INVESTIGATION OF SOME ESSENTIAL OILS USED IN PRESERVATION AND STORAGE OF BEEF *TSIRE* IN NYLON NET

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DEPARTMENT OF ANIMAL SCIENCE,
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MAY, 2025

DECLARATION

I declare that the work in this dissertation entitled **"INVESTIGATION OF SOME ESSENTIAL OILS USED IN PRESERVATION AND STORAGE OF BEEF *TSIRE* IN NYLON NET"** has been carried out by me in the Department of Animal Science. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this Dissertation was previously presented for another degree or diploma at this or any other Institution.

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Name of student	Signature	Date

CERTIFICATION

This dissertation entitled **"INVESTIGATION OF SOME ESSENTIAL OILS USED IN PRESERVATION AND STORAGE OF BEEF *TSIRE* IN NYLON NET"** by Fatima, TANKO meets the regulation governing the award of Master of Science degree (Animal Science), Ahmadu Bello University, Zaria, and is approved for its contribution to scientific knowledge and literary presentation.

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DEDICATION

This dissertation is dedicated to my late father Alhaji Idris Muhammad Tanko, and my late mother Hajiya Rukaiya Hussaini Idris. To my siblings and Alhaji Shehu Usman Salihu.

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ABSTRACT

This study examines the preservative potential of essential oils extracted from Moringa (*Moringa oleifera*), Clove (*Syzygium aromaticum*), and Sesame (*Sesamum indicum*) for extending the shelf life of beef *Tsire* stored in nylon net.A 4×4 factorial arrangement in a Completely Randomized Design was used, fresh beef samples were purchased from the Animal Product Processing Laboratory of the Department of Animal Science, ABU, Zaria. Moringa, Clove, and Sesame oils were procured from a local herbal pointin ABU Zaria. The beef was sliced into uniform strips, washed, and seasoned with a standard *Tsire* spice mix, including groundnut cake powder, ginger, pepper, and salt. The seasoned meat was skewered and roasted at 160°C for 30 minutes to simulate traditional preparation. Three different concentrations (0.5%, 1.0%, and 1.5%) of each essential oil were prepared and applied uniformly to separate beef *Tsire* samples. The treated samples were stored in sterile nylon net to facilitate airflow while preventing contamination. Control samples (without essential oil treatment) were also stored in nylon net for comparison. Total viable count (TVC), yeast and mold count, and coliform bacteria count were assessed using plate count techniques on nutrient agar, potato dextrose agar, and MacConkey agar, respectively. Oxidative Stability (Lipid Oxidation): The thiobarbituric acid reactive substances (TBARS) assay was used to measure malondialdehyde (MDA) formation, an indicator of lipid oxidation. Sensory evaluation was carried out using semi-trained panelist. The beef *Tsire* samples were monitored for 0-72 hours, with periodic microbial and oxidative analyses to determine the effectiveness of the essential oils in prolonging freshness. The data collected were statistically analyzed using ANOVA (Analysis of Variance) to determine significant differences between treatments. Duncan's Multiple Range Test (DMRT) was applied to compare mean values at $p < 0.05$. Clove oil had the highest levels of alkaloids (87.50 mg/g), total phenol (218.43 mg/g), tannins (186.99 mg TAE/g), and DPPH radical scavenging activity (61.60 µg/ml). Sesame oil also exhibited high bioactive compounds, particularly in flavonoid (189.79 mg QE/g) and tannin (176.23 mg TAE/g) content.The microbial analysis revealed that Clove oil at 1.5% concentration reduced total bacterial count by 33.7% compared to the control (105.25 × 10^6 cfu/g versus 69.75 × 10^6 cfu/g, respectively). Lipid oxidation, measured through malondialdehyde (MDA) levels, was significantly lower in Clove oil-treated samples, showing a 49.3% reduction (20.78 mg/kg) compared to untreated samples (40.95 mg/kg). Sensory evaluations indicated that Clove oil improved overall acceptability, scoring 4.5 out of 5 on a hedonic scale, while control samples scored 3.2. Throughout a 72-hour storage period, samples treated with essential oils exhibited enhanced stability, with Sesame oil maintaining the highest lipid content (24.53%) and Clove oil preserving the highest pH (6.75), indicative of delayed spoilage. The findings suggest that Clove, Moringa, and Sesame essential oils can effectively enhance the microbial safety and sensory quality of beef *Tsire*, providing a natural alternative for meat preservation.

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LIST OF ABBREVIATIONS

CFU:	Colony forming unit
CL:	Clove oil
CN:	Control
DNA:	Deoxyribonucleic acid
EOs:	Essential oils
FAO:	Food and Agriculture Organization
GAE:	Gallic acid equivalent
IAR:	Institute for Agricultural Research
IMM:	Intermediate moisture meat
MAP:	Modified Atmosphere Packaging
MDA:	Malondialdehyde
MO:	Moringa oil
MRS:	de Mann Rogosa and Sharpe Agar
PDA:	Potato dextrose agar
SDA:	Sabaround Dextrose Agar
SDW:	Sterile distilled water
SM:	Sesame oil
SSO:	Specific spoilage organism
TBA:	Thiobarbituric acid
TBARS:	Thiobarbituric acid reactive substances
TVC:	Total viable count

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Cattle meat has long been known for its nutritive composition which could explain why it is being the first-choice sources of animal protein for many people all over the world. Meat has a short shelf life of one day or less at ambient temperature (15-30°C) and a few days using nylon net at refrigerated temperature (0-10°C) due to microbial spoilage of both pathogenic and nonpathogenic microorganisms and/or lipid oxidation (Ogbonna *et al.*, 2012). The intricate interplay of its composition, processing, and storage renders it susceptible to microbial growth and spoilage, particularly when stored at room temperature, vulnerability amplified during the rainy season (Onyeaka and Nwabor, 2022). Once the animal has been slaughtered, the meat is fabricated into whole sale or retail cuts. Trim and other cuts of meat are then further processed and ground. This increases the surface area of the meat which allows the increased adherence and growth of the bacteria (Skandamis and Nychas, 2001). Meat has a complex physical structure and chemical composition that is very susceptible to oxidation (Rather *et al.*, 2016).

Tsire is a meat delicacy in Nigeria being sold or hawked in the open and also because of the innate composition of *Tsire* being rich in proteins and possessing a moderate moisture content, creates an environment ripe for microbial proliferation. This poses a series of challenges to food preservation. Elevated humidity levels and erratic temperature fluctuations during this season provide an ideal breeding ground for a spectrum of microorganisms, including bacteria, molds, and yeasts. These microorganisms can not only compromise the safety of the food but also profoundly affect its quality, leading to a reduction in its commercial viability (Pamplona and Keijman, 2020).

Essential oils are natural, volatile liquid, complex compounds characterized by a strong aroma, rarely colored, soluble in lipid and organic solvents. It could be synthesized by all plant organs,

i.e., buds, flowers, oils stem, twigs, seeds, fruits, root, wood or bark, and are stored in secretary cells, cavities, canals, epidemic cells or glandular trichomes (Bozin *et al.,* 2006). Plant essential oils (EOs) serve as a safe alternative to chemical or synthetic antimicrobials and antioxidants to struggle with the food borne pathogens or spoilage organisms, inhibiting lipid oxidation and thus extend shelf life of ground beef application (Bozin *et al.,* 2006). Meat and meat products are the most palatable of highly nutritive value foods for human being as they are important sources for protein, fat, essential amino acids, minerals, vitamins and other nutrients (Shaltout *et al.,* 2019).

On the other hand, they are considered as an ideal culture medium for growth of many organisms because of the high moisture, the high percentage of nitrogenous compounds, plentiful supply of minerals, some fermentable carbohydrates (glycogen) and of a favorable pH for most microorganisms (Shaltout *et al.,* 2019). Essential oils, derived from botanical sources and renowned for their multifaceted bioactive compounds, are increasingly being explored for their antimicrobial properties. These compounds exhibit an array of inhibitory effects against microorganisms, making essential oils an enticing alternative to synthetic preservatives, which have been associated with health and environmental concerns (Farhadi *et al.*2019).

1.2 Problem Statement

Tsire is a popular ready to eat Nigerian meat product that are commonly hawked in the open, sometimes on a tray. This is a major challenge to its quality and acceptability by urban consumers. Also being a moderate moisture product, their handling and storage may pose some challenges, if it is not immediately disposed after processing, there

inherent compositioncharacterized by high protein content and moderate moisture levels-render it prone to microbial growth and spoilage (Pamplona and Keijman, 2020). Currently, there is poor refrigeration and no organic preservatives that is used to store undisposed *Tsire*. Synthetic chemical preservatives used in foods have been implicated in the increased incidence of diseases such as cancer in consumers. Many studies have shown that the use of synthetic preservatives and chemical additives is leading to intoxication, cancer and other degenerative diseases(Dewan *et al.,* 2024).

This has led to a growing consumer concern and the desire to consume healthier meat products containing natural preservatives and additives instead of synthetic ones. While synthetic preservatives offer a solution to prolonging *Tsire*'s shelf life, their association with potential health risks and environmental concerns necessitates a more sustainable and natural approach. Essential oils, derived from botanical sources and renowned for their bioactive compounds, present a promising alternative (Farhadi *et al.,*2019). This generates the need to look for conservation alternatives that cover the same antimicrobial properties and compatibility with meat.

1.3 Justification of the Study

The increasing demand for sustainable food preservation methods is driven by concerns over synthetic preservatives' health implications and environmental impact (Pamplona and Keijman, 2020). Essential oils, being natural compounds derived from plants, provide a sustainable alternative, its popularity extends beyond local markets, with potential for broader economic implications through exports and cultural tourism (Bolouri *et al.*, 2022).

The ability to extend shelf life and maintain product quality could open up new business opportunities and contribute to the livelihoods of those involved in *Tsire* production. As traditional culinary practices interact with modern scientific knowledge, this study will

seek to bridge the gap between indigenous knowledge and scientific advancements. It will contribute to the growing body of research on natural food preservation methods, opening avenues for further studies and applications (Sasse *et al.,* 2009). They are not only a culinary delicacy but also an integral part of West African culture. The ability to extend its shelf life without compromising its sensory attributes can contribute to the preservation of a cherished cultural tradition. The increasing demand for sustainable food preservation methods is driven by concerns over synthetic preservatives' health implications and environmental impact.

1.4 Aimand Objectives of the Study

Thebroad aimof this study was to determine the effect of essential oils on preservation and storage of beef *Tsire* using nylon net.

However, the specific objectives of the study were to:

1. Determine phytochemical composition of the essential oils
2. Determine chemical composition of fresh beef and *Tsire*from beef preserved in essential oils
3. Evaluate sensory attributes of *Tsire*from beef preserved with essential oils
4. Determine storage quality of *Tsire*from beef preserved with essential oils and stored in nylon net

1.5 Research Hypotheses

The following null hypotheses are formulated to guide the research work and was tested at $p \leq 0.05$ level of significance:

$H0_1$: There is no significant difference in chemical composition of *Tsire* processed from beef preserved with essential oils.

$H0_2$: There is no significant difference in sensory attributes of *Tsire* processed from beef preserved with essential oils.

$H0_3$: There is no significant difference in the storage quality of *Tsire* processed from beef preserved with essential oils stored using nylon net.

CHAPTER TWO

LITERATURE REVIEW

2.1 Background Information

The preservation and storage of meat products have always been a significant concern in the food industry, particularly in tropical regions where high ambient temperatures accelerate spoilage(Ayo *et al.*, 2020). The use of essential oils in food preservation has gained significant attention due to their antimicrobial and antioxidant properties. Essential oils from *Moringa oleifera*, *Syzygium aromaticum* (clove), and *Sesamum indicum* (sesame) have been identified as potential natural preservatives for extending the shelf life of food products, including beef *Tsire*. Beef *Tsire*, a traditional spiced and roasted meat dish, it is highly susceptible to microbial spoilage due to its high protein and moisture content. Conventional preservation methods, such as refrigeration and synthetic preservatives, have limitations, prompting the exploration of plant-derived antimicrobials (Abdallah *et al.*, 2023).

Essential oils are volatile compounds extracted from plants with strong antimicrobial, antifungal, and antioxidant activities. They have been widely studied for their potential to replace synthetic preservatives in meat preservation (El Bayomi *et al.*, 2021). These natural compounds function by disrupting microbial cell membranes, leading to cell death. Additionally, their antioxidant properties help prevent lipid oxidation in meat products, thereby maintaining sensory attributes and nutritional quality (Saxena and Sharma, 2020). Moringa oleifera, commonly known as the drumstick tree, is rich in bioactive compounds such as flavonoids, phenolics, and isothiocyanates, which exhibit strong antimicrobial and antioxidant properties (Ghafoor *et al.*, 2021). Studies indicate that Moringa leaf and seed extracts can significantly inhibit the growth of foodborne

pathogens, including *Escherichia coli*, *Salmonella spp.*, and *Staphylococcus aureus* (Rahim *et al.*, 2023).

In a study by Abdallah *et al.* (2023), the aqueous extract of Moringa leaves at different concentrations (0.5%, 1%, and 2%) was applied to ground beef and stored under refrigerated conditions. The results showed a significant reduction in microbial load and an extended shelf life of the meat. Additionally, Moringa oil has been found to prevent lipid oxidation in meat, thereby preserving flavor and texture (El-Sayed and Youssef, 2019).

Clove oil is one of the most extensively studied essential oils for food preservation due to its high content of eugenol, a potent antimicrobial and antioxidant compound (Imran *et al.*, 2023). Eugenol disrupts microbial cell membranes and inhibits lipid peroxidation, making clove oil effective in preserving meat products (Fajdek-Bieda *et al.*, 2025).

According to a study by El Bayomi *et al.* (2021), the application of clove essential oil on meat products significantly reduced fungal contamination, particularly by *Aspergillus flavus*, which is responsible for aflatoxin production. Furthermore, when combined with other natural preservatives, clove oil has been found to enhance the overall stability and safety of meat products (Reis *et al.*, 2022).

Sesame oil is rich in lignans, such as sesamin and sesamol, which contribute to its antioxidant and antimicrobial properties (Siddiq *et al.*, 2005). Studies have shown that sesame oil inhibits bacterial growth and oxidative degradation in food products, making it suitable for meat preservation (Inanç andMaskan, 2012).A recent study by Rafaathaghighi *et al.* (2024) demonstrated that sesame oil, when incorporated into Aloe vera-based edible coatings, significantly delayed the browning and spoilage of fresh meat products. The oil was found to reduce lipid oxidation and microbial growth, thereby extending the shelf life of the meat stored under ambient conditions.

2.2 Meat and Meat Products

Meat is an excellent source of essential nutrients, particularly high-quality proteins, vitamin B complex, iron, and zinc, making it a preferred dietary component due to its high energy content and nutritional value (Lin *et al.*, 2025). In addition to its high-quality protein content, it is a high energy type of food and it is considered to be the food of choice due to its nutritional value (Jihad *et al.*, 2009). However, meat is also a highly perishable food item, as its rich nutrient profile creates an ideal environment for microbial growth and spoilage (Zahraddeen, 2024; Dotche *et al.*, 2025). Improper handling, temperature fluctuations, and prolonged storage increase the risk of bacterial contamination, necessitating effective preservation techniques to maintain meat quality and safety (Khoder *et al.*, 2025).

Processed meat includes products that undergo modifications such as grinding, chopping, seasoning, heat treatment, curing, and drying to enhance flavor, stability, and shelf life (FAO, 2020). These methods alter the texture, moisture content, and microbial load of meat products, leading to the development of intermediate moisture meat (IMM), which is widely used in space travel, military rations, and portable food systems (Wolter *et al.*, 2000). Dehydration, a common preservation technique, effectively reduces water activity, inhibiting microbial growth and extending storage stability (Moutia *et al.*, 2024). Various traditional dehydrated meat products, including kilishi, kundi, dambu nama, balangu, biltong, jerky, charqui, sire, and pastırma, are widely consumed in different regions for their enhanced shelf life and unique sensory properties (Zahraddeen *et al.*, 2024; Jiang *et al.*, 2025).

2.2.1 Traditional meat products

Traditional meat products play a significant role in food security, cultural heritage, and economic sustenance in many parts of Nigeria and Africa. These products rely on smoking, drying, salting, and seasoning as preservation methods, ensuring extended shelf life, microbial safety, and enhanced flavor (Batt, 2014). Traditional meat preservation methods have been integral to African food systems for centuries, particularly in regions where access to modern refrigeration is limited (Aworh, 2023). By utilizing indigenous processing techniques such as drying and spice-based curing, communities can prolong the availability of protein-rich foods, thereby reducing post-harvest losses and strengthening food security (Owusu-Kwarteng *et al.*, 2024).

In addition to their nutritional benefits, traditional meat preservation techniques are deeply embedded in cultural and economic practices. Shaltout (2024) emphasized that smoking and drying meats are not only survival strategies but also heritage food practices that support rural economies through trade in preserved meat products. Furthermore, the economic significance of these methods extends to local meat processing industries, where products like kilishi and suya contribute to household income generation and employment opportunities (Adeyeye, 2017). However, while traditional preservation techniques effectively inhibit microbial spoilage, maintaining proper hygiene and handling practices remains essential to prevent contamination risks (Chukwurah *et al.*, 2025).

The continued use and improvement of traditional meat preservation techniques can play a pivotal role in sustainable food security. Research suggests that integrating modern food safety standards with indigenous knowledge systems will further enhance the

quality, safety, and marketability of preserved meat products across Africa (Aworh, 2023). Several studies have been conducted on traditional meat product;

Uzeh *et al.* (2006) conducted a bacteriological analysis of *Tsire-Suya*, a popular Nigerian ready-to-eat meat product, to assess its microbial contamination and the effectiveness of spices in inhibiting bacterial growth. The study analyzed raw meat and *Tsire-Suya* samples for total viable count, coliform count, and the presence of pathogenic bacteria such as *Pseudomonas aeruginosa, Bacillus cereus, Staphylococcus aureus,* and *Escherichia coli*. The findings revealed that raw meat exhibited significantly higher bacterial counts than the processed *Tsire*-Suya, suggesting that the heat treatment involved in suya preparation effectively reduces microbial load. However, the study also highlighted that poor handling and packaging practices could introduce post-processing contamination. The research concluded that continuous use of antimicrobial spices such as *Afromomum melegueta, Piper guineense,* and *Capsicum frutescens* in suya preparation is highly beneficial, as these spices exhibited strong antibacterial effects against *E. coli, S. aureus,* and *B. cereus* while enhancing flavor and shelf life.Similarly, Osadebamwen (2015) examined the meat industry development in Nigeria, analyzing consumer preference and the implications of microbial safety concerns on meat processing and distribution. The study found that consumer demand for quality meat is rising, driven by increased awareness of foodborne diseases and nutritional concerns. However, challenges such as poor cold chain management, inadequate hygiene practices, and improper preservation methods continue to affect meat safety. The study emphasized the need for improved traditional preservation techniques, such as smoking, drying, and the use of antimicrobial plant-based compounds, to enhance meat safety and marketability.

