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FABRICATION AND CHARACTERIZATION OF BIOACTIVE PACKAGING FILM FROM CORNSTARCH-BEESWAX BLEND INCORPORATED WITH GINGER ESSENTIAL OIL FOR MEAT PRESERVATION.

BY

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UNIVERSITY OF GHANA, LEGON

COLLEGE OF BASIC AND APPLIED SCIENCES

DEPARTMENT OF FOOD PROCESS ENGINEERING

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THIS THESIS IS SUBMITTED TO THE DEPARTMENT OF FOOD PROCESS ENGINEERING OF THE SCHOOL OF ENGINEERING SCIENCES, UNIVERSITY OF GHANA, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF PHILOSOPHY DEGREE IN FOOD PROCESS ENGINEERING.

JANUARY, 2026

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DECLARATIONS

Candidate's Declaration

I hereby declare that this MPhil thesis which has results of my own original research was prepared in accordance with the University of Ghana academic regulations and that no part of it has been presented for another degree in this university or elsewhere

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Declaration I hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Ghana.

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ABSTRACT

Preserving fresh meat with sustainable packaging is vital to maintaining quality and extending shelf life while reducing carbon footprint. Bio-based films, such as cornstarch-beeswax blends, offer an eco-friendly alternative to fossil-based plastics but face hydrophilicity challenges in meat packaging. This study fabricated cornstarch-based bioactive films using distilled water as solvent and glycerol as a plasticizer to enhance flexibility. Beeswax was incorporated at 2.5, 5, 10, and 15% to evaluate effects on hydrophobicity and water resistance, while ginger essential oil (GEO) was added at 5, 10, and 15% to bolster antimicrobial activity. Films were cast and dried in an open oven for 12 hours. Comprehensive characterization included tensile testing, Fourier Transform Infrared (FTIR) spectroscopy, thermogravimetric analysis (TGA), moisture absorption, and dissolution tests. Statistical analyses (ANOVA) were used to assess the effects of beeswax and GEO concentrations on film properties and antimicrobial performance ($p < 0.05$ considered significant). Results show that beeswax at 2.5–5% reduced solubility from 0.32 to 0.20, whereas 10–15% increased solubility (0.24–0.26), indicating a threshold for optimal hydrophobicity. Moisture content and swelling followed similar trends. Beeswax enhanced tensile modulus but reduced elongation. FTIR indicated shifts in OH-related and C–O/CH2 bonding with varying beeswax content; TGA showed improved thermal stability at higher beeswax levels. GEO markedly improved antimicrobial performance, extending inhibition of meat-associated bacteria from day 1 to day 8, with diminishing effectiveness thereafter. Overall, the combined beeswax–GEO system significantly improves film water resistance, mechanical integrity, and antimicrobial efficacy, offering promise for extending meat shelf life with a sustainable packaging approach.

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DEDICATION

This work is dedicated to my family.



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Scanning electron microscopy

SEM 33

2,2-diphenyl-1-pyridine-hydrazyl radical

DPPH 35

Adenosine triphosphate

ATP 26

Beeswax ,

BW 39

Ethylenvinyl alcohol

EVOH **13**

Fourier Transform and Infrared Spectroscopy

FTIR 41

Gas permeability

GS 12

Ginger essential oil

GEO 23

Lipid Oxidation

LO 26

minimum bactericidal concentrations

MBC 32

minimum inhibitory concentrations

MIC 32

Moisture Content

MC 41

inhibition zone diameter

DIZ 32

Polyethylene

PE 13

polylactic acid

PLA 16

Polypropylene

PP **13**

Polyvinylchloride

PVC **13**

Polyvinylidenchloride

PVDC **13**

reducing power

FRP 35

Swelling Degree

SD 41

Thermogravimetric Analysis

TGA 41

Thermoplastic starch

TPS **6**

United Nations Environment Programme

UNEP 1

Water Solubility

WS 42

World Health Organization

WHO **1**

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Food functions as a complex, dynamic system wherein each constituent is subject to continual transformation. Controlling or moderating these changes is crucial to mitigating undesired outcomes in the food distribution system. Food spoilage leads to adverse changes in sensory attributes, including appearance, texture, odor, and flavor, ultimately compromising acceptable quality. This results in significant economic losses and contributes to the scarcity of consumable food products. A substantial quantity of food is wasted due to spoilage, notwithstanding advancements in preservation techniques (Gram et al., 2002; Remenant et al., 2015).

According to the Food and Agriculture Organization (FAO) of the United Nations and the World Health Organization (WHO), approximately one-third of food produced for human consumption is discarded annually (FAO, 2011). Food rejection is predominantly linked to spoilage, defined as any alteration that renders products unacceptable to consumers (Koutsoumanis, 2009). Factors contributing to the loss of quality include physical damage, chemical reactions, infestations by insects and rodents, and microbial proliferation (Gram et al., 2002; Ray and Bhunia, 2013). Despite the utilization of refrigeration, chemical preservatives, and contemporary techniques, estimates indicate that around 25% of all food produced globally is wasted post-harvest or post-slaughter due to microbial spoilage, identifying this as the predominant cause of food quality degradation (Gram et al., 2002; Cenci-Goga et al., 2014).

Among various food items, meat is considered one of the most perishable (Doulgeraki et al., 2012), primarily due to its inherent chemical and enzymatic activities and its suitability as a substrate for a diverse range of microorganisms. This susceptibility arises from its nutrient profile,

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high moisture content, and moderate pH (Dave and Ghaly, 2011). The spoilage of meat is fundamentally driven by three mechanisms: microbial growth, oxidation, and enzymatic autolysis. In addition to lipid oxidation and enzymatic reactions, microbial proliferation is consistently implicated in meat spoilage. The degradation of fats, proteins, and carbohydrates in meat leads to the production of off-odors, off-flavors, and slime formation, rendering the meat unappetizing for human consumption (Ercolini et al., 2006; Nychas et al., 2008).

The scientific interest in meat microbiology emerged as a response to the increasing complexity of meat distribution, particularly with the advent of long-distance shipping and the proliferation of supermarkets in the 1950s, which notably transformed consumer behavior (Nychas et al., 2008). In contemporary society, there has been a notable shift from local markets to global trade, leading to the integration of ready-to-eat meat products into modern diets. This evolving food culture necessitates the enforcement of stringent food quality and safety standards throughout the product's commercial lifespan, especially to meet the rigorous requirements for international trade (FAO, 2021). Ensuring the stability of the characteristics of meat is a critical initial step for producers in the prevention of undesirable changes during storage (FAO, 2021).

Aligned with Sustainable Development Goal (SDG) 2, which addresses food security, the growing global population demands urgent efforts and innovative strategies to sustainably enhance agricultural production (United Nations, 2015). This entails improving the global supply chain, reducing food losses and waste, and ensuring access to nutritious food for those suffering from hunger and malnutrition. Many stakeholders within the international community are optimistic about the potential to eliminate hunger within the next generation, actively collaborating to realize this objective (UN, 2015). To achieve food security, it is essential to focus on two interconnected factors: either increasing the production of food to meet human

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needs or developing innovative, sustainable preservation methods for farmers' produce, thereby ensuring a consistent supply of food to alleviate hunger (UN, 2015).

Meat plays a vital role in fulfilling nutritional requirements and contributes significantly to a balanced diet. According to the Food and Agriculture Organization (FAO, 2021), the overall consumption of white meat has risen dramatically from the 20th to the 21st century. Specifically, per capita poultry consumption has increased by 76.6%, while pig meat consumption has risen by 19.7%. Notably, FAO analysis indicated that in 2021, global meat production reached 357 million tonnes, representing a 53% increase since 2000, with chicken accounting for more than half of this growth (FAO, 2021).

Given these trends, the sustainable preservation of meat is crucial not only for maintaining its quality and safety but also for supporting broader food security initiatives as outlined in the SDG framework. By prioritizing sustainable practices, the meat industry can contribute significantly to the ongoing global efforts to combat hunger and malnutrition, ensuring a reliable supply of nutritious food for populations worldwide (FAO, 2021; United Nations, 2015).

These preservation methods include canning with vinegar, smoking, freezing, irradiation, salting, and the use of chemical preservatives such as sodium benzoate and nitrites. While these techniques have been effective in extending the shelf life of meat, each method also presents certain drawbacks. For instance, excessive smoking has been linked to health issues, and irradiated meat may retain harmful residues, including heavy metals such as cadmium. Furthermore, salting has been associated with an increased risk of circulatory diseases due to high sodium content (Kadam et al, 2022).

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Among the range of packaging options used to preserve meat, petroleum-based materials have been prevalent. However, these non-biodegradable packages pose environmental concerns and are linked to resource depletion due to production pressures. The adverse effects of traditional preservation and packaging practices have prompted a global push to develop and adopt sustainable packaging alternatives (Singh et al., 2024).

The potential adoption of biobased, environmentally friendly, and biodegradable packaging materials is critical not only for extending the shelf life of meat but also for maintaining the sensory properties that define quality meat products. By focusing on innovative packaging solutions that preserve the integrity of meat while being mindful of environmental sustainability, the meat industry can significantly contribute to meeting the needs of a growing population without compromising health or ecological integrity. Such advancements represent a promising pathway towards ensuring that meat retains its nutritional and sensory qualities while aligning with modern sustainability objectives (Kadam et al, 2022).

Biobased polymers have emerged as a promising alternative for developing films specifically designed for meat packaging applications. These materials are derived from renewable resources, with common sources including starch, cellulose, chitin, chitosan, gelatin, collagen, and alginate. Research indicates that cellulose and starch can provide effective gas barriers and possess favorable mechanical properties, making them suitable for packaging purposes (Singh et al., 2024). In addition to their mechanical advantages, several biopolymers exhibit non-toxic, antifungal, and antimicrobial properties, further enhancing their appeal for food packaging (Kadam & Barbhai, 2022).

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Despite these beneficial attributes, biopolymers have not yet fully supplanted conventional polymers in various applications, primarily due to inherent limitations in their mechanical strength.

Researchers have proposed the development of “intelligent” biopolymers capable of monitoring and adapting to environmental conditions to enhance food preservation. Advances in this area involve incorporating active compounds into polymers such as chitosan and gelatin, as well as employing waxes and other functional additives to improve their mechanical, functional, and barrier properties (Singh et al., 2024).

Among the various biopolymers, thermoplastic starch is particularly notable in the biodegradable film industry. However, starch's sensitivity to moisture and mechanical fragility pose challenges for its use in packaging. To address these limitations, researchers have employed mechanical and thermal modifications to starch molecules and added plasticizers to create a gelatinized starch suitable for processing. Cornstarch, in particular, has gained prominence due to its wide availability and ease of access (Kadam et al, 2022).

This research aims to develop an active biobased film using cornstarch, glycerin, beeswax, and ginger essential oil for meat preservation. The incorporation of ginger essential oil not only enhances the antioxidant properties of the film but also aids in extending the shelf life of meat products. These innovative films represent a sustainable solution to mitigate the environmental challenges presented by traditional plastic packaging methods (Souza et al., 2018).

By prioritizing the use of cornstarch films incorporated with natural additives like beeswax and ginger oil, this approach offers a viable alternative for meat packaging that minimizes spoilage and reduces dependence on non-biodegradable plastic materials. Such advancements not only

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contribute to more sustainable packaging practices but also align with broader environmental goals, addressing the pressing issues of plastic waste and food security. Ultimately, these biobased films hold significant potential for revolutionizing meat packaging, making it both eco-friendly and effective in prolonging product freshness (Souza et al., 2018).

1.2 Problem statement

The issue of food waste has become increasingly critical, with the Food and Agriculture Organization (FAO) of the United Nations estimating that approximately one-third of food produced for human consumption is wasted annually (FAO, 2011). According to the Food Waste Index report from the United Nations Environment Programme (UNEP), about 931 million tons of edible food were wasted globally in 2019, equivalent to 17% of the total food available to consumers. (UNEP, 2021) This paradox highlights a disturbing situation: while food overproduction and waste persist across the globe, the hunger crisis continues to escalate. Currently, nearly 690 million people—approximately 8.9% of the world population—are experiencing hunger, a trend that has been on a gradual rise since 2014, revealing persistent challenges associated with malnutrition in all its forms. The COVID-19 pandemic has exacerbated these food security issues by disrupting supply chains and diminishing demand for products such as meats, dairy, and fresh fruits and vegetables. (FAO 2020)

Food waste not only signifies lost opportunities to feed the growing global population but also represents the squandering of precious resources such as land, water, and energy that are consumed throughout the food production process. The environmental repercussions of increased food waste are profound, affecting climate change, water resources, and land utilization. Notably, within the meat sector, an estimated 23% of production is lost or wasted, with the highest

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proportion occurring at the consumption stage (64%), followed by manufacturing (20%), distribution (12%), and primary production along with post-harvest processes (3.5%) (Karwowska, 2021).

In light of this, it has become crucial to identify sustainable methods for preserving meat and reducing spoilage rates. The development of active biobased packaging represents a promising solution to both preserve meat quality and extend its shelf life. Cornstarch, known for its excellent gelatinization properties, is a commonly sourced polymer suitable for fabricating films for meat packaging. However, significant challenges must be addressed to ensure the effectiveness of these biobased films in maintaining fresh meat's quality, safety, and longevity.

Thermoplastic starch (TPS) films are inherently limited by their high hydrophilicity, rendering them unsuitable for humid environments. (Leroy et al., 2022).Therefore, enhancing the properties of TPS is essential, which may involve the incorporation of less volatile, less water-sensitive plasticizers and suitable hydrophobic fillers. (Jamalpour et al., 2025; BMC Chemistry, 2023) This study will explore the challenges posed by microbial growth, oxidation, moisture loss, and the urgent need for sustainable alternatives to conventional plastic packaging.

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In addition, the study will investigate methods to fabricate films that improve hydrophobicity, mechanical strength, and antimicrobial properties. According to Vijayan (2023), beeswax has been shown to enhance the hydrophobicity of films not only through its chemical composition but also by imparting surface roughness. The advantageous characteristics of these bio-coatings include high transparency (over 95% UV-visible transmittance), superior thermal stability

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(thermal degradation temperatures exceeding 250 °C), and reasonable glass transition temperatures, indicating broad applicability in packaging.

Furthermore, ginger, a perennial herb from the Zingiberaceae family, has significant potential in this context. With its origins in Southeast Asia, it is now widely cultivated and valued for its characteristic aroma, taste, and medicinal properties. Ginger essential oil (GEO), derived from the root, possesses numerous bioactive compounds, including bioactive phenols (gingerols, shogaols, and zingerones), which contribute to its efficacy in extending the shelf life of meat. Incorporating ginger essential oil into active packaging not only aligns with the objective of minimizing food spoilage but also represents a sustainable approach to enhancing meat preservation.

