ^{fg}	31.10±0.50 ^f	35.40±0.50 ^g	
	B ₁	B ₁	15.87±0.02 ^a	22.40±0.10 ⁱ	28.00±0.10 ⁱ	28.80±0.10 ^k
		B ₂	15.87±0.02 ^a	23.70±0.10 ^h	29.10±0.01 ^h	30.80±0.10 ^j
G _e	B	15.87±0.02 ^a	25.50±0.50 ^f	32.20±0.10 ^e	35.70±0.70 ^g	
	B ₁	B ₁	15.87±0.02 ^a	23.80±0.10 ^h	29.60±0.10 ^{hg}	33.03±0.60 ⁱ
		B ₂	15.87±0.02 ^a	26.40±0.60 ^g	30.60±0.50 ^{fg}	34.40±0.10 ^h
CV (%)		0.00	1.22	1.80	0.86	
LSD (0.05)		0.00	0.56	1.05	0.60	

Every value displayed is mean \pm standard deviation. $P < 0.05$ indicates a substantial difference between the means in a column with a distinct superscript letter. Where: PHT = postharvest treatments, PM = packaging materials, C = untreated avocado, H_w = hot water, W_x = wax, Ge = garlic extract, B = unpacked avocado, B₁ = polyethylene, and B₂ = carton, LSD = least significant difference, and CV = coefficient of variance.

4.3.7. pH

The interaction of postharvest treatments, packaging materials, and storage period also significantly ($P < 0.05$) affected the pH of avocado fruits. Generally, as the storage period progressed, the pH value decreased significantly. Control samples, which lacked any treatments or packaging, showed a sharp decline in pH from 6.67 to 4.75 over the 12-day storage periods, primarily due to the degradation of organic acids into sugars during respiration (Jacobo-Ve and Hernandez, 2011). However, the pH of a control fruit sample packed in cartons and LDPE decreased more slowly than fruit stored without packaging materials. On days 4 to 12, the pH of the untreated fruit sample packed in cartons decreases from 6.67 to 4.82, and the fruit packed in LDPE decreases from 6.67 to 5.22. The pH of hot-water-treated fruits sampled and packaged in a cartons and LDPE decreases at a slower rate than control fruits (Table 22). The pH of hot water-treated avocado decreases from 6.67 to 5.34 and 5.50 for carton- and LDPE bags packed fruit samples from days 0 to 12.

Wax and garlic extract treatments resulted in the least changes in pH value as presented on Table 22 below. For example, garlic extract-treated samples in cartons and LDPE showed pH values decreasing from 6.67 to 5.53 and 5.67 from day 0 to 12, respectively. However, the pH of wax-treated fruits that were kept in the same packaging materials showed the least decreasing rate from 6.67 to 5.76 and 5.91 over the same storage period (Table 22). The result showed the slow decrease in pH was due to the application of coatings effectively reducing respiration rates and metabolic activity, thereby extending shelf life by modifying the internal atmosphere of the fruits (Getaneh, 2019). Generally, as the storage time increases the pH of avocados treated with a combination of postharvest treatments and packaging materials significantly decreases at a slower rate than control fruits in open environments. This idea is supported by the work of Maftoonazad & Ramaswamy, (2008) who reported that the avocado fruits that were coated with wax showed a higher pH value than the uncoated control sample, which showed a lower pH value as the storage period progressed

Table 22: Interaction effect of postharvest treatments, packaging materials and storage period on the pH of avocado fruits at ambient temperature.

Factors		Storage period (days)			
PHT+PM		0	4	8	12
C	B	6.67±0.03 ^a	5.80±0.10 ^g	5.34±0.01 ⁱ	4.75±0.04 ⁱ
	B ₁	6.67±0.03 ^a	6.32±0.01 ^e	5.41±0.01 ^h	5.22±0.01 ^h
	B ₂	6.67±0.03 ^a	6.24±0.01 ^f	5.34±0.01 ⁱ	4.82±0.01 ⁱ
H _w	B	6.67±0.03 ^a	6.30±0.01 ^e	5.45±0.01 ^g	5.34±0.01 ^g
	B ₁	6.67±0.03 ^a	6.53±0.01 ^{bc}	5.63±0.01 ^e	5.50±0.10 ^{de}
	B ₂	6.67±0.03 ^a	6.45±0.01 ^d	5.54±0.01 ^f	5.4±0.10 ^{fg}
W _x	B	6.67±0.03 ^a	6.64±0.01 ^a	6.54±0.01 ^b	5.64±0.01 ^c
	B ₁	6.67±0.03 ^a	6.68±0.01 ^a	6.57±0.01 ^a	5.91±0.01 ^a
	B ₂	6.67±0.03 ^a	6.66±0.01 ^a	6.56±0.01 ^a	5.76±0.01 ^b
G _e	B	6.67±0.03 ^a	6.49±0.01 ^{dc}	6.32±0.01 ^d	5.43±0.01 ^{fe}
	B ₁	6.67±0.03 ^a	6.58±0.01 ^b	6.54±0.01 ^b	5.67±0.01 ^c
	B ₂	6.67±0.03 ^a	6.55±0.01 ^b	6.38±0.01 ^c	5.53±0.01 ^d
CV (%)		0.40	0.50	0.20	0.80
LSD (0.05)		0.04	0.05	0.02	0.07

Every value displayed is mean ± standard deviation. P<0.05 indicates a substantial difference between the means in a column with a distinct superscript letter. Where: PHT = postharvest treatments, PM = packaging materials, C = untreated avocado, H_w= hot water, W_x= wax, Ge = garlic extract, B = unpacked avocado, B₁ = polyethylene, and B₂ = carton, LSD = least significant difference, and CV = coefficient of variance.