2.2.2 Efficacy of smoking and drying techniques in traditional meat products

Oyewole *et al.* (2024) investigated the nutritional composition and preservation efficacy of smoked dried meat processed using the Nigerian Stored Products Research Institute (NSPRI) smoking kiln. The study aimed to determine the impact of traditional smoking methods on nutrient retention, microbial stability, and shelf life. The findings revealed that smoking significantly reduces moisture content and microbial contamination, preserving the protein and fat composition of meat over an extended period. The study concluded that smoking is a reliable preservation method for traditional Nigerian meat products, enhancing their storage stability and microbial safety. These findings support the preservation techniques used for kilishi, kundi, dambu nama, and balangu, where smoking, drying, and spice-based curing contribute to prolonged shelf life and microbial inhibition.

Adeyeye and Oyewole (2016) further evaluated the efficacy of traditional smoking and drying techniques in Nigeria, particularly for kilishi and kundi. Their study found that open-fire smoking reduces bacterial load by over 80% but noted that improper drying conditions could lead to fungal contamination. The authors recommended controlled drying environments and the use of essential oils with antimicrobial properties to further enhance meat safety and preservation.

2.2.3 Preservation of traditional meat products using spices and essential oils

Several studies have emphasized the role of spices and essential oils in extending the shelf life of traditional meat products. Zahraddeen,(2024) explored the antimicrobial effects of plant-based compounds on traditional Nigerian meat products, highlighting the potential of moringa, clove, and sesame oil in inhibiting spoilage bacteria. The study found that moringa (*Moringa oleifera*) and clove (*Syzygium aromaticum*) essential oils

exhibited strong antimicrobial properties, effectively reducing microbial growth in processed meat products. The research concluded that incorporating essential oils into traditional preservation methods could improve the microbial safety of dried and smoked meats, reducing reliance on synthetic preservatives.

Abubakar *et al.* (2022) examined balangu, a Hausa ethnic grilled meat delicacy in Nigeria, and found that high-temperature grilling effectively reduces bacterial contamination. However, the study cautioned that storage conditions post-grilling could lead to microbial recontamination, emphasizing the importance of spices and natural antimicrobials in post-processing preservation.

2.2.4 Consumer preferences and the marketability of traditional meat products

Consumer preference plays a significant role in shaping the meat industry in Nigeria. Research by Osadebamwen (2015) showed that urban consumers increasingly demand high-quality, hygienically processed meat products, influencing shifts towards improved processing techniques. However, economic constraints often limit access to high-quality meat, leading many consumers to rely on traditional preservation methods that balance affordability with food safety. The study recommended government intervention to promote research and investment in traditional meat preservation, particularly through enhanced drying, smoking, and the incorporation of antimicrobial spices and essential oils.

Balangu

Balangu as it is called in Hausa is a traditional meat product known to be prepared from boneless meat of a sizeable cuts sliced open into sheets of 1 cm in thickness and placed on a wire mesh over the red-hot coal to roast. The mixture of garlic, curry powder, ground pepper, salt, stock and groundnut oil are sprinkled over the meat during roasting.

The meat is turned continuously until it is well roasted. The roasting process could last for 2 hours as reported by Kalla *et al.,* (2005) and Bube (2003).

Tsire

*Tsire*in Hausa is a meat cut delicacy comprising of lean meat obtained from semi membranous of camel, sheep, goat and cattle cut into pieces and sliced with a sharp knife. The sliced meat is then staked on an iron rod and heavily' dusted with spices. The spices include; groundnut cake, aromatic spices, stock cube, salt and ginger. The fire is set by burning the fire wood into red hot charcoal before staking the meat for roasting. The roasting is done in a local tukunyha (clay mold heap that as hole "ithin. where the firewood is burnt into hot red charcoals). The fresh meat staked on an iron rod is fixed into the soil around the glowing charcoal to roast as described by Igene and Mohammed (1993) and Uzeh *et al.* (2006).

Biltong

Biltong is originated from south Africa. Its production involves a series of steps including meat preparation, marination, and low temperature drying. The raw meat is tempered or thawed if it is frozen. Selected cuts of meat are then cut into long strips and fat is trimmed to avoid rancidity during subsequent processing and storage. Once the meat strips have been prepared, there are a number of variations of the marination method. Salt is included in the spice mix in each case. Dipping is used in small scale manufacture but tumbling is used by larger producers. The meat can be hung up for drying immediately after dipping in the spices or it could be left resting in the mixture, preferably at refrigerated temperatures, and then removed and dried. (Kassim, 2013).

Kilishi

Kilishi is a dry meat product common in Northern Nigeria. It has a suitable concentration of dissolved solids that binds the moisture in it sufficiently to inhibit the growth of

spoilage organisms, thus it is a ready to eat and convenient meat product that makes handling and marketing of the product convenient for consumers and retailer (Olusola,2012), It is a traditionally, sun dried Nigeria and Saharan African meat product processed using lean beef in combination with plant ingredients. Kilishi contains about 46% meat and54% non-meat ingredients. Finished product of Kilishi contains about 9.8% fibre/ash (Igene *et al.,* 1993). It is usually processed using lean beef or mutton in combination with plant ingredients, principally defatted groundnut cake (tunkusa) (Igene *et al.*, 1990).

Dambu nama **(Meat floss)**

Meat floss/shredded meat is a dehydrated meat product. It is one of the traditional meat-based products popular among Malaysians and the Asian communities (Huda *et al.*, 2012). However, in Nigeria, it is a popular traditional meat product among the Northerners; it has been produced for years and popularly known as Dambu nama (Ogunsola and Omojola, 2008). Due to its low moisture content, meat floss can be kept with no refrigeration without being drastically changed at room temperature storage and it can also be consumed as snacks (Ockerman and Li, 1999). Raw materials such chicken, beef, fish and pork are suitab e for meat floss preparation (Ogunsola and Omojola, 2008; Huda *et al.,* 2012).

It can also be prepared using products from non-ruminant animals such as rabbit and poultry (Abubakar *et al.,* 2011). Preparation of Dambu nama varies within individuals, for instance in Malaysia, its preparation generally starts with steaming of washed meat until it becomes tender.

The meat is then shredded into fine particles and mixed with spices and coconut milk and afterwards the mixture is fried (Huda *et al.,* 2012). Lard of different levels could also be added before frying the mixture (Ockerman and Li, 1999).

2.3 Meat quality

In processed meat, yield is the main quality parameter as it determines the amount of available product for sale and it is therefore of direct economic importance (Aaslyng, 2002). However, consumer evaluation of eating quality is the major determinant of meat quality, with colour, tenderness, juiciness and flavour of meat being the most important elements (Maltin *et al.,* 2003). Meat and meat products are essential components in the diets of human beings; their consumption is affected by various factors. The most important factors are product characteristics (sensory and nutritional properties, safety, price, convenience among others) and consumer and environment related characteristics (psych logical, health, family or educational aspects, general economic situation, climate, legislation among others) (Jimenez-Colmenero *et al.,* 2001)

However, the main source of consumer complaint and the primary cause of failure to repurchase is the variability in eating quality, especially tenderness (Bindon and Jones, 2001). Some of the qualities assessed in meat include: colour, flavour, juiciness, tenderness and texture. Glycogen could also influence juiciness as an increased concentration of glycogen have been reported to increase the juiciness in beef with a normal pH between 5.5 and 5.75 (lmmonen, 2000).

2.3.1 Meat colour

The first impression consumers have of any meat product is its colour which is the utmost importance. The colour of meat may vary from deep purplish-red of freshly cut beef to light gray of faded curd pork (Rockland and Beuchat, 1997). Fortunately, the colour of meat can be controlled if the many factors that influence it are understood. Fresh and cured meat colour depend on myoglobin. They are considerably different from each other in terms of how they are formed and their over stability. Myoglobin is water-soluble

protein that stores oxygen for aerobic metabolism in the muscle. It consists of a protein portion and a non-protein porphyrin ring with a central iron atom. The iron atom is an important player in meat colour.

The defining factors of meat colour are the oxidation (chemical) state of iron and compounds (oxygen, water or nitric oxide) which are attached to the iron portion of the molecule (Kropf *et al.,* 2004). Muscle pigment concentration also differ among animal species. For example, beef has considerably more myoglobin than pork or lamb, thus giving it a more intense colour. Immediately after cutting meat, its colour is turns quite dark. As oxygen from air comes into contact with the exposed meat surfaces, it is absorbed and binds to the iron. The surface of the meat bloom as myoglobin is oxygenated. This pigment, called 'oxymyoglobin', gives beef its bright cherry red colour, consumers associate this colour with freshness (Kropf *et al.*, 2004).

Meat color is often the first quality parameter consumers evaluate when purchasing fresh or processed meat. It serves as a visual cue of freshness, wholesomeness, and shelf stability. The primary pigment responsible for meat color is myoglobin, which, depending on its chemical state, dictates the perceived color of meat (Mancini and Hunt, 2005).

Factors influencing meat colour stability

pH Decline Postmortem: Rapid pH decline after slaughter can lead to pale, soft, and exudative (PSE) meat, while a slow pH decline can cause dark, firm, and dry (DFD) meat (Hughes *et al.,* 2014). Both conditions negatively impact consumer acceptance and marketability.

Temperature Control: Improper cooling, such as cold shortening or thaw rigor, disrupts muscle structure and reduces color stability. Conversely, controlled chilling preserves color by limiting oxidative processes (Ramanathan *et al.*, 2020).

Packaging and Storage: Modified Atmosphere Packaging (MAP) that balances oxygen and carbon dioxide concentrations enhances the stability of oxymyoglobin, while vacuum packaging preserves deoxymyoglobin (Jeremiah *et al.*, 1995).

2.3.2 Meat Tenderness

Tenderness is universally regarded as one of the most critical attributes of meat quality. It is influenced by the structural and biochemical properties of muscle and connective tissue and is closely related to postmortem aging processes (Koohmaraie, 1996).

Structural Components of Meat Tenderness

Myofibrillar Proteins: Postmortem proteolysis of proteins such as titin, nebulin, and desmin by endogenous proteases (e.g., calpains) improves tenderness during aging (Koohmaraie and Geesink, 2006).

Connective Tissue: The content and thermal stability of collagen significantly affect tenderness. Collagen cross-linking increases with the animal's age, making meat tougher in older animals (Purslow, 2005).

Postmortem Processes Affecting Tenderness

Rigor Mortis: Proper handling during rigor mortis can mitigate toughening caused by cold shortening or electrical stimulation (Ferguson *et al.*, 2001).

Enzymatic Activity: Proteases like calpains and cathepsins play a central role in breaking down myofibrillar proteins (Huff-Lonergan *et al.*, 2010).

2.3.3 Nutritional quality of meat

Meat is an excellent source of high-quality protein, essential amino acids and vitamins and minerals, especially iron. Appreciable percentages of vitamins A, D, E, and K as well as low,but relatively constant amount of minerals (in bones) have been reported in meat (Rice, 1998; Zahraddeen, 2024). The eating quality of meat is generally dependent on digestibility, tenderness and flavour (Olomu, 1995). Muscle proteins are more digestible than connective tissue proteins (mostly collagen) and fat. Generally, meat that is easily chewable is considered to be tender (Olomu,1995).

Fat, particularly fat deposits between muscle cells and muscle bundles is of major importance in assigning meat quality grade, though meat quality does not accurately reflect the texture of meat (Lawrie, 1998). As far as meat quality is concerned, perhaps the most important manifestation of the post mortem denaturation of the muscle protein is their loss of water holding capacity, because in practice, it is a more universal phenomenon than discolorations (Lawrie,1998).

2.4 Factors Affecting Meat Quality

Meat quality variables include wholesomeness, processing yield, convenience, consistency, nutrition, appearance and palatability (Kauffman, 1993). Consumers judge quality of fresh meat by colour, presence of exudates and odour. Fresh meat could have a shelf-life of 3-5days under refrigerated condition (≤ 4℃) due to the growth activities of aerobic psychotrophic spoilage microorganisms. A total number of 107 cfu/ml of meat is considered to be the upper limit of microbial acceptability (Lambert *et al.*, 1992). Microbial growth in fresh meat is the primary factor associated with meat quality reduction, spoilage and economic loss. Brewers *et al.* (1995) stated that extended shelf-life and meat product safety require maintaining low microbial numbers during handling and storage of meat.

Studies conducted by Kauffman (1993) indicated that frozen colour of beef remained attractive for three months when stored in the dark but for only three days under illumination. The rate of fading was affected by illumination level, storage temperature, packaging methods and muscle types. Arnold *et al.* (1993) reported that discoloration in steaks which have been bloomed for 48 hours prior to freezing was less than they have been derived from vitamin E supplementation as compared with control steers. The authors stated that lipid and pigment oxidation in the meat were interrelated, thus retarding the breakdown of lipids should result in a similar delay in myoglobin accumulation.

Increased concern over dietary fat led to studies aimed at evaluating the effect of different feeding regimes on carcass quality and flavor characteristics of meat. Schupp *et al.* (1989) reported that carcasses from cattle finished on forage had less subcutaneous fat and less marbling than those from cattle finished on grains. As far as meat quality is concerned, the important manifestation of post-mortem denaturation of the muscle protein is the loss of water holding capacity (Lawrie, 1998).

In Nigeria, most farmers keep livestock in order to dispose or sell them when fully fattened at a high market value. Poultry breeding is solely for commercial purpose. Poultry farmers in the country enjoy all-year round access to markets for their products. These markets exist in various forms. There are daily and weekly live bird markets while others at strategic period over the year, where a large volume of poultry species are required for religious festivals and other festive occasions. Poultry breeding at a small-holder level are mostly a part-time enterprise to argument the family income. Marketing outlets include direct consumers, processors and institutional buyers; hotels, restaurants, cafeterias, supermarkets, hospitals etc hence, marketing channels are normally investigated in relation to a particular or specific area. Poultry marketing is very

important for production in the sense that they provide mechanisms by which producers exchange their poultry and poultry products for cash and other goods and services.

2.5 Meat microbiology

Microbial contamination of meat could lead to its rapid spoilage. This affects the consumers' acceptability leading to economic loss (Fakhruddin *et al.,* 2003). During process and storage, meat is more prone to pigment and lipid oxidation, thus decreasing organoleptic qualities of meat products posing a major problem in the storing of convenient meat products (Pearson *et al.,* 1983; Verma and Sahoo, 2000; Zahradeen *et al.,* 2020). Bacterial safe limit and rate of spoilage depend upon the numbers and types of micro-organisms initially present, the rate of growth of those microorganisms, conditions of storage (temperature and gaseous atmosphere) and characteristics (pH, water activity of the meat) (James and James, 2002). Chemical reactions that cause offensive sensory changes in foods are mediated by a variety of microbes that use food as carbon and energy source.

These organisms include prokaryotes (bacteria), single-celled organisms lacking defined nuclei and other organelles and eukaryotes, single-celled (yeasts) and multicellular(molds) organisms with nuclei and other organelles. Some microbes are commonly found in many types of spoiled foods while others are more selective in the foods they consume. Multiple species are often identified in a single spoiled food item but there may be one species, a specific spoilage organism (SSO) primarily responsible for production of the compounds, causing off-odour and flavour (Ellin, 2007). Within a spoiling food, there is often a succession of different populations that rise and fall as different nutrients become available or are exhausted. Some microbes such as lactic acid bacteria and molds secret compounds that inhibit competitors (Gram *et al.,* 2002).

2.5.1 Yeast

Yeasts are a subset of a large group of organisms called fungi that also includes molds and mushrooms. They are generally single-celled organisms similar in many ways to bacteria except that they are larger. The reproduction of yeast is by budding process that is adapted for life in specialized, usually liquid environments and, unlike some molds and mushrooms, do not produce toxic secondary metabolites. Yeasts can grow with or without oxygen (facultative) and are well known for their beneficial fermentations that produce bread and alcoholic drinks. They often colonize foods with a high sugar or salt content and contribute to spoilage of maple syrup, pickles, and sauerkraut. Fruits and juices with a low pH are another target, and there are some yeasts that grow on the surfaces of meat and cheese. For instance, 'brown spot' sometimes seen on vacuum-packaged meat six-eight weeks old is caused by yeast (Smits and Brul,2005: Kurtzman, 2006).

2.5.2 Moulds

Moulds are filamentous fungi that do not produce large fruiting bodies like mushrooms. Its growth on-foods is usually identified by the whisker-like or 'fuzzy' appearance of the growth mass. Moulds grow from spore, but they can also grow if any part of the growth mass is transferred to a suitable surface. Molds are very important for recycling dead plant and animal remains in nature but also attack a wide variety of foods and other materials useful to humans. They are well adapted for growth on and through solid substrates, generally produce airborne

spores, and require oxygen for their metabolic processes. Most molds grow at a pH range of 3 to 8 and some can grow at very low water activity levels (0.7-0.8) on dried foods. Spores can tolerate harsh environmental conditions but most are sensitive to heat

treatment. An exception is Byssochlammys, whose spores have a D value of 1-12 minutes at 90℃. Different mold species have different optimal growth temperatures, with some able to grow in refrigerators. They have a diverse secondary metabolism producing a number of toxic and carcinogenic mycotoxins. Some spoilage molds are toxigenic while others are not (Pitt and Hocking, 1997).