1.3 Approach

To address the pressing issue of meat spoilage, this research proposes an innovative approach centered on the development of active packaging films utilizing cornstarch as the primary material, with glycerol acting as a plasticizer. Additionally, beeswax is incorporated to enhance the hydrophobicity of the films, alongside ginger essential oil (GEO) to maximize the shelf life of meat products through its antioxidant properties. The selection of these materials is rooted in their natural origins, availability, and suitability for creating effective bio-based films. Cornstarch, being both widely accessible and cost-effective, contributes to the flexibility and biodegradability of the film. Glycerol, a byproduct of biodiesel production, enhances resistance to moisture and improves flexibility, making the film more adaptable to various environmental conditions. Beeswax, a natural substance produced by bees, offers added water resistance and durability to the films, ensuring their effectiveness in protecting meat from spoilage.By synergistically combining these components, it becomes possible to create bio-based films with desirable

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attributes, including biodegradability, mechanical strength, flexibility, and water resistance. Such films hold promise for a wide range of applications, extending beyond meat packaging to sectors such as agriculture and biomedicine.

Incorporating ginger essential oil into the film formulation amplifies its effectiveness as a preservative. GEO, derived from the root of ginger, is a volatile oil renowned for its distinctive aroma and numerous biological activities. It has significant potential in various industries, including pharmaceuticals, food, and cosmetics (Mesomo et al., 2013). GEO is recognized for its safety profile as a natural compound, with applications in treating gastrointestinal and respiratory ailments (Mahboubi, 2019). Extensive research has highlighted the antioxidant, antifungal, and antibacterial properties of GEO, underpinning its applicability in food preservation (Ju et al., 2018). For instance, nanocapsules utilizing GEO have demonstrated remarkable antibacterial activity against pathogens such as E. coli, Bacillus subtili, and Staphylococcus aureus.(Xin Wang et al,2020) The development of active bio-based films from cornstarch, glycerol, beeswax, and ginger essential oil presents a promising and sustainable solution to mitigate the environmental challenges posed by traditional plastic films in meat packaging. This approach not only aims to extend the shelf life of meat products but also contributes to the ongoing transition toward environmentally responsible packaging solutions, addressing both food waste and ecological sustainability

1.4 Hypothesis

Essential oils derived from plants and spices are recognized as abundant sources of biologically active compounds, including terpenoids and phenolic acids (Burt, 2004). Numerous studies have demonstrated the efficacy of plant essential oils in safeguarding food products from pathogenic

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microorganisms (Rojas-Graü et al., 2006; Kristo et al., 2008). A comparative analysis of the chemical composition of ginger essential oils (GEO), conducted using gas chromatography-mass spectrometry (GC-MS), identified zingiberene and α-curcumene as the predominant constituents. The antibacterial activity of GEO against Staphylococcus aureus and Escherichia coli has been thoroughly investigated, revealing a diameter of inhibition zone (DIZ) of 17.1 mm against S. aureus, with a minimum inhibitory concentration (MIC) of 1.0 mg/mL and a minimum bactericidal concentration (MBC) of 2.0 mg/mL. In contrast, the DIZ against E. coli was measured at 12.3 mm, alongside MIC and MBC values of 2.0 mg/mL and 4.0 mg/mL, respectively (Xin Wang et al., 2020).

Furthermore, the incorporation of beeswax into cornstarch films has been shown to enhance the mechanical properties of the resulting bioplastics, specifically their tensile strength and elongation. Characterization of these films demonstrated that the addition of beeswax and varying concentrations of glycerol resulted in improved physical properties. Following the drying process, the bioplastic samples exhibited an average weight loss of approximately 95%. Moreover, increased concentrations of beeswax and glycerol contributed to a reduction in the degree of swelling of the films (Suharno Rusdi et al., 2022).

In light of the aforementioned findings, this study hypothesizes that the incorporation of ginger essential oil into biobased packaging films made from cornstarch and beeswax will significantly enhance the films' antimicrobial properties and extend the shelf life of meat products. It is further hypothesized that optimum concentrations of beeswax and glycerol will improve the mechanical strength and moisture resistance of the films, thereby contributing to their overall effectiveness

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in food preservation. This research aims to validate these hypotheses by investigating the interactions between the components and assessing their combined effects on biofilm characteristics and performance in meat packaging applications.

1.4 Aims

The aim of this research is to fabricate and characterize bioactive packaging film from cornstarch/beeswax blend incorporated with ginger essential oil for meat preservation.

1.5 Objectives:

i. To fabricate cornstarch-beeswax film incorporated with ginger essential oil.
ii. Characterize the physicochemical, mechanical, barrier, and bioactive properties of the cornstarch–beeswax bio-based films developed for meat preservation.
iii. To investigate the effect of varying beeswax concentrations on the physicochemical, mechanical, barrier, and bioactive properties of the cornstarch–beeswax bio-based films, with the aim of identifying an optimal formulation for meat preservation.
iv. To establish the effectiveness of the bioactive packaging film produced in fresh meat preservation.

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1.6 Significance of the study

The significance of this study on the topic “characterization of bioactive packaging film from cornstarch-beeswax blend incorporated with ginger essential oil for meat preservation” contributes on several perspectives, including sustainability, food safety, economic implications and health benefits. On sustainability and environmental impact, utilizing cornstarch and beeswax as primary raw materials promotes the development of biodegradable packaging which aligns global efforts to reduce plastic waste and reliance on petroleum-based plastic films, which

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add to environmental pollution. On food safety, the incorporation of ginger essential oil, which is known for its antimicrobial and antioxidant properties, enhances the packaging film's ability to preserve meat by inhibiting microbial growth and delaying spoilage processes. This has significant implications for food safety, helping to reduce foodborne illnesses associated with improperly stored meat which is a global concern. Also the use of ginger essential oil as a natural preservatives addresses contemporary consumer concerns about synthetic additives and preservatives in food products. This can contribute to the overall perception of food quality and safety. Finally this research represents a step toward the innovation of multifunctional packaging systems that not only serve as a physical barrier but also actively contribute to food preservation through bioactive properties.



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CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Meat, defined as the flesh obtained from animals, is a nutrient-dense food source, rich in essential proteins, iron, zinc, fatty acids, and vitamins. However, its high moisture content renders it highly susceptible to spoilage. The inherent chemical composition and enzymatic activities within meat contribute to its rapid degradation. As a result of the breakdown of fats, proteins, and carbohydrates, meat becomes prone to the development of undesirable odors, putrefaction, and slime production, rendering it unsafe for consumption. Factors such as moisture levels, temperature, microbial presence, ambient oxygen, and endogenous enzymes significantly affect the shelf life and freshness of meat products. Environmental bacteria, which are ubiquitous, can easily adhere to meat from various sources and contribute to its deterioration. Consequently, numerous preservation technologies have been developed to inhibit or eliminate microbial growth, with the overarching objectives of extending shelf life, ensuring food safety, and enhancing overall product quality. Given the complexity of meat preservation, diverse strategies are necessary to mitigate bacterial proliferation that compromises the physical and biochemical properties of meat. This literature review aims to explore various methods and techniques employed in the preservation of fresh meat and meat products, highlighting the advantages and disadvantages associated with each approach.

2.2 Global Meat Production and Consumption Pattern

Meat products play a substantial role in contemporary diets, and in response to rising demand, global meat production has been steadily increasing. In 2018, worldwide meat production reached

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approximately 340 million tons, representing more than three times the amount produced fifty years prior. (FAO, 2019; Ritchie & Roser, 2019).Within Europe, significant disparities in meat production exist; for instance, Germany accounted for 22.4% of pork production in 2018, while the United Kingdom produced 37.2% of lamb and goat meat. Poland was the leading producer of poultry, with a contribution of 16.7%, and the Netherlands specialized in veal. Alongside rising production levels, per capita meat consumption has also increased, with an average global consumption rise of about 20 kg since 1961; individuals consumed, on average, around 43 kg of meat in 2014 (Ritchie & Roser,2019).

However, the production and consumption of meat and meat products are associated with significant environmental impacts, necessitating a rational approach to managing these products throughout the entire supply chain, including production, processing, transport, and consumption. Minimizing food loss and waste within the meat sector is crucial for both economic and environmental sustainability. According to Gerber et al. (2013), food animal production is responsible for approximately 14.5% of global human-induced greenhouse gas (GHG) emissions, equating to 7.1 gigatons of CO_2 equivalent annually. Beef production contributes the most to these emissions (35.3%), followed by dairy cattle (30.1%), swine (9.5%), and poultry (8.7%). Notably, nearly half of the total GHG emissions from food animal production are linked to the production, processing, and transport of feed, with enteric methane emissions from ruminants and methane and N_2O emissions from manure storage contributing to 39.1% and 9.5% of the total, respectively.

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2.2.1 Food wastage and losses in meat sector

Despite meat accounting for only about 4% of global food loss and waste, it holds a significantly higher economic value compared to other food categories. (Karwowska et al., 2021; Kilibarda et al., 2023). Consequently, while the quantity of wasted meat is less than that of other products such as grains and vegetables, its economic and environmental ramifications are considerable. Ranganathan et al. (2016) highlighted that meat generates the highest emissions per kilogram compared to other food items. In the United States, Buzby and Hyman (2012) estimated the total value of wasted meat products at approximately $83.1 billion, with consumers responsible for around 35% of this waste. In Canada, a study by Abdulla et al. (2013) revealed that red meat accounted for 39.73% of the total waste, while poultry waste stood at around 40.74%.

2.2.2 Causes of Food Loss and Waste in the Meat Sector

Food loss and waste in the meat sector stem from various factors along the supply chain, with reasons differing at each stage. In primary production, losses primarily occur due to farming and rearing conditions as well as transportation issues related to slaughter. Factors such as transport duration and climatic conditions significantly influence mortality rates; Gustavsson et al. (2011) estimated that about 0.2% of pigs incur losses during transport and slaughter. Additionally, animal illness can escalate losses, leading to unnecessary culling to protect consumer health (Lipiński, 2020).

Processing and production contribute to approximately 20% of overall losses in the meat sector, driven by factors such as improper transportation, human error, and product defects. Karwowska, (2021).Moreover, meat and meat products are particularly perishable and require stringent cold storage conditions. Any lapse in temperature control can lead to spoilage, while

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the limited shelf life of meat products often results in waste if not sold by their labeled expiry date. This phenomenon is especially pronounced during retail, where inadequate quality or safety standards can lead to the rejection of products.

Improper packaging can severely increase losses by exposing products to adverse weather conditions during transport, thereby impacting product quality. Inadequate organization in food distribution also contributes to waste, with excess inventory leading to expired shelf life, mechanical damage, and breaches in product packaging. Research illustrates that the total amount of food wasted in Finnish wholesale and retail trade is estimated at 65–75 million kilograms annually (Katajajuuri et al., 2012). Krajewski et al. (2018) further identified that in their analysis of meat product distribution, 1.25% of distributed products faced loss due to management issues, with potential for charitable donation among a significant portion deemed still consumable.

Overall, the comprehensive assessment of the meat supply chain reveals that effective management strategies are necessary to mitigate food loss and waste. Identifying and addressing the key causes at each stage can help prevent significant economic and environmental repercussions of meat spoilage while also supporting sustainable practices in food production and consumption.

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2.2.3 Meat Preservation

According to Yadav and Singh (2004), meat which is defined as the edible flesh of animals is susceptible to spoiling because of its composition. A number of factors influence the freshness and shelf-life of fresh meat, including endogenous enzyme activity, storage temperature, moisture, ambient oxygen, light, and microbes (Zhou et al., 2010). Lipid peroxidation is the main reason why the quality of meat and meat products deteriorates. Preventing lipid peroxidation,

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prolonging the shelf life, preserving nutrients, freshness, and guaranteeing customer safety are the objectives of meat preservation. Moreover, the goal of meat preservation is to provide preserved meat with physico-chemical qualities that meet consumer standards.

2.3 Methods and principles of meat preservation

Preserving fresh meat is commonly achieved through various traditional methods including salting, refrigeration, radiation, and chemico-biopreservation. Salt plays a vital role by reducing water activity within the meat and impeding the growth of spoilage microorganisms on both the surface and internal layers of the meat (Fennema, 1996). Refrigeration techniques such as chilling, super chilling, and freezing help lower the meat's surface temperature, promote moisture reduction, and inhibit endogenous enzymes as well as enzymes related to spoilage organisms (Ockerman and Basu, 2004). Freezing at low temperatures effectively minimizes qualitative changes in frozen meat by minimizing detrimental redox reactions (Hansen et al., 2004). However, the use of irradiation, which is highly effective in deactivating bacteria and suitable for treating packaged meat, may cause color changes due to the vulnerability of myoglobin to energy input (Lawrie and Ledward, 2006). To address this issue, antioxidants like butylhydroxyanisole (BHA), butylated hydroxytoluene (BHT), sodium nitrites, and nitrates are used in conjunction with radiation for meat preservation (Umemura and Kodama, 2006). In meat processing, the primary goal is to preserve the natural, sensory, and visual qualities of the meat to the greatest extent possible (Zhou et al., 2010).

2.4 Techniques and existing methods of meat Preservation.

The advent and rapid rise of supermarkets necessitated advancements in meat preservation, essential for transporting meat over extensive distances while preserving its texture, color, and

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nutritional integrity (Nychas et al., 2008). Traditional meat preservation techniques, including dehydration, smoking, brining, fermentation, refrigeration, and canning, are increasingly being supplanted by chemical, biopreservation, and non-thermal methodologies (Akhter et al., 2009; Akter et al., 2009; Zhou et al., 2010). The primary aims of these preservation methods involve the prevention of microbial, oxidative, and enzymatic degradation. Current meat preservation strategies can be categorized into three principal approaches: (a) temperature control, (b) water activity regulation, and (c) the application of chemical, biological, or physical preservatives. A synergistic application of these techniques effectively decelerates meat decomposition processes. The multifaceted objectives of meat preservation include i) mitigating foodborne infections and intoxications, ii) safeguarding food and meat product safety from microbial threats, iii) curbing food spoilage, iv) prolonging the shelf life of both raw and processed meats, v) improving the overall quality of meat, and vi) minimizing financial losses.

2.4.1 Chilling/Refrigeration

Refrigeration, or chilling, plays a crucial role in reducing or inhibiting spoilage rates at temperatures lower than optimal, effectively suppressing microbial growth and various enzymatic and physico-chemical processes (Cassens, 1994). Fresh meat is typically stored under refrigeration at temperatures between 2 to 4°C. The chilling process is vital for maintaining hygiene, safety, shelf life, appearance, and nutritional quality (Akhter et al., 2022; Zhou et al., 2010). Initially, carcasses are placed in chilled cooling units at 15°C to dissipate body heat, before being transferred to storage freezers set to 5°C. It is essential to ensure sufficient spacing between carcasses to facilitate continuous air circulation. Chilling can be performed through two methods: (a) immersion chilling, where products are submerged in cooled (4°C) water, and (b) air chilling, where carcasses are sprayed with water in a chamber with airflow (Carroll and Alvarado, 2008).