4.3.8. Ascorbic acid

The interaction of postharvest treatments, packaging materials, and storage period significantly ($P < 0.05$) influenced ascorbic acid levels in avocados as demonstrated in Table 23 below. As the storage period increased, the ascorbic acid content decreased at varying rates, depending on the treatments and packaging applied. Control fruits without packaging experienced a rapid decline in AA, dropping to $12.8 \text{ mg}100\text{g}^{-1}$ on day 4 and further to $5.1 \text{ mg}100\text{g}^{-1}$ by day 12, in contrast to control fruits stored in cartons and LDPE bags which retained a higher AA values, decreasing from $12.91 \text{ mg}100\text{g}^{-1}$ to $10 \text{ mg}100\text{g}^{-1}$ in LDPE bags, and from $12.81 \text{ mg}100\text{g}^{-1}$ to $8.01 \text{ mg}100\text{g}^{-1}$ in cartons over the same storage periods. Hot water-treated fruits exhibited even better retention, with higher AA values compared to controls, maintaining levels of $13 \text{ mg}100\text{g}^{-1}$ to $11.01 \text{ mg}100\text{g}^{-1}$ at ambient temperature, $13.53 \text{ mg}100\text{g}^{-1}$ to $12.2 \text{ mg}100\text{g}^{-1}$ with LDPE and $13.2 \text{ mg}100\text{g}^{-1}$ to $11.3 \text{ mg}100\text{g}^{-1}$ with cartons from day 4 to 12, respectively.

Fruits treated with wax showed the highest AA retention, with values of $13.81 \text{ mg}100\text{g}^{-1}$ and $12.51 \text{ mg}100\text{g}^{-1}$ at ambient temperature, $14.41 \text{ mg}100\text{g}^{-1}$ and $13.3 \text{ mg}100\text{g}^{-1}$ in cartons, and $14.52 \text{ mg}100\text{g}^{-1}$ and $13.53 \text{ mg}100\text{g}^{-1}$ in LDPE bags on storage day 4 and 12, respectively. Similarly, garlic extract-treated fruits also demonstrated superior AA retention compared to controls and hot water treatments as presented in Table 23. The AA value of avocado fruit samples that were subjected to garlic extract decreased from 13.53 to $11.9 \text{ mg}100\text{g}^{-1}$, when stored at room temperature, 14.1 to $12.9 \text{ mg}100\text{g}^{-1}$, when packed in LDPE bags, and 13.7 to $12.3 \text{ mg}100\text{g}^{-1}$, when stored in a carton from day 4 to 12, respectively. This indicates garlic extract maintain AA value than untreated and hot-water which was due to application of coatings and appropriate packaging significantly mitigates the oxidative degradation of ascorbic acid (Hellen,2020).

Generally, fruits treated with the interaction of postharvest treatments, packaging materials and short storage day maintained vitamin C content at a higher level than fruits without treatments and held in open environments due to slow oxidative breakdown of ascorbic acid (Hellen,2020). Mani *et al.* (2017), reported that coating and LDPE applied to fruits are used as protective layers, and control o_2 permeability, thus reducing the fruit's autoxidation potential. Thakur *et al.* (2000) reported that during food storage and processing, AA is highly sensitive to degradation when compared to other nutrients due to its oxidation. The result of this study showed that the wax and other coating materials had a significant effect on maintaining ascorbic acid contents because the

coating would serve as the protective layer to prevent the skin content from being in the atmosphere, hence influencing the oxidation process of ascorbic acid in the fruits (Hellen,2020).

Table 23: Interaction effect of postharvest treatments, packaging materials and storage period on the AA of avocado fruits at ambient temperature.

Factors		Storage period (days)			
PHT+PM		0	4	8	12
C	B	15.22±0.00 ^a	12.81±0.01 ^e	9.51±0.01 ^h	5.10±0.01 ⁱ
	B ₁	15.22±0.00 ^a	12.91±0.01 ^e	11.61±0.01 ^g	10.00±10.01 ^g
	B ₂	15.22±0.00 ^a	12.81±0.02 ^e	11.60±0.53 ^g	8.01±0.02 ^h
H_w	B	15.22±0.00 ^a	13.0±0.55 ^e	12.51±0.02 ^f	11.01±0.30 ^f
	B ₁	15.22±0.00 ^a	13.53±0.02 ^{cd}	12.91±0.50 ^{ef}	12.20±0.87 ^{ed}
	B ₂	15.22±0.00 ^a	13.20±0.60 ^{ed}	12.71±0.70 ^{ef}	11.30±0.20 ^f
W_x	B	15.22±0.00 ^a	13.81±0.03 ^{cb}	13.50±0.01 ^c	12.51±0.20 ^{cd}
	B ₁	15.22±0.00 ^a	14.52±0.01 ^a	14.80±0.08 ^a	13.53±0.30 ^a
	B ₂	15.22±0.00 ^a	14.41±0.013 ^a	14.30±0.50 ^a	13.30±0.40 ^{ab}
Ge	B	15.22±0.00 ^a	13.53±0.30 ^{cd}	13.00±0.60 ^{ef}	11.90±0.32 ^e
	B ₁	15.22±0.00 ^a	14.10±0.10 ^{ab}	13.80±0.80 ^c	12.90±0.40 ^{cd}
	B ₂	15.22±0.00 ^a	13.70±0.66 ^{cb}	13.30±0.60 ^{ec}	12.30±0.06 ^{ed}
CV (%)		-	2.40	3.64	3.12
LSD (0.05)		0.00	0.53	0.80	0.60