2.5.3 Bacteria

These are single-celled organisms. The reproduction of bacteria is by cell division. Given favourable conditions, the generation time (the time between consecutive divisions) for some species of bacterial is less than 20 minutes, thus resulting in a rapid increase in numbers, that is, a rapid growth rate. Under favourable conditions, there can be more than a hundred-fold increase in numbers in just two hours. Bacterial growth is controlled by creating conditions unfavorable for rapid reproduction. Spore-forming bacteria are usually associated with spoilage of heat-treated foods because their spores can survive high processing temperatures. Bacteria have an overriding importance to the meat industry and the factors which affect and control growth of bacteria similarly affect the growth of other types of microorganisms. (Fankhauser, 2004)

2.6Meat Preservation and storage

Meat preservation refers to the techniques used to extend the shelf life of meat by preventing spoilage due to microbial growth, enzymatic activity, and oxidation(Omojola *et al.*, 2019). The traditional methods of meat preservation include drying, smoking, and salting, while modern approaches involve refrigeration, freezing and the use of preservatives (Ologhobo and Akpan, 2012).Meat Storage on the other hand involves keeping meat under controlled conditionssuch as temperature, humidity, and packaging—to maintain its freshness, safety, and nutritional quality over time (Okpala, *et al.*, 2021).

Food spoilage refers to the deterioration of food due to microbial growth, enzymatic action, or oxidation, leading to undesirable taste, odor, texture, and appearance (Omojokun, 2013) while food safety is the act of ensuring food is handled, prepared, and stored in ways that prevent contamination and foodborne illnesses (Okpala *et al.*, 2021) in order to extend the shelf life of the food product. The shelf life refers tothe period during which a food product remains safe and retains its desired qualities under recommended storage conditions (Ologhobo and Akpan, 2012). This can be achieved through cold chain management involvinga temperature-controlled supply chain that maintains the safety and quality of perishable foods during storage and transport (Okpala *et al.*, 2021) or the use of preservatives which are basically substances used to inhibit microbial growth, delay oxidation (a chemical process that causes fats in meat to become rancid, negatively affecting taste, color, and quality (Omojokun, 2013) and extend shelf life; these can be natural (e.g., plant extracts) or synthetic (Ologhobo and Akpan, 2012).

2.6.1 Importance of Meat Preservation and Storage

Meat is a highly perishable food product due to its high moisture and protein content, which makes it susceptible to microbial spoilage, lipid oxidation, and enzymatic degradation. The deterioration of meat affects its sensory attributes, nutritional value, and safety, leading to economic losses and health risks (Yang *et al.*, 2025).

Meat preservation refers to the application of various techniques to prevent spoilage, extend shelf life, and maintain the safety and quality of meat products. Preservation methods inhibit microbial growth, slow enzymatic activity, and reduce oxidative deterioration, ensuring meat remains suitable for consumption over time (Yang *et al.*, 2025) while meat storage encompasses the environmental conditions and methods used to keep meat fresh and safe for extended periods. Effective storage practiceshelp retain the

sensory attributes, nutritional value, and microbial safety of meat products (Peng *et al.*, 2025).

Meat preservation and storage has been reported to extend shelf life of meat product by inhibiting microbial activity and oxidative reactions, ensuring meat remains consumable for longer, which is crucial in areas with limited refrigeration (Ologhobo and Akpan, 2012) thereby enhancing food safety by helping to prevent foodborne diseases as achieved by reducing the growth of pathogens such as *Salmonella* and *Escherichia coli* (Okpala *et al.,* 2021). The positive effects of meat preservation and storage has been reported to reduce food wastage and economic losses as it minimizes spoilage, cutting financial losses for farmers, retailers, and consumers (Omojokun, 2013). Its role in supporting food security by extending the usability of meat has also been reported as preservation helps ensure a steady supply of protein-rich food sources (Ologhobo and Akpan, 2012).Various preservation and storage methods have been developed to extend the shelf life of meat, including traditional methods such as drying, smoking, and salting, as well as modern approaches like refrigeration, freezing, vacuum packaging, and the use of natural preservatives (Rahman *et al.*, 2023).

Furthermore, traditional methods of meat preservation and storage have been used for centuries, particularly in regions without refrigeration. Meanwhile, modern techniques such as refrigeration, freezing, vacuum packaging, and the use of natural preservatives have emerged as more efficient means of preserving meat. Preservation methods like freezing and vacuum packaging has a role to play in maintaining nutritional value as they can to help retain essential nutrients in meat, ensuring its health benefits are preserved (Okpala *et al.,* 2021) there by facilitating trade and export. Effective storage and

preservation enable the transportation of meat over long distances, boosting trade opportunities (Omojokun, 2013).

2.6.2 Perceptions of Meat Preservation and Storage

Perceptions of meat preservation and storagevary based on cultural, economic, and technological factors such as traditional against modern methods; with many Nigerian communities relying on smoking and drying due to affordability, but urban areas are increasingly adopting refrigeration (Ologhobo and Akpan, 2012). The use of natural preservatives as againstsynthetic ones is becoming prevalent because consumers are becoming more cautious about synthetic preservatives which hasled to greater interest in plant-based alternatives (Okpala *et al.*, 2021).

Several factors have been attributed to the choice of method (s) of preservation such as;economic considerations as high refrigeration costs were implicated as the major reason that make traditional preservation methods more common in low-income areas (Omojokun, 2013).The cultural and religious beliefs of a people also influence preservation methods as theyare often aligned with storage choices (Okpala *et al.*, 2021).More often than not, awareness and education is another factor that determines the choice of preservation methods as greater knowledge of food safety can shift perceptions toward adopting more effective preservation techniques (Ologhobo and Akpan, 2012).

2.6.3 Role of Natural Extracts in Meat Preservation and Storage

Meat preservation and storage play a crucial role in ensuring food safety, reducing waste, and maintaining nutritional value(Yang *et al.*, 2025). While traditional methods remain popular, there is a gradual shift towards modern techniques influenced by economic factors, consumer awareness, and technological advancements. Adapting preservation

methods to local contexts is essential for improving food security and public health(Peng *et al.*, 2025).

Recent studies have explored the use of bioactive compounds from plants. These plants-based compounds are rich in essential oils which have been reported to improve meat preservation due to their antimicrobial and antioxidant properties (Egbebi and Seidu, 2021).

Ezekiel *et al.* (2020) investigated Moringa oil extract's role in preserving processed chicken thighs. In the study, moringa oil was applied to the meat samples stored under refrigeration and found a significant reduction in microbial load and lipid oxidation, leading to an extended shelf life. Similarly, Ibrahim *et al.* (2021) analyzed Moringa seed oil's effect on processed meat and reported that its high levels of oleic acid and tocopherols played a critical role in preventing oxidative deterioration.

Valarezo *et al.* (2025)assessed clove essential oil's antimicrobial effects on raw beef. Meat samples treated with clove extract exhibited reduced bacterial counts of *Salmonella* and *Escherichia coli* over 10 days, this he attributed to eugenol's strong antibacterial properties while Wang *et al.* (2022) encapsulated clove essential oil in beta-cyclodextrin metal-organic frameworks (β-CD-MOFs) for Chinese bacon preservation, significantly reducing microbial growth and lipid oxidation.

Oboh *et al.* (2018) studied thyme essential oil's efficacy in preserving raw chicken meat. The experiment involved dipping chicken samples in thyme oil solutions before refrigeration. The results showed that thymol and carvacrol, key components of thyme oil, effectively inhibited spoilage microorganisms, extending shelf-life while maintaining meat quality.

Gouveia *et al.* (2016) explored rosemary essential oil's effect on bacterial contamination in fresh beef. Treating beef slices with varying concentrations of rosemary extract

significantly reduced spoilage bacteria while maintaining sensory qualities such as color and texture. The preservative role of rosmarinic and carnosic acids in rosemary was highlighted.

Fernández-López *et al.* (2022) investigated oregano essential oil's preservative effects on minced lamb meat. The study showed a significant reduction in *Listeria monocytogenes* and *Staphylococcus aureus* populations, attributed to carvacrol's antimicrobial activity.

Goni *et al.* (2021) evaluated lemongrass essential oil's role in extending pork shelf-life. The study demonstrated that the treated meat samples exhibited a lower total viable count and maintained sensory attributes over 14 days of storage.

Kumar *et al.* (2019) studied cinnamon essential oil's antimicrobial efficacy in poultry meat storage. Results indicated that cinnamaldehyde-rich cinnamon oil significantly inhibited *Campylobacter* and *Listeria* growth, ensuring microbial safety during refrigeration.

Shan *et al.* (2020) examined basil essential oil's potential in preventing lipid oxidation in stored beef patties. The study concluded that basil oil treatment reduced peroxide values and maintained oxidative stability for up to 12 days.

Rahman *et al.* (2023) investigated ginger essential oil's antioxidant and antimicrobial activities in frozen meat preservation. The findings revealed that ginger oil slowed oxidative degradation and prevented spoilage bacteria growth, making it a viable natural preservative

Chen *et al.* (2023) studied the combined effects of super-chilling and multiple essential oils on beef preservation. The synergistic effect of oregano, thyme, and rosemary extracts extended shelf life up to 24 days, reducing microbial spoilage and oxidative rancidity.

2.7 Essential oils

Essential oils are highly aromatic and volatile compounds obtained from various plant parts, including flowers, roots, bark, leaves, seeds, fruits, and even entire plants through processes such as steam distillation, cold pressing, or solvent extraction (Raut and Karuppayil, 2014;Bakkali *et al.*, 2008). Their diverse chemical composition, primarily consisting of secondary metabolites like terpenes, phenols and aldehydes, contributes to their broad applications in medicine, cosmetics, perfumery, and food preservation (Egharevba and Kunle, 2019; Hyldgaard *et al.*, 2012). Historically, essential oils have been used in traditional medicine for their antimicrobial and therapeutic properties, with their application expanding significantly in the 19th century as demand grew in the fragrance and food industries (Kamatou *et al.*, 2008;Burt, 2004). Currently, over 3,000 essential oils have been identified, with approximately 300 being commercially utilized in various industries worldwide (Teixeira *et al.*, 2013;Shaaban *et al.*, 2012).

The demand for natural food preservatives has increased due to consumer concerns over synthetic additives and their potential health risks. Essential oils (EOs), extracted from various aromatic plants, have gained attention in the food industry for their antimicrobial, antioxidant, and antifungal properties. Their ability to inhibit microbial growth, reduce oxidation, and maintain food quality makes them viable alternatives to conventional preservatives (Chen *et al.*, 2025).

Several studies have demonstrated the effectiveness of essential oils in inhibiting bacterial and fungal growth in meat storage. According to Nordin *et al.* (2025), cinnamon, clove, and star anise essential oils exhibited strong antifungal activity against *Aspergillus flavus* and *Aspergillus niger* when applied to chili paste, suggesting their potential use in meat preservation. The study found that these essential oils significantly inhibited fungal growth and maintained food safety for up to 15 days under refrigerated

conditions.Similarly, Peng *et al.* (2025) investigated the antibacterial properties of cinnamon essential oil encapsulated through electrostatic adsorption. Their study demonstrated that cinnamon oil effectively inhibited *Staphylococcus aureus* and *Escherichia coli* in pot-stewed duck meat, extending its shelf life while preserving its sensory attributes. These findings suggest that encapsulated essential oils can enhance food safety by providing sustained antimicrobial activity.In another study, Ben Miri (2025) provided a comprehensive review of essential oil compositions, highlighting compounds such as eugenol, cinnamaldehyde, thymol, citronellol, limonene, and geraniol exhibit potent antimicrobial activity. The study emphasized that these compounds disrupt microbial cell membranes, leading to cell lysis and death.

EOs were also reported to mitigate against yeasts and molds in meat storage. Yeasts and molds are significant contributors to meat spoilage, especially when antibiotics and synthetic preservatives are not used. Nurzyńska-Wierdak and Walasek-Janusz (2025) studied the biological activity of oregano (*Origanum vulgare*) essential oil and found that its high concentration of carvacrol and thymol effectively inhibited spoilage yeasts such as *Saccharomyces cerevisiae* and *Zygosaccharomyces rouxii* in meat-based food products. Their study demonstrated that even at low concentrations, oregano essential oil significantly delayed yeast growth and improved the stability of stored meat.Similarly, Hari *et al.* (2025) investigated the antifungal potential of thyme and oregano essential oils in preventing aflatoxin contamination. Their study found that *Aspergillus parasiticus*, a common aflatoxin-producing fungus, was unable to synthesize aflatoxins (*B1* and *G1*) when ground oregano and thyme extracts were introduced to the growth environment. These findings highlight the potential of essential oils in reducing mycotoxin contamination in stored meat.

The synergistic effects of essential oil components on antimicrobial efficacy is often enhanced when their compounds interacts.Karaca *et al.* (2025)reported that essential oils rich in phenolic compounds, such as clove and thyme oil, exhibited superior antibacterial effects compared to terpenoid-based oils. Their study suggested that combinations of eugenol, thymol, and carvacrol exerted enhanced inhibitory effects on foodborne pathogens like *Listeria monocytogenes, E. coli,* and *Klebsiella pneumoniae*.Additionally, Mehrnia and Sharifat (2025) demonstrated that nano emulsions of coriander essential oil, combined with *Aloe vera* extracts, significantly improved the antibacterial activity of coriander oil against *Salmonella spp.* in meat storage. This study highlights the potential of nano-encapsulation techniques in enhancing the stability and antimicrobial properties of essential oils for meat preservation.

The mechanism of actions ofessential oils is to act as antimicrobial agents due to their lipophilic nature, allowing them to penetrate microbial membranes and disrupt cellular function. Guo *et al.* (2024) found that cinnamon oil exerted strong antimicrobial effects by altering the integrity of bacterial membranes and interfering with ATP production. Their study showed that the application of cinnamon oil to minced meat products significantly reduced bacterial growth without affecting the meat's sensory properties.Similarly, Carvalho *et al.* (2024) investigated the antimicrobial mechanism of oregano and thyme essential oilsand their findings indicated that these oils compromised the structural integrity of microbial membranes, leading to leakage of intracellular contents and eventual cell death. The study emphasized that essential oils with higher concentrations of thymol, carvacrol, and eugen**ol** exhibited the strongest antibacterial effects.

2.7.1 Importance of Essential Oils

Essential oils' significance extends beyond sensory applications due to their bioactive properties(Chouhan *et al.*, 2017). As secondary metabolites, they serve as plant defense compounds, exhibiting antimicrobial, antiparasitic, insecticidal, antiviral, antifungal, and antioxidant activities (Tajkarimi *et al.*, 2010;Burt, 2004). The antimicrobial efficacy of essential oils was first documented by De la Croix in 1881, laying the foundation for subsequent research on their broad-spectrum antibacterial effects (Oussalah *et al.*, 2007; Hyldgaard *et al.*, 2012). Studies have further highlighted their antiparasitic (Ogbuagu *et al.*, 2020), insecticidal (Regnault-Roger *et al.*, 2012), and antiviral activities (Schnitzler *et al.*, 2011;Sharma *et al.*, 2020). The antifungal potential of essential oils has been validated in numerous studies (Oboh *et al.*, 2018), while their antioxidant properties contribute to their application in oxidative stress prevention and food stabilization (Brenes and Roura, 2010;Sharifi-Rad *et al.*, 2020).

Beyond their therapeutic applications, essential oils have gained prominence in agriculture and the food industry(Catani *et al.*, 2022).

Their natural antimicrobial properties have increased their potential alternatives for enhancing food safety and preservation, reducing the reliance on synthetic preservatives (Tongnuanchan and Burt, 2004;Benjakul, 2014).

Furthermore, essential oils have been explored as growth enhancers in animal production, promoting improved feed efficiency and overall health (Brenes and Roura, 2010). Their natural origin and multifunctional bioactivities align with the increasing demand for clean-label and sustainable agricultural practices, making them viable alternatives to synthetic additives (Sharifi-Rad *et al.*, 2017; Catani *et al.*, 2022)

2.7.2 Components of some plant's essential oils

Essential oils (EOs) are composed primarily of terpenes, phenolic compounds, aldehydes, ketones, and esters, each contributing to their distinct aroma, bioactivity, and preservation potential (Aly *et al.*, 2025). The composition of an essential oil is influenced by various factors, including the plant species, geographical location, extraction method, and storage conditions (Heredia-Bátiz *et al.*, 2025).

The major classes of compounds in essential oils that determine their preservation efficacy, antimicrobial potency, and oxidative stability includes:

1. Terpenes and Terpenoids; terpenes and terpenoids form the largest chemical class in essential oils, classified into monoterpenes, sesquiterpenes, and diterpenes based on the number of isoprene units they contain.

- Monoterpenes (C_{10}) include limonene, α-pinene, and myrcene, they arefound in citrus, pine, and eucalyptus oils. These compounds exhibit antioxidant and antimicrobial activities that help in food preservation (Aly *et al.*, 2025).
- Sesquiterpenes (C_{15})include β-caryophyllene and humulene, which provide strong antibacterial effects a;gainst spoilage organisms (De Lacerda Leite *et al.*, 2021).
- Diterpenes (C_{20}) are less volatile but contribute to the stability and therapeutic effects of essential oils (Heredia-Bátiz *et al.*, 2025).

2. Phenolic Compounds: Phenolic compounds in essential oils are responsible for antioxidant and antimicrobial properties.

- Eugenol (found in clove oil) has been shown to inhibit *Listeria monocytogenes* and *Escherichia coli*, making it a strong candidate for meat preservation (Menon and Garg, 2001).

- Thymol and carvacrol (found in thyme and oregano oils) disrupt bacterial cell membranes, reducing microbial contamination in food products (Mihaylova *et al.*, 2025).
- Vanillin (from vanilla beans) is effective in preventing yeast spoilage in fruit-based products (Bakryi *et al.*, 2025).

Aldehydes and Ketones

- Cinnamaldehyde (from cinnamon oil) has potent antimicrobial properties against foodborne pathogens and is widely used in food preservation (Bakry *et al.*, 2025).
- Citral (from lemongrass oil) has strong antibacterial activity, particularly against Gram-positive bacteria like *Staphylococcus aureus*(Gutiérrez-Pacheco *et al.*, 2023b)

Esters and Alcohols

- Linalool and geraniol, found in lavender and rose oils, exhibit antifungal properties and contribute to the stability of stored foods (Liu *et al.*, 2020).
- Benzyl acetate, commonly found in jasmine oil, contributes to its pleasant fragrance and acts as a mild antimicrobial agent (Bakry*et al.*, 2025).

