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ADDIS ABABA, ETHIOPIA

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EVALUATION OF PACKAGING MATERIALS ON THE QUALITY AND SHELF LIFE OF MANGO *(Mangifera indica L.)*

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A THESIS SUBMITTED TO TECHNICAL AND VOCATIONAL EDUCATION AND TRAINING INSTITUTE FACULTY OF AGRO-FOOD PROCESSING TECHNOLOGY

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BY: DEREJE TOLERA

ADVISOR: CHALA GOWE (ASSISTANT PROFESSOR)

MAY, 2026

ADDIS ABABA, ETHIOPIA

DECLARATION

I hereby declare that the thesis entitled "**Evaluation of Packaging Materials on the Quality and Shelf Life of Mango *(Mangifera indica l.)*"** is my original work carried out under the supervisions of Chala Gowe (Assistant professor). This work has not been submitted to any other university or institution for the award of any degree. All sources of materials used in this study have been properly acknowledged

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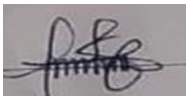
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This is therefore, to certify the thesis has been accepted in partial fulfilment of the requirements for the degree master of science in fruit and vegetable processing technology

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ABSTRACT

Mango (Mangifera indica L.) is a highly perishable climacteric fruit that requires appropriate post-harvest handling to minimize losses and extend shelf life. Significant quantitative and qualitative losses occur during storage and marketing due to inadequate packaging and handling practices. In line with this, the research was conducted to evaluate the effects of different packaging materials on the quality and shelf-life stability of locally available mango variety (Amba Ererro). The study consisted of two components: a community-based survey to assess awareness and perceptions regarding packaging practices and post-harvest losses, and a laboratory-based experimental evaluation of packaging materials. Awareness of the role of improved packaging materials in reducing losses was limited, and access to appropriate packaging options was constrained by cost and availability. The laboratory based work was arranged in a Completely Randomized Design (CRD) with three replications. Seven treatments: (T0 = Control, T1 = plastic sheet, T2 = Polyethylene bag, T3 = Polypropylene bag, T4 = LDPE, T5 = HDPE and T6 = Carton (CFB) were evaluated. Physicochemical parameters (physiological weight loss, firmness, total soluble solids, and pH), microbial quality (disease incidence, disease severity, total microbial load), and sensory acceptance were evaluated at seven-day intervals over 21 days of storage. Analysis of variance (ANOVA) showed significant differences ($p < 0.05$) among treatments for physiological weight loss, pH, and total soluble solids. The treatment packed with a plastic sheet had the lowest physiological weight loss (0.07%), while the control (unpackaged) had the highest physiological weight loss (0.93%), followed by the PEB (16.26%). Mango fruits packaged by plastic sheet had the highest pH value, while the control treatment had the lowest pH values. By evaluating a number of post-harvest metrics, the experiment intended to identify the best packaging choice for maintaining the quality of mango fruit. The findings showed that the packaging materials' capacities to preserve fruit quality varied significantly. These findings can help stallholders choose the best packaging to minimize post-harvest losses and increase market value, and they have practical implications for treating mango after harvest.

Keywords: mango, Packaging materials, shelf life, quality, Stability

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ACRONYMS AND ABBREVIATIONS

APC…… Aerobic Plate Count

ASP,,,

PM----------Packaging Material

PPB……Polypropylene Bag

PPE---------- Personal protective equipment

PS……Plastic Sheet

PWL……Physiological Weight Loss

SPC……..Standard Plate Count

TBC……. Total Bacterial Count

TMC……Total Microbial Count

TMLA……. Total Microbial Load Analysis

TPC……Total Plate Count

TSS ----------Total Soluble Solids

TVC……Total Viable Count

TYMC……Total Yeast and Mold Count

WHO……World Health Organization

1. INTRODUCTION

This chapter deals with the background of the study, statement of the problem, objectives of the study, significance of the study, scope of the study, limitations of the study, research question, operational definition of the key terms, and organization of the study.

1.1. Background of the study

Mango (*Mangifera indica L.*) is one of the most important tropical and subtropical fruit crops in the world. It is regarded as the "king of fruits" because of its alluring flavor, color, and texture and getting more demand globally. The crop belongs to the family Anacardiaceae and originated in Southeast Asia, from where it spread to Africa, the Americas, and other tropical regions [10]. Out of many varieties of mango, Amrapali is a well-known regular variety among the many cultivated varieties and hybrids of mangoes that have a rich diversity bearing dwarf hybrid [2]. Mangos are grown on about 3.7 million hectares of land worldwide. They rank second among tropical fruit crops and fifth overall in the world, behind citrus, banana, grape, and apple. Mango production and international trade are steadily growing [48]. At the moment Asia is the world's largest producer with 34.6 million tons, accounting for roughly 74.30% of the world's total mango production, with the top nations being America [13.00%, 4 million tons], Africa [11.00%, 3 million tons] and Oceania [0.10%, 0.04 million tons]. With a production of 24 million tons in 2020, India is the world's largest mango producer [20]. Mangoes are priced for both food and nutritional value. They are eaten as a dessert as well as a food that provides energy [58]. Mangoes are climacteric fruits that are typically harvested at the green mature stage [10] and subsequently matured to the desired texture and flavor [12]. A considerable percentage of quantitative and qualitative post-harvest losses occur during marketing, since the mango fruit is particularly perishable. Packaging is a crucial and necessary component used specifically to minimize transportation losses at various post-harvest handling stages [2]. Ethiopia has a lot of potential and supportive policies to increase fruit production for the domestic and international markets, as well as for the fresh market. In addition, fruit crops are easily integrated into any agroforestry program, are environmentally friendly, sustain the environment, and offer shade. 12,799 ha of land are used to produce 69,743.39 tons of mangoes [13]. Furthermore, between 2003 and 2013, the area covered by mangoes and their production increased by 247% and 2084.4%, respectively [14]. It is cultivated throughout the

nation, with the main producing regions of western and eastern Ethiopia accounting for more than half of all mango production in Ethiopia [15]. Post-harvest losses in quantity and quality complicate fresh produce cultivation and marketing in Ethiopia. Ethiopia has a lot of potential and supportive policies to increase fruit production for the domestic and international markets, as well as for the fresh market. Presently, there are two significant post-harvest issues limiting the local mango industry. First, the majority of our mangoes are packed in wooden crates, which not only bruise and injure the fruit physically during transit but are also prohibited from being sold in foreign markets due to quarantine issues and the need for specific disinfection procedures required for international trade [12]. Second, because it is inexpensive and readily available in the local market, calcium carbide (CaC2) is frequently used to ripen mango fruit; however, its use in the fruit industry is discouraged [13].Better quality, longer shelf life, and access to foreign markets all depend on proper packaging [1]. According to [66], careful handling during harvesting can minimize mechanical damage and decrease waste later on from microbial attack. In addition, better quality, a longer shelf life, and access to foreign markets all depend on appropriate post-harvest handling and packaging. Thus, maintaining the quality of the produce and extending its shelf life can be greatly aided by appropriate packaging. With this perspective in mind, an experiment will be conducted to assess the impact of packaging materials on the quality and stability of mango storage life [1]. Consequently, the goal of the current study was to assess how various packaging materials affected the quality and shelf life of stability of mango fruit. Therefore, this study was aimed at the investigation of the effectiveness of different packaging materials in extending the shelf life of mango. The specific objective of the study was to evaluate the effect of packaging materials on the physical quality of mango fruits.

1.2. Statement of the Problem

According to (17), mango (*Mangifera indica L.*) is the most important fruit produced and widely consumed in Ethiopia. Despite its considerable economic and nutritional value, as well as its high production potential, the mango subsector has received relatively limited research and development attention. Earlier estimates indicate that mango production reached about 160,000 metric tons, yet a substantial proportion of this output fails to reach consumers in acceptable quality due to post-harvest challenges.

Mango is a highly perishable fruit that undergoes rapid physiological and biochemical changes after harvest. As the study by (23), and (26) indicated, post-harvest losses in Ethiopia are significant and are mainly attributed to poor handling practices, inadequate storage conditions, and the use of inappropriate packaging materials during transportation and marketing. These challenges result in microbial spoilage, moisture loss, mechanical damage, and accelerated ripening, ultimately reducing both shelf life and market value.

Packaging plays a critical role in post-harvest management by protecting fruits from physical injury, minimizing moisture loss, regulating gas exchange, and maintaining appropriate micro-environmental conditions. As reported by (61) indicated, effective packaging can therefore significantly extend shelf life, preserve quality, and reduce quantitative and qualitative losses along the supply chain. However, the effectiveness of packaging materials varies widely depending on their properties and their interaction with factors such as storage temperature, relative humidity, fruit maturity stage, and cultivar. However, there is limited comparative information on how packaging materials influences key quality parameters of mango under local conditions.

Although several studies have investigated mango post-harvest handling, there remains a lack of consistent and context-specific empirical evidence on the comparative performance of different packaging materials under local conditions. This knowledge gap limits the development and adoption of efficient, affordable, and scalable packaging solutions for smallholder farmers and traders in Ethiopia.

Therefore, a systematic evaluation of different packaging materials is essential to identify suitable options that can maintain fruit quality and extend shelf life under prevailing storage and transportation conditions. Addressing this gap will contribute to improved post-harvest management practices, reduction of food losses, and enhancement of the overall mango value chain. Based on these considerations, this study is designed to evaluate the effects of different packaging materials on the quality and shelf life stability of mango (*Mangifera indica* L.) fruit.

1.3. Objectives

1.3.1. General Objective of the Study

To evaluate different packaging materials on the quality and shelf life stability of mango fruits.

1.3.2. Specific Objectives of the Study

To evaluate the community's knowledge and perception of the effects of various packaging materials on the quantity and quality of mango fruit loss

To compare/assess the effects of different packing materials on the sensory quality of mango fruits.

To determine the effects of packaging materials on the physio-chemical, microbiological, properties, and shelf life of mango fruits during storage.

1.4. Scope of the Study

This study focuses on evaluating the effects of selected packaging materials on the quality attributes and shelf life stability of mango (Mangifera indica L.) fruit. The research considers commonly used and alternative packaging options, including paper-based, plastic-based, and biodegradable materials, in order to compare their effectiveness under controlled storage conditions.

The assessment is limited to key post-harvest quality parameters, including physical characteristics (such as weight loss, firmness, and external appearance), chemical properties (including total soluble solids, and pH), and microbial quality. In addition, the study examines changes in these parameters over a defined storage period to determine the extent to which different packaging materials influence the rate of fruit deterioration.

The study is conducted under specified storage conditions, taking into account factors such as temperature and relative humidity, but does not extend to variations in mango cultivar, pre-harvest practices, or large-scale supply chain logistics. The findings are therefore intended to provide practical insights into the role of packaging materials in maintaining mango quality and extending shelf life within a controlled experimental setting.

1.5. Significance of the study

Understanding the influence of different packaging materials on the shelf life and quality of mango (Mangifera indica L.) is important for improving post-harvest management practices. This study contributes to identifying suitable packaging options that can effectively maintain fruit quality during storage and transportation, thereby reducing post-harvest losses and minimizing food waste.

The findings of this research are expected to provide practical insights for farmers, traders, and other actors along the mango value chain by supporting the selection of appropriate packaging materials that enhance product quality and marketability. Improved packaging practices can lead to extended shelf life, better price realization, and increased consumer satisfaction.

In addition, the study offers valuable information for researchers and policymakers by generating empirical evidence on the performance of different packaging materials under controlled conditions. It may also highlight the potential of biodegradable packaging alternatives, contributing to the promotion of environmentally sustainable packaging solutions without compromising fruit quality.

1.6. Limitations of the study

The study is also limited to selected packaging materials and does not cover all possible types or design variations available in practice. As a result, the findings may not fully represent the performance of other packaging options not included in the experiment. In addition, the research is conducted under specific storage conditions and may focus on a particular mango variety and location. These factors may limit the generalizability of the results to other varieties, regions, or supply chain conditions. Moreover, the study does not incorporate an economic analysis of the packaging materials evaluated. Therefore, conclusions regarding cost-effectiveness and practical adoption by farmers, traders, and other stakeholders are beyond the scope of this research.

1.7. Research Questions

The following fundamental research questions were addressed by the study.

What is the level of community knowledge and perception regarding the effects of different packaging materials on quantitative and qualitative post-harvest losses of mango fruits?

How do different packaging materials influence the sensory quality attributes of mango fruits during storage?

What are the effects of different packaging materials on the physicochemical properties, microbiological quality, and shelf life of mango fruits?

How do different packaging materials affect the marketability of mango fruits across different supply chain stages?

These research questions address a range of sensory, physical, and consumer-related aspects of how packaging materials affect mango quality and shelf life. These inquiries can help researchers focus their attention and acquire a thorough understanding of the intricate connection between mango post-harvest characteristics and packaging materials.