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The chilling process commences with the freezing of the carcass and extends throughout holding, cutting, transportation, retail display, and even the customer's home until final consumption. To minimize excessive moisture loss, the relative humidity is typically adjusted to around 90%. The optimal duration for refrigerated storage of fresh meat is generally 5-7 days at temperatures of 4 ± 1°C. It has been noted that ultra-rapid freezing of pre-rigor beef may lead to cold-shortening and toughness (Ockerman and Basu, 2004).

2.4.2 Freezing

Freezing is recognized as one of the most effective techniques for preserving the intrinsic qualities of fresh meat. Meat generally comprises 50-75% water by weight, and the freezing process converts much of this water into ice (Heinz and Hautzinger, 2007). This method effectively inhibits microbial growth and curtails enzymatic activity. A major advantage of freezing is its capacity to maintain the nutritional profile of meat during storage, with only minimal nutrient loss during the thawing process. It is crucial to properly wrap fresh meat prior to freezing to avoid freeze burn, which results from gradual surface dehydration and concentration of surface pigments. The quality of frozen meat is also influenced by the freezing rate; slow freezing can produce large ice crystals that may damage muscle tissue and detract from its appearance, while rapid freezing generates numerous small ice crystals that form uniformly within the muscle, thereby preserving its integrity. As temperatures plummet, the freezing rate increases; nearly 98% of water solidifies at -20°C, while complete crystal formation occurs at -65°C (Rosmini et al., 2004). Below -18°C, microbial proliferation halts, and cellular metabolism in animal tissues ceases completely (Perez-Chabela and Mateo-Otague, 2004). However, enzymatic reactions, oxidative rancidity, and ice crystallization may still contribute to deterioration (Zhou et al., 2010).

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Research indicates that around 60% of the viable microbial population perishes during freezing, but the remaining microbes can rebound during frozen storage (Rahman, 1999).

2.4.3 Drying

Among the oldest preservation techniques, drying has been practiced worldwide, often in conjunction with smoking, and was particularly vital in times or areas where chilling and freezing were impractical. For early humans, drying was essential when the flesh and fat from large game could not be consumed quickly. Dried meats, whether salted or unsalted, were crucial during warfare and maritime transportation. With technological advancements, drying has become more systematic, leading to the development of efficient methods such as vacuum drying, ultrasonic drying, freeze-drying, microwave drying, heat pump drying, pulsed electric field drying, and refractance window drying (Dinçer, 2021). Although these methods are effective, those involving higher temperatures may compromise the quality of dried meats by degrading essential nutrients. Globally, various dried meat products exist, influenced by the type of meat, the drying method employed, and any spices added (Akter et al., 2009; Akhter et al., 2009; Mediani et al., 2022).

2.4.4 Curing

Traditionally, the curing of meat involved the application of rock salt, sea salt, or ground salt to unheated pieces or small cuts of meat to lower water activity, inhibit microbial growth and chemical spoilage, soften the meat, and enhance flavor. In the 19th century, producers learned that certain salts offered superior preservation and improved red coloration in meat. Saltpeter (KNO_3) was identified as a key component in these improved salts, although the underlying chemistry remained unclear until extensive research elucidated the role of nitrites formed from nitrates during the curing process. Studies demonstrated that nitrites contributed to the distinctive red color and thermal stability of cured meat (Lacroix, 2007). Sodium chloride, sodium nitrate,

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sodium nitrite, and sugar emerged as the primary curing agents. Various methods of curing, including dry, pickle, injection, and direct methods, are employed globally, with an extensive history for high concentrations of sodium chloride in food preservation (Dave and Ghaly, 2011). Sodium chloride creates conditions that increase osmotic pressure and reduce water activity, inhibiting microbial growth (Dave and Ghaly, 2011). Even minimal concentrations—around 2% prove sufficient to inhibit some bacteria, while higher concentrations—20% sodium chloride—can restrain numerous spoilage yeasts. However, certain strains of bacteria, such as Bacillus and Micrococcus, exhibit salt tolerance. Sugars are often included to enhance flavor while also reducing water activity in food (Dave and Ghaly, 2011), with many varieties commonly utilized, including dextrose, sucrose, and honey. Nitrites used in the meat processing industry are generally in the form of sodium nitrite or potassium nitrite, aimed at stabilizing color, ensuring flavor, and controlling rancidity. However, concern exists regarding the potential formation of carcinogenic nitrosamines from nitrite use (Ryser and Marth, 1999).

2.4.5 Smoking

Smoking is a date-honored method for extending meat's shelf life by utilizing byproducts from wood decomposition, such as aldehydes, ketones, organic acids, and phenols, to effectively preserve meat. The processes of smoking and curing are interlinked; typically, meat is cured prior to smoking. Modern smoking occurs within specially designed smokehouses where wood or sawdust is combusted at approximately 300°C (Pal, 2014). The resultant smoke comprises a diverse array of organic compounds that enhance the preservation qualities of meat via surface dehydration, pH reduction, and the antioxidant properties inherent to smoke constituents. The ancient origins of smoking likely stemmed from the unintentional discovery of its preservative benefits. Historically, it has been posited that muscle fiber shrinkage and the expansion of

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interstitial spaces serve to promote the preservation benefits of smoke. Smoking practices vary, with cold smoking being one of the oldest techniques and practiced primarily in cooler climates. Cold smoking-performed under humidity conditions designed to reduce water activity—facilitates moisture removal and enhances shelf life. Typically, cold-smoked products experience significant weight loss (15-20%) and present a more uniform flavor profile than warm or hot-smoked products. Warm smoking occurs at temperatures ranging from 23-40°C and typically requires refrigeration due to higher water activity. Hot smoking can be performed at temperatures of 40-100°C, requiring refrigeration or complete cooking due to limited shelf-life extension. (Eat Cured Meat, 2020; TheOnlineGrill, 2020).

2.4.5.1 Smoke Chemistry

The interaction of smoke compounds with meat results in absorbed flavor and color changes. During heating, a reaction transpires between carbonyls in smoke and the amino acids within meat proteins, leading to non-enzymatic browning similar to the Maillard reaction. The production of color in smoked foods is associated with specific carbonyl compounds present in the smoke (Anifantaki et al., 2002; Maga, 1988). While smoking adds distinctive flavors, it can also create carcinogenic compounds, including polycyclic aromatic hydrocarbons (PAHs) and heterocyclic amines (HAAs), which may pose health risks through DNA mutagenesis (Hitzel et al., 2013; Zhang et al., 2021).

2.4.5.2 Antimicrobial and Antioxidants in Smoke

The antimicrobial and antioxidative properties of meat products can be enhanced through smoking (Anastasio et al., 2004; Martinez et al., 2004). The USDA recognizes liquid smoke as

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an effective compound for antioxidant and antimicrobial purposes. Key antimicrobial agents in wood smoke comprise phenols and carboxylic acids, with varying degrees of efficacy (Sunen et al., 2003). Although phenolic compounds demonstrate strong antioxidative properties, non-phenolic derivatives exhibit diminished effects.

2.4.6 Thermal Processing or Cooking

The most crucial role of cooking meat is to eliminate spoilage and pathogenic organisms. The survival of microorganisms post-cooking depends on various factors, including the cooking temperature, time, and specific bacterial types involved. While normal cooking practices do not sterilize meat, they significantly reduce total microbiological loads, extending storage life (Microbe Notes, 2023). Proper handling practices and refrigeration further enhance shelf life, particularly by mitigating contamination after cooking. Among pathogens of concern, Listeria *monocytogenes* has been extensively researched in ready-to-eat meat products due to its cold-temperature resistance and potential for contamination during processing (Abd-El-Malek, 2017). To manage pathogens like *Salmonella*, *Campylobacter*, and *Escherichia coli*, specific internal cooking temperatures must be achieved (Thames, 2020).

Cooking also serves to improve meat flavor, texture, color, and reduce water activity. Traditionally, cooking methods predate civilization, likely commencing through accidental exposure of meat to fire. Despite being a fundamental needs-driven technique, cooking enhances preservation qualities, allowing for a greater variety of meat products based on varying cooking techniques (Microbe Notes, 2023).

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2.4.7 Canning Meat and Meat Products

Canning preserves meat by heating it within sealed containers to destroy spoilage microorganisms and promote safety. During canning, meat undergoes a specific heating process that eliminates harmful microorganisms, establishing a vacuum as jars cool and seal. Proper techniques can preserve sensory attributes of meat. Canned meat products possess a minimum shelf life of two years at room temperature, with various processing stages, including meat preparation, precooking, filling, exhausting, seaming, thermal processing, cooling, and storage (Pal and Devrani, 2018).

To ensure safety and quality, it is imperative that the animals are healthy, unstressed, and properly slaughtered; raw meat is stored correctly; recipes are expertly formulated; processing adheres to good manufacturing practices; and thermal processing is executed at appropriate temperatures and times. Meat products packaged in hermetically sealed containers can be stored at room temperature following sterilization, although challenges arise from temperature extremes, water activity, acidity, redox potential, and preservative applications. (Lawrie et al, 2006)

2.4.8 Sterilization

Sterilization is critical for low-acid foods such as meat, necessitating thorough processes to prevent the survival of microorganisms unless safety hurdles are incorporated. Thermal processing specialists have carefully established time-temperature combinations to ensure microbiological safety while maintaining product quality. Although extreme heat can eradicate microorganisms, it can also significantly compromise sensory quality and nutritional value. Therefore, a balance is necessary to maintain both safety and quality through controlled

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sterilization methods, utilizing the knowledge of the food's characteristics and applicable thermal characteristics.

2.4.10 Irradiation

Irradiation, referred to as "cold sterilization," involves the application of energy to disrupt microorganisms' DNA and kill them without significantly rising food temperature. Gamma radiation and electron beams are commonly employed in food preservation. Beneficial for reducing pathogens and extending shelf life, food irradiation has gained traction as an effective preservation technology (Islam et al., 2022; Rima et al., 2019; Sadakuzzaman et al., 2021). The USDA and authorities allow food irradiation with various sources, including gamma rays and electron beams (Maherani et al., 2016; Indiarto et al., 2020). The method's primary benefits include its capacity to inhibit a vast array of microbial hazards without substantial thermal degradation of food quality. Various irradiation doses cater to different purposes, such as radurization and radopertization. Research supports irradiation's effectiveness and safety in meat preservation, promoting enhanced food quality and safety (Chun et al., 2021; Yemmireddy et al., 2022).

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2.5 Incorporation of Essential Oils in Meat Preservation

The incorporation of essential oils (EOs) into meat preservation strategies is gaining attention due to their rich composition of antimicrobial and antioxidant constituents, which position them as potential natural food preservatives (Conner, 1993; Oussalah et al., 2007). EOs have historically served as flavoring agents in various food and beverage applications. As secondary metabolites derived from plants, they are widely utilized within the spice and food industry. Russo et al.

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(1998) highlighted that individual EO varieties exhibit distinct physiological and biochemical profiles, with specific enzymatic pathways encoded in their genetic makeup guiding their biosynthesis. Typically, EOs are concentrated in particular plant parts such as leaves, bark, or fruits, and may possess differing chemical compositions when found in various organs of the same plant.

When assessing EOs against various microorganisms (Skaltsa et al., 2003; Helander et al., 1998; Kim et al., 1995), the minimum effective inhibitory concentration for highly active compounds was found to be as low as 1 mM, while less active compounds required concentrations up to 3%. The innovative application of EOs to inhibit the proliferation of pathogenic bacteria holds promise for extending the shelf life of food products. Notably, Das et al. (2022) indicated the superiority of mustard oil over soybean and flaxseed oils for meat marination and preservation, positing that EOs in mustard oil may more effectively diminish microbial loads and are recommended for preserving raw broiler meat stored in refrigeration.

Research by Ismail et al. (2001) demonstrated that a solution of 100% sage (Santolina sp.) or thyme significantly reduced Yersinia lipolytica populations on chicken. Manderfeld et al. (1997) identified the antimicrobial efficacy of furocoumarins in parsley against Listeria monocytogenes, Escherichia coli, and various spoilage bacteria. Carrots possess phenolic compounds and EOs demonstrating substantial anti-Listeria activity, including eugenol, cinnamaldehyde, thymol, citronellol, limonene, and geraniol. The potential contamination of chicken by Candida and Rhodotorula in the absence of antibiotics underscores the necessity for effective antimicrobial strategies.

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Research indicates that EOs with concentrations ranging from 50 to 500 ng/ml exhibit heightened efficacy against Staphylococcus aureus, E. coli, and Klebsiella pneumoniae compared to lower concentrations. Compounds such as clove, cinnamon, cardamom, thyme, tea tree, marjoram, ho leaf, and sage exemplify this trend. (Man et al., 2019; Mahmoud et al., 2016).Furthermore, vanillin, a significant constituent of vanilla beans, effectively mitigates spoilage yeast in apple puree, impacting species such as Saccharomyces cerevisiae, Zygosaccharomyces rouxii, and Debaryomyces hansenii (Cerutti and Alzamora, 1996). Moore and Atkins (1977) observed that cultivating garlic impeded the growth of Candida, Cryptococcus, Thodotorula torulopsis, and Trichosporon. Studies have demonstrated that the addition of ground oregano and thyme extracts precludes aflatoxin production by Aspergillus parasiticus. Additionally, both thymol and carvacrol have been shown to completely inhibit the growth of Aspergillus flavus, Aspergillus niger, Geotrichum candidum, Mucor spp., and Penicillium spp. on potato dextrose agar at pH 5.5 (Akgul and Kivanc, 1988). Concentrations of cinnamon at 0.02, 0.2, 2.0, and 20% effectively inhibited the growth of Aspergillus parasiticus and aflatoxin production (Bullerman, 1974). Mustard oil-containing pickles and sauerkraut have demonstrated resistance to spoilage caused by yeasts including Saccharomyces ellipsoideus, Saccharomyces cerevisiae, and Mycoderma vini (Shelef, 1984).

The compounds inherent in EOs exhibit antibacterial properties attributable to their lipophilic nature, enabling them to compromise cellular membranes, disrupt energy supply, and inflict substantial damage to both outer and plasmic membranes (Rhayour et al., 2003; Lambert et al., 2001). EOs rich in phenolic compounds consistently demonstrate superior antibacterial activity relative to terpenoids, as noted by Cosentino et al. (1999). Nevertheless, even minimal

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concentrations can exert effects through synergistic interactions. Specific varieties of sage, thyme, oregano, and clove display notable antibacterial activity (Paster et al., 1995). Moreover, recent studies by Ali et al. (2022) suggest that bee honey, containing various antioxidants, may contribute to reducing microbial loads and enhancing the shelf life of meat and meat products.