Ismail *et al.* (2001) found that using a solution made of 100% sage (Santolina sp.) or thyme dramatically decreased the number of *Yersinia lipolytica* on chicken. Manderfeld *et al.* (1997) reported on the antimicrobial activity of furocoumarins in parsley against *Listeria monocytogenes*, *Escherichia coli*, and spoilage bacteria

Cloves have phenolic compounds and their EOs have considerable anti-listeria activity. These EOs include eugenol, cinnamaldehyde, thymol, citronellol, limonene, and geraniol. Essential oils (EOs) with concentrations between 50 and 500 ng/ml were more effective at killing *Staphylococcus aureus*, *E. coli*, and *Klebsiella pneumoniae* than those with concentrations lower than 50 ng/ml. This was the case for clove, cinnamon, cardamom,

thyme, tea tree, marjoram, ho leaf, and sage. A key component of vanilla beans, vanillin, significantly inhibits spoilage yeast in apple puree, including *Saccharomyces cerevisiae*, *Zygosaccharomyces rouxii*, and *Debaryomyces hansenii*(Cava-Roda *et al.*, 2010).

Li *et al.* (2024)found that cultivating garlic stunted the development of Candida, Cryptococcus, *Thodotorula torulopsis*, and Trichosporon. *Aspergillus parasiticus* can't make aflatoxins (B1 and G1) if ground oregano and thyme and their extracts are added to the growth environment. At pH 5.5, thymol and carvacrol completely stop the growth of *Aspergillus flavus*, *Aspergillus niger*, *Geotrichum candidum*, Mucor spp., and Penicillium spp. on potato dextrose agar (Akgul and Kivanc, 1988). Inhibition of *Aspergilus parasiticus* growth and aflatoxin generation by concentrations of 0.02, 0.2, 2.0, and 20% cinnamon, respectively (Bullerman, 1974). Essential oils from spices can hinder the recovery of heat-injured yeasts by damaging structural and metabolic enzymes (Vandana and Barua, 2023). Because of their lipophilic nature, the compounds found in EOs have antibacterial properties that can be used to attack the membrane's integrity, reduce the cell's energy supply, and cause significant damage to the cell's outer membrane or plasmic membrane (Lambert *et al.,* 1992). Essential oils high in phenolic compounds have better antibacterial effects than terpenoids, as reported by Masyita *et al.* (2022). However, even very small elements might contribute through their synergistic interactions with one another. Sage, some types of thyme, several varieties of oregano, and clove have been found to have antibacterial properties (Liu *et al.* 2017).

2.7.3 Method of extraction of essential oils

The method of essential oil extraction plays a crucial role in determining its chemical composition, purity, and application potential in food preservation. The primary extraction techniques include steam distillation, solvent extraction, cold pressing, and

advanced methods like supercritical fluid extraction (SFE). Each method has distinct advantages and limitations, influencing the final essential oil properties (Khan *et al.*, 2023).

- Steam Distillation; Steam distillation is the most commonly used method for essential oil extraction, utilizing steam to release volatile compounds from plant material. The process involves passing steam through plant material, carrying essential oil vapors into a condensation system where they are separated from water (Ashaq *et al.,* 2024). This method is efficient for extracting heat-stable essential oils but may lead to partial degradation of heat-sensitive compounds, affecting the oil's bioactivity and aroma (Gonçalves *et al.*, 2025).

- Cold Pressing (Mechanical Expression); Cold pressing, primarily used for citrus essential oils, involves mechanical pressure to rupture oil glands in the plant's peel, releasing essential oils. This method preserves thermally sensitive bioactive compounds such as limonene and linalool, making it ideal for applications requiring high antioxidant activity ((Moraga-Babiano *et al.*, 2025)). However, it is limited to oil-rich plant materials and may yield lower concentrations of essential oil compared to other methods.

- Solvent Extraction on the other hand utilizes organic solvents such as ethanol or hexane to dissolve essential oils from plant materials, followed by solvent evaporation to obtain the final extract. This method is effective for heat-sensitive compounds and produces highly concentrated extracts (Egharevba*et al.*,2019). However, residual solvent traces and changes in the chemical composition due to solvent interactions can affect essential oil purity and safety for food applications (Ashaq *et al.*, 2024).

- Supercritical Fluid Extraction (SFE); The Supercritical CO_2 extraction is an advanced method that uses supercritical carbon dioxide to dissolve essential oils, allowing efficient extraction at lower temperatures while preserving delicate bioactive compounds. Studies have shown that SFE yields higher purity essential oils with enhanced antioxidant and antimicrobial activity compared to steam distillation (Ashaq*et al.*, 2024). This method is environmentally friendly and free of solvent residues, making it suitable for food and pharmaceutical applications.

It is however noted that the choice of extraction method influences the chemical profile, purity, yield, and bioactivity of essential oils. For yield the supercritical fluid extraction (SFE) and solvent extraction generally produce higher yields than steam distillation and cold pressing (Ashaq *et al.*, 2024). The chemical composition tends to be altered withsteam distillation due to the loss of thermolabile compounds, while solvent extraction can introduce undesirable chemical residues (Gonçalves *et al.*, 2025). In terms of antimicrobial and antioxidant activity, SFE-extracted essential oils retain higher bioactivity due to minimal thermal degradation, making them ideal for applications in food preservation (Ashaq*et al.*, 2025). The environmental impact was also assessed and it was discovered that solvent extraction poses higher environmental and health concerns compared to steam distillation and SFE, which are considered greener alternatives ((Moraga-Babiano *et al.*, 2025)).

2.8 The Useof Essential Oils (EO) for Meat Preservation

EOs have long been used as flavoring agents in food and beverages(Oussalah *et al.*, 2006). They are secondary metabolic products of plants and are utilized in numerous spice and food industry applications due to their diverse content of antimicrobial and antioxidant compounds, as they have the potential to serve as natural food preservatives

(Oussalah *et al.,* 2007). However, their effectiveness as food preservatives depends on factors such as minimum inhibitory concentration (MIC), target microbial spectrum, mode of action, and interactions with food matrix components (Hyldgaard *et al.,* 2012). When tested against different EOs and different microorganisms (Oussalah *et al.*, 2006b), the minimum level of inhibitor ranged from 1 mM for active compounds to 3% for less active compounds. Inhibiting the growth of pathogenic bacteria and expanding food's shelf life by using EOs as natural antibacterial agents is a novel idea. Das *et al.* (2022) stated that mustard oil may be used for meat marination and preservation to extend the shelf life of refrigerated meat rather than soybean and flax seed oils. The pattern of EOs in the mustard oil might reduce the microbial load more effectively, and it is recommended that mustard oil be used in the preservation of raw broiler meat in refrigerated storage.

A thorough understanding of these parameters ensures their optimal integration into food systems without compromising sensory properties or product stability.Russo *et al.* (1998) found that each variety has a unique physiological and biochemical form, with enzymatic mechanisms that are coded in its DNA and guide biosynthesis by forming its parts in a certain way. Commonly, they are concentrated in a single region, such as the leaves, bark, or fruit, and when they occur in different organs of the same plant, they frequently have distinct chemical identities. Due to their diverse content of antimicrobial compounds, EOs have the potential to serve as natural food preservatives (Conner and Beuchat, 1984). Terpenoids and phenolic compounds are the most common active compounds in EOs (Oussalah *et al.,* 2007).

Among such extracts, *Moringa oleifera, Syzygium aromaticum* (clove), and *Sesamum indicum* (sesame) oil have gained attention for their effectiveness in extending the shelf life of meat products (Meireles *et al.*, 2020)

2.8.1 Moringa

Moringa oleifera, commonly referred to as the drumstick tree or horseradish tree, is a fast-growing, drought-resistant plant belonging to the Moringaceae family. It is native to the sub-Himalayan regions of India, Pakistan, and Bangladesh but is widely cultivated in tropical and subtropical regions, including Nigeria (Leone *et al.*, 2015). Due to its nutritional and medicinal properties, moringa has gained global recognition as a superfood and a potential raw material for pharmaceutical, cosmetic, and food industries (Meireles *et al.*, 2020).

Various parts of the plant such as leaves, seeds, bark, roots, and flowers are utilized in traditional and modern medicine. The seeds, in particular, are known for their high oil content, which is comparable to conventional vegetable oils such as olive oil ((Adeyemi *et al.*, 2021b)

Moringa is highly valued for its rich bioactive composition, including vitamins, minerals, proteins, and polyphenols, which contribute to its antioxidative, antimicrobial, and therapeutic properties (Gopalakrishnan *et al.*, 2016). Its antioxidant activity helps to reduce lipid oxidation, which is a key factor in meat spoilage. Studies by Mashau *et al.* (2021)have shown that the inclusion of *Moringa* extract in meat products significantly reduces microbial load while maintaining nutritional quality.

Its essential oil is composed of oleic acid, α-pinene, β-caryophyllene, eugenol, and flavonoids, contributing to its medicinal and preservative qualities (Angane *et al.*, 2022). The oil is also rich in phytosterols, polyphenols, and terpenoids (Yu, 2025).

Moringa oilis extracted via cold pressing or solvent extraction methods. The oil is rich in monounsaturated fatty acids (primarily oleic acid),as the rich composition of oleic acid is

up to 75% and an omega-9 fatty acid that has been linked to heart health and anti-inflammatory effects (Glew *et al.,* 2008). It also contains significant amounts of antioxidants such as vitamin E and carotenoids, which help reduce oxidative stress and protect cells from damage. The strong antioxidant properties,makes it beneficial for preventing aging and promoting skin regeneration thus its use in cosmetics for its moisturizing and anti-aging benefits, improving skin elasticity, and treating skin conditions like acne and eczema (Anwar *et al.*, 2007).

Moringa oil is also known for its nutritional value when used in food. It is high in healthy fats and has been used in the preparation of salads, sauces, and dressings, particularly in traditional medicine (Glew *et al.*, 2008). Tocopherols, sterols, and phenolic compounds also contributes to its stability and bioactivity (Shahbaz *et al.*, 2024). Studies have shown that moringa oil exhibits remarkable oxidative stability, making it suitable for long-term storage and industrial applications (Núñez-Gastélum, 2023). The chemical composition of moringa essential oil includes key bioactive compounds such as flavonoids, phenolics, and glucosinolates, which are responsible for its antimicrobial, anti-inflammatory, and antioxidant effects (Kashyap *et al.*, 2022). Additionally, the presence of phytochemicals such as quercetin and kaempferol enhances its efficacy as a natural preservative (Pareek *et al.*, 2023). Fekadu *et al.*(2017) reported that moringa oil has been shown to exhibit antimicrobial activity against a range of bacteria and fungi, which supports its use in wound healing and as a natural preservative in food products. Rahim *et al.* (2023) investigated the antibacterial efficacy of *Moringa oleifera* seed oil against *Escherichia coli*, *Staphylococcus aureus*, and *Pseudomonas aeruginosa*. The study found that moringa oil exhibited strong antibacterial properties, attributed to its high concentration of isothiocyanates and phenolic compounds. The results suggest that moringa essential oil can serve as a natural antimicrobial agent for food preservation and medical

applications. In a study by El-Sayed and Youssef (2019), moringa oil was incorporated into dairy products to evaluate its ability to prevent oxidation. The findings showed that the moringa oil effectively reduced lipid oxidation, maintaining the freshness and nutrient composition of stored dairy products. This suggests that moringa essential oil can be a potential natural preservative in food storage and processing. Al-Ghanayem *et al.* (2022)reported that moringa oil possesses significant anti-inflammatory and wound-healing properties. The oil has been traditionally used in treating skin infections, burns, and inflammatory conditions due to its ability to reduce oxidative stress and enhance cellular repair.

2.8.2Clove

Clove (*Syzygium aromaticum*) is an evergreen tree belonging to the Myrtaceae family, native to Indonesia but cultivated in various tropical regions, including Madagascar, Sri Lanka, and India. Clove buds are widely recognized for their strong aroma and medicinal properties (Rahman *et al.*, 2023).The primary bioactive compound in clove oil is eugenol, which accounts for 70–90% of the oil's chemical composition (Burt, 2004). It also contains β-caryophyllene, and eugenyl acetate with other notable constituents being acetyl eugenol, vanillin, methyl salicylate, and flavonoids (Batiha *et al.*, 2020)which has gained attention for its preservative potential in meat products.Eugenol has been shown to possess potent antibacterial, antifungal, and antiviral properties (Shan *et al.*, 2007).Traditionally, clove has been used in food, cosmetics, and pharmaceutical industries due to these antimicrobial, antioxidant, and anti-inflammatory activities (Shan *et al.*, 2020).

Clove oil is extracted from the dried flower buds of *Syzygium aromaticum*. However, essential oils can also be obtained from its leaves and stems, although bud-derived oil is

of superior quality due to its higher eugenol content (Liñán-Atero *et al.*, 2024). The essential oil composition varies depending on the part of the plant used, with bud oil containing up to 85% eugenol, whereas leaf oil has a lower percentage, often mixed with eugenyl acetate and β-caryophyllene (Kamatou *et al.*, 2008).

There are several methods of extraction of clove essential oils including steam distillation which is the most common and widely used method for obtaining high-quality clove oil. In this process, steam passes through the clove buds, breaking down the plant's oil glands and releasing volatile compounds, which are then condensed and collected (Dhifi *et al.*, 2016).Hydro-distillation is a similar process to steam distillation which is used to obtain clove oil but it involves direct boiling of cloves in water. Though cost-effective, this method may lead to slight degradation of thermolabile compounds (Ratri *et al.*, 2020). The supercritical fluid extraction (SFE) is a modern method that can be used to obtain clove oil. It uses supercritical CO_2 as a solvent to extract essential oil at controlled temperature and pressure. This technique enhances oil purity while preserving bioactive compounds (Yazdani *et al.*, 2005) and solvent extraction uses organic solvents like ethanol to extract essential oil, yielding a product with a different chemical profile than distilled oils, mainly used in perfumery (Aziz *et al.*, 2023). Among these, steam distillation remains the preferred method for large-scale extraction due to its balance between efficiency and preservation of essential oil integrity (Chilev and Peshev, 2025).

Clove oil exhibits a broad-spectrum of antimicrobial activity. It is effective against various bacteria, including *Escherichia coli, Salmonella typhimurium*, and *Staphylococcus aureus* (Oussalah *et al.*, 2007; Burt, 2004). Its antimicrobial action is primarily due to the inhibition of bacterial cell wall synthesis and disruption of cell membranes (Deans and Ritchie, 1987).

Clove essential oil has been widely studied for its applications in various fields,Pawar and Thaker (2006) assessed the antifungal activity of clove oil against *Aspergillus niger*. Their study revealed that clove oil completely inhibited fungal growth at low concentrations, demonstrating strong antifungal potential. The antimicrobial efficacy of clove oil is largely attributed to eugenol, which disrupts microbial membranes and inhibits enzyme activity. This property makes clove oil a promising alternative to synthetic fungicides in food preservation (Poojara *et al.*, 2025). The antioxidant properties of clove oil in food preservation were reported by Harlina *et al.* (2018)who conducted an experiment to evaluate the impact of clove oil on lipid oxidation in meat storage. The results demonstrated that clove oil prolonged meat shelf life by reducing rancidity and oxidative degradation. The study concluded that clove oil is an effective natural antioxidant, making it suitable for use in food packaging and preservation.

2.8.3Sesame

Sesame (*Sesamum indicum*) is an ancient oilseed crop valued for its nutritional, medicinal, and economic significance. It thrives in semi-arid and tropical regions, making it a key crop for food security and global trade (Sanni *et al.*, 2024). It is a high-value cash crop, primarily cultivated in India, Sudan, and Nigeria, where it plays a key role in export markets and smallholder farming. Its oil is used in cooking, cosmetics, and pharmaceuticals, but its production faces challenges like price volatility and post-harvest losses (Sanni *et al.*, 2024).

The oil extracted from its seeds is widely used in food, cosmetics, and pharmaceuticals due to its stability and bioactive properties (Warra, 2012).Sesame is a drought-resistant plant with a deep root system, enabling it to grow in low-rainfall areas(Wei *et al.*, 2022).

The crop is prone to seed shattering, leading to yield losses, but modern breeding programs aim to develop non-shattering, disease-resistant varieties (Sanni *et al.*, 2024b).

Sesame oil is extracted from the seeds, which contain 45-55% oil, rich in oleic and linoleic acids (Warra, 2012). The extraction method plays a crucial role in determining the oil's quality, purity, and bioactive compound retention. Cold pressingas described by Imran *et al.* (2023), is the most natural and traditional method, involving mechanical pressure to extract oil without heat or chemicals, thereby preserving its natural antioxidants and nutritional properties. Solvent extraction, widely used in industrial production, involves the use of organic solvents such as hexane to maximize yield, but this process may degrade some bioactive compounds. Supercritical CO_2 extraction, an advanced method explored by Galanakis (2021), employs high-pressure carbon dioxide to extract oil at low temperatures, preserving volatile bioactive components and producing high-purity sesame oil. The choice of extraction method depends on the intended nutritional, medicinal, or industrial application of the oil.

Sesame seeds are rich in lignans (sesamin, sesamol, sesamolin), polyunsaturated fatty acids (PUFAs), and tocopherols, which provide antioxidant, antimicrobial, and health benefits. The high vitamin E and mineral content enhances its use in functional foods and therapeutic applications (Sanni *et al.*, 2024b).

Sesame oil is a vegetable oil extracted from sesame seeds (*Sesamum indicum*), it has been widely utilized in culinary, medicinal, and industrial applications for centuries. It is particularly valued in Asian and Mediterranean cuisines, where it enhances flavor, nutrition, and food stability (Bhat*et al.*, 2014). The oil's high content of polyunsaturated fatty acids (PUFAs), tocopherols, and lignans contributes to its antioxidant, antimicrobial, and anti-inflammatory properties, making it beneficial for health and wellness (Wei *et al.*, 2022). Additionally, sesame oil plays a critical role in traditional

medicine, with research indicating its protective effects against cardiovascular diseases and oxidative stress (Bedigian, 2011). These attributes make sesame oil a versatile and highly valued product in food processing, pharmaceuticals, and cosmetic industries.The oil extracted from sesame seeds is highly stable and resistant to rancidity, making it a promising natural preservative in food products. Recent studies have explored its efficacy in extending the shelf life of perishable foods, reducing microbial contamination, and providing various health benefits (Hussain *et al.*, 2018).