Every value displayed is mean ± standard deviation. P<0.05 indicates a substantial difference between the means in a column with a distinct superscript letter. Where: PHT = postharvest treatments, PM = packaging materials, C = untreated avocado, H_w= hot water, W_x= wax, Ge = garlic extract, B = unpacked avocado, B₁ = polyethylene, and B₂ = carton, LSD = least significant difference, and CV = coefficient of variance.

4.4. Sensory Quality of Avocado Juice after 12 Days of Storage

The final state of avocado fruits and juice from all samples was evaluated visually as presented in Table 24 below. The appearance of untreated avocado fruit that was kept without packaging materials showed a change from green to the darkest. The skin of this fruit showed shriveling and

extreme softening and the possibility of being discarded after a 12-day of storage period. The untreated avocado fruits that were packaged in LDPE and cartons showed the development of mold and the formation of moisture droplets on the skin, implying a loss of moisture from fruits, which resulted in higher physiological weight loss. The avocado fruit sample that treated with wax and garlic extract displayed a more aesthetic and appealing appearance. The shiny exterior, dark skin, and slight mold development were observed in these fruit samples. The mold development and formation of moisture droplets were more observed in fruit samples that were packaged LDPE and cartons. This accumulation of moisture on the surface of fruits causes the development of bacteria. Even if hot water treatments were being used to eliminate surface bacteria, wax and garlic extract-coated samples displayed a lower mold development rate.

Table 24 below presented the interaction effect of postharvest treatments and packaging materials on the appearance, color, flavor, taste, and overall acceptance of avocado juice after 12 days of storage. As exhibited in Table 24 below, the combined effect of postharvest treatments and packaging material on the sensory quality of avocado juice showed a significant difference after 12 days of storage time. The main evaluated quality parameters were appearance, colour, taste, flavor, and overall acceptability of fruits. When juice from all streams was checked for their appearance the juice from untreated avocado that was devoid of packaging materials showed a very bad appearance (1.1 ± 0.32), while those packaged in LDPE (1.8 ± 0.8) and cartons (2.4 ± 0.7) also scored poor results. The juice from hot water treated and packaged at ambient condition (3.5 ± 0.7) scored fair appearance, while those in LDPE (4.6 ± 0.52) and carton (4.6 ± 0.52) recorded good appearance when compared to control samples. The highest value of appearance was scored for juice that emerged from fruits that subjected to combined treatments of wax and garlic extract with LDPE packaging materials (4.9 ± 0.424 and 4.9 ± 0.32), respectively. The avocado juice from wax and garlic extract treated samples with LDPE and carton packaging materials scored very good appearance compared to all treatments. The appearance of juice from the control sample was slightly black and not pleasant. However, juice from fruit that were treated with LDPE and cartons showed a very good appearance.

The colour of juice from the untreated sample that was kept at room temperature scored the poorest value (1.2 ± 0.42), while those stored in polyethylene and cartons scored good results: (2.1 ± 0.74 and 2.5 ± 0.71), respectively. The highest value (4.9 ± 0.42) of colour was recorded by juice from

wax-treated fruits that were packaged in LDPE bags. The taste and flavor of juice from different streams of medium showed significant ($P < 0.05$) difference due to the effect of postharvest treatments and packaging materials on avocado fruits. The very bad taste and flavor were recorded for juice from untreated fruits that were kept without packaging materials. As observed from Table 24 below, the lowest taste and flavor value of 1.2 ± 0.42 was recorded for juice from untreated fruits that kept without packaging materials. However, the excellent and highest taste and flavor value of 4.9 ± 0.32 was scored for fruit samples that were treated with wax and garlic extract and stored in low density-polyethylene and cartons. But significantly there is no difference between fruit that is treated with hot water, wax, and garlic extract and kept in LDPE in terms of taste and flavor.

Generally, sensory evaluation revealed significant differences in the quality of avocado juice derived from various treatments and packaging materials. Additionally, it was not recommended to taste juice from untreated and hot-water treated samples after day 8, while those fruits stored in wax and garlic extract could be tasted till day 12. Juice from untreated fruits received the lowest scores in appearance, taste, and overall acceptability, indicating that the lack of postharvest treatment adversely affects sensory attributes. In contrast, juice from wax- and garlic extract-treated fruits scored highest across all sensory parameters, highlighting the effectiveness of these treatments in enhancing the sensory quality of the fruit (Getaneh, 2019). The juice from untreated fruits not only appeared darker and less appealing but also exhibited off-flavors associated with spoilage. Conversely, the juice from fruits treated with edible coatings maintained a vibrant color and desirable taste, which is crucial for consumer acceptance (Veltman *et al.*, 2000).