2. LITERATURE REVIEW

2.1. Related Works

2.1.1. Description and Origin of Mango

As cited by [10], one of the most significant commercial crops, the mango [Mangifera indica L.], commonly referred to as “the King of fruits, “is the second most economically significant tropical fruit product in the world. According to [2], more than 1000 varieties have been documented worldwide, and it is thought to have originated in Southeast Asia. Mangoes come in a wide variety of cultivated and hybrid kinds. After citrus, bananas, grapes, and apples, mangoes were the second most popular tropical fruit crop worldwide [12]. Even though

mangoes are grown and produced all over the world, Asian nations produced the most, followed by Americans and Africans in that order. [20]

2.1.2. Global production status of mango

As one of the most extensively grown and traded tropical and subtropical fruit crops worldwide today, mango is an economically significant as well as nutrient-rich crop. The tropical evergreen fruit tree known as the mango (Mangifera indica (L.)) is farmed for commercial purposes in many nations. It is thought to have come from Southeast Asia, and over a thousand different varieties have been found worldwide [12]. Mangos are grown on about 3.7 million hectares of land worldwide. They rank second among tropical fruit crops and fifth overall in the world, behind citrus, banana, grape, and apple. The majority of global production is shared by Asian nations (77%), Americans (13%), and African nations (10%). [20] is the second-most valuable tropical fruit commodity in the world economically. Nutritionally, it is one of the most widely consumed fruits worldwide. Mangoes are commercially grown in over 88 countries, with India, China, Thailand, Indonesia, and Mexico leading the way, and can be grown in tropical and subtropical regions [19].

2.1.3. Nutritional importance of mango fruits in Ethiopia

Mangoes are known for their delicious flavor, appealing peel color, pleasant aroma, general eating qualities, and superior nutritional content [4]. Customers' acceptance of mangoes is determined by these characteristics since they frequently judge the quality of fruits by their appearance [5]. For example, the presence of carotenoids causes the color of the peel to turn yellow and orange, which can be used as a visual indicator of mango maturity [6]. Mangoes are priced for both food and nutritional value [8]. Additionally, people are becoming more conscious of quality and safety. They seek and are prepared to pay a higher price for safe quality mangoes.

2.1.4. Mango’s Current Production Condition and Potential Future in Ethiopia

Ethiopia has a lot of potential and supportive policies to increase fruit production for the domestic and international markets, as well as for the fresh market. Ethiopia's agro-ecology is suitable for producing tropical and temperate fruit crops [9]. About five million farmers depend on fruit production for their livelihoods, which supports the local economy by generating jobs

and foreign exchange earnings [64]. In addition, fruit crops are easily integrated into any agroforestry program, are environmentally friendly, sustain the environment, and offer shade. As reported by [11], mango is the fruit that is grown in the various regional states of Ethiopia, with banana coming in first in the Gambela and Southern Ethiopia regions. Bananas, mangoes, oranges, avocados, and papayas are the main fruits that are grown in the nation with the greatest emphasis [68]. In Ethiopia, mangoes are the second most important fruit crop after bananas [54]. In the 2018–19 production seasons, 1,337,049.26 quintals of mango were produced, yielding a productivity level of 68.87 quintals per hectare [54]. Bananas, mangoes, avocados, papayas, oranges, and bananas accounted for 63.30%, 10.66%, 17.29%, 5.0%, and 2.8% of the total amount of cultivated land in the regions (areas) of Guraghe and Yem Special Woreda, respectively [55]. Ethiopia's major mango-producing regions are Amhara, SNNPR, West and East Oromia and Harari [51]. The South Nation Nationality Peoples' Region (SNNPR) is famous for its mango production, with a 47% share of the total production in the country [56]. Mangoes are the most widely cultivated fruit crop in Ethiopia in terms of economic significance, with bananas coming in first. The primary fruits produced and exported are bananas, citrus fruits, mangoes, avocados, papayas, and grapes. In terms of total production and area coverage, mangoes ranked second and third place among Ethiopia's fruit crops, respectively.

Table 1. Summary of the major fruit crops produced in Ethiopia in 2012/2013 cropping season/year

Fruit crop	Area(ha)	Production (Q)	Productivity(Q)
Avocado	8938	256,331	28.68
Banana	36,012	302502	84
Lemon	754,29	55,167	73
Mango	8808	697,507	79
Oranges	2,999	357,4450	119

(Source: CSA, 2013, Agricultural sample survey result)

To date, a great deal of research has been done in Ethiopia on the limitations of the mango value chain and the evaluation of post-harvest losses [59; 7; 57; 5; 8; 69; 5; 6]. Nonetheless, the bulk of studies have concentrated on disease, marketing strategies, mango production

techniques, and the uptake of improved varieties [57]. Africa produced an estimated 2,236,000 metric tons of mangoes in 2002; Egypt, Madagascar, Nigeria, Sudan, Tanzania, and Zaire were the main producers [65]. Despite being one of the most significant fruits in Ethiopia, this crop has not received much attention despite having a lot of potential [43]. According to the study by [3] database, mangoes account for 34.9% of all fruit area and 20.7% of all fruit produced. Over the past ten years, there has been a 45–50% increase in mango acreage and production. Ethiopia is located in a tropical region with plenty of space for mango cultivation. Ethiopia produces mangoes on a variety of scales, from small commercial plantations to homesteads. Mangoes are currently the most widely grown fruit crop in the nation in terms of both production (1,245,615.60 q year−1) and area coverage (28,695 ha) [53]. Mangoes are well suited to traditional agricultural systems because they require relatively little in the way of land preparation, care, and maintenance, and they yield a comparatively high amount of fruit per unit area and time. According to recent reports, in some parts of the country's southern regions, mangoes are displacing important food crops like maize and sweet potatoes as well as other fruit crops like lemon and lime [38]. Mango production has grown by 247% and area coverage by 208.4% during the last ten years (2003–2013). It is cultivated throughout the nation, with the main producing regions of western and eastern Ethiopia accounting for more than half of all mango production in Ethiopia. Mango, one of the most adaptable and extensively grown fruit crops in tropical and subtropical regions, is grown primarily in the Gambela and Southern Ethiopia regions and is cultivated in more regional states of Ethiopia than banana [11]. Post-harvest losses in quantity and quality complicate fresh produce cultivation and marketing in Ethiopia. For processed food and fresh agricultural products, conventional petroleum-based plastic packaging has been widely used for decades. This is mostly because of its affordable price, ease of use, ease of production, and desirable physiochemical properties [7]. But as people's knowledge of the issues surrounding plastics has grown including the use of nonrenewable resources, safety concerns, and significant environmental contamination and accumulation customer preferences have changed in favor of renewable, biodegradable, and environmentally friendly packaging materials [8]. Mango fruit storage is crucial for extending its shelf life and controlling its supply to the market. Temperature and relative humidity must be effectively controlled during the storage period in order for it to be successful [9]. In addition, appropriate post-harvest handling and packaging are necessary to preserve higher

quality and a longer shelf life while gaining access to global markets [10]. Consequently, using the right packaging can be essential to preserving the produce's quality and extending its shelf life. Post-harvest losses in quantity and quality complicate fresh produce cultivation and marketing in Ethiopia. Its market potential is dependent on the quality of the fruit and market accessibility, just like it is with other fresh commodities, but the fruit itself is highly perishable. A significant quantity of fruits is lost annually as a result of improper handling, shipping, packing, and storage facilities [12]. Following harvest, fresh produce can be thought of as existing in a living form since it keeps on breathing and transpiring until its food and water reserves run out.

2.1.5. Constraints of mango production in Ethiopia

According to a study conducted by [20], the primary obstacles were access to reasonably priced agricultural inputs, primarily pesticides and fertilizers, followed by disease and pests. Other major challenges include the limited availability of improved varieties, inadequate marketing systems, gaps in knowledge and skills related to pre-production and post-production practices, flower and fruit drop, and the biennial bearing behavior of mango trees. The difficulties mentioned above are comparable to those that mango growers in northern and northeastern Ethiopia have reported. As of [14], a lack of all-weather roads, free-grazing animals, low market prices, diseases and pests, a shortage of land, a lack of irrigation water, an inadequate supply of grafted seedlings, fruit theft, and a lack of access to equipment are some of the factors contributing to the situation. Because it is highly climacteric and extremely perishable, this fruit requires specific post-harvest handling to prolong its storage life. Consequently, it experiences the highest post-harvest losses. Each year, significant quantities are lost due to improper handling, shipping, packing, and inadequate storage facilities.

Post-harvest losses of the same horticultural commodities in Ethiopia's state farm and peasant sectors are estimated to be 25-35% due to a number of factors working together. This significant loss was ascribed to inadequate handling, storage facilities, transportation, and packaging [11].A 30% yield loss in mangoes is estimated to result from incorrect post-handling. Mango damage increased by 30% as a result of post-harvest application and inadequate storage. According to [22], cited by [49], significant quantities of fruits are lost annually as a result of improper handling, shipping, packing, and storage facilities. Inadequate

facilities, skills, and knowledge for planting, harvesting, and handling mangoes after harvest are the primary barrier to Ethiopia's mango production [49].

2.1.6. Post-harvest losses of mango fruits due to improper uses of packaging materials

In sum, as stated by [10], mango fruits are highly perishable; therefore, substantial quantitative and qualitative post-harvest losses happen at various points in the supply chain and storage. Increasing food availability from current output requires reducing post-harvest losses and quality degradation [17]. In Ethiopia, studies indicate that mango losses directly attributable to poor packaging are approximately 2.5%, while overall postharvest losses along the mango value chain reach about 41%. Inadequate packaging also contributes indirectly to mechanical damage and bruising losses estimated at 7.5%. [37].

Through extensive extension education programs, farmers must become more aware of ways to reduce mango post-harvest losses at all levels. Food security, nutrition, and farmer's financial stability are all adversely affected by post-harvest losses.

2.1.7. Causes of Quality Loss

As the research referenced in [18] indicates the mango quality is strongly influenced by both internal and external quality factors and criteria's. Mangoes that show no external damage and meet quality standards are more likely to be accepted by consumers. According to [19], the mangoes great flavor, alluring scent, lovely color, taste, and nutritious qualities are what make it so popular in the global market. The goal of post-harvest handling or treatment is to maximize quality while reducing fruit damage and premature ripening. According to [12, inputs are required at every stage, from picking to the consumer, in order to precisely maintain fruit quality and the storage climate. Maintaining acceptable quality at the consumers' stage requires careful packing and packaging [96]. As of [10], packaging is regarded as a crucial factor in influencing the physiochemical alterations of mango fruit as it ripens. As reported by [14] and [16], packaging's primary functions include protection against mechanical damage, microbial contamination, and WL and reducing respiration rates or postponing ripening [13]. As per the research conducted by [9], there is a strong correlation between a rise in TSS and a decrease in mango firmness.

2.1.8. Role of packaging materials on mango fruit quality and shelf-life stability

As reported by [23], growing public awareness of the issues surrounding plastics, including their use of nonrenewable resources, potential hazards, large environmental accumulation, and contamination, has led to a shift in consumer preferences toward packaging materials that are renewable, biodegradable, and environmentally friendly. According to [1], fruit post-harvest management involves a number of procedures, one of which is packaging.. Packaging is the most important tool for managing highly perishable commodities after harvest. It plays a crucial and indispensable role at various stages of post-harvest handling, primarily aimed at minimizing transportation losses. In addition, appropriate post-harvest handling and packaging are necessary to preserve higher quality, longer shelf life, and access to global markets. As of [28], an attractive package greatly enhances the product's reputation for quality in both home and international markets.. Mango quality and storage life are significantly influenced by various post-harvest procedures. Packaging is commonly used to extend shelf life and reduce post-harvest losses. Other methods include hot water treatment, fungicide dipping, chlorine washing, and calcium chloride washing. The study on mango post-harvest handling and packaging was conducted to reduce post-harvest losses, extend shelf life, preserve quality, and minimize post-harvest diseases.

As of (61), improved packaging practices can lead to extended shelf life, better price realization, and increased consumer satisfaction

Packaging plays a vital role in protecting mangoes intended for market distribution, whether for use, storage, or sale. It involves the process of designing, evaluating, and creating packages to ensure the product remains safe and maintains its quality throughout the supply chain. Products that are frequently packaged include cartons, boxes, cans, bottles, bags, envelopes, wrappers, and containers. Many businesses have started figuring out how to sell their products through better packaging and design in response to the growing demand for packaging. Strong, eye-catching packaging designs serve two purposes: they draw the customer's attention and shield the goods from breakage and damage. Since packaging design is the most effective way

to grab customers' attention, the demand for packaging has been rising rapidly. In addition to branding, your product's packaging design has the power to make or break you in the market. Techniques for guaranteeing that goods are delivered to customers in good condition with the least amount of loss in the art, science, or technology needed to prepare food for storage, transportation, or sealing from the point of production. A scientific and financial function designed to maximize sales points while reducing delivery loss. Packaging is the process of shielding materials from external influences. It involves creating five different types of containers and isolating contents to the same known degree. Food value addition is an essential aspect [98]. According to [98], packing material keeps the pulp firmness, thickness, and peel-to-pulp ratio lower while maintaining the peel. At various stages of post-harvest treatments, packaging is a crucial and vital component that is especially used to minimize transpiration losses [22].