The chemical composition of sesame essential oil includes lignans (sesamin, sesamolin, and sesamol), polyunsaturated fatty acids (PUFAs), phenolic compounds, and tocopherols. These compounds are responsible for the strong antioxidant, antimicrobial, and anti-inflammatory properties of the oil. Sallam *et al.* (2021) investigated the composition of sesame oil and found that sesamol was the most active antioxidant compound, contributing significantly to oxidative stability. Additionally, sesame oil contains oleic and linoleic acids, which enhance its nutritional profile and its ability to function as a preservative in food storage. The presence of tocopherols (Vitamin E) further improves the oil's stability by preventing lipid oxidation (Wei *et al.*, 2022).

Sesame essential oil also exhibits strong antimicrobial properties, making it effective against bacteria, fungi, and foodborne pathogens. In a study conducted by Sallam *et al.* (2021), sesame oil was tested as a natural preservative in meatballs stored at 3°C for 18 days. The results indicated that sesame oil significantly reduced bacterial growth, with sesamol and sesamin inhibiting the proliferation of *Escherichia coli* and *Staphylococcus aureus*. Similarly, Bhat*et al.* (2014) reported that sesame oil exhibited strong antifungal activity, effectively suppressing the growth of *Aspergillus niger* in stored grains.

The antioxidant properties of sesame oil have also been widely studied by Wei*et al.* (2022) who evaluated the stability of sesame oil under accelerated storage conditions and

found that the presence of sesamol and other lignans reduced oxidative degradation, prolonging the shelf life of stored oils and food products. The study concluded that sesame oil is an effective natural antioxidant, capable of replacing synthetic preservatives in food processing.

The incorporation of sesame oil in food preservation techniques has been explored in edible coatings, bioactive packaging, and direct application as a preservative. Wei *et al.* (2022) tested sesame oil-based edible coatings on fresh meat products and found that the oil inhibited bacterial growth while preserving the sensory qualities of the meat.

Sesame oil has also been used in dairy products to stabilize fats and prevent oxidation. (Ayouaz *et al.*, 2022) found that adding sesame oil to milk-based products improved their storage stability, preventing rancidity and maintaining nutritional integrity. The study suggested that sesame oil could be a potential natural preservative for dairy and processed food industries.

CHAPTER THREE

MATERIALS AND METHODS

3.1Location of study

The study was conducted in the Animal Products and Processing Laboratory of the Department of Animal Science, Ahmadu Bello University, Zaria, Nigeria. Zaria is located within the Northern Guinea Savannah Zone of Nigeria, with latitude 11^0 09' 01.78'' N and longitude 7^0 39' 14.79'' E at an altitude 671m above sea level (Ovimaps, 2023). The climate is relatively dry with a mean annual rainfall of 700-1400mm. the rain starts at between late April and early May to mid-October. The dry season begins around the middle of October, with cold weather that ends in February. This is followed by relatively hot weather between March and April just before the rain begins. The mean minimum daily temperature is from 14-24^0C during the cold season while the mean maximum daily temperature is from 19-36^0C during the hot season. The mean relative humidity during the dry and wet seasons is 21% and 72%, respectively (IAR, 2022).

3.2 Experimental Design

The experimental design was 4 by 4 factorial arrangement, in a complete randomized design (CRD), four (4) treatments containing moringa oil, clove oil, sesame oil and the control using four (4) storage periods (0-, 24-, 48- and 72-hours using nylon net).

3.3Sourcing of Beef sample

10kg of fresh raw beef from a matured bull was purchased from the slaughter house of the Department of Animal Science, Ahmadu Bello University, Zaria. The cut of beef used in this experiment was taken from a portion of the semi membranous muscle of a mature bull. The meat was trimmed of all visible bones and connective tissue. It was cut into chunks of 12 cm long and 6 mm wide. The chunks were sliced into 0.15-0.30 mm thickness in the same direction of the muscle fiber using a long knife with a very sharp blade. Weight was taken, recorded and labeled.

3.4Sourcing of Essential Oils

A bottle containing thirty milliliters (30ml) each of oil from moringa, clove and sesamewas obtained from the Herbal Point at North gate, Ahmadu Bello University Zaria. Essential oils were analyzed for their phytochemical composition; total phenolic compounds, alkaloids, flavonoids and antioxidant activities before it was applied for treatment of the meat products.

3.5 Determination of Phytochemical Composition of Essential Oils

3.5.1 Determination of total phenolic content of the essential oils

Total phenolic content of Moringa and clove oil was determined by colour metrically at 725 nm, using the method described by Adebiyi *et al.* (2008). Essential oil stock solution (0.5 mL) was mixed with 20 mL of deionised water in a 25 mL volumetric flask. Then,

0.625 mL of Folin-Ciocalteu reagent was added and mixed thoroughly. After 3 minutes, 2.5 mL of sodium carbonate was added and made up to final volume with deionised water. The absorbance was read after 30 minutes at 725nm (Hitachi U-1100 double-beam UV/vis spectrophotometer). A mixture of water and reagents was used as a blank. The result was obtained as mg of gallic acid equivalent (GAE) per g of dry essential oil.

3.5.2 Determination of alkaloid content in the essential oils

About 2.5ml of Essential oil was weighed into a 250ml beaker and 200ml of 10% acetic acid in ethanol was added, it was covered and allow to stand for 4hours.at 25℃. This was filtered with filter paper No. 42 and the filtrate was concentrated using a water bath (Memmert) to one quarter of the originalvolume. Concentrated ammonium hydroxide was added drop wise to the extract until the precipitate was complete. The whole solution was allowed to settle and the precipitate was collected and washed with dilute NH_4OH (1% ammonia solution). It was then, filtered with pre-weighed filter paper. The residue on the filter paper is the alkaloid, which is dried in the oven at 80°C. The alkaloid content was calculated and expressed as a percentage of the weight of the sample analyzed.The residue is the alkaloid which was dried and weighed as described by Edema *et al.*(2009).

3.5.3 Determination of flavonoids content in the essential oils

The oil samples (10 ml)were extracted repeatedly with 100ml of 80% aqueous methanol at room temperature. The whole solution was filtered through whatman filter paper No. 42 (125mm). The filtrate was later transferred into a crucible and evaporated into dryness over a water bath and weighed to a constant weight(Kareem *et al.*, 2024).

Calculation

$$\%\text{flavonoids} = \frac{(\text{weight of crucible + residue}) - (\text{weight of crucible}) \times 100}{\text{Weight of sample analyzed}}$$

3.5.4Determination of Tannin Content of Essential Oils

A measure of 1ml of sample was boiled in 400 ml of water for 30 min, transferred to 500 ml volumetric flask and diluted up to the mark,shaked well and filtered.100 mg of tannic acid was dissolved in 1 liter of water. Fresh solution was prepared for each determination (1 ml = 0.1 mg of tannic acid). Pipette 0 to 10 ml aliquots of the standard tannic acid solution into 100-ml volumetric flasks containing 75 ml of water. Add 5 ml Folin-Denis reagent and 10 ml Na_2CO_3 solution into each of the volumetric flasks and make up to 100 ml with water. An aliquot of the filtrate containing not more than 0.1 mg of tannic acid is used to proceed as thestandard, to obtain mg tannic acid from the standard curve. Samples were mixed well and the color was measured after 30 min at 760 nm against experimental blank adjusted to absorbency(Sallam *et al.*, 2021).

$$\text{Tannin as Tannic acid \%} = \frac{\text{mg of tannic acid} \times \text{Dilution} \times 100}{\text{ml of sample taken} \times \text{wt. of sample taken} \times 1000 \text{ for colourdevelopment}}$$

3.5.5 Antioxidant activity of the essential oils

The antioxidant activity of the essential oil was determined by the DPPH (2,2-diphenyl-1picrylhydrazyl) radical scavenging method used by Apata *et al.* (2013) based on Manyi *et al.* (2014). A solution of 0.135 mM DPPH in methanol was prepared and 1.0 ml of this solution was mixed with 1.0 ml of extract prepared in methanol containing 0.025 - 0.5 mg of the plant extracts and standard drugs separately (BHT and rutin). The reaction mixture was vortexed thoroughly and left in the dark at room temperature for 30 min. The absorbance of the mixture was measured spectrophotometrically at 517 nm. The ability of the plant extract to scavenge DPPH radical was calculated by the equation:

DPPH radical scavenging activity = {(Abs control – Abs sample)/(Abs control)} × 100

Where; Abs control is the absorbance of DPPH radical + methanol;Abs sample is the absorbance of DPPH radical + sample extract or standard.

3.6Preparation of *Tsire*

The traditional processing technique for *Tsire* preparation was used with some modification (Olaoye and Dodd, 2009). About 10 kg fresh boneless beef was cutand sliced with a sharp knife andwashed in sterile distilled water (SDW), cut into pieces (approximately 13.5g) and then hanged on sterile arrowed sticks (2-3 pieces per stick)and dusted with spices made up of groundnut oil, seasoning cube, salt, curry, ginger, groundnut cake powder, dried pepper and garlic powder. The staked meat was allowed to roast around a glowing charcoal fire as described by Igene and Mohammed (1983). The fire was set by burning the fire wood into red hot charcoal at 120-140ºC before staking the meat for roasting. Groundnut oil was sprinkled on the meat pieces, before and during the grilling process, to simulate the traditional technique of avoiding burning or charring (Onilude *et al.*,2002). The roasting was done on a local *tukuba* (a heap of soil) built for the same purpose as described by Igene and Mohammed (1983); Umar *et al.* (2020). The flow chart is presented in Appendix 1.

The application of the essential oils sourced from moringa, clove and sesame were done 30minutes after the *Tsire* has been grilled and cooled. Using pastry brush, 250ml each of the essential oils (sesame, clove and moringa) for 50 sticks of *Tsire*was used (approximately 5ml per stick of*Tsire*).

3.7 Sensory Evaluations of *Tsire*

The quality and acceptability of *Tsire* preserved with essential oils was assessed. Sensory attributes include, colour, taste, aroma, juiciness, tenderness and overall acceptability (Civille *et al.*, 2024) with a score sheet on a 5-point hedonic scales sheet which was used, 1 = dislike extremely, 2=dislike slightly, 3= neither like nor dislike, 4= like slightly, 5=

like extremely as outlined by Berdos *et al.*(2020). A total of 20 respondents (semi-trained panelists) in the Department of Animal Science, Ahmadu Bello University, Zaria was constituted for the evaluation of the products. Each panelist was provided with clean water, tooth-picks, no sugar cracker biscuit to clean their palette between samples and serviette before the evaluation. Each sample was blind coded to reduce bias. All *Tsire* samples were stored at room temperature in a nylon net.

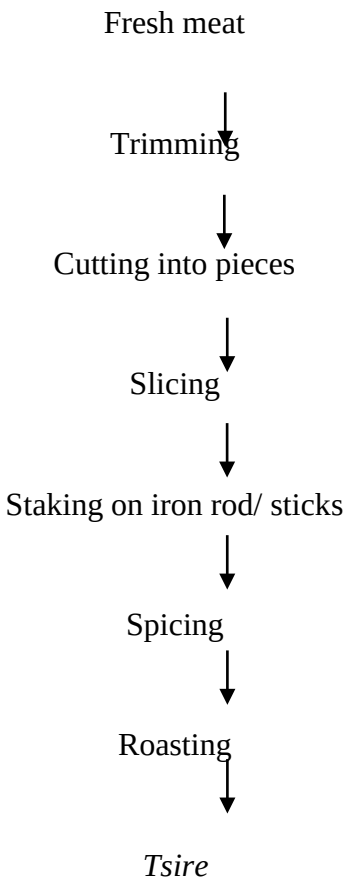


Figure 1: Flow chart showing the production processing of *Tsire*

Table 3.1: Ingredient composition for *Tsire* production

Ingredients	**Common name**	**Scientific name**	**Proportion (%)**
Common salt	Salt	NaCl	8.50
Seasoning cube	Maggi		7.50
Ginger	Ginger	*Zingiber officinale*	6.00
Garlic powder	Garlic	*Allium sativum*	6.00
Dried pepper	Pepper	*Capsicum annum*	12.00
Groundnut cake powder	Kulikuli	*Arachis hypogea*	16.00
Curry powder	Curry	*Murraya koeniigi*	0.80
Groundnutoil (ml)	Oil	*Arachis hypogea*	43.20
Total			**100.00**

3.8Determination of Proximate Composition of Fresh Beef and *Tsire*

The samples were analysed in duplicate. The moisture, protein, fat and ash contents of fresh beef and*Tsire*samples was determined using the standard methods of AOAC (2007) and Shkabrou *et al.* (2021) at the Biochemical Laboratory, Department of Animal Science, Faculty of Agriculture, Ahmadu Bello University, Zaria.

3.9 Experiment II: Effect of storage period on the shelf-life stability of *Tsire* preserved with essential oils

The preserved *Tsire* samples was wrapped in nylon net and stored for 0,24, 42 and 72hours at ambient temperature. Samples were removed at specified hours and subjected to proximate, pH, microbial, MDA, and sensory evaluations.

3.9.1Proximate composition of *Tsire*under storage

The samples to be used for the analysis was analyzed in duplicate. The moisture, protein, fat and ash contents of the *Tsire*samples was determined using the standard methods of AOAC (2007) and Shkabrou *et al.* (2021) at the Biochemical Laboratory, Department of Animal Science, Faculty of Agriculture, Ahmadu Bello University, Zaria.

3.9.2pH of *Tsire*under storage

The pH of the samples were determined by the method described by Onwuka (2018) with slight modification. About 10g meat sample of the *Tsire* was put into a beaker, 45 ml distilled water was added, homogenized by a homogenizer. First, the pH meter probe was cleaned with deionized water, and then remove the water with filter paper. The cleaning and test samples was performed at room temperature (24.9 ◦C). And the pH probe was

inserted into the supernatant by taking the supernatant liquid then recorded when the reading was stable. Each sample was measured three times.

3.9.3 Determination of thiobarbituric acid (TBA) of *Tsire*under storage

The determination of thiobarbituric acid (TBA) was done at the Biochemistry Laboratory, Department of Biochemistry Faculty of Life Sciences Ahmadu Bello University Zaria. The analysis was done according to the processes cited by Zeb and Ullah (2016).The TBA number was conveyed as milligrams of malondialdehyde equivalents per kilogram of samples (Schmedes *et al.,* 1989). Ten grams of the sample was blended with 48 mL of distilled water. Two ml of 4% ammonium chloride (to bring the pH to 1.5) was added to the previous contents in a warring blender for 2 min and left at room temperature for 10 min. The mixture was quantitatively transferred into Kjeldahl flasks and was washed with an additional 50 mL of distilled water, followed by an antifoaming preparation and a few glass beads. The Kjeldahl distillation apparatus was assembled and the flask heated to 50 ◦C. Distillates was collected at 10 min from the start of the boiling. The distillates (50 mL) was mixed, and then was pipetted into a glass stoppered tube. Then, 5 mL TBA reagent (0.2883/100 mL of glacial acetic acid) was added, the tube was stoppered, shacked and immersed in a boiling water bath for 35 min. A blank was similarly prepared using 5 mL distilled water with 5 mL of TBA reagent and treated like the sample. After heating, the tube was allowed to cool under tap water for 10 min. A portion was transferred to a curette and the optical density (D) of the sample was read against the blank using a spectrophotometer at a wavelength of 538 nm. Calculation of the TBA value was done using the following equation, which expresses the result as mg malonaldehyde equivalent/kg food sample: TBA value = K × A532 where A532 is the absorbance of the test sample at 532 nm.

3.9.4Microbial evaluation of *Tsire*under storage

One gram of each sample was homogenized in 9 ml sterile distilled water and 10-fold serial dilutions was carried out. One milliliter of the appropriate dilutions was mixed with molten medium (45°C) using de Mann Rogosa and Sharpe Agar (MRS) for LAB; potato dextrose agar (PDA) supplemented with streptomycin for yeasts; MaConkey agar for coliform; and nutrient agar for total viable counts. Incubation period was 48 h except for yeast (72 h).

Isolation of yeast and moulds

The media of choice used was Sabaround Dextrose Agar (SDA) containing Chloramphenicol (50mg). The SDA was prepared and sterilized following the manufacture procedure manual. After sterilization, the media was allowed to cool to 45 °C and poured into the Petri dish containing 1ml of the inoculated sample using pour plate method then allowed to solidify for some minutes and incubated at 28 °C for 5days using nylon net (Cheesbroug, 2005) Emerging colonies was then counted, calculated and expressed as log cfu/ml and further identified through microscopy.

3.10 Data Analysis

All the analysis were carried out in triplicates and data obtained were analyzed using analysis of variance (ANOVA) method of SAS (2002). Where the variance ratio (F-values) proved significant, Tukey HSD test was used to separate the means.

3.11 Model for experiment I and II

$Y_{ijk} = \mu + T_i + S_j + (T^* S)_{ij} + \varepsilon_{ijk}$

Y = Observation

μ = Population

T_i = Effect of Essential oils

S_j = Storage Period

$(T*S)_{ij}$ = Interaction between treatment and storage period

ε_{ijk} = Random error

CHAPTER FOUR

RESULTS

4.1Phytochemical Composition of the Essential Oils

The phytochemical composition of the four essential oils—moringa oil, clove oil, and sesame oil is shown in Table 4.1. The values varyamong the oils, indicating differences in their potential antioxidant and bioactive properties.Clove oil exhibited the highest alkaloid content (87.50 mg/g), followed by sesame oil (57.00 mg/g) and moringa oil (42.50 mg/g). The total phenol content was highest in clove oil (218.43 mg/g), followed by sesame oil (115.42 mg/g) and moringa oil (93.78 mg/g).

Flavonoids, another class of antioxidants, were most abundant in sesame oil (189.79 mg QE/g), followed by clove oil (160.12 mg QE/g). Moringa oil had the lowest flavonoid content (112.53 mg QE/g), suggesting it may offer comparatively lower antioxidant benefits. Clove oil had the highest tannin content (186.99 mg TAE/g), followed by sesame oil (176.23 mg TAE/g) and moringa oil (129.97 mg TAE/g. DPPH radical scavenging activity (an indicator of antioxidant capacity) was highest in clove oil (61.60 µg/ml), followed by moringa oil (47.08 µg/ml) and sesame oil (44.35 µg/ml).

4.2 Proximate Composition of Fresh Beef

The proximate composition of fresh beef is an important parameter in assessing its nutritional quality, stability, and suitability for preservation. The results of the proximate composition analysis are presented in Table 4.2.