2.5.1 Antioxidants in Meat Preservation

The inclusion of essential oils (EOs) into meat preservation methods is increasingly recognized due to their intrinsic antimicrobial and antioxidant properties, presenting a viable avenue for natural food preservation (Conner, 1993; Oussalah et al., 2007). EOs have been traditionally employed as flavoring agents across food and beverage sectors. They are identified as secondary metabolites from plants, with extensive applicability in the spice and food industries. As noted by Russo et al. (1998), each EO variety possesses a unique physiochemical identity, governed by enzymatic processes encoded in their DNA. Generally, these oils are concentrated in certain plant parts, exhibiting distinct chemical profiles when sourced from various plant organs.

The diverse antimicrobial constituents of EOs render them promising candidates for natural food preservation (Conner and Beuchat, 1984; Connor, 1993). Burt (2004) indicates that steam distillation is the standard commercial technique for obtaining EOs, yet methods such as low-temperature, high-pressure liquid carbon dioxide extraction have shown potential for achieving more natural organoleptic profiles, potentially enhancing antimicrobial properties (Moler, 1998). Additionally, hexane extraction has been shown to yield greater antimicrobial efficacy than steam distillation (Packiyasothy and Kyle, 2002). Research has established that the antioxidative capabilities of plant extracts are closely tied to the extraction solvent utilized (Yanishlieva et al.,

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2006), with supercritical carbon dioxide extraction being effective in preserving antioxidant characteristics (Tipsrisukond et al., 1998). The predominant active constituents in EOs, terpenoids, and phenolic compounds (Oussalah et al., 2007) have been assessed for their inhibitory effects against various microorganisms (Skaltsa et al., 2003; Helander et al., 1998; Kim et al., 1995), revealing a range of minimum inhibitory concentrations from 1 mM for potent compounds to 3% for less robust ones.

The potential of EOs to inhibit pathogenic bacterial growth and prolong food shelf life is an innovative approach to meat preservation. Notably, Das et al. (2022) recognized the efficacy of mustard oil for marinating and preserving refrigerated meat, suggesting its antimicrobial properties may be superior to those of soybean and flaxseed oils, effectively reducing microbial loads in raw broiler meat.

2.6 Meat packaging

The word "food packaging" refers to the use of technology to protect food products from various factors that can cause damage. In the food production industry, packaging is considered an important technological aspect that constantly evolves. Food security and safety are closely related concerns. While there is a need to address the challenge of feeding the growing global population, it is equally important to tackle foodborne illnesses, which continue to pose a significant threat to human health. It is possible to overcome these obstacles by constantly innovating and improving food packaging. In addition to offering advertising, convenience of use, and easy sealing, packaging protects, maintains, and preserves items. In order to minimize food waste and its negative effects on the environment, an efficient food packaging method should

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guarantee that product attributes are preserved at the point of sale. Throughout history, humans have made efforts to preserve food to avoid spoilage and contamination. Early methods included creating a primitive vacuum by eliminating air from containers. In more recent times, studies have shown that altering the concentration of air constituents, such as increasing CO_2 levels, can extend the shelf-life of food. These findings have influenced modern food preservation techniques. (Parry, 2014)

In the context of food production, the idea of shelf-life is essential. It describes the time when a product experiences subtle changes in its sensory qualities while still being safe to eat, depending on certain storage circumstances. Food is protected from different degradation processes by packaging and technological interventions. Because meat is so perishable, it needs special consideration when it comes to shelf life. Meat shelf life can be affected by several factors, including oxidation processes, bacterial growth, and enzyme activity. These are highly influenced by the sort of packaging used and the surrounding conditions, especially at the point of sale. The meat business is primarily concerned with processing techniques that offer longer shelf lives and safe packaging options.

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2.6.1 Function of Meat Packaging

Packaging serves multiple roles in the context of meat and meat products. Firstly, it serves the purpose of containment throughout the various stages of production, storage, and transportation. Additionally, a crucial role of packaging is to safeguard the meat and its products by preserving their inherent qualities during storage and ensuring compliance with quality standards necessary for selling. Packaging acts as a shield, protecting meat products against potential hazards such as

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mechanical, chemical, and biological threats, which include contamination from microorganisms, parasites, dirt, and toxic substances. While packaging acts as a barrier against secondary contamination, it should not solely depend on this aspect to prevent initial contamination. To effectively mitigate meat spoilage, packaging must be combined with other treatments, following the "hurdles technology" approach that restricts the growth of microorganisms.

Another significant aspect of packaging is its promotional function, often referred to as being a "silent seller." Based on its primary functions, packaging can be categorized into three levels. The primary level involves direct contact between the packaging material and the product, aiming to prevent any chemical or physical contamination from the surrounding environment. Its purpose is to uphold the chemical and sensory properties, such as moisture and flavor. The secondary level, known as pre-packaging, complements the sales unit by providing protection against mechanical stresses during storage and transportation. Lastly, tertiary packaging refers to the outer packaging, which facilitates shipment, transportation, and palletizing of the products. Both secondary and tertiary packaging serve functional roles in food transportation.

2.6.2 Properties of Materials Utilized in Meat Packaging

Synthetic materials, such as plastic films or foil, are commonly utilized in meat packaging, often combined with outer materials like cardboard boxes. The selection of inner packaging materials considers specific requirements, such as flexibility, mechanical strength, lightness, absence of odor, hygiene, recyclability, resistance to extreme temperatures, resistance to oil and fats, effective gas barrier properties, sealing capability, and cost of production (Kumar et al., 2019).

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The properties of a material, including its molecular structure, molecular weight, and chemical composition, determine its characteristics. Gas permeability is a crucial feature of both synthetic (plastics) and natural (cellulosic) polymer materials, enabling the exchange of oxygen, carbon dioxide, and water vapor between the interior and exterior of the packaging (Kumar et al., 2019). To protect the packaged meat, the film used must prevent moisture evaporation and the entry of oxygen. Oxygen can have detrimental effects on unpackaged meat during long-term storage, leading to color changes, myoglobin oxidation, and a shift from red to dark red, grey, or green tones. Hence, films impermeable to oxygen are preferred in this regard. However, for fresh ready-to-sell meat portions, films that allow oxygen permeability are desired to maintain the bright red color (Ghoneim et al., 2018).

Light exposure, whether natural or artificial, accelerates undesirable oxidation, rancidity, and color changes in meat and meat products. Transparent packaging films, though visually appealing, do not offer sufficient protection against light. For light-sensitive or light-exposed products, opaque or colored films like aluminum foil are used. Enhancing the light-barrier properties of packaging materials can be achieved by incorporating UV stabilizers or absorbers, even in transparent films. Additionally, the utilization of metallized packaging films effectively slows down fat photo-oxidation (Ghoneim et al., 2018).

2.7.2 Film-Forming Materials for Packaging

In the field of meat packaging, a majority of films are made from synthetic plastic materials. Commonly used synthetic materials for meat packaging include Polyethylene (PE), Polypropylene (PP), Polyvinylchloride (PVC), Polyester (PET), Polyamide (PA), Polyvinylidenchloride (PVDC), and Ethylenvinyl alcohol (EVOH). There has been a growing

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emphasis on sustainability and the use of renewable resources, particularly in the development of packaging materials derived from plants and fermentation by-products. According to Robertson (2019), bio-based packaging materials mainly come from annually renewable sources, excluding paper-based materials due to their longer renewal time, which can take anywhere from 25 to 65 years depending on the species and country. Although ongoing research aims to enhance materials from renewable sources and promote a more sustainable packaging industry, their commercialization is currently limited.

Edible films, which are thin (less than 254 μm), and sheets (more than 254 μm) are typically produced separately from the food product, while edible coatings are directly applied to the surface of the food. These types of packaging materials help extend the shelf-life of products, improve material efficiency, reduce pollution, contribute to nutritional value, accommodate various food types, and can even incorporate antimicrobial and antioxidant agents.

Edible films made from polar biopolymers like polysaccharides and proteins exhibit efficient gas barrier properties and moderate mechanical properties at low humidity. However, these properties deteriorate significantly under high humidity conditions. Proteins and polysaccharides also tend to produce water-sensitive films with inadequate moisture barrier performance. On the other hand, hydrophobic lipids are effective at preventing moisture migration but have inferior mechanical properties compared to hydrocolloid films due to their non-polymeric nature. Currently, most composite films consist of a lipid layer supported by a polysaccharide or protein layer, or involve dispersed lipid materials in a polysaccharide or protein matrix (Krochta and De Mulder-Johnston, 1997).

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Biopolymers are organic materials derived exclusively from biological sources, with their arbon originating from biomass. These materials can be obtained directly from biomass or indirectly produced by it. While not all biopolymers are both edible and biodegradable, they are easily compostable, have low environmental impact, and offer renewability advantages. Cellulose, for instance, is directly extracted from natural sources, while starch, derived from various sources, consists of amylose (a linear glucose polymer) and amylopectin (a branched glucose polymer). Pectins, which are polymers of galacturonic acid, can be partially esterified with methyl alcohol and used to create edible coatings. Varghese et al. (2023) Future bio-based materials are expected to incorporate blend combinations of polymers and nanoclays, referred to as bionanocomposites, to achieve the desired barrier and mechanical properties necessary in the food industry (Tharanathan, 2003)

2.8 Challenges Associated with Meat Packaging

The preservation of fresh meat and the challenges associated with packaging are critical in the food industry (Dainelli et al., 2017). Fresh meat is highly perishable and maintaining its quality, safety, and shelf life necessitate appropriate packaging (Dainelli et al., 2017). Key challenges in meat preservation are centered on microbial growth, oxidation, and moisture loss (Dainelli et al., 2017). Packaging materials serve as a protective barrier against external factors and play a crucial role in addressing these challenges (Dainelli et al., 2017).

However, conventional packaging materials like plastic films often result in adverse environmental impacts (Chițea et al., 2020). Therefore, it is imperative to develop innovative and

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sustainable packaging solutions that efficiently preserve fresh meat while minimizing waste and environmental pollution (Chițea et al., 2020). Future research in this domain can focus on the development of bio-based films, active packaging technologies, and intelligent packaging systems to enhance the preservation of fresh meat (Chițea et al., 2020). These advancements will not only contribute to better meat preservation but also reduce the negative environmental footprint associated with packaging.

2.9 Biodegradable and Biopolymer Films

Plastic waste has become a significant global environmental concern due to its non-biodegradable nature and detrimental effects on ecosystems. In recent years, increased efforts have been made to develop sustainable alternatives to conventional plastics. Biodegradable and biopolymer plastic films have emerged as promising solutions to address the plastic waste crisis. This review aims to explore the current state of research on biodegradable and biopolymer plastic films, including their properties, applications, and environmental impact.

2.10 Properties of Packaging

The properties of food packaging materials encompass various factors, such as barrier properties, mechanical strength, chemical resistance, and compatibility with food products. Barrier properties refer to the ability of packaging to prevent the transfer of moisture, oxygen, and other gases. Mechanical strength ensures that packaging can withstand handling and transportation without damage. Chemical resistance ensures that packaging does not react with the food or alter its quality. Compatibility with food products refers to the packaging's ability to maintain the taste, aroma, and freshness of the food.

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2.11 Properties of Biodegradable and Biopolymer Plastic Films

Biodegradable plastic films are designed to naturally break down through the action of microorganisms, thereby reducing their environmental impact. These films are typically made from renewable resources such as starch, cellulose, and polylactic acid (PLA). Biopolymer plastic films, derived from natural polymers, can be either biodegradable or non-biodegradable. Both types offer desirable properties, including good mechanical strength, flexibility, and transparency. However, these properties may vary depending on the specific material used and the manufacturing process.

2.12 Applications of Biodegradable and Biopolymer Plastic Films

Biodegradable and biopolymer plastic films have found extensive applications in various industries. In the food packaging sector, they are used for wrapping fresh produce, snacks, and ready-to-eat meals, providing an effective barrier against moisture, oxygen, and other contaminants to prolong the shelf life of food products. Additionally, these films are used in agriculture as mulch films, reducing reliance on synthetic plastic films and promoting sustainable farming practices. Moreover, they have been employed in the pharmaceutical, textile, and personal care industries, among others. (Tharanathan, 2003).

2.13 Environmental Impact of Biodegradable and Biopolymer Plastic Films

One of the primary advantages of biodegradable and biopolymer plastic films is their reduced environmental impact compared to conventional plastics. Biodegradable films break down into harmless substances, such as water, carbon dioxide, and biomass, through natural processes,

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significantly reducing plastic waste accumulation in landfills and marine environments. However, the environmental impact of these films is not without challenges. Their production requires energy and resources, and proper waste management systems and infrastructure are essential for their effective disposal and overall sustainability. (Siracusa et al., 2008)

2.14 Plasticization

Plasticizers represent a significant category of low molecular weight, non-volatile substances extensively employed as additives in the polymer industry (Sejidov and Mansoori, 2005). Their primary function is to enhance the flexibility and process ability of polymers by effectively lowering the second order transition temperatures, specifically the glass transition temperature (Tg). According to the International Union of Pure and Applied Chemistry (IUPAC, 2025), a plasticizer is defined as "a substance or material incorporated in a material (usually a plastic or elastomer) to increase its flexibility, workability, or distensibility." The incorporation of plasticizers results in various alterations in polymer properties, including reduced deformation tension, hardness, density, viscosity, and electrostatic charge, while simultaneously enhancing the flexibility, fracture resistance, and dielectric constant of the polymer matrix (Rosen, 1993). Additionally, plasticizers influence several other properties, including the degree of crystallinity, optical clarity, electrical conductivity, flame resistance, and susceptibility to biological degradation.

2.15 Plasticizers in Biopolymer Films

The application of natural-based polymer films is contingent upon multiple factors, such as cost, availability, functional attributes, mechanical properties (including strength and flexibility), optical characteristics (gloss and opacity), barrier requirements (permeability to water vapor, O_2,

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and CO_2), and structural resistance to moisture, along with sensory acceptance. These features are notably affected by variables such as the structural matrix material (including its conformation, molecular weight, and charge distribution), the conditions during film fabrication (including solvent type, pH, concentration, and temperature), and the specific type and concentration of additives (such as plasticizers, crosslinking agents, antimicrobials, and antioxidants) (Debeaufort & Quezada-Gallo, 1998). The dehydration process of these matrices results in the formation of robust cohesive films, which often necessitate the addition of plasticizers. Such additives mitigate intermolecular forces within the polymer chains, thereby enhancing flexibility and mobility. This plasticization is crucial for improving film flexibility, decreasing brittleness, and preventing shrinkage during handling and storage (Bordes et al, 2004).