As the study by [96] showed, to preserve higher quality, increase shelf life, and gain access to global markets, proper post-harvest handling and packaging are necessary. Packaging is one of the several phases in the post-harvest treatment of fruits since it is the most essential instrument for handling highly perishable goods after harvest. For improved quality, a longer shelf life, and access to a global market, proper post-harvest handling and packaging are necessary. As of (24) report indicated, the role of packaging was primarily to reduce respiration rate of fruit and vegetables by retarding metabolic activities. As a result, appropriate packaging can be crucial for preserving the produce’s quality and increasing its shelf life.

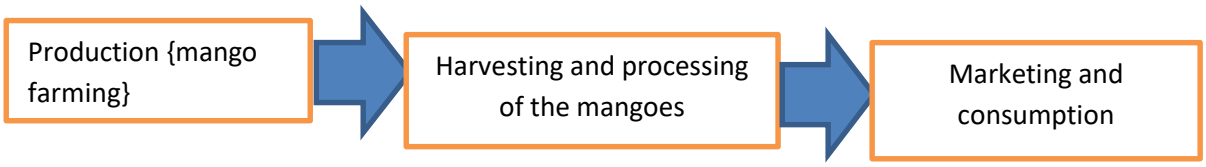
2.1.9. Postharvest Handling of Mango

Post-harvesting is the process of handling fruit as soon as it has been harvested. Picking, field collection, transportation, sorting, grading, packaging, and storage are examples of post-harvest operations. Fruit quality uniformity, fruit free from pests and diseases, and fruit safety are the goals of post-harvest. Due to its climacteric and very perishable nature, which necessitates specific post-harvest management to prolong its storage life, the fruit has the longest post-harvest losses [12].

2.1.10. Value Chain of Mango in Ethiopia

As the study by [26] shows, organizations and coordination issues, strategies, and power dynamics among the numerous chain actors are all included in the concept of a value chain. The phrase "value chain "refers to the full range of activities required to take a good [or service] from its conception through every stage of production, client delivery, and the final disposal. Agricultural input suppliers, mango growers, intermediaries, processors, and service providers are the actors in Ethiopia's mango value chain. According to [18], Ethiopia's mango value chain consists of five primary stages: input supply and production, harvesting and post-harvest marketing, processing, and consumption. Mangoes go through a number of processes in a mango value chain [see figure1 below]. From conception to various stages of processing, the activities require integrating the physical transformation of the mangoes with the inputs from service providers. The process of delivering mango products to end consumers and managing waste disposal is also part of the value chain [19]. Multiple individuals contribute to transforming the mango products from its original form to its final use. The actors include those who provide inputs, those who manufacture the goods, and those who process and use them.. As a result it's critical to carefully schedule and oversee each step of the mango value chain [17].

The flowchart/diagram of the mango value chain is indicated below.



[Source: Mango value chain analysis, 2016]

Figure 1 an example of a basic mango value chain

2.2. Chemical and biochemical changes during ripening and storage

As the study by [24] shows, fruit ripening involves biodegradation processes, primarily caused by hydrolysis enzymes, such as polymerization, substrate utilization, and chloroplast loss. According to [25], these processes also involves various biosynthetic activities, including the synthesis of proteins and nucleic acids, maintenance of mitochondria, oxidative

phosphorylation, formation of phosphate esters, and other metabolic pathway-related synthesis.

2.2.1. Organic acids

As the experiment conducted by [26] showed, about 80–90% of the total acidity in fruits is composed of non-volatile organic acids, with malic and citric acids being the most common. During fruit development, the concentration of total and non-volatile acid decreases, reaching a minimum at the ripe stage. According to [27], the fruit's primary source of respiratory energy is organic acids. In various mango cultivars, citric and malic acids are the most common organic acids; however, tartaric, oxalic, ascorbic acid, and succinic acids have also been identified.

2.2.2. Total Soluble Solid (TSS)

QA Supplies, LLC provides a hand refractometer with a range of 0-45 ^{0} Brix to determine the total soluble solids (^{0} Brix). The percent TSS on the scale was recorded after one or two juice drops were placed on the refractometer prism. 20 ^{0}C was used as a standard temperature to calibrate the reading [28].

3. METHODOLOGY/MATERIALS AND METHODS

3.1. Description of the Experimental Site

The raw material (matured mango fruits) was collected from Kombolcha Woreda, Harar, and also the survey was undertaken in this area. But laboratory analysis was conducted at the FTI Agro-Food Processing laboratory, Addis Ababa, and other related labs.

3.2. Assessment of community perception and attitude on post-harvest loss due to improper packaging materials

Prior to the survey's administration, a conversation was held with the district and zonal agricultural offices to gather pertinent data and identify peasant associations with the potential to produce mangoes. In order to choose the households that produce mangoes, a three-stage sampling procedure was used. Firstly, the primary mango-producing Kebeles were chosen using the purposive sample method. In the second phase, the number of farmers selected from

each kebele was ascertained using probability proportional to size. In the third stage, random sampling was employed to choose the sample of farmers who produce fruits, taking into account the sampling frame that was gathered from each kebele. The determination of sample size was resolved by means of the [29] sampling formula with a 90 percent confidence level (CL).

$$n = \frac{N}{1+N(e)^2}$$

n= sample size for the research use

N= total number of HHs in fruit-producing village going to be selected

e = margin of error at 5

A total of about 210 respondents were assessed during the survey using a semi structured questionnaire survey. Out of these, 198 were males while 12 of them were female respondents. The total population size were 442 households in the fruit producing villages of the kebele. The information was explored in the local language (Afan Oromo) in order to get reliable information by introducing the main aim of the research work to make the respondents confident while responding to the survey questions. Information about the awareness of the community about the impact of different packaging materials on quantitative, qualitative, and monetary loss was assessed.

3.2.1. Visual quality assessment

Subjective visual quality assessment (extent of damage, sap contamination and others) of the fruits was conducted during the survey using participatory approach with the community. Specific scale of measurement for extent of damage (1= No damage, 2 = Less damage 3 = moderate damage, 4 = highly damaged) and for sap contamination (1 = no contamination to 5= highly contaminated) was used to assess these parameters.

3.2.2. Laboratory-based evaluation

In 2024 G.C., the survey and experiment were conducted. For the purpose of the experiment, healthy mango fruits were gathered in and around Harar; those with consistent size, health, and color were chosen. The fruits were thoroughly cleaned, left in 100 parts per million chlorinated

water, and then dried in the shade to eliminate any remaining surface water before packing. The packed fruits were labeled then kept in ambient conditions for storage. Various packaging materials are used to package the fruits. The seven packaging materials/treatments were used in the experiment: T0 = control, T1 = plastic sheet, and T2 = PEB, T3 = PPB, T4 = LDPE. T5 = HDPE bag, and T6 = Carton (CFB).

3.3. Sampling Techniques and Sampling Size

Mango (Mangifera indica L.), locally known as "Amba ererro," was collected from the Harar area based on visual maturity indices. Fruits were carefully selected to ensure uniformity in size, color, shape, and physiological maturity, and only those free from visible defects, mechanical damage, and disease were included in the study.

A total of 1,233 mango fruits, with an overall weight of approximately 240.73 kg, were collected and used for the experiment. From this, 97.33 kg of mango fruits were allocated for chemical analysis, while 143.73 kg were used for sensory evaluation and visual quality assessment. This careful selection and allocation ensured consistency and reliability in evaluating the effects of different packaging materials on fruit quality and shelf life.

3.4. Experimental Design and Treatment Structure

The packaging materials used in this experiment were selected based on their availability and common use at the community level. A total of seven treatments were considered, including a control. The treatments consisted of: Control (T0), Paper Sheet (PS), Perforated Ethylene Bag (PEB), Polypropylene Bag (PPB), Low-Density Polyethylene (LDPE), High-Density Polyethylene (HDPE), and Carton packaging.

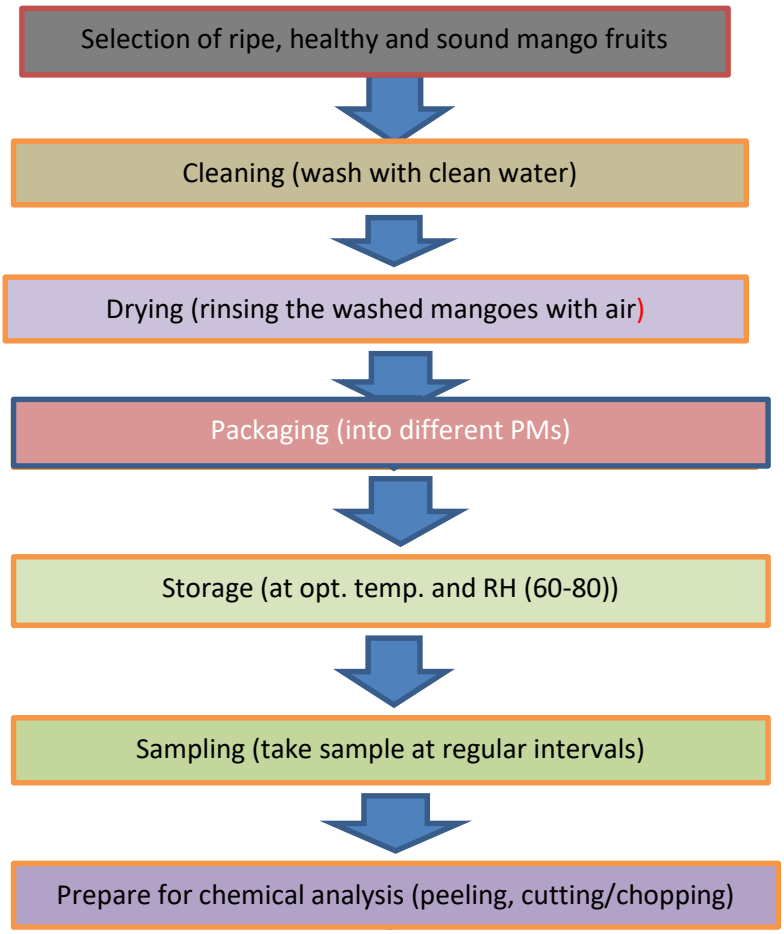
The experiment was laid out using a Completely Randomized Design (CRD) with seven treatments and three replications and there was ten mango fruits per treatment. Each treatment was randomly assigned to an experimental unit within each replication to minimize bias. In total, 21 experimental units were used, calculated as the product of the number of treatments

and replications. Each replication contained all seven treatments, and the assignment of treatments within each replication was completely randomized.

3.5. Experimental Procedures

Mango fruits are harvested from the surrounding areas of Harar and are green in color. Fruit maturity were assessed using uniformly unblemished fruit. Mangoes that were uniformly sized, green, and fresh were gathered from nearby local growers and chosen at random for the experiment. Next, fruits with comparable dimensions, forms, and hues were chosen. To minimize microbial populations on the surfaces and eliminate field heat and soil particles, the hands were cleaned with tap water while wearing gloves. The fruits were divided into different packing materials after being cleaned. Containers made of plastic are rinsed and cleaned. The same day that the cleaned fruits are surface dried, prepackaging and disinfection procedures are carried out. All treatments are placed in the packaging materials for further study/analysis.

Flow diagram of the procedure of mango fruit preparation for chemical analysis (TSS and PH) is summarized in figure 2.below



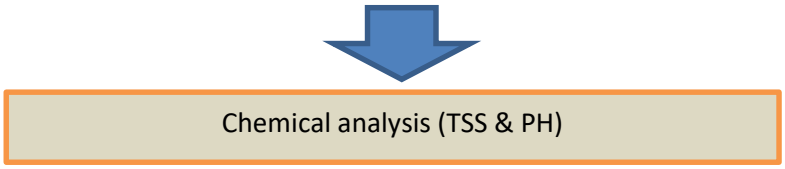


Figure 2 . Summarized flow diagram of the procedure of mango fruits preparation for chemical analysis [10)

3.6. Data Collection and Quality Assessment

Data for the experiment were collected based on physical, chemical, and microbial quality parameters of mango (*Mangifera indica* L.) fruits. Both physical attributes and physicochemical analyses were employed to evaluate the effects of different packaging materials on fruit quality and shelf life.

For each treatment, a random sample of mango fruits was taken at each sampling interval to ensure representativeness. Approximately one kilogram of packaged fruit, or an equivalent amount of unpackaged fruit (control), was randomly selected for analysis. To avoid repeated measurements on the same sample, a fresh set of fruits was used for each sampling date.

The fruits were evaluated at four storage intervals: day 1, day 7, day 14, and day 21. During the storage period, samples were subjected to a range of analyses, including physical, chemical, and microbial assessments.