Table 24: The interaction effect of postharvest treatments, packaging materials and storage period on sensory quality of avocado fruit and juice.

Factors		Sensory parameters of avocado juice				
PHT+PM		Appearance	Colour	Taste	Flavor	Overall Acceptability
C	B	1.10±0.32 ^f	1.20±0.42 ^e	1.20±0.42 ^f	1.20±0.42 ^f	1.17±0.21 ^g
	B ₁	1.80±0.80 ^e	2.10±0.74 ^d	2.20±0.80 ^e	2.00±0.80 ^e	2.02±0.43 ^f
	B ₂	2.40±0.70 ^d	2.50±0.71 ^d	2.60±0.52 ^{de}	2.40±0.52 ^e	2.47±0.34 ^e
H_w	B	3.50±0.70 ^c	3.40±0.70 ^c	3.10±0.60 ^d	3.30±0.82 ^d	3.32±0.44 ^d
	B ₁	4.6±0.52 ^a	4.50±0.53 ^{ab}	4.70±0.50 ^a	4.70±0.48 ^a	4.63±0.27 ^b
	B ₂	4.6±0.52 ^a	4.20±0.8 ^b	4.10±0.87 ^{ab}	4.20±0.92 ^{cb}	4.27±0.42 ^c
W_x	B	4.7±0.32 ^a	4.80±0.32 ^a	4.90±0.32 ^a	4.90±0.32 ^a	4.90±0.13 ^a
	B ₁	4.9±0.42 ^a	4.90±0.42 ^a	4.90±0.32 ^a	4.90±0.32 ^a	4.87±0.13 ^a
	B ₂	4.8±0.5 ^a	4.90±0.32 ^a	4.50±0.53 ^{ab}	4.80±0.42 ^a	4.70±0.20 ^{ab}
Ge	B	4.1±0.6 ^b	4.40±0.84 ^{ab}	3.90±0.90 ^c	3.80±0.42 ^c	4.05±0.20 ^c
	B ₁	4.9±0.32 ^a	4.80±0.42 ^a	4.90±0.32 ^a	4.90±0.32 ^a	4.87±0.13 ^a
	B ₂	4.60±.52 ^a	4.60±0.52 ^{ab}	4.90±0.32 ^a	4.60±0.52 ^{ab}	4.67±0.17 ^{ab}
CV (%)		13.90	15.20	14.80	14.70	7.30
LSD (0.05)		0.47	0.52	0.50	0.49	0.25

Every value displayed is mean ± standard deviation. P<0.05 indicates a substantial difference between the means in a column with a distinct superscript letter. Where: PHT = postharvest treatments, PM = packaging materials, C = untreated avocado, H_w= hot water, W_x= wax, Ge = garlic extract, B = unpacked avocado, B₁ = polyethylene, and B₂ = carton, LSD = least significant difference, and CV = coefficient of variance.

5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1. Summary

This thesis investigates the impact of various postharvest treatments, packaging materials and storage periods on the physicochemical and sensory quality of Hass avocados, a highly perishable commodities. Despite Ethiopia's status as a significant producer of avocados, substantial postharvest losses occur due to improper handling, inadequate treatments, and storage practices. The study aims to identify effective methods to reduce these losses. Thereby improving the shelf life and marketability of avocados.

The study data collection was conducted in 2024 from October to November in the Food Science and Postharvest Technology Laboratory of Oda Bultum University. The Hass avocado sample was obtained from Melkasa Agricultural Research Center, which is located in the East Shewa zone of Oromia Regional State, 117 km from Addis Ababa and 429 km from Haramaya University. The selected samples were immediately transported and stored at room temperature in Oda Bultum University's Food Science Laboratory, where sample preparation, treatment, and storage trials were carried out. The avocado samples were visually inspected at the laboratory to ensure that they were not subjected to any damage during transportation and, if they were damaged avocados were excluded from the samples (Getinet *et al.*, 2011.) All work surfaces, tools, and utensils were cleaned and disinfected. Avocados were treated and tested at room temperature over 12-days of storage periods. The packaging materials needed for the experiment, such as cardboard (carton) and plastic polyethylene bag as well as: Finally, postharvest treatments: garlic cloves used for preparation of garlic extract were collected from Oda Bultum University's local market, Chiro and bee wax was obtained from Oda Bultum University's bee farm.

The coating was done by dipping fruits in respective treatment combination of the solutions. The fruits were stored at room temperature for 12 days. The quality attribute such as Physical (WL, firmness, percentage of marketability fruits) and chemicals (moisture content, total soluble solids, titratable acidity, ascorbic acid, and pH) were evaluated periodically at four-day intervals over 12-days storage periods. The study utilized a full factorial design and was carried out under optimal laboratory conditions. The data recorded on different quality parameters were statistically analyzed using SAS software version 9.0 while the LSD test was used to compare differences between treatments.