Fresh beef had a moisture content of 75.22%, indicating a high-water activity level, which plays a significant role in its perishability. The dry matter content was 24.78%, representing the total solid components, including proteins, lipids, and minerals. The

crude protein content was 21.15%, confirming that fresh beef is a rich source of dietary protein. Proteins contribute to the structural and functional properties of meat, influencing its texture and overall quality.

The lipid content was 8.71%, which contributes to the flavor, tenderness, and energy value of beef. Lipids are also essential in the sensory characteristics of meat products. The ash content, representing the total mineral composition, was 1.78%, indicating the presence of important minerals necessary for human nutrition. The carbohydrate content was 3.20%, which is primarily derived from glycogen and other muscle sugars.

These findings establish the nutritional profile of fresh beef and serve as a reference for evaluating the impact of preservation methods on its chemical and sensory attributes during storage.

4.3 Effects of Essential Oils on Proximate Composition of *Tsire* Stored at Room Temperature

The main effects of essential oils on proximate composition of *Tsire* stored at room temperature is shown in Table 4.8. The study assessed the influence of various essential oils (clove oil (CL), Control (CN), moringa oil (MO), Sesame oil (SM)) on the proximate composition of *Tsire* (a spiced meat product). The findings are summarized as follows: Variations in moisture content across treatments were not significant ($P = 0.087$), with values ranging from 10.74% (CL) to 10.85% (MO). Moringa oil recorded the highest ash content (4.31%), while control had the lowest (3.88%) ($P < 0.001$).

Sesame oil exhibited the highest lipid content (24.53%), significantly ($p<0.05$) exceeding other oils. The control group had the lowest lipid content (19.49%).The control had the highest protein content (51.95%), whereas Moringa oil was associated with the lowest (47.23%) ($P < 0.05$). Clove oil contained the most fiber (3.33%), with Sesame and Control having comparable lower levels ($P < 0.05$). Clove oil had the highest carbohydrate levels (15.67%), and Sesame oil the least (9.89%) ($P < 0.05$).

Table 4.1: Phytochemical composition of the essential oils

Composition	Moringa oil	Clove oil	Sesame oil
Alkaloids Content (mg/g)	42.50	87.50	57.00
Total phenol	93.78	218.43	115.42
Flavonoids (mg QE/g)	112.53	160.12	189.79
Tannins (mg TAE/g)	129.97	186.99	176.23
DPPH RSA (µg/ml)	47.08	61.60	44.35

Values are averages of two determinations.

Table 4.2: Proximate composition of Fresh Beef

Parameter	Composition (%)
Dry Matter	24.78
Moisture	75.22
Crude Protein	21.15
Lipid	8.71
Ash	1.78
Carbohydrate	3.20

Table 4.3 Effect of essential oils on proximate composition of *Tsire* stored at room temperature

Essential oil	Moisture	Ash	Lipid	Protein	Fibre	CHO
Clove	10.74	4.05^{c}	19.93^{c}	49.62^{c}	3.33^{a}	15.67^{a}
Control	10.84	3.88^{d}	19.49^{d}	51.95^{a}	3.16^{c}	13.83^{c}
Moringa	10.85	4.31^{a}	22.43^{b}	47.23^{d}	3.26^{b}	15.21^{b}
Sesame	10.80	4.18^{b}	24.53^{a}	50.65^{b}	3.17^{c}	9.89^{d}
SEM	0.032	0.012	0.088	0.012	0.005	0.092
Pvalue	0.087	<0.001	<0.001	<0.001	<0.001	<0.001

abc Means with different superscripts along the same column differs significantly ($p<0.05$); SEM= Standard error of mean

Table 4.4 Effect of storage period on proximate composition of *Tsire* stored at room temperature

Storage Period (hours)	Moisture	Ash	Lipid	Protein	Fibre	CHO
0	9.62^{c}	4.14^{a}	23.80^{a}	53.61^{a}	3.40^{a}	8.83^{d}
24	10.25^{b}	4.12^{a}	21.31^{c}	47.96^{d}	3.19^{b}	16.38^{a}
48	10.33^{b}	4.10^{a}	22.53^{b}	48.97^{b}	3.17^{c}	14.10^{c}
72	13.05^{a}	4.06^{b}	18.75^{d}	48.90^{c}	3.16^{c}	15.29^{b}
SEM	0.032	0.012	0.088	0.012	0.005	0.092
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

abc Means with different superscripts along the same column differs significantly ($p<0.05$); SEM= Standard error of mean

4.4Effects of Storage Period on Proximate Composition of *Tsire* Stored at RoomTemperature

The main effects of storage period on proximate composition of *Tsire* stored at room temperature is shown in Table 4.4. Storage significantly impacted proximate composition. Moisture increased with storage, peaking at 13.05% at 72hours ($P < 0.05$). Ash content was highest at 24hours (4.14%) but decreased slightly over time ($P < 0.05$).

4.5Interaction of Essential Oils and Storage Period on Proximate Composition of *Tsire* Stored at Room Temperature

The proximate composition of *Tsire* treated with different essential oils and stored over time is presented in Table 4.5. The results indicate significant variations ($p<0.05$) in moisture, ash, lipid, crude protein, fibre, and carbohydrate (CHO) content among the treatments across different storage periods.

The moisture content varied significantly across the treatments and storage periods. At day 1(0 hour), sesame-treated *Tsire* exhibited the highest moisture content (10.44%), while moringa-treated *Tsire* recorded the lowest (8.35%).

4.6 Effects of Essential Oils on MDA and pHStored at Room Temperature

Table 4.6 shows that essential oils had varying impacts on MDA and pH levels in *Tsire*. The result showed that Moringa oil exhibited the highest MDA levels (40.95), indicating increased lipid oxidation, while Clove oil resulted in significantly($p<0.05$) lower MDA (20.78), comparable to the control group. Clove oil maintained the highest pH (6.75), suggesting its potential buffering capacity, while other oils and the control exhibited lower pH values (6.59–6.61).

4.7 Effect of Storage Period on MDA and pH Stored at Room Temperature

Table 4.7 presents the effect of storage duration on lipid oxidation, measured as malondialdehyde (MDA) levels, and pH of *Tsire* stored at room temperature. The results indicate significant ($p<0.05$)variations in both parameters, highlighting the influence of storage time on oxidative stability and acidity regulation in meat products.

MDA levels increased significantly ($p<0.05$)with storage time, indicating progressive lipid oxidation. At 0 hours, the lowest MDA level (20.20 mg/kg) was recorded. By 24 hours, MDA levels increased to 26.58 mg/kg, representing a significant ($p<0.05$) rise compared to the initial value. This trend continued at 48 hours, where MDA levels further increased to 27.51 mg/kg, although the difference between 24 and 48 hours was not statistically significant. However, by 72 hours, MDA reached its peak value of 29.84 mg/kg, which was significantly higher than all previous time points. The observed increase in lipid oxidation over time suggests the progressive deterioration of meat quality during storage.

The pH of *Tsire* was significantly ($p<0.05$)influenced by storage duration. At 0 hours, the initial pH was 6.59, indicating a fresh product. A slight but significant increase was observed at 24 hours (6.66) and peaked at 48 hours (6.73). However, by 72 hours, pH declined to 6.59, returning to its initial value. The observed increase in pH up to 48 hours suggests a temporary accumulation of alkaline metabolites, possibly due to microbial activity or protein degradation. The subsequent drop at 72 hours may be attributed to acid formation from microbial fermentation or lipid oxidation byproducts.

4.8 Interaction Effects of Essential Oils and Storage Period*Tsire*Stored at Room Temperature

Table 4.8 presents the interaction effects of essential oils and storage duration on lipid oxidation, measured as malondialdehyde (MDA) levels, and pH of *Tsire* stored at room temperature. The results indicate significant ($p<0.05$)variationsamong treatments and storage periods, with essential oils exhibiting different levels of oxidative stability and pH retention.

MDA levels, which indicate lipid oxidation, were significantly affected by essential oil treatments and storage periods. At 0 hours, Moringa-treated *Tsire* exhibited the highest MDA levels (25.86 mg/kg), suggesting the highest initial oxidation, whereas control (16.67 mg/kg) and clove-treated samples (17.42 mg/kg) showed significantly($p<0.05$) lower values. Sesame-treated *Tsire* recorded intermediate oxidation levels (20.84 mg/kg). By 24 hours, oxidation increased across all treatments, with Moringa reaching 42.41 mg/kg, significantly ($p<0.05$)higher than other treatments ($p<0.05$). Clove-treated *Tsire* had a comparable oxidation rate to control (20.94 mg/kg vs. 21.26 mg/kg), while sesame-treated *Tsire* showed slight oxidation (21.69 mg/kg).

At 48 hours, the oxidation rate increased further, particularly in Moringa-treated samples (44.34 mg/kg), while other treatments exhibited minor variations. Clove-treated samples had lower oxidation levels (21.58 mg/kg), similar to control (21.91 mg/kg). By 72 hours, the highest oxidation levels were observed in Moringa-treated *Tsire* (51.18 mg/kg), while sesame-treated samples recorded moderate oxidation (24.04 mg/kg). Clove oil-treated samples exhibited the lowest oxidation increase over time, with an MDA level of 23.19 mg/kg.

The pH values of *Tsire* varied significantly ($p<0.05$) with storage time and essential oil treatments. At 0 hours, Clove-treated samples recorded the highest pH (6.80), while Moringa-treated samples had the lowest pH (6.45). Control and sesame treatments showed similar pH values (6.55). At 24 hours, Clove-treated *Tsire* maintained the highest pH (6.75), while the lowest was observed in Sesame-treated samples (6.60). Moringa and control samples recorded identical values (6.65).

At 48 hours, Clove-treated *Tsire* still exhibited the highest pH (6.80), followed closely by Moringa (6.75) and Sesame (6.70). Control samples remained stable (6.65). By 72 hours, pH values generally decreased, with Control-treated *Tsire* recording the lowest pH (6.50), while Clove-treated *Tsire* maintained the highest pH (6.65). Moringa- and Sesame-treated samples had similar pH values (6.60).

4.9 Effect of essential oils on organoleptic properties of processed*Tsire*

The effect of essential oils on organoleptic properties of processed beef *Tsire*is shown in Table 4.9. The results showed that there were significant ($P<0.05$) differences in the product colour, tenderness, juiciness and overall acceptability while aroma showed no significant ($P>0.05$) differences. The colour scores showed significant variation ($p < 0.05$) among treatments. The control sample (3.10±1.20) had the highest colour rating, suggesting that beef *Tsire* without essential oil had the most desirable appearance. The Moringa oil sample (1.95±1.19) had the lowest score while clove oil (2.50±1.05) and Sesame oil (2.53±0.96) showed intermediate colour values. The Sesame oil (3.30±1.13)and clove oil (3.25±1.33)samples were rated highest for tenderness while the control sample (2.29±1.49) andMoringa oil (2.20±1.01)had significantly lower scores.

The juiciness of the samples varied significantly ($p < 0.05$) among treatments. Sesame oil (3.42±1.26) had the highest juiciness score, which aligns with its performance in

tenderness. Moringa oil (2.95±1.10), the control sample (2.95±1.35)and Clove oil sample (2.96±1.27)had lower juiciness score. Significant differences ($p < 0.05$) were observed in the overall acceptability of the products. The control sample (3.75±1.33),Sesame oil (3.74±1.19)and Moringa oil sample (3.45±0.99)were the most preferred while Clove oil sample (2.45±1.28) had the lowest acceptability score.

4.10 Effects of Essential Oils on Microbial Count on Microbial Count of Beef *Tsire* Stored in Nylon Net

The effects of various essential oils (Moringa oil, Clove oil, Sesame oil) and a control on microbial counts of *Tsire* (a spiced meat product) were analyzed. The results are summarized in Table 4.2. the result showed that Sesame oil had the highest yeast count at 73.75×10^4 cfu/g, while moringa oil recorded the lowest (38.50×10^4 cfu/g) ($P<0.05$). The *Tsire* samples Moringa oil had the highest mold count (16.67×10^4 cfu/g), whereas Clove oil had the lowest (8.25×10^4 cfu/g). Significant differences were observed ($P < 0.05$). The control group had higher bacterial loads (105.25×10^6 cfu/g) compared to clove oil, which had the least bacterial count (69.75×10^6 cfu/g) ($P<0.05$).

Table 4.5Interaction effect of essential oils and storage period on the proximate composition of *Tsire* stored at room temperature

Parameters	Storage Period (Hours)	Control	Clove	Moringa	Sesame	LOS
Moisture	0	9.91^{b}	9.79^{b}	8.35^{c}	10.44^{a}	*
	24	10.65^{a}	10.23^{b}	10.30^{b}	9.81^{c}	*
	48	10.63^{a}	10.22^{c}	10.35^{b}	10.10^{c}	*
	72	12.19^{c}	12.73^{b}	14.40^{a}	12.87^{b}	*
Ash	0	3.92^{c}	4.10^{b}	4.27^{a}	4.27^{a}	*
	24	3.89^{d}	4.08^{c}	4.30^{a}	4.21^{b}	*
	48	3.90^{d}	4.00^{c}	4.38^{a}	4.12^{b}	*
	72	3.82^{d}	4.00^{c}	4.30^{a}	4.10^{b}	*
Lipid	0	15.60^{d}	24.68^{c}	29.51^{a}	25.44^{b}	*
	24	22.76^{b}	18.71^{d}	22.86^{a}	20.89^{c}	*
	48	23.77^{b}	16.99^{d}	20.55^{c}	28.82^{a}	*
	72	15.85^{d}	19.36^{b}	16.80^{c}	22.99^{a}	*
Crude Protein	0	56.90^{a}	53.40^{c}	50.42^{d}	53.72^{b}	*
	24	53.03^{a}	53.13^{a}	40.55^{c}	45.14^{cb}	*
	48	47.46^{c}	48.42^{b}	47.30^{c}	52.71^{a}	*
	72	50.42^{b}	43.51^{c}	50.66^{b}	51.03^{a}	*
Fibre	0	3.55^{a}	3.38^{a}	3.46^{a}	3.20^{b}	*
	24	3.00^{c}	3.33^{a}	3.20^{b}	3.22^{b}	*
	48	3.05	3.30	3.18	3.13	NS
	72	3.02^{c}	3.29^{a}	3.20^{b}	3.14^{b}	*
CHO	0	13.69^{a}	8.03^{b}	3.20^{d}	6.15^{c}	*
	24	9.67^{c}	13.86^{b}	3.22^{d}	19.99^{a}	*
	48	14.24^{c}	20.39^{b}	3.13^{d}	4.26^{a}	*
	72	17.73^{b}	20.41^{a}	3.14^{d}	9.18^{c}	*
	SEM	0.023	0.064	0.176	0.10	

Table 4.6 Effects of Essential Oils on MDA and pH on *Tsire* stored at room temperature

Essential Oils	MDA	pH
Control	20.194^{b}	6.588^{b}
Moringa	40.946^{a}	6.613^{b}
Clove	20.781^{b}	6.750^{a}
Sesame	22.198^{b}	6.613^{b}
SEM	0.597	0.013
P value	<0.0001	<0.0001

abc Means with different superscripts along the same column differs significantly ($p<0.05$); MDA= Malondialdehyde, SEM= Standard error of mean

Table 4.7 Effect of storage period on MDA and pH of *Tsire* stored at room temperature

Storage Period (hours)	MDA	pH
0	20.20^{c}	6.59^{c}
24	26.58^{b}	6.66^{b}
48	27.51^{b}	6.73^{a}
72	29.84^{a}	6.59^{c}
SEM	0.597	0.013
P value	<0.0001	<0.0001

abc Means with different superscripts along the same column differs significantly ($p<0.05$); MDA= Malondialdehyde, SEM= Standard error of mean

Table 4.8: Interaction effects of Essential oils and storage period on MDA and pH countof *Tsire* stored at room temperature

Parameters	Storage Period (Hours)	Control	Clove	Moringa	Sesame	SEM
MDA	0	16.67^{c}	17.42^{c}	25.86^{a}	20.84^{b}	1.194
	24	21.26^{b}	20.94^{b}	42.41^{a}	21.69^{b}	1.194
	48	21.91^{b}	21.58^{b}	44.34^{a}	22.22^{b}	1.194
	72	20.94^{c}	23.19^{b}	51.18^{a}	24.04^{b}	1.194
pH	0	6.55^{c}	6.80^{a}	6.45^{c}	6.55^{b}	0.026
	24	6.65^{b}	6.75^{a}	6.65^{b}	6.60^{c}	0.026
	48	6.65^{b}	6.80^{a}	6.75^{b}	6.70^{b}	0.026
	72	6.50^{b}	6.65^{a}	6.60^{b}	6.60^{b}	0.026

^{abc}Means with different superscripts along the same column differs significantly ($p<0.05$); MDA= Malondialdehyde, SEM= Standard error of mean

4.11Effect of Storage Periodon Microbial Count of Beef *Tsire* Stored in Nylon Net

Microbial loads varied significantly ($p<0.05$) over the storage period (0–72hours), with a marked increase in counts as storage duration increased. At 24hours, yeast count was minimal (1.25×10^4 cfu/g) but increased sharply by 72hours (134.75×10^4 cfu/g).Mold count decreased progressively from 24hours (21.92×10^4 cfu/g) to 72hours (1.00×1041.00 times 10^4 cfu/g). Bacterial counts rose steadily, peaking at 72hours (170.00×10^6 cfu/g).

4.12Interaction Effect of Essential Oils and Storage Period on Microbial Count of Beef *Tsire* Stored in Nylon Net

Table 4.12 presents the microbial count (yeast, mold, and bacteria) of beef *Tsire* treated with different essential oils and stored at room temperature. The results indicate significant variations ($p<0.05$) among treatments and storage periods, with essential oils exhibiting varying degrees of antimicrobial effects.

The yeast count varied significantly ($p<0.05$)across storage durations and treatments. At 0 hour, all treatments except sesame oil exhibited no yeast growth (0.00×10^4 cfu/g), whereas sesame-treated *Tsire* recorded a significantly ($p<0.05$)higher yeast count (13.00×10^4 cfu/g). At 24 hours, yeast growth increased substantially in all treatments, with sesame oil-treated samples maintaining the highest count (30.00×10^4 cfu/g), followed by control (20.00×10^4 cfu/g) and clove oil (20.00×10^4 cfu/g), while moringa oil exhibited the lowest growth (2.00×10^4 cfu/g). At 48 hours of storage, yeast count peaked in sesame oil-treated samples (119.00×10^4 cfu/g), whereas moringa oil-treated samples recorded the lowest count (18.00×10^4 cfu/g). By the third day (72 hours), yeast count remained highest in sesame-treated *Tsire* (160.00×10^4 cfu/g) and lowest in clove oil-treated samples (114.00×10^4 cfu/g), with control (131.00×10^4 cfu/g) and moringa oil (134.00×10^4 cfu/g) showing intermediate values.