Freshly harvested mango fruits were packed using seven different treatments: plastic sheet, low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP) bags, polyethylene bags, corrugated fibreboard cartons (CFB), and an unpackaged control. All samples were stored under ambient conditions at a temperature of approximately 25°C and relative humidity of about 60% for a total storage period of 21 days.

Fruit quality was evaluated by measuring key parameters, including physiological weight loss (PWL), firmness, total soluble solids (TSS), pH, disease incidence (DI), disease severity index (DSI), total microbial load analysis (TMLA), shelf life, and overall marketability. These

parameters were used to assess the extent of quality deterioration and the effectiveness of each packaging material in maintaining post-harvest quality.

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Figure 3 Collection of green and matured mango fruits



Figure 4 Dividing mango fruits randomly into different packaging materials (Treatments]

3.7. Physicochemical characteristics

3.7.1. Physicochemical quality

3.7.1.1. Percentage of weight loss

A certain number of fruits were marked at the start of the experiment from each treatment and kept separate for periodic weighing using digital balance (TWIII, USA) to calculate weight loss during storage. Following the method of (48), the percent weight loss was calculated as:

$$\text{Weight loss (\%)} = \frac{\text{Weight of fresh fruit (g)} - \text{Weight after interval (g)}}{\text{Weight of fresh fruits (g)}}$$

3.7.1.2. Pulp firmness

Assessment of firmness is important in the evaluation of fruit susceptibility to physical or mechanical damage or post-harvest handling [58]. When assessing a fruit's vulnerability to mechanical or physical damage or post-harvest handling, firmness assessment is crucial. [66] Mentioned a similar approach. Firmness of mango was determined by hand feeling using a numerical rating scale or system with the specific scale of measurements for the extent of damage, (the 6-point hedonic scale) of **1-6, where 1 = mature hard**, **2 = sprung, 3 = between sprung and eating ripe, 4 = eating ripe** and **5 = over ripe, and 6 = unfit for consumption,** were used to assess these parameter**s.** Fruit softness was measured using a subjective evaluation of whether the mango yielded to thumb pressure [1 = very hard to 5 = overripe] in order to record ripening rates. Assessing pulp firmness is crucial for determining how susceptible fruits are to mechanical or physical post-harvest handling [14]. The firmness of fruit was measured subjectively by hedonic scale (1 = very hard to 5 = overripe), method driven by (18)

3.7.2. Chemical Analysis

3.7.2.1. Total Soluble Solids

The total soluble solids content of the fruits was determined using a hand refract meter (Bellinghama+ Stanley 45-02, UK) and the results will be expressed in ^{0} Brix.

Following the methodology of [32], the Total Soluble Solids ^{0} Brix) were calculated using a hand refract meter (QA Supplies, LLC) with a range of 0-45 ^{0} Brix. The refract meter prism was covered with one or two drops of juice, and the percentage of TSS on the scale was noted.

The measurement was adjusted using a 20 °C reference temperature. The methods outlined by [32] and [33] are used to determine the TSS. Juice was extracted using a juice extractor (Type 6001x, USA) and an aliquot. To measure TSS, place one or two drops of clear juice on the prism of an A tago N hand refract meter, which has a range of 0 to 32^{0} Brix and resolutions of 0.2^{0} Brix. Before being used, the refract meter's prism is dried with tissue paper and cleaned with distilled water in between samples. The refract meter was calibrated using distilled water with a TSS of 0%.

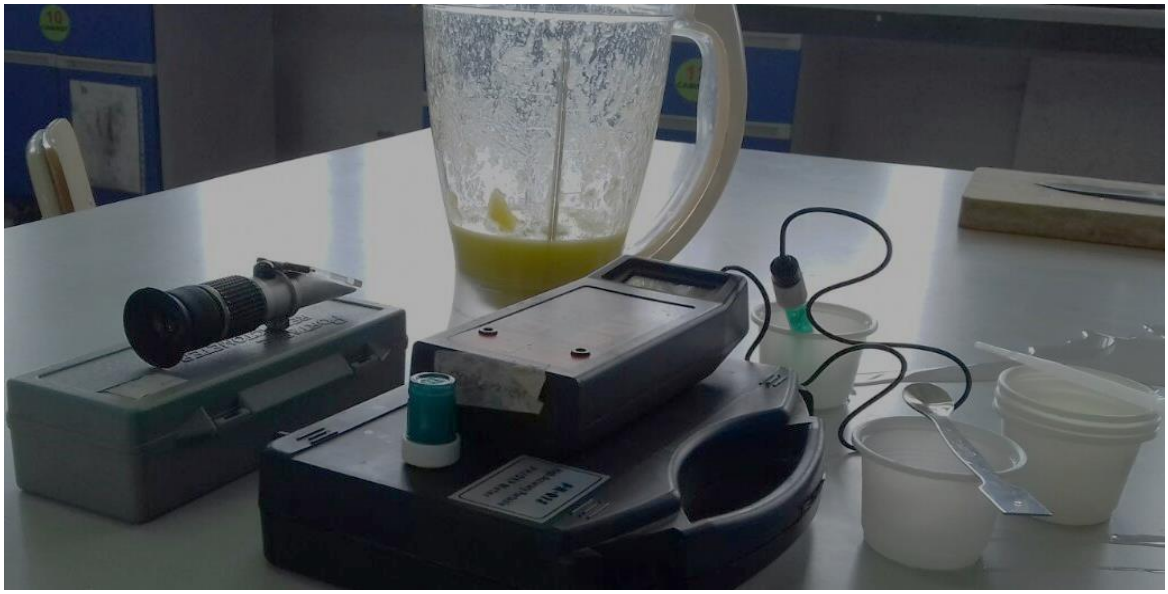


Figure 5 Taking and recording TSS (0 Brix's) of mango fruit sample for lab analysis

3.7.2.2. The PH

The standard procedures were followed to determine the acidity of fresh tissue as a percentage of citric acid [34]. A standard pH meter (CP-50-5) that has been calibrated was used to measure the fruit juice's pH, which is an equilibrium measure of the concentration of hydrogen ions in juice. Using a juice extractor (Type 6001x, USA), mango juice was extracted from the sample, and clear juice was used for the analysis. Juice was extracted using an aliquot, as stated in [35]. Mango juice's pH is determined using a pH meter in accordance with [33] and [35]. Measuring the pH of mango fruit is an important step in evaluating its quality and freshness. The procedure to determine the PH of mango fruit. Analyzing the pH of mango fruit is a crucial

step in determining its freshness and quality. A methodical approach of (71) and (11).was used to ascertain the pH of mango fruit:

Tools required: Mango fruit, a digital or analog PH meter, optional pH buffer solutions, distilled water, optional PH 4.01 and pH 7.00 buffers (recommended for calibration).

First, the mango sample was prepared (Sample preparation)

A ripe and fresh mango fruit was selected. Distilled water was used to wash the mango in order to get rid of any dirt, bacteria, or impurities. A tiny portion of the mango fruit was sliced off about 1 to 2 cm in diameter. Any fibers or seeds were eliminated from the sample. **Second, the mango juice was taken out or extracted using a fruit press or mortar and pestle, by crushing the sample**

The juice was gathered into a sanitized container.

Third, the pH meter was prepared for use

Before using the digital pH meter, ensure it is turned off and properly zeroed. Make sure the analog pH meter is calibrated in accordance with the manufacturer's instructions if you're using one.

Fourth, the pH was calibrated

After extracting the mango juice, the pH meter probe was inserted into it. The probe was allowed to a full 30 seconds to stabilize before taking a reading. A pH reading was obtained from the device. The note of the pH level was taken.

Fifth, the pH meter was calibrated before use

If you are using a digital pH meter, use buffer solutions with pH 4.01 and pH 7.00 to calibrate it. Pay attention to the manufacturer's calibration instructions.

Sixth, the outcome was documented and analyzed carefully to ensure accurate interpretation of the results.

The pH value that was measured and compared with the standard range of pH values for mango fruits, which is usually between 3.5 and 5.5, should your measured value be outside of this range, it might be a sign of contamination or spoiling.



Figure 6 Chopping and slicing mango fruits for lab analysis (TSS and PH a and b) below



Figure 7 Chopping and slicing mango fruits for lab analysis (TSS and PH a and b) below

3.7.1.5. Microbial quality analysis

3.7.1.5.1. Disease incidence

During the storage period, the incidence and severity of post-harvest diseases were evaluated. Different methods were used to identify fungal spoilage, including observing the appearance of rotten fruits. Post-harvest mango infection is affected by orchards sanitation and especially cleaning and pruning that are important to minimize the rate of disease infection [11**].** According to the methodology described by [31**],** once infections had been identified, the numbers of infected fruits exhibiting any one symptom out of the total number of mango fruits sampled were used to calculate the disease incidence. Disease incidence (percentage of diseased fruits), and disease severity (percentage of area affected on the fruit on average) were then obtained. Disease incidence was determined following the method outlined [28), using the following formula:

$$\text{Percentage of disease incidence} = \frac{\text{Number of infected fruits}}{\text{Total number of fruits Assessed}} * 100$$

3.7.1.5.2. Disease severity

The record of disease levels according to the infected surface area on the fruits was observed in order to assess the severity of the disease. Following a methodology of [36], a scale of 1 to 6 was used to measure it, with 1 denoting no infected surface area and 2, 3, 4, 5, and 6 for infected surface areas of >0%–5%, >5%–25%, >25%–50%, >50%–75%, and >75%, respectively. Next, using the following equation, the percent severity index of fungal infection was estimated from the numerical ratings of all the samples combined

As the method described by (33), the record of disease levels on the infected surface area of the fruits were observed to assess the severity of the disease.

$$\text{Percent severity index} = \frac{\text{Sum of numerical ratings}}{\text{Total number of fruit examined} * \text{maximum grade}} * 100$$

3.7.1.6. Total microbial load analysis

The methodology of [31] was used to determine the microbial qualities. For the purpose of determining bacteria and fungi, respectively, twenty-eight grams of nutrient agar and thirty-

nine grams of potato dextrose agar (PDA) were dissolved in one liter of deionized water. Using a sterile pipette, 1 g of each sample was added to a test tube holding 9 ml of deionized water. The sample was then homogenized for 1 minute using a vortex mixer. Up until the 10-5 dilution, serial dilution was maintained. After that, the plates were plated on nutrient agar and PDA and inoculated with 0.1 ml of the 10-5 dilutions. According to [72] methodology, bacterial counts on aerobic count plates was ascertained and counted using a digital colony counter following a 24-hour incubation period at 37°C. Meanwhile, PDA plates were incubated at 30°C for three days [37] until no change in colony numbers was observed. Colony forming units per gram (CFU/g), which represent the total colony count, were converted to microbial load as follows.

$$ML = \frac{N}{VX\ R}$$

Where, ML = Microbial load

N = Number of colonies

V = Value of Dilution

R = Dilution factor (expressed in cell/ml) (4).

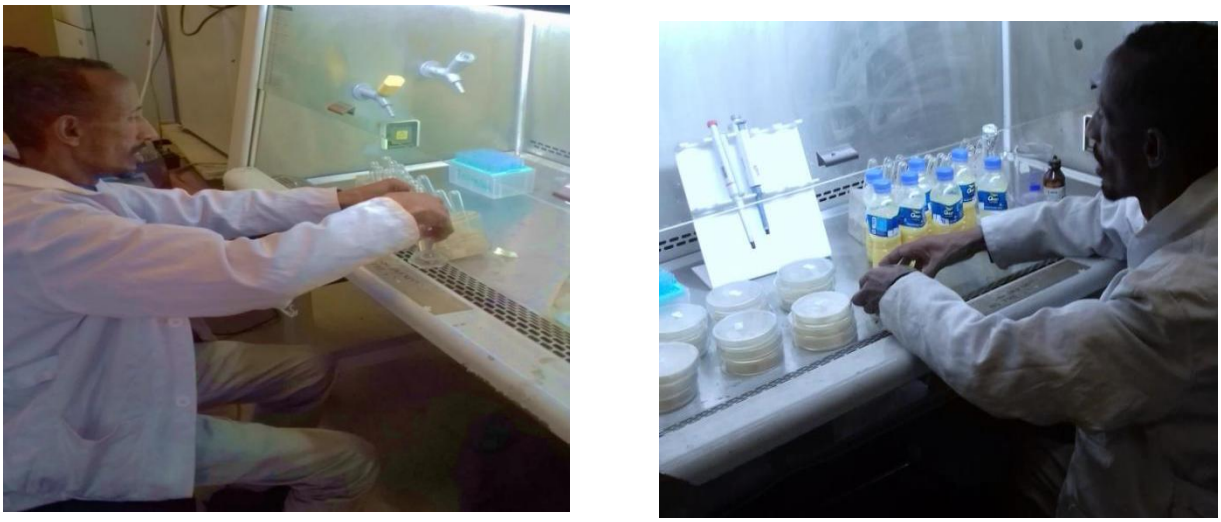


Figure 8 Serial dilution for TPCs and YMCs

3.7.1.6.1 Total bacteria

Determining the Total Bacterial Count (TBC) is crucial to assess the microbiological quality of mango fruit and detect potential spoilage. The number of live aerobic bacteria per milliliter or gram of a product is estimated using the aerobic colony count. The methodology of [31] is the procedure for determining TBC using the serial dilution method.