However, several studies have documented the detrimental impacts of plasticizers on certain attributes of edible films. Specifically, an increase in gas, solute, and water vapor permeability has been observed, alongside decreased cohesion, which adversely affects the mechanical properties of the films. Thus, the properties of biopolymer-based films reflect a delicate balance between the crosslinking degree of the polymer matrix often essential to mitigate water solubility, albeit introducing brittleness and the incorporation of plasticizers to enhance workability (Vieira et al., 2011). When the concentration of a plasticizer exceeds a critical threshold, it can surpass the compatibility limit with the biopolymer, leading to phase separation and plasticizer exclusion (Cheng et al., 2006).

Biopolymers and plasticizers are typically hygroscopic, which means that the moisture content of these films is significantly influenced by ambient humidity. Furthermore, water, as the principal

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solvent in the realm of natural biopolymer technology, acts to lower the glass transition temperature and increase the free volume of the biomaterials, effectively serving as a natural plasticizer. The role of water molecules in plasticizing biopolymers has been comprehensively documented in existing literature (Karbowiak et al., 2006). Besides water, polyols, as well as mono-, di-, and oligosaccharides, are among the most frequently utilized plasticizers. Polyols are particularly advantageous in plasticized hydrophilic polymers (Zhang & Han, 2006). Glycerol (GLY), in particular, is widely incorporated into hydrocolloid films due to its strong hygroscopic properties, which help in preventing film brittleness (Cuq et al., 1997; Karbowiak et al., 2006).

The primary materials for fabricating edible and/or biodegradable films consist of polysaccharides, proteins, and lipid compounds. Polysaccharides exhibit commendable film-forming capabilities and provide effective barriers against oils and lipids; however, they have limited moisture barrier properties. In contrast, protein-based films often demonstrate superior mechanical and barrier properties compared to polysaccharide-based films. Lipid compounds are also employed to create edible films due to their excellent moisture barrier performance, although they can introduce textural and organoleptic issues. Recently, numerous studies have focused on developing composite films that integrate one or more lipid compounds with a hydrocolloid-based structural matrix (Guilbert et al., 1997). This paper seeks to underscore recent advancements concerning the utilization of natural plasticizers in polysaccharide-, protein-, and lipid-based films, as well as films derived from microbial sources.

Glycerol is a significant by-product of biodiesel production, with each processing cycle generating approximately 10% (w/w) waste glycerol. This surplus has contributed to an oversaturated glycerol market, which presents environmental challenges due to its

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underutilization. Numerous studies are exploring effective ways to leverage glycerol to produce value-added chemical commodities, thereby promoting sustainable consumption and production practices.

Chemically, glycerol (CAS number 56-81-5; molecular formula $C_3H_8O_3$) also known as glycerin or propane-1,2,3-triol based on IUPAC nomenclature—serves as a critical component in lipid structures. Triglycerides, whether derived from fats or oils, are composed of glycerol linked to three long-chain fatty acids at each of its hydroxyl functional groups. As a polyhydric alcohol, glycerol is characterized by its structure, which includes three hydroxyl groups.

At ambient conditions, glycerol appears as a clear, viscous, colorless, and odorless liquid with hygroscopic properties. The presence of three hydroxyl groups facilitates the absorption of moisture from the atmosphere through hydrogen bonding. Additionally, glycerol is fully miscible with water, a defining characteristic of its chemical nature. Due to its strong bonding capability, glycerol has a high boiling point of approximately 302.15 K (290 °C) and is classified as a semi-volatile compound, making it particularly compatible as a plasticizer in food packaging applications.

Glycerol's potential as a bio-based material allows it to contribute to the creation of biocompatible and biodegradable polymers for various applications, through processes including direct polymerization, fermentation, and chemical conversion. In the food packaging industry, glycerol plays a pivotal role as a plasticizer, enhancing the flexibility and ductility of bio-derived packaging materials. For example, native unplasticized starch films are often too brittle for practical handling, while incorporating glycerol into starch films significantly improves their

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flexibility and processability. However, this enhancement in mechanical properties often comes at the expense of their water and gas barrier characteristics.

Finally, in conclusion, glycerol's multifaceted applications in biobased films demonstrate its importance not only as a by-product of biodiesel production but also as a vital component in developing sustainable materials for the packaging industry and beyond.

2.16 Properties of Beeswax

Beeswax, a natural substance produced by honeybees, is secreted by worker bees from glands on their abdomen to construct the hexagonal cells of the honeycomb (Marques et al., 2017). The unique properties of beeswax have led to its extensive utilization for various purposes by humans throughout history.

The melting point of beeswax is noteworthy, as it possesses a relatively high melting point ranging from 62 to 64 degrees Celsius (144-147 degrees Fahrenheit). Consequently, it remains solid at room temperature but easily melts when exposed to heat. This property makes beeswax an ideal component for candles, ensuring a slow and clean burn (Razmilic et al., 2020). Another essential property of beeswax is its hydrophobic nature, which means it does not mix with water. This characteristic enables its utilization in waterproofing materials such as fabrics, leather, and wood, and also as a protective barrier on the skin to retain moisture and prevent water loss (Warshaw et al., 2007).

Moreover, beeswax exhibits natural adhesive properties, becoming sticky when heated, making it a valuable natural adhesive in crafts, woodworking, cosmetics, and personal care products

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(Dušková et al., 2020). Its non-toxic and hypoallergenic qualities further contribute to its safe use in various applications, including lip balms, lotions, and creams. Beeswax serves as a natural emulsifier as well, effectively binding ingredients together in formulations (Ghosh et al., 2006).

Additionally, beeswax emits a pleasant aroma, exuding a subtle, sweet scent that adds to its appeal in scented products like candles and perfumes (Kostiainen et al., 2014). This aroma is often associated with warmth and comfort, enhancing the overall experience. Overall, beeswax is a versatile and valuable natural substance with multiple properties that make it highly sought-after in various industries. Its high melting point, water-repellent nature, adhesive properties, and hypoallergenic qualities render it an excellent choice for candles, cosmetics, woodworking, and more.

2.17 Structure of beeswax.

Beeswax, which serves as a major constituent of honeycomb, is produced by worker bees through the secretion of small flakes from the underside of their abdomens. These flakes are then molded into honeycomb structures. Characterized as soft to brittle, beeswax has a specific gravity of approximately 0.95 and a melting point above 60°C. It comprises a minimum of 284 different compounds, primarily consisting of various long-chain alkanes, acids, esters, polyesters, and hydroxy esters. These compounds include cerotic acid (hexacosanoic acid, $CH_3(CH_2)_{14}COOH$), the ester formed between cerotic acid and triacontanol ($CH_3(CH_2)_{29}OH$), myricin (myricyl palmitate, $CH_3(CH_2)_{14}COO(CH_2)_{12}CH_3$), and hentriacontane ($CH_3(CH_2)_{29}CH_3$). Hentriacontane makes up approximately 8-9% of beeswax and its stability and resistance to water contribute to its role as a structural component. (Tulloch, 1980; Fratini et al., 2016; Kostić et al.,

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2020).Although insoluble in water, beeswax can be dissolved in solvents like carbon tetrachloride, chloroform, or warm ether. The precise composition of beeswax can vary depending on the geographical location.

Structure of components found in beeswax.

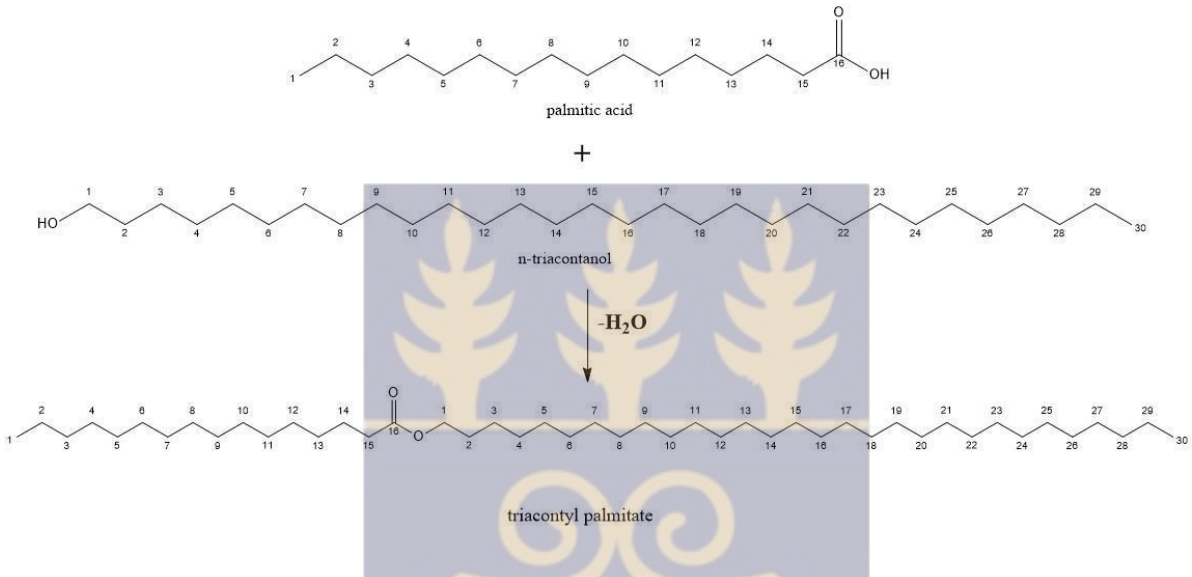


Figure 1……. Various compounds in beeswax

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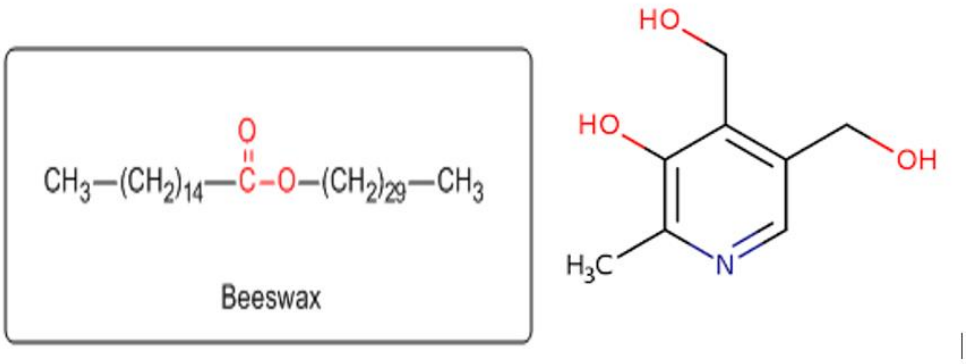


Figure 2 …….Chemical formula of beeswax

2.18 The Role of Corn Starch in Film Formation

Cornstarch, also known as corn flour, finds extensive use in culinary applications. However, its applications extend beyond the kitchen, as it plays a crucial role in film formation across diverse industries. Film formation refers to the process of creating a thin, continuous layer of material on a surface, which has numerous practical applications. One of the key reasons cornstarch is employed in film formation is its ability to form a gel-like substance when mixed with water. This gel formation is facilitated by the presence of amylose and amylopectin, two starch molecules found in cornstarch. When water is added, these molecules absorb the liquid and swell, resulting in the formation of a thick, viscous gel (Trakttorová et al., 2019). The gel-like consistency is crucial in film formation as it allows for easy spreading and coating of surfaces. Upon application to a surface, the cornstarch gel dries over time, leaving behind a solid film. This film acts as a protective barrier, preventing moisture loss and providing a smooth and even surface (Zhong et al., 2013).

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Biodegradable films produced using cornstarch are increasingly favored due to their ecological benefits. These films can serve as packaging materials, agricultural mulches, or even disposable cutlery. Cornstarch-based films are preferred over conventional plastic films as they are derived from renewable resources and can be easily broken down by microorganisms, thereby reducing environmental pollution (Ahmed et al., 2020).

Furthermore, cornstarch contributes to the mechanical strength and flexibility of the films. The amylose and amylopectin molecules form a network structure upon drying, ultimately yielding a resilient and cohesive film. This enables the film to withstand mechanical stress, such as bending or stretching, without breaking or cracking (Jeevana et al., 2018).Moreover, cornstarch films can be customized by incorporating various additives to enhance their properties. For example, plasticizers can be added to increase flexibility and elongation, making the film more resistant to tearing. Similarly, antimicrobial agents can be integrated to prevent bacterial or fungal growth, extending shelf life (Li et al., 2014).

2.19 Ginger Oils

Preservation of food is a critical concern due to various environmental factors and safety issues that can result in food spoilage and endanger consumers' health. Factors such as moisture, light, oxygen, and microorganisms contribute to the deterioration of food quality (Redfearn et al, 2023). Additionally, the presence of chemical residues from pesticides, heavy metals, and microbial toxins can directly impact consumer well-being (Esmaeili et al., 2021). Foodborne pathogens like Escherichia coli, Salmonella typhimurium, Staphylococcus aureus, Listeria monocytogenes, and Campylobacter pose significant risks to both the gastrointestinal and nervous systems (Lawal et

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al., 2023). Moreover, the emergence of drug-resistant microorganisms and increased tolerance to chemical preservatives add to the challenges faced in food preservation (Gyawali & Ibrahim, 2014).

In response to these concerns, consumers now prefer natural preservatives over chemical additives such as sodium benzoate, sodium propionate, potassium sorbate, and nitrite (Al-Maqtari et al., 2021). The exploration of safe and readily available natural preservatives has become an appealing option. Plant extracts, particularly plant polyphenols and essential oils, have gained attention as important components of natural preservatives (Hadidi et al., 2022). For example, ginger, a monocotyledonous plant, is highly valued for its nutritional properties, with its rhizome having medicinal properties and an aromatic smell. The characteristic aroma and spiciness of ginger are attributed to the presence of gingerol and shogaol in ginger essential oil (GEO). Ginger contains various components such as fatty oil, protein, carbohydrates, crude fiber, ash, water, and volatile oil. GEO, in particular, has significant potential applications in medicinal and phytopharmaceutical contexts. Traditional medicine has employed ginger and its essential oil as an anti-inflammatory treatment for rheumatoid arthritis (Zhang, 2019).

Several studies have investigated the bioactive components of GEO and their antibacterial and antioxidant properties against both pathogenic and spoilage microorganisms in food (Wang et al., 2020). Multiple research studies have specifically examined the antibacterial and antioxidant effects of ginger essential oil (GEO) against harmful microorganisms in food. Wang et al. (2020), Ivanović et al. (2021), and Berechet et al. (2023) have found that GEO is rich in sesquiterpenes such as α-gingerene, β-sesquiterpene, and camphene. Currently, GEO is utilized in various food preservation applications, including the preservation of bread, fruits, vegetables, frozen seafood,

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and chilled poultry. Additionally, researchers have been exploring the potential of natural essential oils derived from other sources such as Cinnamomum cassia (Kačaniová et al., 2021), Thymus zygis (Duarte, 2022), oregano (Llana-Ruiz-Cabello et al., 2016), orange (Sanchez et al., 2022), hemp (Moreno, 2022), and bergamot (Kulkarni et al., 2022) as food preservatives. However, the limited water solubility and susceptibility to oxygen, moisture, heat, and light pose challenges to the use of ginger and other plant oils. To tackle these issues, novel delivery systems such as emulsions, Pickering emulsions, encapsulation in solid particles, and degradable food packaging films/coatings made with polysaccharide/protein matrices have emerged as potential solutions to enhance the application of these oils (Wang et al., 2020; Ivanović et al., 2021; Berechet et al., 2023).