Mold growth varied significantly across treatments and storage periods. At 0 hour, control samples exhibited the highest mold count (22.00×10^4 cfu/g), followed by clove oil (19.00×10^4 cfu/g) and moringa oil (19.67×10^4 cfu/g), whereas sesame oil-treated samples had the lowest mold count (2.00×10^4 cfu/g). By 24 hours, mold count decreased in all treatments, with moringa oil-treated *Tsire* having the highest count (20.00×10^4 cfu/g) and sesame oil-treated *Tsire* the lowest (4.00×10^4 cfu/g). At 48 hours, mold count significantly ($p<0.05$)increased in moringa-treated *Tsire* (27.00×10^4 cfu/g), while control (6.00×10^4 cfu/g) and clove oil (2.00×10^4 cfu/g) exhibited lower mold growth. By 72 hours, mold count reduced drastically, with control and moringa-treated *Tsire* recording no mold growth, while sesame-treated *Tsire* had the highest mold count (3.00×10^4 cfu/g).

Bacterial count showed significant($p<0.05$) variations across storage durations and treatments. At the point of production (0 hour) control samples exhibited the highest bacterial count (131.00×10^6 cfu/g), whereas sesame-treated *Tsire* had the lowest (7.00×10^6 cfu/g). By 24 hours, bacterial count peaked in moringa oil-treated *Tsire* (166.00×10^6 cfu/g), followed by control (36.00×10^6 cfu/g) and clove oil (18.00×10^6 cfu/g), while sesame-treated samples had the lowest count (14.00×10^6 cfu/g). At 48 hours, bacterial count significantly increased in sesame-treated *Tsire* (152.00×10^6 cfu/g), while control samples exhibited a relatively lower count (71.00×10^6 cfu/g). By 72 hours, bacterial count reached its peak in sesame-treated *Tsire* (207.00×10^6 cfu/g), whereas clove oil-treated samples had the lowest bacterial count (114.00×10^6 cfu/g), with control (183.00×10^6 cfu/g) and moringa oil (176.00×10^6 cfu/g) showing intermediate values.

Table 4.9Effect of essential oils on organoleptic properties of processed*Tsire*

Essential Oil	Colour	Aroma	Tenderness	Juiciness	Acceptability
CONTROL	3.10±1.20[a]	3.00±1.24	2.29±1.49[b]	2.95±1.35[b]	2.45±1.33[b]
CLOVE OIL	2.50±1.05[b]	2.60±1.50	3.25±1.33[a]	2.96±1.27[b]	3.75±1.28[a]
MORINGA OIL	1.95±1.19[c]	2.15±0.88	2.20±1.01[b]	2.95±1.10[b]	3.45±0.99[a]
SESAME OIL	2.53±0.96[b]	2.67±1.19	3.30±1.13[b]	3.42±1.26[a]	3.74±1.19[a]

abc Means with different superscripts along the same column differs significantly ($p<0.05$); SEM= Standard error of mean

Table 4.10: Effects of Essential oils on microbial count of *Tsire* stored at room temperature

Essential Oils	Yeast (10^4cfu/g)	Mold (10^4cfu/g)	Bacteria (10^6cfu/g)
Control	47.5^{c}	10.00^{b}	105.25^{b}
Clove	57.25^{b}	8.25^{c}	69.75^{d}
Moringa	38.50^{d}	16.67^{a}	131.50^{a}
Sesame	73.75^{a}	9.00^{bc}	95.00^{c}
SEM	0.306	0.441	0.771
P value	<0.0001	<0.0001	<0.0001

abc Means with different superscripts along the same column differs significantly ($p<0.05$);
SEM= Standard error of mean

Table 4.11: Effect of storage period on microbial count of *Tsire* stored at room temperature

Storage Period (hours)	Yeast (10^4cfu/g)	Mold (10^4cfu/g)	Bacteria (10^6cfu/g)
0	1.25^{d}	21.92^{a}	59.25^{c}
24	13.25^{c}	11.75^{b}	56.75^{c}
48	67.75^{b}	9.25^{c}	115.50^{b}
72	134.75^{a}	1.00^{d}	170.00^{a}
SEM	0.306	0.441	0.771
P value	<0.0001	<0.0001	<0.0001

abc Means with different superscripts along the same column differs significantly ($p<0.05$);
SEM= Standard error of mean

Table 4.12: Interaction effect of essential oils and storage period on the microbial count of beef *Tsire* stored at room temperature in nylon net

Parameters	Storage Period (hours)	Control	Clove	Moringa	Sesame	SEM	P value
Yeast (10^4cfu/g)	0	0.00^{b}	0.00^{b}	0.00^{b}	13.00^{a}	0.612	0.0001
	24	20.00^{b}	20.00^{b}	2.00c	30.00^{a}	0.612	0.0001
	48	39.00^{c}	95.00^{b}	18.00^{d}	119.00^{a}	0.612	0.0001
	72	131.00^{b}	114.00^{c}	134.00^{b}	160.00^{a}	0.612	0.0001
Mold (10^4cfu/g)	0	22.00^{a}	19.00^{b}	19.67^{b}	2.00^{c}	0.880	0.0001
	24	12.00^{b}	11.00^{b}	20.00^{a}	4.00^{c}	0.880	0.0001
	48	6.00^{b}	2.00^{c}	27.00^{a}	27.00^{c}	0.880	0.0001
	72	0.00^{c}	1.00^{b}	0.00^{c}	3.00^{a}	0.880	0.0001
Bacteria (10^6cfu/g)	0	131.00^{a}	28.00^{c}	64.00^{b}	7.00^{d}	1.541	0.0001
	24	36.00^{b}	18.00^{c}	166.00^{a}	14.00^{d}	1.541	0.0001
	48	71.00^{c}	119.00^{b}	120.00^{b}	152.00^{a}	1.541	0.0001
	72	183.00^{b}	114.00^{c}	176.00^{b}	207.00^{a}	1.541	0.0001

abc Means with different superscripts along the same column differs significantly ($p<0.05$); SEM= Standard error of mean

CHAPTER FIVE

DISCUSSION

5.1 Phytochemical Composition of Clove, Moringa and Sesame Essential Oils

Alkaloids are known for their antimicrobial and pharmacological properties, suggesting that clove and sesame oils may have stronger bioactive effects compared to groundnut oil (Rahim *et al.*, 2023).The significantly higher alkaloid concentration in clove oil suggests that it may have stronger antimicrobial effects, which can contribute to inhibiting microbial growth during meat preservation. This aligns with previous findings that alkaloids from *Syzygium aromaticum* (clove) possess potent antibacterial properties against foodborne pathogens (Adeyemi *et al.*, 2021).

Phenolic compounds contribute to antioxidant activity, higher values in clove and sesame oils indicates they may likely have superior oxidative stability and health benefits compared to groundnut oil, which had the lowest phenol content (Symoniuk *et al.*, 2022).The high phenolic content in clove oil is consistent with previous studies (Zheng *et al.*, 2019), which have reported eugenol as a major phenolic compound in clove essential oil with strong antioxidant and antimicrobial activities.

Flavonoids, known for their antioxidant and free radical scavenging activities, varied across the essential oils, with sesame oil having the highest concentration (189.79 mg QE/g), followed by clove oil (160.12 mg QE/g) and moringa oil (112.53 mg QE/g). This suggests that sesame oil may contribute more effectively to delaying lipid oxidation in meat products(Ullah *et al.*, 2020; Muscolo*et al.*, 2024). However, the high flavonoid content in clove oil also suggests its role in oxidative stability, which is beneficial for preserving beef *Tsire*.

Tannins are known for their antimicrobial properties and their ability to enhance food preservation, indicating that clove and sesame oils could be more effective in preventing microbial spoilage (Rahim *et al.*, 2023).The high tannin concentration in clove oil further supports its potential as an effective natural preservative, as tannins have been shown to exhibit antimicrobial activity against spoilage bacteria (Erdogan *et al.*, 2020).

The DPPH radical scavenging assay measures the ability of a compound to donate hydrogen and neutralize free radicals. Clove oil demonstrated the highest antioxidant activity (61.60 µg/ml), followed by moringa oil (47.08 µg/ml) and sesame oil (44.35 µg/ml). This suggests that clove oil has the strongest ability to prevent oxidative deterioration in meat products, which is essential for prolonging the shelf life of beef *Tsire*. The observed antioxidant activity corresponds with the high levels of phenolics and flavonoids in clove oil, reinforcing its effectiveness as a preservative.Higher DPPH in cloves suggests that clove oil has the strongest antioxidant potential, which aligns with its high phenol and tannin contents (Cortés-Rojas *et al.*, 2014; Muscolo*et al.*, 2024).

The variations in phytochemical composition among the three oils suggest different levels of effectiveness in preserving beef *Tsire*. Clove oil, with the highest levels of alkaloids, total phenols, tannins, and antioxidant activity, is likely to be the most effective in preventing microbial spoilage and lipid oxidation. Sesame oil, with its high flavonoid content, may also contribute significantly to oxidative stability, while moringa oil, despite having lower concentrations of some phytochemicals, may still offer preservative benefits.

The findings suggest that essential oils, particularly clove oil, could serve as natural, chemical-free preservatives for meat products.

5.2 Proximate Composition of Fresh Beef

Proximate analysis is essential in assessing the nutritional quality and storage stability of fresh beef. The results present the composition of dry matter, moisture, crude protein, lipid, ash, and carbohydrate in fresh beef, which provides a basis for evaluating the impact of preservation treatments in subsequent analyses

Moisture content plays a critical role in the shelf life, microbial stability, and sensory attributes of fresh beef. The moisture content of fresh beef in this study was 75.22%, while the dry matter content was 24.78%. This high moisture level is consistent with findings in previous studies (Pellissery *et al.,* 2019), where fresh meat exhibited moisture levels ranging between 72% and 78%. The high moisture content makes fresh beef highly perishable, as it provides a favorable environment for microbial growth and enzymatic activities. Reducing moisture through preservation techniques, such as the use of essential oils and storage in nylon net, may enhance shelf stability and reduce spoilage rates.

Crude protein, a key nutritional component of meat, was found to be 21.15% in fresh beef. This value aligns with the reported protein content of lean beef in existing literature, which ranges from 18% to 23% depending on breed, age, and muscle type (Ahmad *et al.*, 2018). Protein plays a crucial role in muscle structure and functionality, but it is also susceptible to degradation during storage due to microbial and enzymatic actions. Effective preservation techniques minimize protein degradation to maintain the nutritional quality and texture of beef *Tsire* over time.

The lipid content of fresh beef was 8.71%, which is within the expected range for standard beef cuts (7–12%) (Prates, 2025). Lipids are significant in flavor development and juiciness, but they are also prone to oxidation, leading to rancidity and off-flavors during storage. Lipid oxidation is a major concern in meat preservation, and the application of antioxidant-rich

essential oils (such as clove and sesame oil) could help in delaying oxidative rancidity and extending shelf life.

Ash content, which represents the mineral composition of fresh beef, was found to be 1.78%. This is similar to previously reported values (1.5%–2.0%) in various beef studies (Muchenje *et al.*, 2008). The mineral content in meat includes calcium, phosphorus, magnesium, and trace elements, which are vital for human nutrition. While essential oils may not significantly impact ash content, they could contribute to preserving mineral bioavailability by reducing microbial spoilage and oxidation processes.

The carbohydrate content of fresh beef was 3.20%, which is relatively low since meat is not a primary source of carbohydrates. The small amount of carbohydrates present is mainly due to glycogen and other residual muscle sugars, which can influence pH levels and meat quality during storage. During prolonged storage, glycogen breakdown and microbial activity can alter the pH balance, affecting meat quality. This reinforces the need for effective preservation methods to maintain meat freshness and prevent spoilage.

The proximate composition of fresh beef highlights its high moisture, protein, and lipid content, which makes it highly perishable. The susceptibility of proteins to degradation, lipids to oxidation, and moisture to microbial activity necessitates the application of preservation strategies such as natural essential oils to extend shelf life.

5.3 Effect of Essential Oils on the Proximate Composition of *Tsire* Stored at Room Temperature

The proximate composition of beef *Tsire*, a traditional spiced and roasted meat product, is crucial in determining its nutritional quality, stability, and shelf life. The results in Table 4.3 reveal the main effects of different essential oils (clove, moringa, and sesame) on the moisture, ash, lipid, protein, fibre, and carbohydrate contents of *Tsire* stored at room temperature. The

differences observed in proximate values indicate the influence of essential oils on preservation and nutrient retention in *Tsire* over the storage period.

The moisture content of *Tsire* obtained showed no statistically significant difference between treatments. This indicates that the application of essential oils did not significantly affect the moisture retention of *Tsire* during storage. The low moisture content across all treatments is beneficial in reducing microbial growth and enzymatic activities, both of which contribute to spoilage (Lawrie, 1998). Moisture reduction is a critical factor in meat preservation, as lower water activity inhibits bacterial proliferation, thereby extending shelf life (Muchenje *et al.*, 2008).

Ash content, which represents the total mineral composition, varied significantly among treatments. *Tsire* preserved with moringa oil had the highest ash content, followed by sesame, clove and the control. This variation suggests that moringa and sesame oils contributed to better mineral retention during storage. The high ash content in essential oil-treated samples may be due to their antimicrobial and antioxidant properties, which help in reducing oxidative deterioration and mineral losses (Nartey *et al.*, 2021). This agrees with Abdollahi *et al.* (2025), who reported that bioactive compounds in Moringa enhance mineral preservation.The lower ash content in the control group indicates that without preservatives, minerals may have been lost through oxidation or leaching.

The lipid content of *Tsire* was significantly affected by essential oil treatment. Sesame oil-treated *Tsire* had the highest lipid content, followed by moringa, clove and the control. The increase in lipid content in essential oil-treated samples may be attributed to their lipophilic nature, which enhances fat retention and reduces oxidation (Dzudie *et al.*, 2004). Essential oils, particularly sesame and moringa, contain bioactive compounds that help in slowing down lipid oxidation, thereby maintaining fat integrity and reducing rancidity (FAO, 2020). Sesame oil's high lipid content supports findings by Shah *et al.* (2025), who noted that lipid-rich oils may

provide structural stability but are susceptible to oxidation over time. Clove oil's moderate lipid preservation, coupled with high carbohydrate content, reflects its antioxidant efficacy, likely due to eugenol.In contrast, the control group had the lowest lipid content, which suggests higher susceptibility to oxidative lipid degradation over time.

Protein content varied significantly across treatments. The highest protein content was observed in the control group, followed by sesame oil-treated *Tsire*, clove and moringa. The control group retained the highest protein content throughout storage, aligning with findings by Ayo *et al.* (2020), which demonstrated that groundnut oil based *Tsire* effectively protect protein structures in meat products. This can be attributed to its antioxidant and antimicrobial properties, which limit protein denaturation and microbial proteolysis.The reduction in protein content in essential oil-treated samples could be due to protein-lipid interactions, which affect nitrogen solubility during storage (Purslow, 2022). Essential oils, despite their antimicrobial benefits, may lead to protein denaturation due to their bioactive components (Muchenje *et al.*, 2008). However, the protein content across all treatments remained relatively high, indicating that *Tsire* remains a nutrient-dense meat product despite the preservation process.

Crude fibre content was significantly different among treatments. *Tsire* preserved with clove oil had the highest fibre content (3.33%), followed by moringa (3.26%), sesame (3.17%), and the control (3.16%). The increased fibre content in essential oil-treated samples suggests that these oils may have a stabilizing effect on the structural components of the meat, preventing excessive degradation of fibrous materials (Lawrie, 1998). Fibre contributes to digestibility and textural properties, and its retention in preserved *Tsire* enhances its overall dietary quality.

Carbohydrate content was also influenced by essential oil treatments. The highest carbohydrate content was recorded in clove-treated *Tsire*, followed by moringa, the control and sesame. The variation in carbohydrate levels may be due to differences in glycogen breakdown and microbial activity during storage. Clove oil-treated *Tsire* exhibited the highest carbohydrate

content, possibly due to its strong antimicrobial properties, which help in reducing microbial degradation of residual sugars ((Nartey *et al.*, 2021). Conversely, the significantly lower carbohydrate content in sesame oil-treated *Tsire* suggests that it may have accelerated carbohydrate metabolism, potentially influencing the energy composition of the product.

The results demonstrate that essential oils significantly influence the proximate composition of *Tsire*, affecting mineral retention, lipid oxidation, protein stability, and carbohydrate metabolism. The use of clove, moringa, and sesame oils in meat preservation offers the following potential benefits:

5.4 Effect of Storage Period on the Proximate Composition of *Tsire* Stored at Room Temperature

The storage duration of *Tsire* at room temperature significantly influenced its moisture, ash, lipid, protein, fibre, and carbohydrate contents. The findings provide insights into how prolonged storage affects the nutritional stability and quality of *Tsire*, with implications for shelf life, spoilage, and consumer acceptability.

Moisture content increased significantly over the storage period. The moisture content increased progressively and peaked at 72 hours. The increase in moisture content over time suggests that *Tsire* absorbed environmental humidity or underwent water migration within the meat matrix, leading to higher water activity (Lawrie, 1998). Elevated moisture levels at 72 hours indicate a higher risk of microbial growth, which could compromise product safety and shelf stability (Muchenje *et al.*, 2008). The relatively low initial moisture content at 0 hours reflects the drying effect of the roasting process, which is essential for extending shelf life.

The ash content, representing the total mineral composition, showed a slight but significant decrease over time. The ash content was highest at 0 hour, with minimal reduction at 24 hours and 48 hours, and a more pronounced decrease at 72 hours. The gradual decline in ash content

suggests that prolonged storage might lead to mineral leaching or oxidative degradation of certain inorganic components (Dzudie *et al.*, 2004). The slight but significant decrease at 72 hours may also indicate protein denaturation and mineral loss due to lipid oxidation ((Nartey *et al.*, 2021).