Equipment needed: mango fruit samples, sterile containers, autoclave or hot air oven, incubator (37°C ± 1°C), agar plates (e.g., Plate Count Agar or Mannitol Salt Agar), micropipettes or loop, sterile distilled water, and pH indicator (optional).

Sample preparation

A fresh, ripe mango fruit was selected. The fruit was cut into small pieces (about 1-2 cm^3) to release the juice. The juice was transferred to a sterile container. Mixed well to ensure uniform distribution of bacteria.

Serial dilution

A series of serial dilutions were prepared using sterile distilled water:

10^ (-1) dilution: 1 mL of sample juice + 9 mL of sterile water

10^ (-2) dilution: 1 mL of 10^ (-1) dilution + 9 mL of sterile water

10^ (-3) dilution: 1 mL of 10^ (-2) dilution + 9 mL of sterile water and so on up to 10^ (-6) dilution

Plating

A 0.1 mL of each diluted sample was transferred to separate agar plates using a micropipette or loop. The inoculum was spread evenly over the plate surface using a sterile spreader or glass rod. Each dilution was repeated

Incubation

The agar plates were incubated at 37°C ± 1°C for 24-48 hours. The growth and colony counts was observed

Colony counting

The colonies were counted by using a stereo-microscope or magnifying glass on each plate.

Using the following formula, the colony-forming units per milliliter (CFU/mL) was calculated for each dilution:

CFU/m: Dilution factor x number of colonies per plate

The overall bacterial count was determined

Add up the CFU/mL values from each dilution to find the total bacterial count (TBC):

TBC = Σ (Dilution factor x CFU/mL)

Results Interpretation

The TBC was examined against the recommended limit (usually less than 10^5 CFU/mL) for mango fruit. Should the TBC surpass the threshold, it might suggest spoilage or contamination.

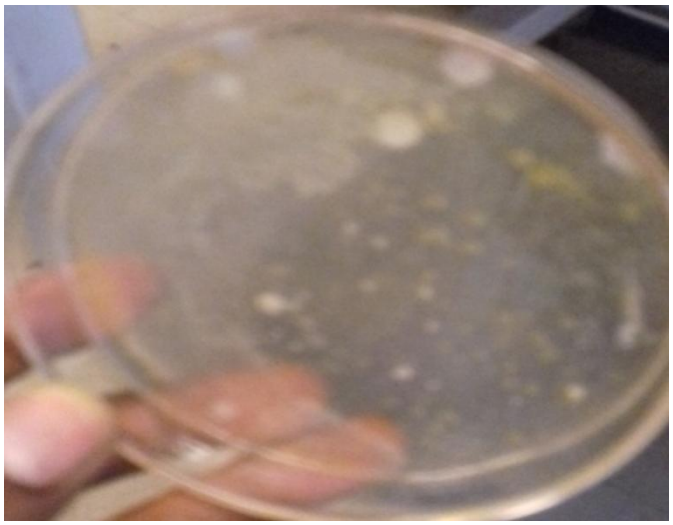


Figure 9. Counting colonies after incubation

3.7.1.6.2. TOTAL FUNGI (TYMC (CFU/g))

Determining the Total Yeast and Mold Count (TYMC) is essential to evaluate the microbiological quality of mango fruit and detect potential spoilage. Here's the step-by-step

procedure for determining TYMC using the serial dilution method. Packaging would, of course, help to prevent environmental microbial propagules from contaminating the fruits. The Total Yeast and Mold Count (TYMC) must be ascertained in order to assess the mango fruit's microbiological quality and identify any possible spoiling. The methodology described by the [72] is used to determine TYMC by serial dilution method in the following step-by-step manner.

The following materials are required: samples of mango fruit, sterile containers, an autoclave or hot air oven, an incubator (25°C ± 2°C), micropipettes or loops, sterile distilled water, and pH indicator (optional).

Sample preparation

A ripe, fresh mango fruit is selected. The fruit was cut into tiny pieces, about 1-2 cm in size to extract the juice. The juice was transferred into a clean container. The juice was mixed thoroughly to ensure even dispersion of microorganisms

Serial Dilution

A series of serial dilutions were prepared using sterile distilled water:

10^ (-1) dilution: 1 mL of sample juice + 9 mL of sterile water

10^ (-2) dilution: 1 mL of 10^ (-1) dilution + 9 mL of sterile water

10^ (-3) dilution: 1 mL of 10^ (-2) dilution + 9 mL of sterile water

and so on up to 10^(-6) dilution

A 0.1 mL of each diluted sample was placed onto individual agar plates using a micro-pipette or loop.

. The inoculum was evenly distributed over the plate surface, using a glass rod or sterile spreader. Every dilution was continued

Incubation

For five to seven days, the agar plates were incubated at 25°C ± 2°C. The colony growth was observed and counted

Colony Counting

The colonies were counted by using a stereo-microscope or magnifying glass on each plate. Using the following formula, the colony-forming units per milliliter (CFU/mL) was calculated for each dilution:

CFU/mL: Dilution factor x number of colonies per plate

The Total Yeast and Mold was Counted

The CFU/mL values from each dilution was added up to determine the total yeast and mold count (TYMC):

TYMC = Σ (Dilution factor x CFU/mL)

Interpretation of the results

The TYMC was evaluated in relation to the recommended limit (usually less than 10^3 CFU/mL) for mango fruit.

If the TYMC value is higher than the threshold, it could suggest spoilage or contamination.

3.8 Storage-life

A determination of storage life was made using the procedures outlined in [38]. Fruits were removed at the first sign of visible wilting after each treatment's fruits were assessed during storage. A fruit was removed one by one until the final fruit which was predicted to vary depending on the treatments was no longer marketable. The following formula was used to calculate the shelf-life index, which took into account the number of fruits that were marketable as well as the amount of storage time.

$$\textbf{Shelf-life index} = \frac{1}{N \sum[(n_i - n_{i+1})d_i]}$$

Where N is the total number of fruits under observation, di is the number of days after storage, and in is the number of marketable fruits on the ith day, and ni+1 is the number of marketable fruits on the (i+1)th day. The amount of time that a packaged good remains marketable or of acceptable quality under particular storage circumstances is known as its shelf life. A product's

shelf life is determined by its initial quality, the degree of quality change that can be tolerated, the state of the environment, the best qualities of the packaging materials, and the compatibility of the food product with the packaging [49]. After being stored for 21 days, the mango finished its shelf life (30% loss) in those days. The shelf life decreases with increasing ethylene release. The longest time for mango fruits stored in poly sheets to reach the end of their shelf life. Mangoes stored in cartons reached the end of their shelf lives before the other. This might be the result of the treatment materials and ethylene's synergistic effects [81]. Mango growers, retailers, and wholesalers must preserve quality and extend the shelf life of their products for export markets. Fruit quality is maintained, and its shelf life is extended with proper packaging and storage temperature. An important first step in extending the mango's shelf life is choosing the right wrapping materials. Fruits are shielded from mechanical damage (such as vibration and compression damage) during handling and transit by wrapping materials. Therefore, using the right wrapping materials at the right temperature is essential. The shelf life decreases with increasing ethylene release. The longest-lasting mango fruits were those stored in poly sheets; mango fruits stored in carton boxes, reached the end of their shelf lives sooner than the other fruits. This might be the result of ethylene and the packaging material's combined effects [81].

3.9. Marketability of mango

A determination of storage life was made using the procedures outlined in (40). This suggests that the predominance of dispersed suppliers, traders, and sellers defined the mango markets. Farmers do not always have timely access to market information. Farmers obtain erroneous price and market information from unofficial sources such as friends, neighbors, and traders; as a result, farmers lack access to stated prices (12). According to the result in (12), 94.3% of respondents said that the interaction between supply and demand determined the price of fruit. This indicates that throughout the process, buyers and sellers' bargain and ultimately decide to swap the goods for the predetermined costs. In this scenario, farmers are compelled to sell their produce at the local market due to the decreasing fruit prices [2]. Fresh mangoes must be marketed correctly in order for the consumer to receive them in optimal condition. This includes using the ideal humidity and temperature levels as well as the right packaging and handling techniques. According to [66], careful handling during harvesting can minimize mechanical damage and decrease waste later on from microbial attack. The most crucial

physical post-harvest management technique is handling and storing products at low temperatures [68]. Mangoes are traditionally packaged using nested packaging; however, the efficacy of these materials has not yet been studied and documented.

Table 2. Market performance of mango in terms of marketing margin with respect to the share of actors in each channel

Actors	Price in Birr	Channel I	Channel II	Channel III	Channel IV
Producers	Selling price	180	160	170	170
	Farmers share	100	80	73.9	77.3
	TGMM %		20	26.1	22.7
Local collectors	Selling prices			195	220
	Margin			25	50
	Mkg margin %			10.9	22.7
	TGMMa%			41.8	100
Retailers	Selling prices		200	230	
	Margin		40	35	
	Mkg margin %		20	15.2	
	TGMMr%		100	58.2	
Final consumer price		180	200	230	220
TGMM			40	60	50

[Source; Survey result, [12]

Fruits were evaluated subjectively in accordance with [39]. The degree of visible mold development, decay, shriveling, or dehydration, as well as the fruit's smoothness and shine, were used to determine the descriptive quality attributes. The following formula was used to determine the proportion of marketable fruits during storage.

$$Maketable\ mango\ fruits\ (\%) = \frac{Number\ of\ marketable\ mango\ fruits}{Total\ number\ of\ mango\ fruits} x\ 100$$

Thus, the current study aims to determine the optimal packaging material and assess the impact of various packaging materials on the shelf-life of mango fruits.

3.10 Data Analysis

Analysis of variance (**ANOVA**) for the parameters was done using Minitab version19, statistical software, and comparison of the treatment means with significant difference was made by the LSD test at a 5% probability level.

The experimental flow chart/diagram or the experimental frame work of the study is summarized below.

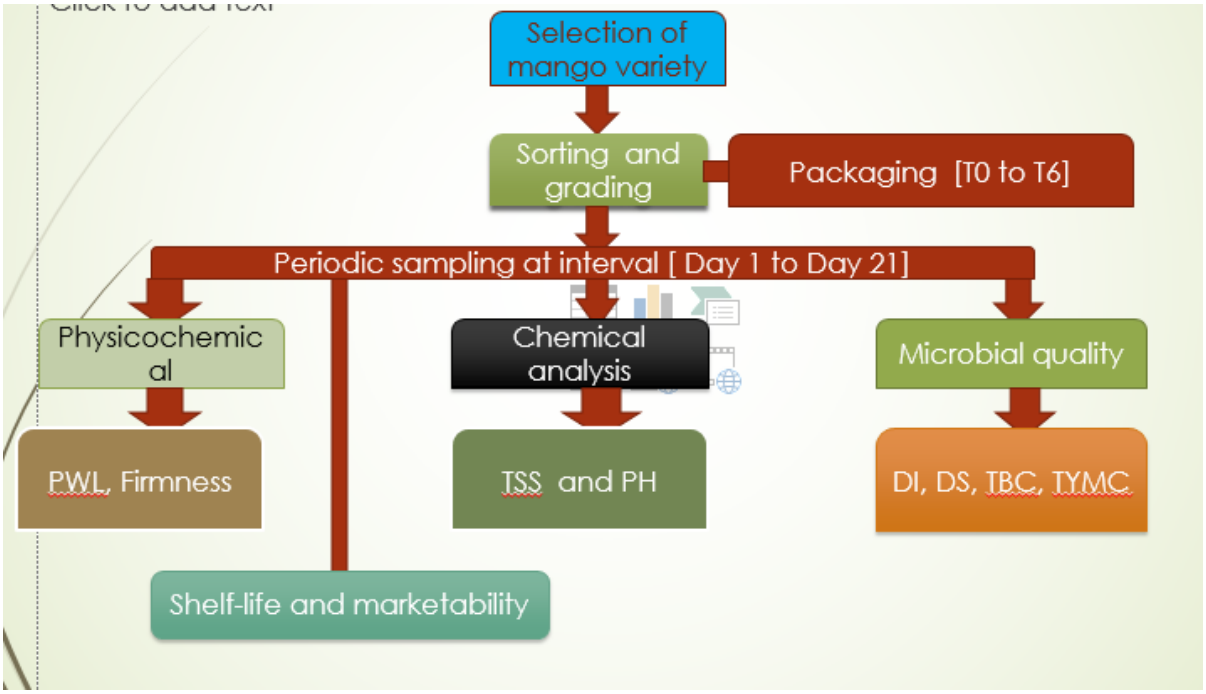


Figure 10. The summarized diagram of experimental frame work of the study [Source: [49]]

4. RESULT AND DISCUSSION

The effect of different packaging material on shelf life and quality of mango fruits was determined in terms of physiological weight loss, firmness, TSS, pH, DI, DSI, TML shelf life and marketability, which were discussed separately in the following section for the packaging period after harvest according to statically results and respondent responses. According to the statistical and respondent responses, the impact of various packaging materials on the shelf-life and quality of mango fruits was assessed in intervals of seven days by measuring the

following parameters: PPWL, firmness, TSS, pH, DI, DS, TMLA, shelf life and marketability, and the outcome made it abundantly evident that any ripening therapy will raise TSS and total sugar while lowering acidity.