The findings revealed that postharvest treatments significantly affected the physicochemical quality of avocados, particularly in terms of weight loss, firmness, decay losses, and titratable acidity. Fruits treated with wax and packed in low-density polyethylene (LDPE) exhibited the best quality, maintaining higher firmness (2.90 ± 0.01) and marketability (100%) rates compared to untreated samples. The study found that untreated avocados showed a rapid increase in weight loss from 9.12% to 48.3% during the storage period of day 4 to 12. The combination of garlic extract and LDPE packaging also demonstrated notably lower weight loss from 0.8% on day 4 to 1.9% on day 12, compared to control and hot water treatments. Chemical analyses showed that the interaction of postharvest treatments, packaging materials and storage periods impact pH, moisture content (MC), total soluble solids (TSS), titratable acidity (TA), and ascorbic acid (AA) content significantly. The wax treatment with combination of LDPE effectively maintained higher (5.91 ± 0.01) pH levels and lower (28.8 ± 0.1) TA, indicating better quality preservation. Additionally, TSS values increased over the storage time, with untreated samples exhibiting the highest (41.00 ± 1.00) values, highlighting the rapid softening and spoilage of untreated fruit.

Sensory assessments, conducted by untrained panelists, indicated significant differences in taste, appearance, and overall acceptability among the various treatments. Avocado juice from untreated fruit received the lowest scores in all sensory attributes, while juice from fruits treated with wax and garlic extract scored the highest, reflecting enhanced consumer acceptability.

5.2. Conclusions

This study comprehensively examined the effects of postharvest treatments, packaging materials, and storage periods on the physicochemical and sensory quality of avocado fruits. The findings underscore the critical role of these factors in enhancing the overall quality and marketability of avocados, which are highly perishable commodities. The results demonstrated that postharvest treatments, particularly the application of edible coatings such as wax and garlic extract, significantly reduced physiological weight loss and decay rates compared to untreated fruits. These treatments effectively formed protective barriers, minimizing moisture loss and inhibiting microbial growth, which are crucial for extending shelf life. The study revealed that untreated avocados exhibited accelerated spoilage, with significant weight loss and decay, emphasizing the necessity of postharvest treatment interventions. Packaging materials also played a vital role in preserving the quality of avocados during storage. Polyethylene bags proved to be the most

effective in maintaining firmness, reducing decay loss, and enhancing marketability. In contrast, fruits stored at room temperature without packaging deteriorated rapidly, highlighting the importance of proper packaging in postharvest management.

The interaction effects between postharvest treatments and packaging materials were particularly noteworthy. Avocados treated with wax or garlic extract and stored in polyethylene bags exhibited the best physicochemical qualities, including higher firmness, lower titratable acidity, higher pH, lower total soluble solid, lower decay loss, and better marketability. Furthermore, the study found that extended storage periods adversely affected all quality parameters, with significant declines in firmness and ascorbic acid content. The gradual decrease in pH and increase in total soluble solids indicated that prolonged storage led to over-ripening and nutrient degradation. Thus, optimal storage conditions and durations are crucial for maintaining the quality of avocados. In conclusion, this research highlights the importance of integrating effective postharvest treatments, appropriate packaging materials and storage periods to enhance the quality and extend the shelf life of avocados. These findings provide valuable insights for producers, distributors, and retailers aiming to improve the marketability and consumer satisfaction of avocados.

5.3. Recommendations

The findings from this study highlight the critical role of postharvest treatments, packaging materials and storage period in maintaining the quality of avocado fruits. In a developing country like Ethiopia, where the struggle for food security continues, the loss of a substantial amount of food due to spoilage during the postharvest handling of fruits and vegetables is a serious issue. Implementing effective postharvest treatments and using suitable packaging materials for avocados can significantly reduce the losses experienced from farm to consumer. Additionally, extending the shelf life of fresh avocados can help address challenges faced in both local and global markets. Therefore, further research and attention should focus on the following aspects.

- a) Adoption of effective postharvest treatments, optimal packaging solutions and storage practice.
- b) Promote the use of biodegradable and recyclable packaging materials to minimize environmental impact. Encourage whole and retail sellers to adopt eco-friendly practices in their operations.

- c) Encourage use of edible and biodegradable organic treatments, such as beeswax and garlic extract, which enhance product quality while reducing reliance on synthetic chemicals, thereby benefiting the environment.

The study demonstrated that wax and garlic extract treatments significantly reduce weight loss, decay, and maintain firmness.

- d) Encouraging organic postharvest treatments and sustainable practices can enhance product appeal in international markets, where organic produce often commands higher prices. Involving local communities in decision-making processes regarding avocado production and postharvest practices can enhance sustainability and ensure that the benefits of avocado cultivation reach all stakeholders.
- e) Conduct research to assess the long term effects of different postharvest treatments on avocado quality across various storage durations, aiming to establish best practices for maintaining optimal fruit quality.
- f) Additional studies should focus on the specific needs and characteristics of Ethiopian avocado varieties, including their response to different postharvest treatments, packaging materials, and storage period and storage conditions. Partnerships with universities and research institutions can facilitate the development of innovative postharvest technologies tailored for local conditions

By implementing these recommendations, Ethiopia can significantly improve its avocado production, enhance fruit quality, and increase competitiveness in both local and international markets. Continued efforts in research, education, and policy support will be essential for achieving these goals.

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7. APPENDICES

7.1. Appendix I Sensory Evaluation Sheet

Sensory evaluation of avocado juice

In this sensory evaluation of avocado juice, you are given with samples of juice that emerged from different combination of treatments and packaging materials after 12-days of storage.

- ✓ Write the sample code in the given space provided, then
- ✓ you are kindly requested to evaluate the juice sample obtained from avocado subjected to combination of different treatments and packaging materials after 12-days of storage using the following instruction:

Like very much = 5, Like moderate = 4, neither like nor dislike = 3, Dislike moderately = 2, Dislike extremely = 1

Please do not forget to rinse your mouth between samples at the end.