2.20 Antioxidant effect

Many earlier studies have demonstrated the significant antioxidant properties of ginger essential oil (GEO) and its active compounds (Si et al., 2018; Tarfaoui et al., 2022; Sethi et al., 2016; Wang et al., 2023). The primary compounds in GEO that contribute to its antioxidant activity are the phenolic compounds called gingerols, gingerones, and gingerenols (Si et al., 2018). The specific chemical composition of these compounds determines their unique antioxidant capacity and biological activities (Si et al., 2018).

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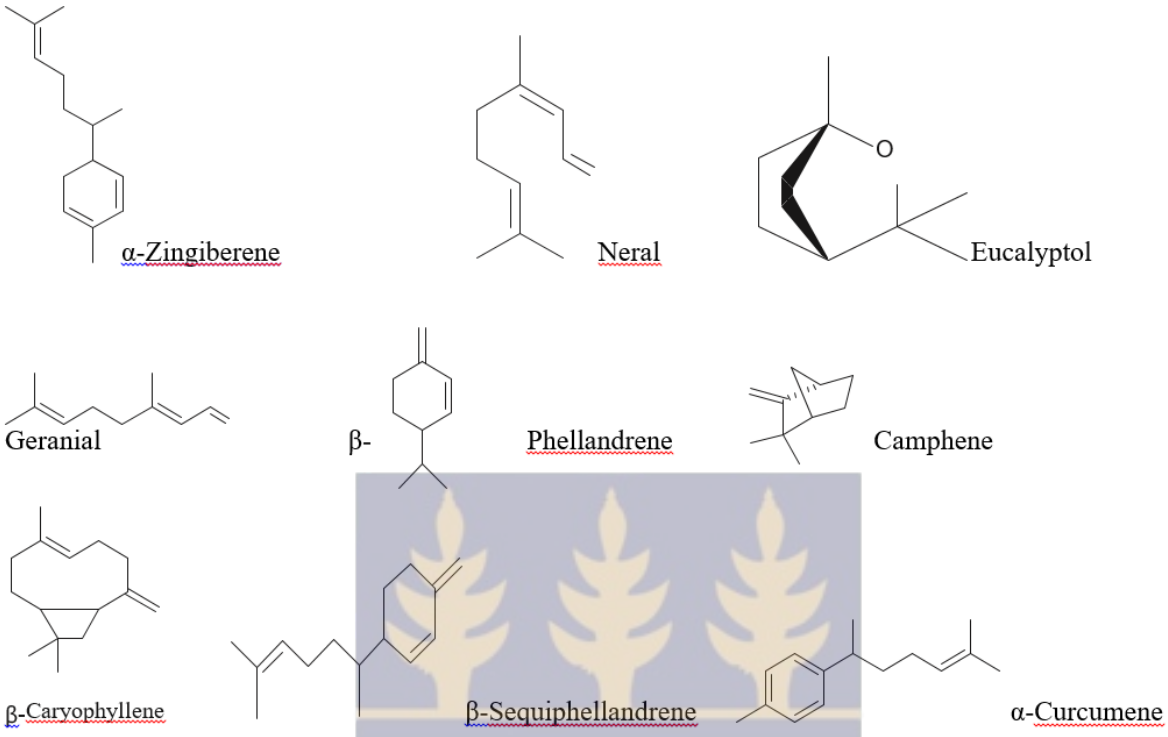


Figure 3 Structure of compounds present in GEO

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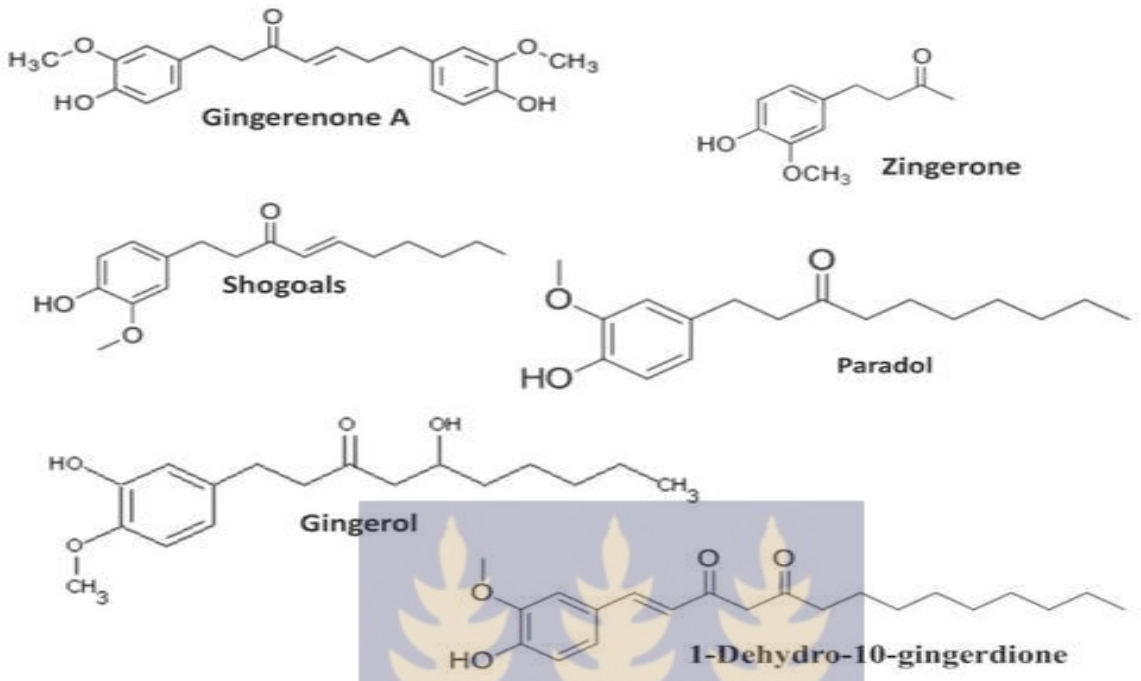


Figure 4 . Compounds Present in GEO

Si et al. (2018) demonstrated that ginger extract was effective in slowing the reduction of headspace oxygen and inhibiting fat oxidation in rapeseed oil. The antioxidant capacity of ginger extract was found to be higher when its initial concentration was higher, particularly at elevated temperatures (Si et al., 2018). Tarfaoui et al. (2022) evaluated the antioxidant activity of different extracts of ginger and found that the ethanolic extract exhibited the highest antioxidant capacity as determined by the 2,2-diphenyl-1-pyridine-hydrazyl radical (DPPH) assay and the ferric reducing power (FRP) assay. The high phenolic content in ginger was attributed to its superior antioxidant activity (Tarfaoui et al., 2022).

Sethi et al. (2016) reported the Inhibitory Concentration 50 percent concentrations of ginger oil for various antioxidant assays. The IC50 concentrations for DPPH, inhibiting OH, and inhibiting nitric oxide were 77.76 µg/mL, 68.90 µg/mL, and 69.70 µg/mL, respectively. For scavenging

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superoxide anions, the IC50 concentration was 49.38 μg/mL. The RP50 for Fe3+ reducing capacity was 160.77 μg/mL, and the chelating capacity of Fe2+ was 101.72 μg/mL (Sethi et al., 2016). Furthermore, Wang et al. (2023) also confirmed the antioxidant activity of ginger through their study.

In conclusion, ginger essential oil and its biologically active compounds, such as gingerols, gingerones, and gingerenols, possess significant antioxidant properties, which can inhibit lipid oxidation (Si et al., 2018). The antioxidant capacity of ginger is influenced by its chemical composition, with the phenolic components playing a crucial role (Tarfaoui et al., 2022). Several studies have reported the antioxidant potential of ginger extract and ginger oil using various assays, highlighting its reliability as an antioxidant source (Si et al., 2018; Sethi et al., 2016; Wang et al., 2023).

2.21 Benefits of Essential Oils (EOs)

Several investigations have examined the antibacterial characteristics of essential oils (EOs) obtained from diverse plant sources. But the in vitro results don't always translate well into using EOs as meat preservatives in real-world situations. However, several EOs have shown promise in acting as meat preservatives, such as rosemary, cinnamon, bay, sage, garlic, oregano, and ginger (Irkin et al., 2011; Skandamis and Nyachas, 2002; Tsigarida et al., 2000).

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2.22 Mechanisms of action of essential oils in the preservation of meat

2.22.1 Preservation against Microbial Spoilage

The effectiveness of essential oils (EOs) in combating microorganisms is enhanced when they directly interact with them. However, the direct application of EOs to meat can affect its sensory properties and overwhelm consumers with intense aromas, making it challenging and costly to use on a large scale. To overcome these challenges, the concept of active packaging has been proposed, where EOs are incorporated into packaging materials or released gradually through evaporation.

Studies have shown that incorporating specific EOs into active packaging inhibits the growth of harmful bacteria and putrefaction products in meat. Another approach is to include sachets that slowly release EOs in packaged meat. The use of EOs in meat preservation also offers nutritional value and potential health benefits due to the presence of phytochemical constituents. EOs possess antimicrobial properties due to various chemical compounds present in them, including terpenes, alcohols, phenolics, and esters. The antimicrobial effects of EOs depend on their composition, concentration, and proportions of chemical constituents. The disruption of cell membranes is one of the primary mechanisms through which EOs exhibit antimicrobial activity. The lipophilic components present in EOs can penetrate cell walls and cause changes in membrane stability, resulting in the disintegration of the plasma membrane and subsequent loss of essential components needed for microbial survival. EOs also disrupt energy transduction processes in bacterial cells, leading to a decline in ATP levels, disturbance in ATP synthesis and hydrolysis, and disruption of various proteins involved in respiration and metabolism.

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Additionally, EOs can coagulate cellular contents and inhibit enzymes necessary for bacterial metabolism. The effectiveness of EOs may vary depending on the growth stage of the target cells, with dividing cells being more susceptible to their destructive effects.

2.23 Preservation against Lipid Oxidation (LO)

In addition to their antimicrobial effects, essential oils (EOs) possess the capacity to preserve meat by preventing the oxidation of lipids. Meats containing saturated fats are susceptible to oxidative degradation, resulting in the development of undesirable flavors when exposed to air. However, treating meat with oregano and sage EOs prior to storage has been found to mitigate oxidative deterioration. The presence of phenolic compounds in EOs imparts antioxidant properties that effectively protect meat products from lipid peroxidation and spoilage. However, it is worth noting that certain EOs can exhibit prooxidant cytotoxic properties in eukaryotic cells by causing damage to mitochondrial membranes. Like other antioxidants, EO phenols can transition from an antioxidative to a prooxidative state at high concentrations. At elevated concentrations, EOs can adversely affect mitochondrial membranes, leading to the release of superoxide ions and other reactive species that can damage DNA. Moreover, high concentrations of EOs can oxidize phenolic compounds, resulting in the generation of phenoxyl radicals that further harm proteins and DNA.

2.24 Current challenges of EOs in meat preservation

In spite of the demonstrated potential of essential oils (EOs) in preserving meat, there are several obstacles that need to be overcome before their widespread use as meat preservatives. While laboratory studies have shown the effectiveness of EOs and their chemical components in preserving meat, it is challenging to apply these findings directly to whole meat preservation. The

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interaction between EOs and meat constituents often requires higher concentrations of EOs to achieve the same results as observed in laboratory tests. However, using elevated concentrations of EOs for significant antimicrobial activity can result in detrimental changes in the quality, taste, and aroma of the meat. Even at low concentrations, certain potent EOs can cause undesirable sensory changes in preserved meat. Although EOs are generally considered hypoallergenic, there have been documented cases of contact allergies to EOs, and their widespread use may potentially increase allergy incidents. Therefore, more safety studies are required before extensively using EOs in meat preservation.

While EOs can eliminate specific targeted bacterial populations in meat preservation, they may also create conditions favoring the growth and virulence of other harmful microorganisms due to changes in the overall microbial ecosystem. The individual components of EOs do not possess sufficient effectiveness in deactivating meat spoilage organisms. However, when combining specific EOs, such as Origanum majorana and Thymus vulgaris, an additive effect against meat spoilage organisms has been observed, emphasizing the importance of understanding the impact of EOs and optimizing their combinations for effective preservation against both spoilage and pathogenic microorganisms.

The viability of utilizing essential oils (EOs) as meat preservatives largely depends on maintaining the stability and bioactivity of their constituent phytochemicals. However, the physical stability of most phytochemicals in EOs is often compromised when they interact with meat constituents, a phenomenon attributed to the strong binding capacity of proteins and fats in meat to volatile EO compounds. This interaction reduces the antimicrobial effectiveness of EOs, thereby limiting their direct application in meat preservation. To overcome this challenge, encapsulation techniques—such as nano-encapsulation—have been proposed as a promising

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solution, as they protect volatile compounds, enhance stability, and ensure controlled release during storage. Such approaches have been shown to improve the preservation efficacy of EOs in meat and meat products (Ojeda-Piedra et al., 2022).

2.25 Chemical Composition of GEOs

The functional properties of essential oils derived from plants are closely linked to their chemical composition. Ginger essential oil (GEO) contains active chemical components which can be categorized into two main groups: monoterpenes (with the general formula $(C_5H_8)n$) and sesquiterpene hydrocarbons and oxygenated hydrocarbon compounds, including aldehydes, phenols, esters, oxidized ethers, alcohols, and ketones. GEO is composed of approximately 1,000 monoterpenes and 3,000 sesquiterpene hydrocarbons, along with other minor stimulating components. (Kamal et al., 2022)The primary compounds found in GEO are sesquiterpene hydrocarbons such as α-Zingiberene (18.0–28.0%), Geranial (7.8–13.8%), Neral (5.3–10.5%), Trans-Caryophyllene (9.0–10.8%), Eucalyptol (5.0–5.5%), β-Phellandrene (4.9–5.5%), Camphene (5–11.5%), α-Pinene (2.1–3.0%), and Heptan-2-ol (1.0–2.0%). These compounds contribute to the distinctive flavor, aroma, and antibacterial as well as antioxidant activities of GEO (Abdullahi et al., 2020; Mahboubi, 2019).