4.1. Physiological weight loss (PWL) (%)

The analysis of variance (ANOVA) revealed that there is no a statistically significant difference between the means of the treatment groups except for the firmness retention and TSS values in the initial day [Day 1]. As indicated on Table 5 above, the highest values of firmness, pH, shelf life and marketability were recorded on the initial day, while the minimum values were noticed after 14 days of the storage periods. In addition, the maximum scores of the parameters PWL, DI, DSI, and TMLA were observed at 14 DAS whereas the minimum values were seen at the beginning of the sample taking. The highest firmness was recorded in the treatment T5 with the value of [77.32%], followed by T4 [68.23%] while lowest values were recorded in the control groups, To [32%], followed by plastic sheets [37.57%]. On the first sampling date [initial day], mango fruits were mainly fresh, healthy, and in their natural state, so statistical differences among treatment groups may not be significant.

Table 3. Evaluation of different packaging materials on all parameters of mango fruits during the storage periods of day1 (day zero)

Treatments	**Parameters**							
	PWL	**Firmness**	**TSS**	**PH**	**DI**	**DSI**	**S/L**	**Mkg**
Cl	0.48^{a}	32^{c}	9^{c}	2.04^{b}	24.67^{a}	41^{a}	99.48^{b}	99.71^{a}
T_1	0.07^{a}	37.57^{c}	10^{bc}	2.81^{ab}	26.33^{a}	34.36^{a}	100^{a}	100^{a}
T_2	$0,39^{a}$	$52b^{c}$	14^{ab}	2.96^{ab}	19.67^{a}	28.73^{a}	100^{a}	99.91^{a}
T_3	0.37^{a}	43.67^{c}	13.48^{ab}	2.67^{b}	18^{a}	36.03^{a}	100^{a}	100^{a}
T_4	0.33^{a}	68.23^{ab}	11.61^{abc}	2.74^{b}	20.33^{a}	45^{a}	100^{a}	99.33^{a}
T_5	0.44^{a}	78.65^{a}	12.29^{abc}	2.62^{b}	14.67^{a}	34.36^{a}	100^{a}	100^{a}
T_6	$0,38^{a}$	47.15^{c}	15.53^{a}	3.11^{a}	25.33^{a}	39^{a}	100^{a}	100^{a}
Mean	0.39	51.13	12,27	2.70	21.29	37.45	99.93	99.83
CV	0.07	1.58	0.31	0.44	1.23	2.63	0.22	0.31
LSD (5%)	**NS**	*	*	**NS**	**NS**	**NS**	**NS**	**NS**

CV = Coefficient of Variation LSD = Least Significant Difference NS = Non significant

There was a significant difference ($P < 0.001$) in mango fruit weight loss (WL) among the treatment groups 7 DAS, indicating that at least one group mean differed from the others. The physiological loss in weight (PWL) of the fruits generally increased over the storage period, starting slowly and accelerating over time. As indicated in the table 4 below, mangoes stored in plastic sheets had the lowest PWL (0.07%), whereas the control treatments (T0) had the highest PWL (0.93%). According to [10], this was due to factors such as shriveling, high respiration rates, water loss and physiological deterioration. This finding aligns with the results of [27], who reported that fruit weight loss after harvest is primarily due to water loss. Mango fruits stored in plastic films generally lost the least amounts of weight compared to those stored in the control and other packaging materials. Similar result was reported by the finding of (48), which stated that weight loss of fruits in plastic sheet was by far lower than from unpackaged fruits. The reduced rate of respiration and transpiration in the plastic films likely contributed to the lower weight loss, whereas the higher rates in unpackaged fruits may have caused greater weight loss due to physiological factors like unable to maintain steady humidity levels, increased transpiration rates, and water loss, . In general, fruits stored in plastic sheets lost the least amount of weight compared to mango fruits stored in the control and the remaining package packing materials.

4.2. Pulp firmness

The analysis of variance (ANOVA) revealed significant differences in firmness retention among the various packaging materials ($p < 0.05$), indicating that there is a statistically significant difference between the means of the treatment groups. Fruit firmness gradually decreased over the 21-days of storage periods, with a significantly faster reduction observed in the control group compared to fruits packaged in the rest of packaging materials. The data clearly show that fruit firmness generally decreased as the storage period progressed or advanced. Among the treatments, the highest firmness was recorded in T5 (78.65%), closely followed by T1 (77%), while the lowest value was noticed the control treatment, To (17.33%). Two or three mechanisms have been linked to the softening or loss of hardness during ripening. The first is the conversion of starch to sugar that is soluble. The second occurs when pectic chemicals dissolve and cause the cell walls to break down or the middle lamella to become less cohesive. The third is the osmosis process, which transfers water from the peel to the pulp during ripening [46].

Table 4. Evaluation of different packaging materials on PWL and firmness of mango fruits during the storage period of 21 days

Factor	PWL			Firmness		
Treatments	Storage periods			Storage periods		
	Day7	Day14	Day21	Day7	Day14	Day21
Control	0.93a	1.16a	0.67a	45.33d	34f	17.33[f]
Plastic sheet	0.07d	0.17d	0.25c	77a	70.83b	58.67ab
Polyethylene	0.41bcd	0.40cd	0.90b	71.90b	65.90c	52.80bc
Polypropylene bag	0.61abc	0.74bc	0.92b	65.31c	62.31d	48.98c
LDPE	0.54abc	0.54c	1.00b	64.43c	60.43d	42.77d
HDPE	0.26cd	0.42cd	0.66bc	76.32a	77.32a	59.52[a]
Carton	0.68ab	0.92ab	1.06b	47.15d	40.81e	36.15e
Mean	0.5	0.61	0.78	64.20	59	45.17
CV	0,31	0.35	0,45	2.28	2.75	6.10

CV = coefficient of variation LDPE = Low Density Polyethylene HDPE = High Density Polyethylene PWL = Physiological Weight Loss

4.3. Total soluble solid [0 Brix's)

The ANOVA analysis revealed a statistically significant difference between the means of the treatment groups ($p < 0.05$), indicating that at least one group mean differs from the others. In the control groups. TSS levels increased rapidly, indicating quick ripening without packaging. This rapid increase in TSS in the untreated fruits highlights the importance of packaging in managing the ripening process and maintaining fruit quality during storage. Fruits treated with PPBs had *the* highest TSS value (17.09 ^{0} Brix), followed by fruits treated with cartons (15.53 °Brix), while the control group had the lowest TSS value (11.23 ^{0} Brix at day one). The average values showed that T0 had the lowest Brix score (11.23) at day 1 and the highest (17.09) at day 21. At the end of the storage period, both TSS and PH reached their peaks 17.09 ^{0} Brix and 5.09 ^{0} Brix respectively.

The increasing trend in TSS during the 21-day storage period was due to the biochemical conversion of starch into sugar, the breakdown of cell wall during the ripening process, suppressed respiration, metabolic processes and the oxidative loss of organic acids [2]. In line with the present study, the findings of [9] and [50], confirms that the TSS of fruits increase along the storage time. An initial rise in TSS levels in mango fruits, followed by a decline, was generally observed under ambient storage conditions, regardless of postharvest treatments. As the PH dropped towards the end of the storage period, the TSS in mangoes continued to rise.

Table 5. Evaluation of different packaging materials on the TSS (^{0} Brix's) and PH (%) of mango fruits over 21 days of the storage period.

TSS				PH		
Treatments	Storage periods			Storage periods		
	Day7	Day14	Day21	Day7	Day14	Day21
Control	12.1^{5b}	16.34^{a}	11.23^{c}	2.66^{b}	3.55^{a}	3.47^{a}
Plastic sheet	12.21^{b}	12.21^{b}	12.56b^{c}	3.39a^{b}	4.17^{a}	3.80^{a}
Polyethylene	14.87^{a}	14.87^{a}	15.44^{a}	4.10^{a}	5.09^{a}	4.99^{a}
PPB	16.33^{a}	13.11^{b}	17.09^{a}	3.89a^{b}	3.88^{a}	3.01^{a}
LDPE	12.01^{b}	12.01^{b}	12.01b^{c}	3.33a^{b}	4.49^{a}	3.96^{a}
HDPE	12.29^{b}	11.46^{b}	14.53a^{b}	3.80a^{b}	3.78^{a}	4.04^{a}
Carton	15.53^{a}	15.5^{3a}	15.45^{a}	3.56a^{b}	4.48^{a}	4.33^{a}
Mean	12.77	13.62	14.04	3.53	4.20	3.94
CV	6.24	0.43	0.31	0.66	0.85	19.36
P-value	0.00	0.00	0.00	0.00	0.14	0.47

CV=Coefficient of variation TSS = Total Soluble Solid LDPE = Low Density Polyethylene HDPE = High Density Polyethylene

*Means in the same column by the same letters are not significantly different at P ≤ 0.05. ** Highly significant at 1% level * Significant at 5% level ns = non-significant DAS - days after storage. Mean with the same letter in the same column are not significant different, LSD= least significant difference among treatment. Means that do not share a letter are significantly different.*

As the pH drops to its termination points, the TSS of mangoes steadily rises. Over the course of 21 days of storage, the pH increased considerably among all treatments, although the acidity content showed a diminishing tendency.

4.4. pH of mango fruits

The results show that different packaging materials do not significantly affect the PH levels of mango fruits during storage ($p > 0.05$). The pH level is an important indicator of ripeness and overall fruit quality, with higher pH values indicating more advanced ripening. The highest and the lowest values of mango fruit PH stored at different packaging material was observed in the polyethylene bag T2{5.09} and the control groups To {2.66} respectively as shown in the table 5.above. [8], reported that the PH of mango fruits increased from 3.00 at harvest to 5.33 at the fully ripe stage. Similar to the TSS values, the PH of mango fruits kept for 21 days also increases from the initial day to the last day steadily then after drops slowly throughout the storage periods.

The highest PH values of mango under the ambient storage conditions could be attributed to the faster conversion rate of acids to sugar, due to the faster respiration rates experienced by mangoes during ripening, the development of free acids, the consumption of organic acids during respiration, and pectin hydrolysis [29]. Consequently, as the fruit matured or was stored for longer periods, its acidity decreased, and its PH increased. Mangoes' increasing PH value and ripening process are positively correlated. As a result, as fruit grew more mature or was stored for longer period of time, its acidity decreased and its pH increased [49].

The present study is similar to that of [48 and 7], which stated that the increasing trend in pulp PH could be attributed to acid oxidation during storage, which raises PH, as well as genetic variations between varieties. The acidity thus decreased with advancing maturity or increasing storage duration with a corresponding increase in fruit pH. In general, pH of the mango fruit increased with the advancement of fruit ripening (18).

4.5. Disease incidence (%)

The analysis of variance (ANOVA) results indicated that there is a statistically significant difference in disease incidence among the different packaging materials ($p < 0.05$). The incidence of disease in mango fruits packed in each material was assessed. The fruits were

examined visually to check for microbial infection and rotting. Disease incidence, particularly mold and fungal growth, can severely impact fruit quality and marketability. The results show that the type of packaging material significantly affects the disease incidence of mango fruits during storage. The highest disease incidence was recorded in mango fruits kept in open-ground treatments [89.12%], while the lowest incidence was observed in fruits stored in HDPE packaging [28.82], followed by cartoon treatments with the value of [57.67%]. The HDPE bags has the lowest value of disease incidence due to their moisture and oxygen barrier properties, provide a barrier against external contaminants, offer good protection and air circulation, which helps prevent excess humidity and related diseases [53]. This study is in agree with the findings of [66],which stated that the LDPE bags performed well due to their good barrier against the external contaminants and protections (66). Control groups have the highest disease incidence, with significant mold and fungal growth observed early in the storage period. The control treatments showed the maximum disease incidence because of increased rate of respiration, enhanced metabolic activities, and faster deterioration rates.

In sum, the packaged mango fruits have the highest disease incidence as compared to the open ground treatments over the storage periods of 21 days.