Gender: M F

Sensory Evaluation Sheet

S/No	Sample code	Sensory profile				
		Appearance	Colour	Flavor	Texture	Taste
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						

Additional comments _____

7.2. Appendix II ANOVA Tables

1. ANOVA Interaction effects of postharvest treatments, packaging materials and storage periods on WL (%) of avocado fruits for day 4.

Source	SS	DF	MS	F Value	Pr > F
Postharvest Treatments	272.6	3	90.87	1129.16	<.0001
Storage Materials	14.15	2	7.075	87.92	<.0001
Postharvest Treatments*	6.345	6	1.057	13.14	<.0001
Storage Materials					

Where: S = Source of variation, DF = degree of freedom, SS = Sum square, MS = Mean square, WL= physiological weight loss and a significant difference was at $P < 0.05$.

2. ANOVA Interaction effects of postharvest treatments, packaging materials and storage periods on firmness of avocado fruits for day 4.

Source	SS	DF	MS	F Value	Pr > F
Postharvest Treatments	3.95	3	0.98	37.75	<.0001
Storage Materials	0.82	2	0.41	15.67	<.0001
Postharvest Treatments*	0.52	6	0.087	3.33	0.0157
Storage Materials					

Where: S = Source of variation, DF = degree of freedom, SS = Sum square, MS = Mean square, and a significant difference was at $P < 0.05$.

3. ANOVA Interaction effects of postharvest treatments, packaging materials and storage periods on decay loss of avocado fruits for day 4.

Source	SS	DF	MS	F Value	Pr > F
Postharvest Treatments	0.00	3	0.00	–	–
Storage Materials	0.00	2	0.00	–	–
Postharvest Treatments*	0.00	6	0.00	–	–
Storage Materials					

Where: S = Source of variation, DF = degree of freedom, SS = Sum square, MS = Mean square, and a significant difference was at $P < 0.05$

4. ANOVA Interaction effects of postharvest treatments, packaging materials and storage periods on percentage of marketability of avocado fruits for day 4.

Source	SS	DF	MS	F Value	Pr > F
Postharvest Treatments	0.00	3	0.00	–	–
Storage Materials	0.00	2	0.00	–	–
Postharvest Treatments*	0.00	6	0.00	–	–
Storage Materials					

Where: S = Source of variation, DF = degree of freedom, SS = Sum square, MS = Mean square, and a significant difference was at $P < 0.05$.

5. ANOVA Interaction effects of postharvest treatments, packaging materials and storage periods on moisture content of avocado fruits for day 4.

Source	SS	DF	MS	F Value	Pr > F
Postharvest Treatments	96.94	3	32.3	40.80	<.0001
Storage Materials	16.20	2	8.101	10.23	0.0006
Postharvest Treatments*	8.07	6	1.35	1.70	0.1640
Storage Materials					

Where: S = Source of variation, DF = degree of freedom, SS = Sum square, MS = Mean square, and a significant difference was at $P < 0.05$

6. ANOVA Interaction effects of postharvest treatments, packaging materials and storage periods on TSS of avocado fruits for day 4.

Source	SS	DF	MS	F Value	Pr > F
Postharvest Treatments	24.06	3	8.02	30.23	<.0001
Storage Materials	2.85	2	1.42	5.37	0.0119
Postharvest Treatments*	1.59	6	0.26	1.00	0.447
Storage Materials					

Where: S = Source of variation, DF = degree of freedom, SS = Sum square, MS = Mean square, and a significant difference was at $P < 0.05$.

7. ANOVA Interaction effects of postharvest treatments, packaging materials and storage periods on pH of avocado fruits for day 4

Source	SS	DF	MS	F Value	Pr > F
Postharvest Treatments	59.6	3	19.87	30.10	<.0001
Storage Materials	9.73	2	4.87	7.37	0.0032
Postharvest Treatments*	0.29	6	0.049	0.07	0.9981
Storage Materials					

Where: S = Source of variation, DF = degree of freedom, SS = Sum square, MS = Mean square, TSS = Total soluble solid and a significant difference was at $P < 0.05$

8. ANOVA Interaction Effects of Postharvest Treatments, Packaging Materials and Storage Periods on TA of Avocado Fruits for Day₄

Source	SS	DF	MS	F Value	Pr > F
Postharvest Treatments	598.23	3	199.41	14.56	<.0001
Storage Materials	137.74	2	68.87	5.03	0.0150
Postharvest Treatments*	106.76	6	17.79	1.30	0.2954
Storage Materials					

Where: S = Source of variation, DF = degree of freedom, SS = Sum square, MS = Mean square, TA = Titratable Acidity and a significant difference was at $P < 0.05$

9. ANOVA Interaction effects of postharvest treatments, packaging materials and storage periods on AA of avocado fruits for day 4.

Source	SS	DF	MS	F Value	Pr > F
Postharvest Treatments	10.44	3	3.48	3103.73	<.0001
Storage Materials	0.89	2	0.44	396.26	<.0001
Postharvest Treatments*	0.498	6	0.083	74.11	<.0001
Storage Materials					

Where: S = Source of variation, DF = degree of freedom, SS = Sum square, MS = Mean square, TA = Titratable acidity and a significant difference was at $P < 0.05$

10. ANOVA Interaction effects of postharvest treatments, packaging materials and storage periods on WL (%) of avocado fruits for day 8.