The chemical composition of GEO may vary slightly among different studies. However, previous research has consistently identified α-zingiberene as the most abundant compound in GEO at 26.0%, followed by β-sesquiphyllandrene (8.1%), α-curcumene (7.99%), and β-bisabolene (7.47%), among others (Feng et al., 2018). The extraction methods employed can also influence the chemical composition of GEO. For instance, when studying the essential oil extracted from coral ginger root in Qingzhen, Guizhou Province, China, supercritical fluid extraction revealed

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that the major compounds were sabinene (53.38%), terpinen-4-ol (22.66%), and triquinacene, 1, 4-bis (methoxy) (9.64%). In contrast, steam distillation yielded sabinene (16.19%), terpinen-4-ol (16.26%), triquinacene 1, 4-bis (methoxy), and ferulic acid methyl ester (16.88%) as the main components (Yang, Luo, Peng, Zhao, & Yu, 2009).

Furthermore, the chemical composition of GEO can also be influenced by the variety of ginger used. For example, a study by Ravi Kiran et al. (2013) compared the chemical composition of 17 ginger varieties from northern India, revealing that Assam Tinsukia (NE4) had the highest citral content (23.66 ± 1.60%), Meghalaya Mahima (NE9) had the highest zingiberene content (38.33 ± 0.42%), and Manipur I (NE11) exhibited the highest sesquiterpene hydrocarbon content (58.45 ± 1.50%). Similarly, Nampoothiri et al. (2012) investigated the essential oil composition of three sub-Himalayan ginger varieties, finding that α-gingerene was the most abundant compound in gorubathane oil and thingria oil, while geranial (20.07%) and neral (9.44%) were major constituents in shingboi oil.

Moreover, studies have shown that the content of total flavonoids and phenols in GEO decreases significantly with an increase in harvesting time (Gatabazi et al., 2022). The International Organization for Standardization (ISO) specifies the desirable composition of ginger oil from China and turmeric oil from India, indicating the expected ranges of α-zingiberene, β-sesquiphellandrene, ar-curcumene, camphene, and β-bisabolene concentrations in these oils (Mahboubi, 2019).

2.26 Chemical compounds in essential oil from ginger.

Table 1.Chemical Compounds in ginger essential oil

Chemical Compounds	Range of Conc %	Formula	Reference

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α-Zingiberene	0-28	$C_{15}H_{24}$	Aristide et al(2013)
Trans-Caryophyllene	9.0-10.8	$C_{15}H_{24}$	Benoit et al (2013)
Geranial	7.8-13.8	$C_{10}H_{16}O$	Aristide et al(2013)
β-Sesquiphellandrene	6.5-11	$C_{15}H_{24}$	Hoferl et.al (2015)
Neral	5.3-10.5	$C_{10}H_{16}O$	Aristide et al (2013)
Camphene	5.0-11.5	$C_{10}H_{16}$	Benoit et al (2013)
Eucalyptol	5.0-5.5	$C_{10}H_{18}O$	Castiblanco et al (2015)
B-Phellandrene	4.9-5.5	$C_{10}H_{16}$	Hoferl et.al (2015)
α-Curcumene	4.4-11.5	$C_{15}H_{22}$	Razmjou et al (2013)
α-Pinene	2.1-3.0	$C_{10}H_{16}$	Aristide, , et al (2013)
Myrcene	1.8-2.0	$C_{10}H_{16}$	Benoit et al (2013)
Heptan-2-ol	1.0-2.0	$C_7H_{16}O$	Hoferl et.al (2015)
Linalyl propionate	1.0-1.5	$C_{13}H_{22}O_2$	Razmjou et al (2013)

2.27 Antibacterial Properties

Ginger essential oil (GEO) has been shown to possess significant inhibitory effects against various Gram-positive and Gram-negative bacterial strains (Beristain-Bauza et al., 2019). Research by Ghasemzadeh et al. (2018) found that S. aureus was the most sensitive pathogen to ginger extract, followed by Bacillus cereus, Pseudomonas aeruginosa, and E. coli, with minimum inhibitory concentrations (MIC) ranging from 0.78 µg/mL to 1.56 µg/mL. Interestingly, the antibacterial activity of GEO was found to increase with higher drying temperatures.

Wang et al. (2020) investigated the antibacterial activity of GEO against S. aureus and E. coli and observed that it had a higher inhibitory effect on S. aureus compared to E. coli. The inhibition

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zone diameter (DIZ) for S. aureus was 17.1 mm, while for E. coli it was 12.3 mm. The MIC values for S. aureus and E. coli were 1.0 mg/mL and 2.0 mg/mL, respectively, and the minimum bactericidal concentrations (MBC) were 2.0 mg/mL and 4.0 mg/mL, respectively. The main antibacterial mechanism of GEO was found to be the disruption of bacterial cell membranes, leading to leakage of macromolecules and eventual bacterial death.

In another study by Wibowo et al. (2020), two essential oils derived from Elephant ginger and Emprit ginger rhizome were tested for their antibacterial activity against various bacteria. Both oils exhibited antibacterial effects, with MIC values ranging from 250 µg/mL to 1000 µg/mL and MBC values ranging from 500 µg/mL to 1000 µg/mL. The MIC values of both oils against S. aureus were found to be 250 µg/mL. Moreover, Elephant ginger oil showed stronger antimicrobial activity, inhibiting the growth of five species including S. aureus, Bacillus subtilis, B. cereus, E. coli, and Methicillin-resistant S. aureus (MRSA), while Emprit ginger rhizome essential oil inhibited the growth of three species including S. aureus, E. coli, and MRSA. Microscopic examination revealed that the essential oils disrupted the cell membranes of bacteria, leading to increased permeability and altered bacterial morphology.

Apart from its antibacterial effects, GEO also exhibits inhibitory effects against some fungi. Prakash et al. (2012) reported that a combination of turmeric and GEO significantly suppressed the growth of Aspergillus flavus (LHP-6), a toxic food-borne strain, with an MIC of 2.5 µL/mL. The combination of essential oils also hindered the growth of a toxic strain of A. flavus and reduced the production of aflatoxin. Another study by Madegowda et al. (2016) explored the antifungal activity of GEO against A. flavus and Aspergillus ochraceus, revealing a minimum bactericidal concentration (MBC) of 160 ppm for A. florus and 175 ppm for A.

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ochraceus. The antifungal mechanism of GEO involved damaging the fungi's cell walls and affecting their metabolism. Scanning electron microscopy (SEM) analysis demonstrated that ginger oil caused deformation of mycelium and loss of conidia.

Furthermore, GEO exhibits inhibitory effects against certain fungi, as shown in the research by Abdullahi et al. (2020). In their study, the antifungal activity of GEO was tested against five fungi, including Fusarium oxysporum, Pyricularia oryzae, Colletotrichum falcatumss, Ganoderma boninense, and Rigidoporus microporus. GEO had different levels of growth inhibition, with the highest inhibitory effect observed on F. oxysporum (50.38 ± 0.5) and the lowest on G. boninense (27.46 ± 0.5) at a concentration of 1 µL/mL. The sensitivity order (descending) of the fungi was found to be F. oxysporum > C. falcatum > P. oryzae > R. microporus > G. boninense.

2.28 Application in Food Preservation

In recent times, ginger essential oil (GEO) has been explored as a natural food preservative. Kasi et al. (2017) conducted a study on the use of ginger extract for preserving peanut oil and found that it exhibited significant antioxidant activity, reduced the risk of aflatoxin contamination, and improved the stability of the oil. GEO also demonstrated low cytotoxicity, making it a safe option for food applications particularly against HepG2 and WI-38 cells (Ahmed et al., 2021). However, there are limitations to using GEO as a food preservative due to its volatile nature, hydrophobicity, and interactions with other food components, which can affect sensory quality (Mattje et al., 2019). To overcome these limitations, encapsulation techniques such as emulsion systems have been explored. Emulsions, including nano and Pickering emulsions, have been utilized as delivery systems for GEO in food preservation (Jafarizadeh-Malmiri,2022). Nanoemulsions, characterized

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by small droplet sizes, enhanced stability, and efficient transport of active ingredients, have shown promise in preserving plant essential oils (Gardesh et al., 2016).

Various methods, including microfluidization and ultrasonication, have been employed to prepare GEO nanoemulsions, resulting in reduced particle size and improved stability (Alexandre et al., 2016; Noori, Zeynali, & Almasi, 2018; Cai & Wang, 2021). Additionally, low-energy methods like solution displacement and self-emulsification have also been used for GEO nanoemulsion preparation (Firoozi, et al, 2020). These nanoemulsions have exhibited increased antibacterial and antioxidant activities (Farshbaf-Sadigh et al., 2021), but their antimicrobial efficacy may be affected by factors such as particle size and component content (Ibrar et al., 2022). Moreover, GEO nanoemulsions have been successfully applied directly to food preservation, demonstrating improved microbial control in chicken breasts (Tang et al., 2022) and reduced formation of harmful compounds in beef patties (Esfahani et al, 2019). Alternatively, researchers have explored Pickering emulsions, which utilize polysaccharides and proteins as stabilizers, for incorporating GEO into food systems (Cahyana et al., 2022; Chen et al., 2023). Additionally, combining GEO emulsions with biodegradable food packaging films and coatings has shown potential for enhancing antioxidant and antibacterial activities while reducing undesirable flavors and odors (Jafarizadeh-Malmiri et al, 2022).

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CHAPTER THREE

METHODOLOGY AND MATERIALS

3.1 Materials and Reagents

The low molecular weight cornstarch (≥99% purity) and glycerin (≥99.5% purity) were procured from Ranny chemicals from Accra for this study. Cornstarch served as the primary polymer, while glycerin functioned as a plasticizer. Beeswax, obtained directly from the farm in Brong Ahafo, was utilized as a hydrophobic material in the film. Ginger essential oil,(>95% purity) purchased from trusty herbal clinic, was employed to enhance the shelf life of meat. Lecithin, obtained from Micrite company, was used as an emulsifier in the films.

3.2 Preparation of the beeswax gel films.

In the preparation of the beeswax gel films, beeswax of varying mass concentrations (wt/wt) 2.5%, 5%, 10% and 15% was melted in 50 ml of distilled water, with the addition of glycerol. The mixture was heated and stirred at 20 rpm, maintaining a temperature range of 60-67℃ due to the varying concentration of beeswax for 10-15 minutes. Thorough stirring ensured complete dissolution of the beeswax. Subsequently, 2g of cornstarch flour was carefully incorporated into the mixture, and stirring continued for an additional 30 minutes until a colorless gel was formed. (Suharno Rusdi et al., 2022).

3.3 Film casting.

The prepared gel was poured onto a plastic petri dish to create a thin film. A spatula was used to spread the mixture evenly, ensuring uniform distribution of the film. The film was then left to dry for 12 hours in a hot air oven at a specified temperature of 65ºC. To prevent cracks or uneven surfaces, close attention was paid to the drying process of the film.

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Table 2: Shows the sample nomenclature with the addition of glycerol and beeswax (wt.%).

Sample	Cornstarch(g)	Glycerol Conc(%)	Beeswax Conc
BW0	2	0.5	0%
BW2.5	2	0.5	2.5%
BW5	2	0.5	5%
BW10	2	0.5	10%
BW15	2	0.5	15%

3.4 Heat Treatment of Prepared Films

The prepared films, namely BW0% (beeswax 0wt%), BW2.5% (beeswax 2.5wt%), BW5% (beeswax wt5%), and BW15% (beeswax 15wt%), was subjected to heat treatment. These films were placed on trays and subjected to pre-heated hot air conditions in an oven set at 65℃ for a duration of 24 hours. Subsequently, the films were removed from the oven and allowed to cool for approximately two hours before they were characterized.

3.5 Preparation of films Incorporated with Ginger Essential Oil

With a weight of 5%, beeswax was measured and melted in 50ml distilled water for a duration of 10 minutes. Simultaneously, 2g of cornstarch was measured and dissolved in the 50ml of distilled water. Glycerin was added to the mixture as a plasticizer. The entire mixture was stirred for 30 minutes to allow gelatinization to occur. Furthermore, different concentrations of ginger essential oil, specifically 5%, 10%, and 15%, were introduced into the optimal film composition. The ginger essential oil was thoroughly mixed using a magnetic stirrer with the film blend to ensure a uniform distribution. Additionally, a drop of lecithin was added to facilitate emulsification and homogenization in the mixture.

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The film, along with the incorporated ginger essential oil, was then cast onto a plastic petri dish. Subsequently, the film was dried in an air dry oven for 12 hours at a controlled temperature of 55℃. This process was repeated, as previously mentioned, to obtain the films that incorporated ginger essential oil.



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3.6 Flow Chart Diagram of Methodology

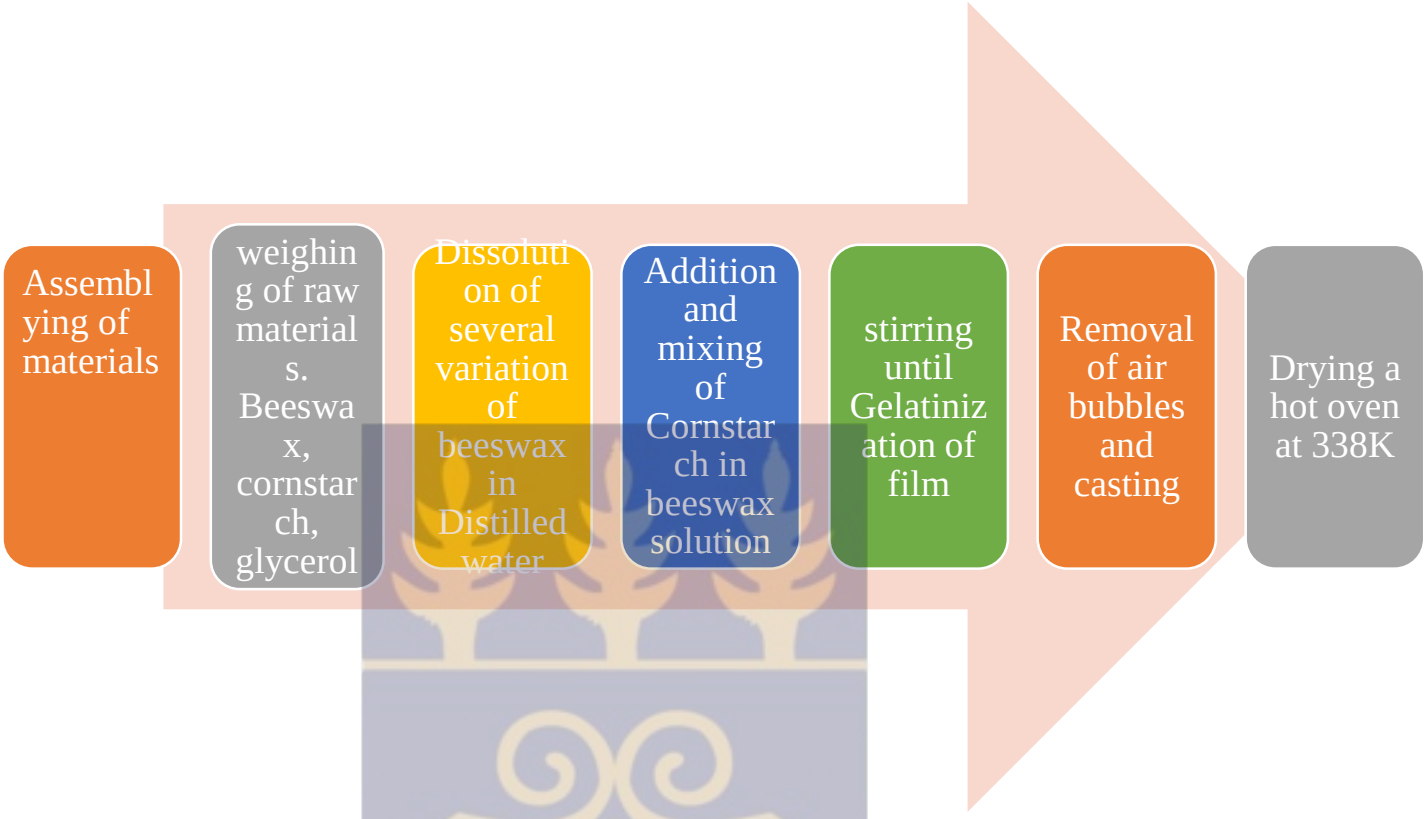


Figure 5: Flow of methodology

3.7 Characterization of Films

This study aimed to evaluate the influence of beeswax and ginger essential oil (GEO) on the chemical interactions, mechanical properties, and thermal stability of the films, as well as their behavior in aqueous environments of varying pH conditions (neutral, acidic, and basic).