Table 6. Evaluation of different packaging materials on microbial quality during storage periods of 21 days

Disease incidence (%)				**Disease severity (%)**		
Treatments	**Storage periods**			**Storage periods**		
	Day7	**Day14**	**Day21**	**Day7**	**Day14**	**Day21**
Control	43.45^{a}	52.12^{a}	89.12^{a}	42.36^{ab}	53.36^{a}	87.03^{a}
Plastic sheet	32.45c^{d}	30.45^{cd}	34.45^{ef}	34.36^{cd}	35.70^{bc}	36.03^{b}
Polyethylene	33.32^{c}	39.32^{cd}	39.32^{e}	38.02^{bc}	39.69^{bc}	40.69^{c}
PPB	38.48 ^{b}	38.8^{2bcd}	44.82^{d}	38.71^{bc}	41.05^{bc}	47.05^{cd}
LDPE	36.08b^{c}	40.58^{bc}	50.75^{c}	45.08^{a}	41.70^{b}	40.03^{dc}
HDPE	28.82^{d}	32.48^{d}	32.82^{f}	36.53^{d}	35.20^{c}	36.30^{e}
Carton	39.17^{b}	42.33a^{b}	57.67^{b}	46.49^{a}	49.49^{a}	53.57

Mean	35.97	39.44	49.85	39.65	42.31	48.66
CV	0,05	2.05	2.50	1.91	2.83	4

CV = Coefficient of variance PPB = Polypropylene Bag LDPE = Low Density Polyethylene HDPE = High Density Polyethylene

4.6. Disease Severity (%)

The analysis of variance (ANOVA) shows that there is a statistically significant difference between the means of the treatment groups ($p < 0.05$). The results show that the type of packaging material significantly affects the disease severity of mango fruits during storage. Postharvest diseases were the primary cause of quality loss in most mango fruits. Disease severity was measured by counting the numbers of fungal colonies on the surface of the fruits. The number of fungal colonies on the fruit's surface was used to gauge the severity of the disease. Fresh produce, including fruits, can be contaminated by pathogenic microorganisms at various stages, from farm to fork/ table [49]. The number of fungal colonies on the fruit's surface was used to gauge the severity of the disease.

According to the results, the maximum and the minimum values were observed in the control groups (samples) and plastic sheet packaging materials with the value of (87.03%) on day21 of T_0 and 34.36% on Day 7 of T1 respectively. The plastic sheet packaging material has the lowest disease severity because of protect mango fruits from external contaminants, maintain their quality during storage, provided a more favorable environment for mango fruits by maintaining higher humidity levels, and preventing moisture. The magnitude of disease severity was minimum on the packaged samples due to: protect external contaminants, create mild atmosphere around the fruit, and maintain fruit firmness by minimizing transpiration [47]. By calculating the diameter of the lesions and the area that the fungus affected, the severity of the fungal disease was determined [44].

Table 7. The maximum rating scale (1-5) has been used for assessment of the disease severity

Rating scale	Disease percentage
1	1-5
2	5-25
3	25-50

4	50-75
5	75-100

(**Source** [39].

By retaining greater humidity levels and limiting moisture loss, the plastic sheets might have also given mango fruits a more hospitable environment [42]. Moreover, the packaging materials significantly reduced disease severity by minimizing the growth of fungal colonies on the fruit surface.

Overall, during the storage periods of 21 days, the severity of the disease was higher on the control treatments than the rest of packaging materials.

4.7. Total microbial load analysis (TMLA)

The majority of food items require microbiological analysis, which is one of the most important criteria. Using the NMKL reference methods, food product samples were subjected to analysis for fungal count and total plate count (TPC). To attain the accurate numbers of counts on a fruit sample, at least one petri plate should have countable numbers of colonies (between 25 and 250) following the incubation periods of the plates. Here is a table summarizing the Total Bacterial Count (TBC) and Yeast and Mold Count (YMC) for mango fruits packaged with different materials over the storage period (Day 1, Day 7, Day 14, and Day 21) which indicated the corresponding outcomes [Table 8]. The values are presented in terms of microbial load (CFU/g).

Table 8. TMLA (TPCs and TYMCs) of mango fruits packed with different packaging materials over time (21 DAS)

SN	**Treatments**	**TBCs**				**TYMCs**			
		D_1	**D_7**	**D_{14}**	**D_{21}**	**D_1**	**D_7**	**D_{14}**	**D_{21}**
1	**C_1**	$2.5x10^3$	$0.0x10^3$	$5x10^4$	$2.0x10^4$	$3x10^2$	$3x10^{-2}$	$6x10^{-2}$	$4x10^{-3}$
2	**T_1**	$0.5x10^3$	$4.5x10^3$	$3x10^{-3}$	$5x10^{-3}$	$1x10^{-2}$	5x10	2.5x10	0.5x10
3	**T_2**	1.2x10-^{3}	2.4x10-	2x10-^{3}	1.2x10	$0.5x10^2$	$3x10^2$	$3x10^2$	2x10
4	**T_3**	2.8x10	$3.5x10^3$	$4.5x10^3$	$4x10^{-4}$	$1.3x10^2$	2.5x10	$1x10^{-2}$	3.5x10
5	**T_4**	$0.2x10^{-3}$	$2x10^{-3}$	2.5x10	1.5x10	0.9x10	$2x10^{-2}$	2.8x10	2.5x10
6	**T_5**	$3.4x10^{-3}$	5.8x10	0.5x10	$2x10^{-3}$	1.1x10	$4x10^{-2}$	$4x10^{-2}$	$3x10^{-2}$

7	**T_6**	$1.0x10^{-3}$	1.5x10	$2x10^{-3}$	$3x10^{-3}$	0.8x10	$1x10^{-2}$	1.5x10	2x10

(Source: Laboratory result)

During the storage period, the overall microbial load of mango fruits kept in polyethylene bags varied from 2.4 to 3.0 log CFU/Ml. The control samples had the greatest mean mold and yeast counts [6.0 log CFU/g] and the highest bacterial counts of [5.0 log CFU/ml]. The range of the overall mean yeast counts was 4.0 log cfu/g to 6.0 log cfu/g. The international reference level, or threshold, states that the total aerobic bacteria should be between ≤ 10 6 and 10 7. The presence of microbes in high numbers (TVCs >4log10 CFU/mL) is responsible for the spoilage of fruit samples (31). This result was similar with that of (30), which stated that the higher concentration of TPC and TYMC in the fruit samples indicates the contamination of the produces. Among mango fruit samples analyzed, 17.49% of the samples had the total viable bacterial counts while 23.72% had total fungal counts.

According to FAO and WHO guidelines, the findings of the TPC and YMC analysis were within the safe and acceptable range.

4.7.1. Total bacteria (TBCs)

Analysis of variance (**ANOVA**) results indicated significant differences in TBC and YMC among the different packaging materials **($P < 0.05$)**. The results show that the type of packaging material significantly affects the total microbial load of mango fruits during storage. Microbial load, including bacterial and fungal growth, can severely impact fruit quality and safety. The control samples had the maximum mean bacterial counts of 3.7 to 4.2 log10 cfu/ml whereas the plastic sheet treatment had the least bacterial counts of 0.3 cfu/ml. The plastic sheet packaging material has the average bacterial counts between 1.0 log 10 cfu/ml, whereas the carton materials have the mean TBCs of 1.65 to 3.0 log 10 cfu/ml. As a research conducted by (8) indicated, the highest TBCs in the control treatment was due; to physiological deterioration, exposure to the external contaminants, and increased in the TSS contents during ripening as well as extended storage periods. If the TBC exceeds the limit, it may indicate spoilage or contamination. The microbial richness and diversity varied according to the ripening stages of the mango fruits. During ripening, acidity decreases while sugar increases and becomes available to microorganisms.

Overall, the population of bacteria was lower on packaged mango fruits compared to unpackaged mango fruits.

Table 9. SPCs (cfu/ml) of mango fruit samples during the storage periods of 21days

SN	Treatments	TBCs			
		D_1	D_7	D_{14}	D_{21}
1	C_1	$2.5x10^3$	$3.0x10^3$	$3.2x10^4$	$4.2x10^4$
2	T_1	$1.5x10^3$	$2.5x10^3$	$1x10^{-3}$	$3x10^{-3}$
3	T_2	$2x10^{-3}$	$4x10^{-3}$	$3.2x10^{-3}$	1.2x10
4	T_3	1.8x10	$3.5x10^3$	$3.5x10^3$	$1x10^{-4}$
5	T_4	$1.2x10^{-3}$	$2x10^{-3}$	2.5x10	2.5x10
6	T_5	$2.2x10^{-3}$	2.8x10	3.5x10	$3x10^{-3}$
7	T_6	$1.0x10^{-3}$	1.5x10	$2x10^{-3}$	$3x10^{-3}$

(**Source: Laboratory result)**

4.7.2. Total fungus (TYMCs)

The analysis of variance (ANOVA) shows that there is a statistically significant difference between the means of the treatment groups ($p < 0.05$). Determining the Total Yeast and Mold Count (TYMC) is essential to evaluate the microbiological quality of mango fruit and detect potential spoilage. During the storage periods of 21 days, the TYMCs runs from 0.3 to 5.5 cfu/ml and reaches the peak at 8.2 cfu/ml in all treatments. The maximum and the minimum fungal counts were observed in the control samples and the polyethylene bag with the value of (4.7 to 4.9 cfu/g) and (0.27 cfu/g) respectively. The TYMCs of polypropylene bag and low density polyethylene was from 1.3 to 5.5 cfu/ml. Among the different treatments, polyethylene bags is the most effective in controlling the TMC for all mango fruits. Generally, 25-250/30-300 colonies per agar plate were prescribed as the acceptable CFUs/plate for accurate counting. Many bacteria and fungi can cause the post-harvest decay. However, it is well established that the major post-harvest losses of fruit and vegetables are caused by species of the fungi [52]. As outlined by (48), polyethylene bags had the minimum fungal counts due to, protect external contaminants, create mild atmosphere around the fruit, and maintain fruit firmness by minimizing transpiration.

Therefore, polyethylene bags seem to be a promising, feasible, economically sound way, and sustainable solution to maintain post-harvest quality and extend the shelf life of mango fruits.

Table 10. . TYMCs from mango fruit samples over the storage period of 21 DAS

SN	Treatments	TYMCs			
		D_1	D_7	D_{14}	D_{21}
1	C_1	$1.8x10^2$	$3x10^{-2}$	$3x10^{-2}$	$8.1x10^{-3}$
2	T_1	$0.3x10^{-2}$	1.5x10	5.5x10	3.5x10
3	T_2	$1.5x10^2$	$3x10^2$	$2x10^2$	3.3x10
4	T_3	$1.3x10^2$	4.5x10	$3x10^{-2}$	5.5x10
5	T_4	0.9x10	$2x10^{-2}$	1.8x10	2.5x10
6	T_5	1.1x10	$2x10^{-2}$	$3x10^{-2}$	$2x10^{-2}$
7	T_6	0.8x10	$1x10^{-2}$	1.5x10	2x10

(**Source: Laboratory result)**

4.8. Shelf life (days)

The analysis of variance (**ANOVA**) indicates a statistically significant difference between the means of the treatment groups (**$P < 0.05$**), suggesting that at least one group mean differs from the others. The shelf life is defined as the time between harvesting and the final edible stage. According to [62], a product's shelf life is influenced by the initial quality of the food product, the extent of acceptable quality change, current environmental conditions, the protective properties of packaging materials, and the compatibility of the food product with the packaging.. The highest and lowest shelf life of mango fruits during the 21-day storage period were observed in the treatments using plastic sheets (T1) and the open ground treatments (T0), with values of 20 and 1 days, respectively, as shown in the table above.. Following the control groups, the cartoon materials had the lowest effectiveness in preserving the produce. As the study by (29) showed, plastic sheet packaging materials were effective in maintaining the quality and extending the shelf life of mango fruits because of, reduce water loss, protect fruits from external contaminants, delayed ripening and improved firmness retention

Table 11. Evaluation of different packaging materials on the shelf life and marketability of mango fruits 21 DAS

Treatments	Shelf life			Marketability		
	Storage periods (days)			Storage periods (days)		
	Day 7	Day 14	Day 21	Day 7	Day 14	Day 21

Control	8.33[d]	0.5d	0.93[c]	13.00[ab]	5.00[e]	3.33[d]
Plastic sheet	20.00[a]	7.00a	4.00[a]	42.33[a]	37.00[a]	33.00[a]
Polyethylene bag	18.00[ab]	4.00bc	2.00[abc]	29.70[de]	31.00[ab]	28.33[ab]
PPB	16.00[ab]	2.33bcd	1.67[bc]	32.67[cd]	27.67[bc]	24.33[bc]
LDPE	14.33[bc]	2.33bcd	2.00[abc]	26.00[ef]	23.67[c]	21.00[c]
HDPE	17.33[ab]	5.00ab	3.00[ab]	35.33[bc]	34.67[a]	31.67[a]
Carton	11.33[cd]	2.17cd	1.00[bc]	22.67[f]	16.67[d]	6.67[d]
Mean	15.05	3.33	1.90	32.52	23.67	21.19
CV	0.61	0.07	2.24	2.20	1.91	7.50

LDPE = Low Density Polyethylene HDPE = High Density Polyethylene CV = Coefficient of variation

As the storage periods progressed, the shelf life of mango fruits declined and then started to drop gradually. According to [37], the non-marketability parameters, such as bruising, shriveling, damaging, and disease-infected fruits, were evaluated and assessed to ascertain the fruits' shelf life from the time of harvesting to the marketable stage. Mango shelf life is measured by the number of days that the fruit was deemed marketable up until 50% of it was unmarketable. Every day, the fruit is evaluated, and when half of it is deemed unmarketable, it is discarded, and the number of days it took to do so is noted. Because of its impact on physiological activity, which delays the senescence of fruit in storage, lowering the storage temperature substantially extends the shelf life of perishable goods [48].