Source	SS	DF	MS	F Value	Pr > F
Postharvest Treatments	1678.42	3	559.47	6359.24	<.0001
Storage Materials	149.53	2	74.76	849.81	<.0001
Postharvest Treatments* Storage Materials	158.81	6	26.47	300.85	<.0001

Where: S = Source of variation, DF = degree of freedom, SS = Sum square, MS = Mean square, WL= physiological weight loss and a significant difference was at $P < 0.05$

11. ANOVA Interaction effects of postharvest treatments, packaging materials and storage periods on firmness of avocado fruits for day 8.

Source	SS	DF	MS	F Value	Pr > F
Postharvest Treatments	6.96	3	2.32	137.81	<.0001
Storage Materials	1.15	2	0.57	34.13	<.0001
Postharvest Treatments* Storage Materials	0.26	6	0.043	2.54	0.0479

Where: S = Source of variation, DF = degree of freedom, SS = Sum square, MS = Mean square, and a significant difference was at $P < 0.05$

12. ANOVA Interaction effects of postharvest treatments, packaging materials and storage periods on decay loss of avocado fruits for day 8.

Source	SS	DF	MS	F Value	Pr > F
Postharvest Treatments	2359.89	3	589.97	445.73	<.0001
Storage Materials	492.06	2	246.033	185.88	<.0001
Postharvest Treatments* Storage Materials	909.52	6	151.58	114.53	<.0001

Where: S= Source of variation, DF = degree of freedom, SS = Sum square, MS = Mean square, and a significant difference was at $P < 0.05$

13. ANOVA Interaction effects of postharvest treatments, packaging materials and storage periods on percentage of marketability of avocado fruits for day 8.

Source	SS	DF	MS	F Value	Pr > F
Postharvest Treatments	3581.9	3	1193.96	2.39	<.0001
Storage Materials	1717.74	2	858.87	1.72	<.0001
Postharvest Treatments*	2131.36	6	355.23	7.105	<.0001
Storage Materials					

Where: S = Source of variation, DF = degree of freedom, SS = Sum square, MS = Mean square, and a significant difference was at $P < 0.05$

14. ANOVA Interaction effects of postharvest treatments, packaging materials and storage periods on moisture content of avocado fruits for day 8.

Source	SS	DF	MS	F Value	Pr > F
Postharvest Treatments	95.24	3	31.75	87.16	<.0001
Storage Materials	15.33	2	7.74	21.04	<.0001
Postharvest Treatments*	5.00	6	0.834	2.29	0.0688
Storage Materials					

Where: S = Source of variation, DF = degree of freedom, SS = Sum square, MS = Mean square, and a significant difference was at $P < 0.05$

15. ANOVA Interaction effects of postharvest treatments, packaging materials and storage periods on TSS of avocado fruits for day 8.

Source	SS	DF	MS	F Value	Pr > F
Postharvest Treatments	85.37	3	28.46	103.59	<.0001
Storage Materials	4.015	2	2.01	7.31	0.0033
Postharvest Treatments*	3.30	6	0.55	2.00	0.1048
Storage Materials					

Where: S = Source of variation, DF = degree of freedom, SS = Sum square, MS = Mean square, TSS = Total Soluble Solid and a significant difference was at $P < 0.05$.

16. ANOVA Interaction effects of postharvest treatments, packaging materials and storage periods on pH of avocado fruits for day 8.

Source	SS	DF	MS	F Value	Pr > F
Postharvest Treatments	1188.7	3	396.24	1131.18	<.0001
Storage Materials	168.87	2	84.44	241.05	<.0001
Postharvest Treatments*	172.5	6	28.75	82.08	<.0001
Storage Materials					

Where: S= Source of variation, DF=degree of freedom, SS=Sum square, MS=Mean square, TSS = Total Soluble Solid and a significant difference was at $P < 0.05$

17. ANOVA Interaction effects of postharvest treatments, packaging materials and storage periods on TA of avocado fruits for day 8.

Source	SS	DF	MS	F Value	Pr > F
Postharvest Treatments	10.17	3	3.39	5.15	0.0024
Storage Materials	2.46	2	1.23	1.87	0.1599
Postharvest Treatments*	0.467	6	0.078	0.12	0.9940
Storage Materials					

Where: S= Source of variation, DF=degree of freedom, SS=Sum square, MS=Mean square, TSS = Titratable acidity and a significant difference was at $P < 0.05$

18. ANOVA Interaction effects of postharvest treatments, packaging materials and storage periods on AA of avocado fruits for day 8.

Source	SS	DF	MS	F Value	Pr > F
Postharvest Treatments	38.87	3	12.96	58830.2	<.0001
Storage Materials	5.014	2	2.51	11381.9	<.0001
Postharvest Treatments*	4.514	6	0.75	3416.10	<.0001
Storage Materials					

Where: S = Source of variation, DF = degree of freedom, SS = Sum square, MS = Mean square, AA = Ascorbic Acid and a significant difference was at $P < 0.05$

19. ANOVA Interaction effects of postharvest treatments, packaging materials and storage periods on WL (%) of avocado fruits for day 12.