Lipid content was significantly affected by storage time, showing a progressive decline from 0 hours to 72 hours. The highest lipid content at 0 hours indicates freshness and minimal oxidation, while the reduction over time reflects lipid degradation and rancidity. The observed lipid reduction at 24 hours and 48 hours suggests early stages of oxidation, whereas the sharp decline at 72 hours highlights significant lipid deterioration, potentially affecting flavor, texture, and shelf life (FAO, 2020). Lipid oxidation leads to the formation of off-flavors and rancid odors, which lower consumer acceptability and nutritional value (Purslow, 2022).

Protein content declined significantly during storage. Protein content gradually decreased with storage duration. This reduction may be attributed to protein denaturation, Maillard reactions, and enzymatic activity, leading to structural changes and loss of nitrogenous compounds (Muchenje *et al.*, 2008). The decline in protein content at 24 hours suggests early proteolytic degradation, while the relative stabilization at 48 and 72 hours may indicate that protein loss slows as oxidation progresses. Despite this reduction, *Tsire* remained a protein-rich food product, making it an excellent dietary source of essential amino acids.

Fibre content decreased significantlywith prolonged storage. At 0 hours, fibre content was 3.40%, which declined to 3.19% at 24 hours, 3.17% at 48 hours, and 3.16% at 72 hours. The slight but significant reduction suggests that storage duration affects the integrity of beef *Tsire*fibres, possibly due to oxidative stress and enzymatic breakdown (Lawrie, 1998). Since fibre plays a role in meat texture and digestibility, its decline may affect mouthfeel and sensory attributes of stored *Tsire*.

Carbohydrate content showed significant variations during storage. Initially, at 0 hours, carbohydrate content was lowest, increasing significantly at 24 hours, followed by a decline at 48 hours and 72 hours. The increase at 24 hours may be due to glycogen breakdown and Maillard reactions, which enhance flavor and colour formation in roasted meat (Dzudie *et al.*, 2004). The subsequent decline at 48 hours may indicate microbial utilization of residual sugars, while the increase at 72 hours suggests further Maillard reactions and caramelization effects that influence the appearance and taste of beef *Tsire* (Nartey *et al.*, 2021).

5.5 Interaction Effect of Essential Oils and Storage Period on the Proximate Composition of Beef *Tsire*

The increase in moisture content over time, particularly in moringa-treated samples, aligns with findings by Smith *et al.* (2021), who reported similar hygroscopic tendencies in meat products stored at room temperature. The essential oils appear to influence moisture retention differently, with sesame and clove maintaining lower moisture levels compared to moringa.

Higher ash content in moringa-treated samples suggests a superior ability to retain minerals during storage. This finding is consistent with studies by Dahiya and Garg (2025), who demonstrated that plant-based treatments enhance mineral retention in food products.

Lipid degradation over time is expected due to oxidative processes, as noted in previous studies (Martins *et al.*, 2020). The higher lipid retention in sesame-treated *Tsire* could be attributed to the antioxidant properties of sesame oil, which has been reported to delay lipid oxidation (Lee *et al.*, 2021).

The decline in protein content is in agreement with research by Adekunle *et al.* (2022), who observed similar reductions in stored meat products due to microbial degradation. The stability of protein in sesame and control samples may be linked to better preservation of amino acids.

The relatively stable fibre content across treatments suggests that fibre components are less susceptible to storage degradation. This observation aligns with findings by Lu *et al.* (2022), who reported minimal changes in fibre content during storage of plant-enriched meat products.

The increasing CHO content in clove-treated *Tsire* over time may be linked to carbohydrate concentration effects due to moisture loss. Previous research by Kim *et al.* (2021) highlighted a similar trend in dried meat products, where carbohydrate levels increased as moisture content declined.

5.6 Effects of Essential Oils on MDA and pH

The study highlighted significant lipid oxidation in *Tsire* during storage, as reflected by MDA levels. Clove oil's ability to suppress lipid oxidation aligns with findings by Gómez *et al.* (2024), who demonstrated the antioxidant properties of eugenol in Clove oil, effectively reducing MDA in meat products. In contrast, Moringa oil's poor performance may be attributed to its lower concentration of antioxidants, as noted by Abdollahi *et al.,* (2025).

pH dynamics

The stabilization of pH by Clove oil is consistent with its buffering properties and ability to inhibit microbial-induced acid production. Jamali *et al.* (2021)observed similar results in meat treated with cinnamon oil nanoemulsions, where pH stability indicated microbial suppression. Conversely, Moringa oil's fluctuation in pH could reflect enhanced microbial activity due to inadequate preservative properties.

The dual role of clove oil in minimizing lipid oxidation and maintaining pH stability makes Clove oil a promising natural preservative. The limited efficacyof moringaoil necessitates reformulation, potentially with other antioxidants or preservatives. Prolonged storage enhances lipid oxidation and impacts pH, underscoring the importance of effective preservation strategies.

5.7 Effects of Storage Period on MDA and pH of *Tsire* at room temperature

The increasing trend in MDA levels over storage time is indicative of lipid oxidation, a major concern in meat preservation. Lipid oxidation leads to rancidity, off-flavors, and deterioration of nutritional quality and consumer acceptability (Martins *et al.*, 2020). The significant rise in MDA at 24 hours and the peak at 72 hours suggest that oxidative stability declines rapidly within the first three days of storage, similar to findings by Smith *et al.*(2021). The progressive lipid oxidation observed is consistent with previous studies indicating that unsaturated fatty acids in meat are prone to oxidative degradation over time (Johnson *et al.*, 2019).

The fluctuations in pH values provide insights into microbial activity and biochemical changes occurring during storage. The increase in pH up to 48 hours aligns with studies that suggest protein breakdown and microbial activity lead to the accumulation of alkaline byproducts such as ammonia and amines (Adekunle *et al.*, 2022). However, the decline in pH at 72 hours supports the hypothesis that organic acid formation due to microbial fermentation and oxidative byproducts leads to increased acidity (Kim *et al.*, 2021).

These findings suggest that*Tsire* stored beyond 48 hours at room temperature undergoes significant oxidative deterioration, affecting both flavor and safety. It is recommended that *Tsire* be consumed within 48 hours or stored under refrigerated conditions to minimize oxidation and microbial growth.

5.8 Interaction Effects of Essential Oils and Storage Period on MDA and pHof *Tsire*Stored at Room Temperature

The significant interaction effect between essential oils and storage period indicates that the antioxidant and antimicrobial efficacy of essential oils varies depending on the duration of storage.

Moringa oil showed a decline in efficacy over time, likely due to oxidative degradation of its bioactive components. This observation is consistent with Saini *et al.* (2014), who reported that prolonged exposure to oxygen and light reduces the stability of antioxidants in moringa oil. Clove oil maintained its efficacy throughout the storage period, underscoring its stability and potency. Fekadu *et al.* (2017) highlighted that clove oil's eugenol content remains effective under varying storage conditions, making it a reliable natural preservative. While sesame oil demonstrated moderate efficacy, its antioxidant and antimicrobial activity was not as pronounced as clove oil. Anwar and Bhanger (2003) emphasized that sesame oil's effectiveness depends on the concentration of its active compounds, which may be lower compared to clove oil.

The study revealed that clove oil is the most effective natural preservative for *Tsire*, maintaining low lipid peroxidation (MDA) levels and stable pH during storage. Moringa oil showed high initial efficacy but diminished over time, while sesame oil demonstrated moderate effectiveness. These findings highlight the potential of essential oils, particularly clove oil, as alternatives to synthetic preservatives for improving the shelf life and quality of meat products stored at room temperature.

5.9 Effect of Essential Oils on Organoleptic Properties of Processed*Tsire*

The results indicate that the choice of essential oil significantly affects the organoleptic properties of beef *Tsire*. Sesame oil performed best overall, with the highest scores in tenderness, juiciness, and acceptability, making it a promising natural preservative for maintaining the desirable texture and taste of *Tsire*. The control sample was highly rated for colour which suggests that natural beef *Tsire* remains the preferred option when freshness is ensured (Zahradden *et al.*, 2024).Moringa oil had the lowest colour score, which could be due to pigment degradation or interactions with meat proteins. However, it did not significantly

reduce acceptability, meaning it could still be useful if its impact on colour can be minimized. Clove oil, on the other hand, was preferred for improving tenderness, likely due to its strong antioxidant properties which could enhance consumer acceptability (Balarabe *et al.*, 2016; Shah *et al.*, 2025). The higher juiciness and tenderness of Sesame oil-treated samples suggest that it helps maintain meat quality during storage, likely due to its high lipid content, which may slow moisture loss (Farhadi *et al.*2019; Domínguez*et al.*, 2021).

5.10 Effect of Essential Oils on Microbial count of *Tsire*Stored at Room Temperature

The results highlight the significant impact of essential oils on microbial activity. Clove oil exhibited superior antimicrobial properties, achieving the lowest bacterial and mold counts. This observation aligns with research by Bai *et al.* (2022), who reported strong antimicrobial effects of eugenol, the active compound in Clove oil, against foodborne pathogens in meat products. Additionally, Alfattani *et al.* (2025)highlighted the potency of essential oils in inhibiting *Clostridium perfringens* in meat matrices. The ability of clove oil to maintain its efficacy over multiple storage days suggests it is a superior candidate for shelf-life extension.

In contrast, moringa oil showed limited effectiveness, potentially due to lower concentrations of antimicrobial phytochemicals. Moringa oil exhibited inconsistent performance, with higher mold and bacterial counts compared to clove oil. This finding is consistent with Abdollahi *et al.* (2025), who emphasized that the antimicrobial activity of essential oils varies significantly with their phytochemical composition. The lower efficacy could stem from limited concentrations of bioactive compounds like is thiocyanates in moringa oil.

Although sesame oil demonstrated initial antimicrobial effects, microbial counts escalated over storage. Shah *et al.* (2025) observed a similar trend in meat treated with plant-based oils, attributing this to the limited stability of the active compounds under oxidative conditions.

Moreover, the lipid-rich nature of sesame oil may provide a conducive environment for microbial growth upon degradation.

5.11 Effect of Storage Period on Microbial Loads of *Tsire*Stored at Room Temperature

Microbial proliferation increased with prolonged storage, especially for yeast and bacteria. The exponential growth pattern underscores the role of storage conditions in microbial dynamics. The observed reduction in mold counts over time may result from competition with faster-growing bacteria and yeasts under the given conditions. The exponential increase in microbial counts with storage duration underscores the importance of preservative stability. Research by Zhu *et al.* (2024) on cinnamon oil Nano emulsions demonstrated the critical role of formulation in sustaining antimicrobial activity.

5.12Interaction effect of essential oils and storage period on the microbial load of *Tsire*Stored at Room Temperature

The interaction analysis revealed that microbial dynamics depend on both the type of essential oil and storage duration. Clove oil minimized microbial growth effectively over extended storage, indicating its potential as a preservative. On the other hand, Sesame oil, while initially suppressing bacterial counts, exhibited a sharp increase by 72hours, suggesting its efficacy diminishes over time. The study underscores the potential of essential oils, particularly clove oil, as natural preservatives for spiced meat products like *Tsire*. Incorporating these oils could extend shelf life, reduce spoilage, and enhance food safety without synthetic additives. Clove oil emerges as a viable natural preservative, capable of enhancing food safety while aligning with consumer preferences for clean-label products. The lesser efficacy of moringa and sesame oils suggests a need for their reformulation, possibly by combining them with synergistic compounds like nanoemulsions (Silva, 2023). Regulatory support for incorporating essential oils in food preservation can encourage innovation in extending shelf life while ensuring safety.

CHAPTER SIX

SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.1 Summary

This study investigates the effectiveness of essential oils from Moringa, Clove, and Sesame in preserving and storing beef *Tsire* using nylon net.Fresh beef samples were purchased from the Animal Product Processing Laboratory of the Department of Animal Science, ABU, Zaria. Moringa, Clove, and Sesame oils were procured from a local herbal product dealer.The beef was sliced into uniform strips, washed, and seasoned with *Tsire* spice mix, including groundnut powder, ginger, pepper, and salt.The seasoned meat was skewered and roasted at 160°C for 30 minutes to simulate traditional preparation. A measure of5mlof essential oil was applied uniformly to each beef *Tsire*stick.The*Tsire* samples were stored in sterile nylon net to facilitate airflow while preventing contamination.Control samples (without essential oil treatment) were also stored in nylon net packaging for comparison.

Total bacterial count (TBC), yeast and mold count were assessed using plate count techniques on nutrient agar, potato dextrose agar, and MacConkey agar, respectively.Oxidative Stability (Lipid Oxidation): The thiobarbituric acid reactive substances (TBARS) assay was used to measure malondialdehyde (MDA) formation, an indicator of lipid oxidation.Sensory evaluation was carried out using semi-trained panelist.The beef *Tsire* samples were monitored for 3 days, with periodic microbial and oxidative analyses to determine the effectiveness of the essential oils in prolonging freshness.The data collected were statistically analyzed using ANOVA (Analysis of Variance) to determine significant differences between treatments. Duncan's Multiple Range Test (DMRT) was applied to compare mean values at $p< 0.05$.

The phytochemical analysis of the essential oils showed that clove oil had the highest levels of alkaloids (87.50 mg/g), total phenol (218.43 mg/g), tannins (186.99 mg TAE/g), and DPPH

radical scavenging activity (61.60 µg/ml). Sesame oil also exhibited high flavonoid (189.79 mg QE/g) and tannin (176.23 mg TAE/g) content. Moringa oil had moderate levels of phytochemicals, while groundnut oil (control) had the lowest values across all parameters.The results on microbial analysis revealed that sesame oil had the highest yeast count, while Moringa oil had the lowest. Clove oil minimized bacterial loads, whereas the control group had the highest. Storage duration significantly influenced microbial growth, with yeast and bacterial counts increasing over time, while mold counts declined. Interaction effects revealed that Sesame oil-treated samples exhibited the highest microbial counts at 72 hours, whereas Clove oil consistently suppressed microbial growth. Clove oil effectively reduced lipid oxidation, while Moringa oil exhibited the highest MDA levels. pH values fluctuated over time, with Clove oil maintaining the most stable levels. Storage duration increased lipid oxidation, peaking at 72 hours, while pH fluctuated but generally declined over time. Interaction effects showed Clove oil had lower MDA levels across all storage periods, whereas Moringa oil exhibited significant fluctuations.

Proximate composition analysis revealed that Sesame oil had the highest lipid content, while Clove oil had the highest fibre and carbohydrate levels. The control group had the highest protein content, whereas Moringa oil had the lowest. Storage duration significantly affected proximate composition, with moisture and carbohydrate levels increasing over time, while lipid, protein, and fibre contents declined. Interaction effects showed that Moringa oil-treated samples retained the highest moisture content, while Clove oil-treated samples exhibited higher fibre and carbohydrate levels.The organoleptic properties of *Tsire* varied based on essential oil treatment. Significant differences were observed in color, tenderness, juiciness, and overall acceptability, while aroma showed no significant variation. Clove oil improved texture and overall acceptability, while other treatments affected sensory attributes differently.

6.2 Conclusions

The following conclusions were made from the findings of this study:

1. Clove oil had the highest levels of alkaloids (87.50 mg/g), total phenol (218.43 mg/g), tannins (186.99 mg TAE/g), and DPPH radical scavenging activity (61.60 µg/ml). Sesame oil also exhibited high bioactive compounds, particularly in flavonoid (189.79 mg QE/g) and tannin (176.23 mg TAE/g) content.
2. The application of clove essential oil resulted into reduced bacterial (69.75 x 10^6 cfu/g) and mold (8.25 x 10^4 cfu/g), followed by sesame oil with intermediate bacterial (95.00 x 10^6 cfu/g) and mold (9.00 x 10^4 cfu/g) counts while moringa oil (131.50 x 10^6 cfu/g and 16.67 x 10^4 cfu/g) the control (105.25 x 10^6 cfu/g and 10.00 x 10^4 cfu/g) had higher bacterial and mold counts. Bacterial and yeast count increased with increase in storage periods while mold count declined.
3. Lipid content was higher in sesame oil treated samples than other treatment groups while crude protein was higher in the control sample followed by those treated with sesame oil, and clove oil while the moringa oil group had lower value. Lipid and crude protein contents decline with increase in storage days.
4. Sensory evaluation revealed that theClove oil (3.75±1.33),Sesame oil (3.74±1.19)and Moringa oil sample (3.45±0.99)were the most preferred while Control sample (2.45±1.28) had the lowest acceptability score.
5. Clove oil, sesame oil and the control samples had lower lipid oxidation rates than moringa oil treated sample which had higher lipid oxidation. Also, lipid oxidation increases with increase in storage days with day 0 having lower MDA while day 72 had the highest MDA.

6.3 Recommendations

It was therefore recommended that:

1. Food processors should incorporate clove essential oil as a natural preservative for its effectiveness in reducing bacterial and mold counts to enhance microbial safety and shelf stability of food products such as beef *Tsire*.
2. Since these oils contributed to higher sensory acceptability, their application should be encouraged in food processing industries to enhance product quality and consumer preference.
3. Government and regulatory agencies should establish guidelines for using essential oils in food preservation to ensure safety and efficacy.
4. Further study should be carried out with improved storage techniques such as vacuum packaging or refrigeration in maintaining nutritional quality over time where products needs to be stored over time since lipid and crude protein content decline with storage duration.
5. Further studies should determine the optimal concentration of each essential oil to maximize preservation efficacy without altering sensory attributes.

6.4 Contributions to Knowledge

The following contributions to knowledge were made:

1. Total bacterial count of processed beef *Tsire* can be reduced by 33.73% and 9.74% by inclusion of clove and sesame essential oils.
2. The overall acceptability of beef *Tsire* can be improved by 28.99%, 34.67% and 34.49% by inclusion of moringa, clove and sesame essential oils, respectively.

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APPENDICES

Appendix I: Parameter of meat quality traits

Quality traits	Parameters	Acceptability	Unacceptable
Palatability	Juiciness	Moist	Lack of flavour
	Tenderness	Tender	Tough or mushy
	Flavour	Typical of spec	e Acid taste, boar taint, rancid
Appearance	Texture	Firm	Dry, mushy, soft
	Fat colour	White	Yellow
	Meat colour	Red/ pink	Brown, grey green

Source: Laird (2006).

Appendix II: Grades TVC (total viable count)/g at 30°C Description

1	<1/2 million	Satisfactory
11	1/2 million	Passable
III	10 million and more	Unsatisfactory

Wilson *et al.*, 1991