4.9. Marketability of mango fruits

The ANOVA analysis shows that there is a statistically significant difference between the means of the treatment groups (p-value = 0.033). This suggests that at least one group mean is different from the others. By assessing non-marketability parameters such as bruising, shriveling, damage, and disease infection, the shelf life of the fruits was calculated from the day of harvest to the point at which they could be sold [37]. During the storage periods of 21 days, each sample was examined and the values were recorded at seven day intervals. Mango

fruits packed in plastic sheet packaging material have superior quality characteristics because this material can maintain ideal humidity and temperature during storage [70]. Mango fruits stored in plastic sheets recorded the highest marketability percentages (42.33%) and mean values (37.44), followed by HDPE with a percentage and mean value of 35.33% and 33.89, respectively. The lowest marketability was observed in the open ground treatments, with a percentage of 3.33% and a mean value of 7.11. As the study by (17) showed, the control treatments had the least marketability percentage because of, higher rates of moisture loss, rapid softening, accelerated ripening, and increased disease incidence.

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

Mango [Mangifera indica L.], is one of the most significant commercial crops, commonly referred to as " the King of fruits," is the second most economically important tropical fruit product in the world. It is highly perishable and undergo substantial post-harvest losses as the result of poor handling, and inadequate packaging during storage and transit. The purpose of this study was to assess how various packaging materials: - control, plastic sheet, polyethylene bag, polypropylene bag, LDPE, HDPE, and carton affect the shelf life and quality of mango fruits during the storage period. By evaluating a number of post-harvest metrics, including PWL, firmness, TSS, pH, DI, DSI, TMLA, marketability, and overall shelf life, the experiment intended to identify the best packaging choice for maintaining the quality of mango fruit. All of the recorded parameters showed a significant ($p < 0.05$) difference in the analysis of variance (ANOVA).The control (unpackaged) treatment had the greatest physiological weight loss (0.93%), followed by the carton (CFB) (0, 92%), while the plastic sheet had the lowest weight loss (0.07%). Fruits treated with a PPB had the highest TSS value (17.09 ^{0} Brix), followed by T6 (15.53 ^{0} Brix), while the control group had the lowest TSS value (11.23 ^{0} Brix). Among mango fruit samples analyzed, 17.49% of the samples had the total viable bacterial counts while 23.72% had total fungal counts. The TBCs and TYMCs ranges from 3.07 CFU/ml to

3.08 CFU/ml, which is safe and at acceptable level according to ISO, FAO, and WHO standards.

The untreated mangoes in the control groups had the highest rates of microbial development and deterioration, which led to the shortest shelf life and the lowest marketability. In contrast to unpackaged mangoes, which usually showed dropping TSS and lower pH values because of rapid ripening, moisture loss, and microbial activity, packaged mangoes had shown greater TSS and more stable pH values during the course of storage periods. .

Out of the seven treatments used in this experiment, the plastic sheet seems to be a promising, appropriate packaging material, and sustainable solution to maintain post-harvest quality and extend the shelf life of mango fruits.

In summary, the results indicated that selecting appropriate packaging option can significantly enhance mango fruit shelf-life, and maintain its marketability by reducing physic-chemical, biochemical, and microbial deterioration.

5.2. Recommendations

Based on the key findings of the study, the following recommendations were made or suggested for the future implementations

The stakeholders should adopt suitable packaging options to reduce post-harvest losses and extended mango shelf life. Hence, plastic sheet was suggested as an appropriate packaging material for postharvest handling and storage of mango fruits to maintain quality and extend shelf life. Another crucial area that needs focus is awareness creation, and training for the target groups who are involved in mango production value chains.

Therefore, additional studies and further research investigation should be made at different times so as to produce a definitive suggestion, to generalize findings, and to come up with a conclusive recommendation.

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7. Appendices

Appendix figure 1. Collection of green and matured mango fruits





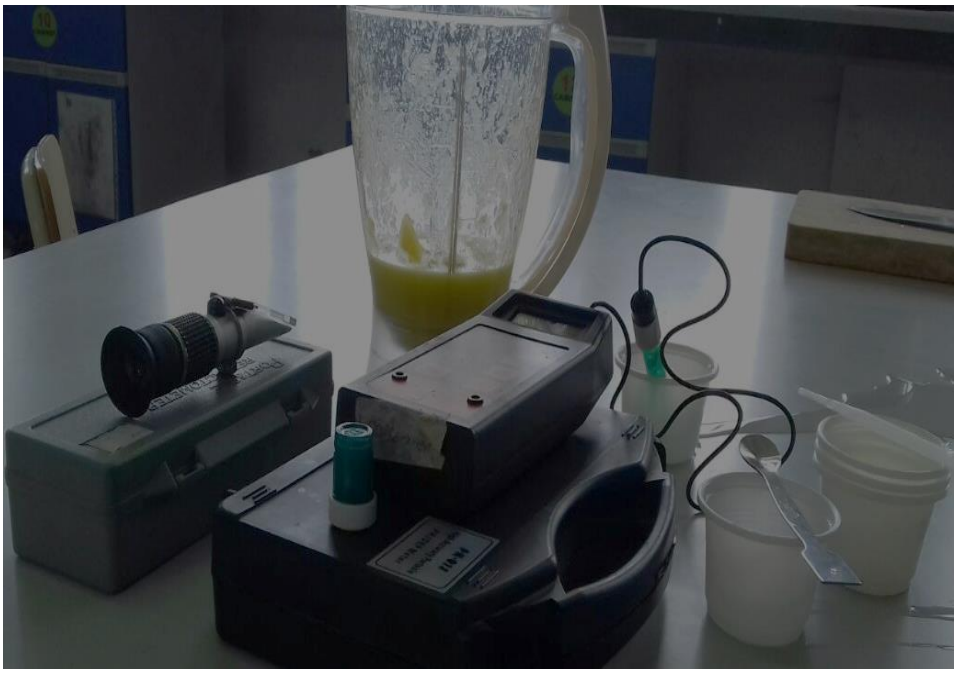
Appendix figure2. Dividing mango fruits randomly into different packaging materials (Treatments).



Appendix picture 3. Chopping and slicing mango fruit for TSS and PH analysis in the lab



Appendix figure 4. Taking and recording TSS (^{0} Brix's) of mango fruit sample for lab analysis



Appendix Figure 5. Measuring and taking the PH of mango fruit sample during lab analysis

Appendix Table 1. Analysis of Variance for PWL of mango fruits

Source	DF	SS	MS	F-Value	P-Value
Treatment	6	1.4582	0.24304	10.74	0.000
Error	14	0.3169	0.02263		
Total	20	1.7751			

Appendix Table 2. Analysis of Variance for firmness of mango fruits

Source	DF	SS	MS	F-Value	P-Value
Treatment	6	3209.34	534.890	143.05	0.000
Error	14	52.35	3.739		
Total	20	3261.69			

Appendix Table3. Analysis of Variance for TSS mango fruits

Source	DF	SS	MS	F-Value	P-Value
treatment	6	63.17	10.5288	14.34	0.000
Error	14	10.28	0.7345		
Total	20	73.46			

Appendix table 4. Analysis of Variance for PH of mango fruits

Source	DF	SS	MS	F-Value	P-Value
treatment	6	4.047	0.6745	3.11	0.037
Error	14	3.034	0.2167		
Total	20	7.080			

Appendix table5. Analysis of Variance for disease incidence (DI)

Source	DF	SS	MS	F-Value	P-Value

treatment	6	429.38	71.563	36.06	0.000
Error	14	27.78	1.984		
Total	20	457.16			

Appendix table6.Analysis of Variance for disease severity index (DSI)

Source	**DF**	**SS**	**MS**	**F-Value**	**P-Value**
treatment	6	830.47	138.412	28.31	0.000
Error	14	68.46	4.890		
Total	20	898.93			

Appendix table 7. Analysis of Variance for shelf-life of mango fruits

Source	**DF**	**SS**	**MS**	**F-Value**	**P-Value**
treatment	6	84.17	14.0278	15.11	0.000
Error	14	13.00	0.9286		
Total	20	97.17			

Appendix table 7.Analysis of Variance for marketability of mango fruits

Source	**DF**	**SS**	**MS**	**F-Value**	**P-Value**
treatment	6	2255.14	375.857	70.47	0.000
Error	14	74.67	5.333		

Sensory evaluation format for mango fruit firmness

The sensory evaluation of different attributes of stored mango was observed according to the opinion of test panel judges which comprises 12 members. This format provides a comprehensive evaluation of the products sensory attributes, including appearance, odor, taste, texture/mouth feel, and overall acceptability. The rating scales allow panelists to provide a subjective assessment of the product's quality and acceptability. Mango fruit firmness determination is a crucial quality control parameter!

A format for mango fruit firmness determination using rating scales and hedonic scales:
Mango Fruit Firmness Determination and Evaluation: Form

SN	Attributes	Rating scales/scores							
1	Mature hard								
2	Sprung								
3	Between sprung								
4	Eating ripe								
5	Over ripe								

Firmness Rating Scale:

1 (Very Soft=over matured)

2 (Soft=eating ripe)

3 (Medium=between sprung and eating ripe)

4 (Firm=sprung)

5 (Very Firm= mature had)

Hedonic Scale:

How would you rate the firmness of this mango fruit?

Rating Scale:

1 (Very Dissatisfied)

2 (Dissatisfied)

3 (Neutral/Indifferent)

4 (Satisfied)

5 (Very Satisfied)

Additional Comments or Suggestions:

_____

_____

_____

Evaluation Criteria:

Firmness: The extent to which the mango fruit yields to pressure when squeezed.

Resistance to compression: The ability of the mango fruit to resist compression when pressed.

Instructions:

1. Select a mango fruit and hold it firmly between your thumb and index finger.
2. Apply gentle pressure to the fruit, increasing the pressure gradually.
3. Evaluate the firmness of the fruit using the rating scale provided.
4. Record your rating on the form.
5. Repeat the evaluation process for each mango fruit sample.

By using both a rating scale and a hedonic scale, you can assess not only the objective firmness of the mango fruit but also the subjective acceptability of that firmness. This can help you better understand how consumers might perceive the product's quality.

Note: You can adjust the rating scale and hedonic scale to suit your specific needs and preferences.

Name:----------

Signature:----------

Date:----------

Sensory evaluation format of mango fruit for DSI

The sensory evaluation of different attributes of stored mango was observed according to the opinion of test panel judges which comprises 12 members. This format provides a comprehensive evaluation of the products sensory attributes, including appearance, odor, taste, texture/mouth feel, and overall acceptability. The rating scales allow panelists to provide a subjective assessment of the product's quality and acceptability. Mango fruit firmness determination is a crucial quality control parameter!

A format for mango fruit firmness determination using rating scales and hedonic scales:
Table 2.3. The disease severity of mango fruit was measured according to the level of infected surface area on the fruit using a 1-6 scale where, **1=not infected, 2=5%, 3=25%, 4=50%, 5=75% and 6. =75-100%**

Treatment	Respondents score					
Control						
Plastic sheet						
Polyethylene bag						
Polypropylene bag						
LDPE						
HDPE						
Carton						

Firmness Rating Scale:

1 (No disease or infection=0%)

2 (Very mild disease= 1-15%)

3 (Mild disease=16-25%)

4 (Moderate disease=26-50%)

5 (Severe disease=51-75%)

6[Very severe disease=76-100%]

Hedonic Scale:

How would you rate the firmness of this mango fruit?

Rating Scale:

1 (Very Dissatisfied)

2 (Dissatisfied)

3 (Neutral/Indifferent)

4 (Satisfied)

5 (Very Satisfied)

Additional Comments or Suggestions:

_____

_____

_____

Evaluation Criteria:

Instructions:

1. Select a mango fruit and then observe the extents of infected areas on the fruit..

3. Evaluate the DS of the fruit using the rating scale provided.

4. Record your rating on the form.

5. Repeat the evaluation process for each mango fruit sample.

By using both a rating scale and a hedonic scale, you can assess not only the objective firmness of the mango fruit but also the subjective acceptability of that firmness. This can help you better understand how consumers might perceive the product's quality.

Note: You can adjust the rating scale and hedonic scale to suit your specific needs and preferences.

Name:----------

Signature:----------

Date:----------