Source	SS	DF	MS	F Value	Pr > F
Postharvest Treatments	5104.02	3	1701.3	5515.02	<.0001
Storage Materials	534.15	2	267.08	865.76	<.0001
Postharvest Treatments* Storage Materials	900.08	6	150.014	486.28	<.0001

Where: S = Source of variation, DF = degree of freedom, SS = Sum square, MS = Mean square, WL= physiological weight loss and a significant difference was at $P<0.05$

20. ANOVA Interaction effects of postharvest treatments, packaging materials and storage periods on firmness of avocado fruits for day 12.

Source	SS	DF	MS	F Value	Pr > F
Postharvest Treatments	20.7	3	6.90	3746.61	<.0001
Storage Materials	1.655	2	0.83	449.32	<.0001
Postharvest Treatments* Storage Materials	0.405	6	0.067	36.65	<.0001

Where: S = Source of variation, DF = degree of freedom, SS = Sum square, MS = Mean square, and a significant difference was at $P<0.05$.

21. ANOVA Interaction effects of postharvest treatments, packaging materials and storage periods on decay loss of avocado fruits for day 12.

Source	SS	DF	MS	F Value	Pr > F
Postharvest Treatments	7270.7	3	1817.7	796.33	<.0001
Storage Materials	660.03	2	330.02	144.58	<.0001
Postharvest Treatments* Storage Materials	911.36	6	151.9	66.54	<.0001

Where: S = Source of variation, DF = degree of freedom, SS = Sum square, MS = Mean square, and a significant difference was at $P<0.05$.

22. ANOVA Interaction effects of postharvest treatments, packaging materials and storage periods on percentage of marketability of avocado fruits for day 12.

Source	SS	DF	MS	F Value	Pr > F
Postharvest Treatments	5829.25	3	1943.083	5770.20	<.0001
Storage Materials	1969.034	2	984.52	2923.63	<.0001
Postharvest Treatments*	2080.55	6	346.76	1029.74	<.0001
Storage Materials					

Where: S = Source of variation, DF = degree of freedom, SS = Sum square, MS = Mean square, and a significant difference was at $P < 0.05$

23. ANOVA Interaction effects of postharvest treatments, packaging materials and storage periods on moisture content of avocado fruits for day 12.

Source	SS	DF	MS	F Value	Pr > F
Postharvest Treatments	96.94	3	32.3	40.80	<.0001
Storage Materials	16.2	2	8.10	10.23	0.0006
Postharvest Treatments*	8.07	6	1.35	1.70	0.1646
Storage Materials					

Where: S = Source of variation, DF = degree of freedom, SS = Sum square, MS = Mean square, and a significant difference was at $P < 0.05$

24. ANOVA Interaction effects of postharvest treatments, packaging materials and storage periods on pH of avocado fruits for day 12.

Source	SS	DF	MS	F Value	Pr > F
Postharvest Treatments	96.94	3	32.3	40.80	<.0001
Storage Materials	16.2	2	8.101	10.23	0.0006
Postharvest Treatments*	8.07	6	1.35	1.70	0.1646
Storage Materials					

Where: S = Source of variation, DF = degree of freedom, SS = Sum square, MS = Mean square, and a significant difference was at $P < 0.05$.

25. ANOVA Interaction effects of postharvest treatments, packaging materials and storage periods on TSS of avocado fruits for day12.

Source	SS	DF	MS	F Value	Pr > F
Postharvest Treatments	77.07	3	25.69	124.79	<.0001
Storage Materials	15.51	2	7.76	37.68	<.0001
Postharvest Treatments*	1.25	6	0.21	1.01	0.4400
Storage Materials					

Where: S = Source of variation, DF = degree of freedom, SS = Sum square, MS = Mean square, TSS = Total Soluble Solid and a significant difference was at $P < 0.05$

26. ANOVA Interaction Effects of Postharvest Treatments, Packaging Materials and Storage Periods on TA of Avocado Fruits for Day₁₂

Source	SS	DF	MS	F Value	Pr > F
Postharvest Treatments	2659.53	3	886.51	338.00	<.0001
Storage Materials	337.79	2	168.89	64.40	<.0001
Postharvest Treatments*	74.40	6	12.40	4.73	0.0026
Storage Materials					

Where: S = Source of variation, DF = degree of freedom, SS = Sum square, MS = Mean square, TA = Titratable Acid and a significant difference was at $P < 0.05$

27. ANOVA Interaction effects of postharvest treatments, packaging materials and storage periods on AA of avocado fruits for day 12.

Source	SS	DF	MS	F Value	Pr > F
Postharvest Treatments	158.34	3	52.78	1311.33	<.0001
Storage Materials	17.89	2	8.95	222.34	<.0001
Postharvest Treatments*	24.19	6	4.033	100.19	<.0001
Storage Materials					

Where: S = Source of variation, DF = degree of freedom, SS = Sum square, MS = Mean square, AA = Ascorbic Acid and a significant difference was at $P < 0.05$

7.3. Appendix III: List of Figures



Figure 3: Garlic extract



Figure 4: Beeswax



Figure 5: The initial day of treating avocado with different postharvest treatments before storage



Figure 6: Physical appearance of avocado after 12 days of storage



Figure 7: Physical appearance of avocado juice



Figure 8: TSS by Abe Refractometer



Figure 9: pH measurement by standard pH meter



Figure 10: Titration of avocado juice sample