3.7.1 Fourier Transform and Infrared Spectroscopy (FTIR) Analysis

The FTIR analysis was performed using a PerkinElmer UATR Two spectrometer equipped with an attenuated total reflectance accessory. The measurement range was 450 - 4000 cm^-1, and the resolution was set to 4 cm^-1. Before conducting the analysis, the holding crystal was cleaned

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with ethanol. The films were then prepared for spectral analysis. The data obtained from the analysis was imported into Origin Pro 2019 software to generate the FTIR spectra.

3.7.2 Thermogravimetric Analysis (TGA)

TGA was carried out using an SDT Q600 V20.9 Build 20 DSC-TGA equipment, capable of simultaneously recording DSC and TGA. Five samples B0, B 2.5, B5, B10, B15 weighing between I mg and 5 mg were heated at a rate of 10℃/min until they reached a temperature of 600℃..

3.7.3 Moisture Content, Swelling Degree, Water Solubility, and Test of Film Stability in Water

Moisture Content (MC)

The initial weights of the films were measured and recorded as W1. The films were then placed in an oven and heated at 105℃ for 24 hours. Afterward, the films were reweighed immediately (W2) to prevent moisture absorption from the atmosphere. The moisture content was calculated using the following equation (Cazon et al., 2020)

$$\text{Moisture Content} = \frac{w1-w2}{\text{W2} * 100\%}$$

Swelling Degree (SD)

To determine the extent of swelling, film samples were dried at 105℃ for 24 hours, and their weights were recorded as W2. Subsequently, the dried film samples were placed in a bowl containing 100 ml of distilled water for another 24hours. After immersion, the weights of the films were recorded as W3, from which the swelling degree was calculated using the equation:

$$\text{Swelling degree} = \frac{w3-w2}{\text{W2} * 100\%}$$

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Water Solubility (WS)

Water solubility provides an indication of the complete dissolution of the films in water. Initial weights of the films were represented as W1, weights after oven drying at 105℃ for 24 hours as W2, weights after immersion in water for specific time periods as W3, and weights after drying the films previously immersed in water at 105℃ till a uniform weight was achieved as W4. The water solubility was calculated as:

$$\text{Water Solubility} = \frac{w2-w4}{\text{W2} * 100\%}$$

3.7.4 Microbial analysis on meat

Media preparation

Microbial analysis was conducted using two different agar media to ensure comprehensive detection. Nutrient agar was employed to determine the total viable microbial count, while selective/differential agar (e.g., MacConkey agar for coliforms or PDA for fungi) was used to isolate and quantify specific spoilage organisms. This dual-media approach provided both general and targeted insights into the antimicrobial effectiveness of the bioactive films." (e.g., Gram et al., 2002; Ray & Bhunia, 2013)

Plate Count Agar

17.5g of the agar powder was weighed into sterile media bottle, 1000ml of distilled water was added and heated to boil, autoclaved at 121^{o}C for 15mins and kept in a water bath at 45^{o}C. The nutrient agar powder provides a baseline count of total viable microorganisms present on the meat surface

Eosinmethylene Blue Bile Agar.

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38.5g of the agar powder was weighed into sterile media bottle, 1000ml of distilled water was added and heated to boil, and autoclaved at 121°C for 15minutes. Potato Dextrose **Agar.**39g of the agar powder is weighed into sterile media bottle, 1000ml of distilled water was added and heated to boil, and autoclaved at 121°C for 15minutes.Potato Dextrose Agar was used to identify and quantify particular spoilage organisms such as yeast and mold.

3.8 Method for Plate Count Analysis

The pour plate technique was used. 10g of the sample was weighed aseptically into sterilized stomacher bags, 90ml diluents was added and homogenized by blending using the Stomacher blender. 1ml aliquots of the mixture were pipetted aseptically into sterile disposable petri dishes in duplicates, 15ml of the molten agar was added and swirled, and the plates were allowed to solidify and incubated at 37◦C. The plates were examined after incubation (8 days) and colonies counted.

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CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Objective 1: To Determine the Effects of Beeswax and GEO on the Physiochemical properties of cornstarch film.

4.2 Effect of Ginger Essential Oil Concentration on the Physical Properties of Cornstarch Beeswax Films

The first objective of the study is to fabricate cornstarch-beeswax film incorporated with ginger essential oil.



Figure 7: Samples of blends with varied GEO inclusion

The films with 0% and 5% GEO maintained proper formulation due to the stability of the matrix and the effective dissolution of components, leading to uniform films. Alternatively, higher percentages of ginger essential oil, specifically at 10% and 15%, induced adverse effects such as phase separation and compromised rheological properties, ultimately resulting in films that were inadequately formulated. (Akhtar et.al 2022).This correlation underscores the

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importance of optimizing essential oil concentrations to achieve desired film characteristics while ensuring the functional efficacy of such biopolymeric blends.

4.3 Characterization of Cornstarch-Beeswax Films

The characterization included properties of film in terms of the chemical interaction in the film (FT-IR analysis), thermal stability of the film (TGA), Mechanical properties (Tensile strength, elongation at break, and Young's Modulus), and the interaction of the films with moisture (solubility in water at neutral, basic and acidic media, water pressure, etc.).

4.3.1 Chemical Interaction in the Film

Fourier Transform and Infrared Spectroscopy (FTIR) Studies

Figure 6 is the spectral representation of cornstarch and beeswax blends film

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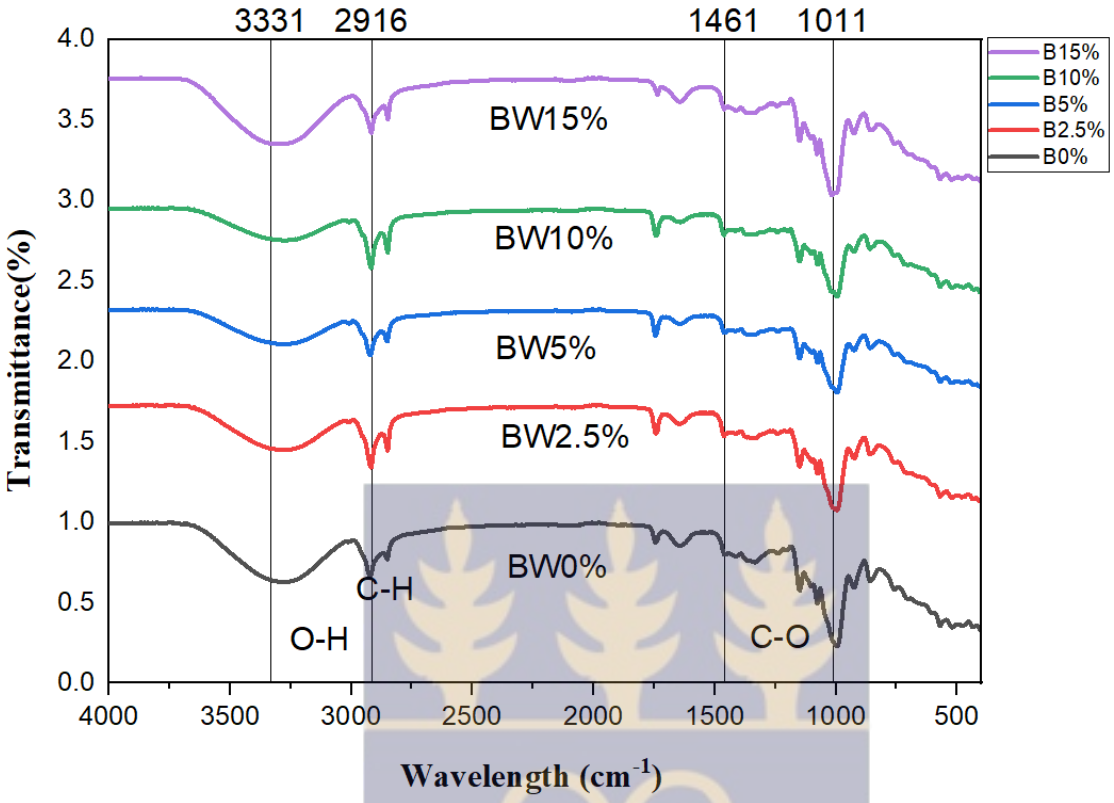


Figure 6~~7~~ : FTIR of Cornstarch-beeswax blends

Molecular Interactions.

The physicochemical properties of films are closely linked to the molecular interactions within the polymer matrix. The FT-IR spectra of cornstarch films incorporating various hydrophobic agents are presented in Figure 7. All films exhibited absorption peaks near 3300 cm−1 (O-H stretching vibrations), 2916 cm−1 (C-H stretching vibrations), and in the range of 1461 to 1011 cm−1 (C-O vibrations) (Geng, et al, 2009). Peaks observed at 1732 cm−1 and 1642 cm−1 indicate the presence of the (C=O) functional group, which is associated with alkanoic acids, as well as a

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(C=C) bond (Diyana et al., 2021). Lastly, the peak observed between 1012 and 998 cm−1 suggests the emergence of (C−O) bonds.

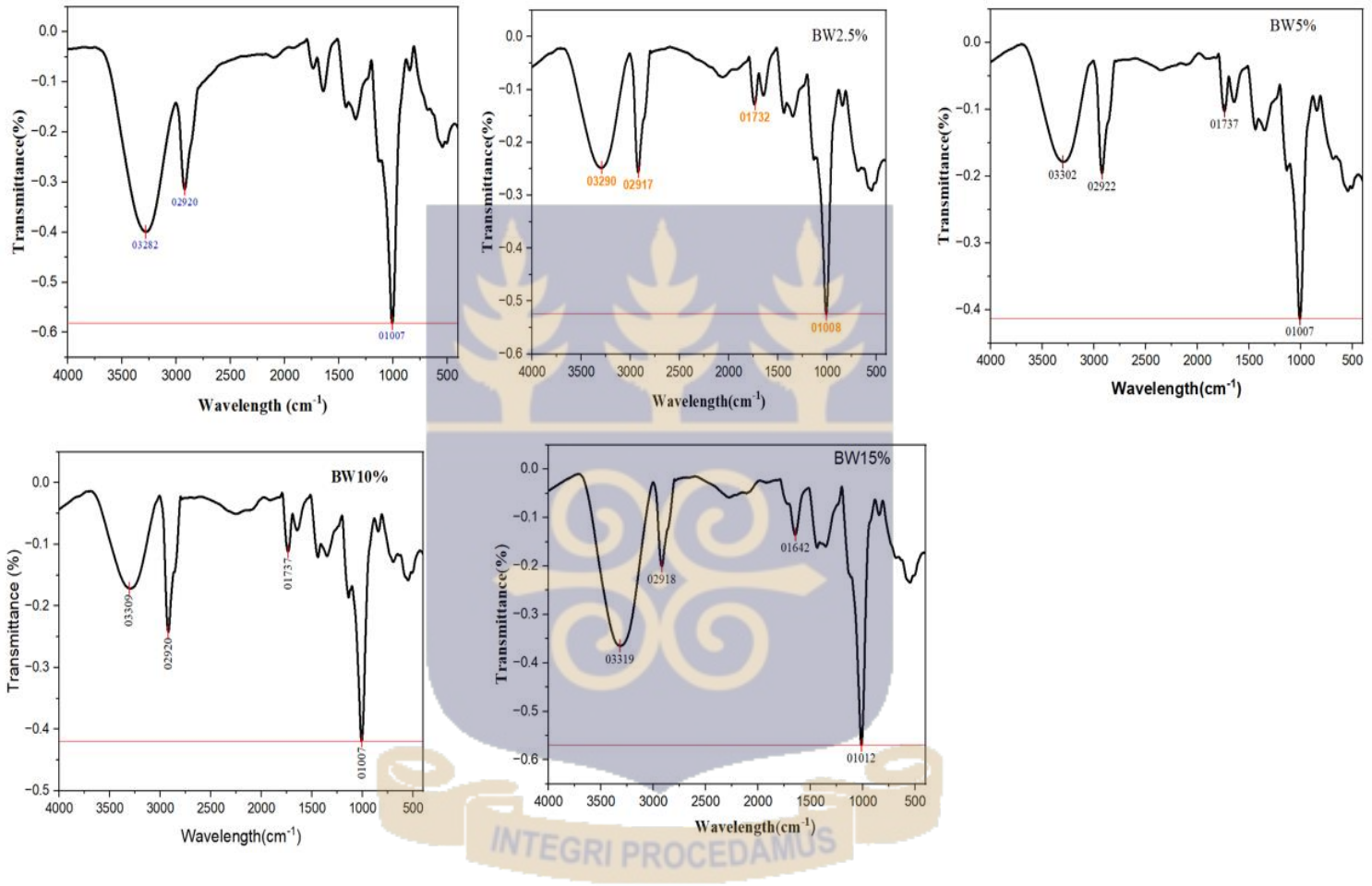


Figure 7~~8~~: FTIR Graphs show various Peaks of various beeswax inclusions.

While the FT-IR spectra of the films containing the beeswax hydrophobic agent generally resembled those of the control films, slight variations in the width, amplitude, and intensity of their characteristic peaks were noted. Specifically, the presence of hydrophobic agents resulted in shifts of the peaks to either lower or higher wavenumbers. For instance, the characteristic peak at 3282 cm−1 (O-H stretching vibrations) shifted to a higher wavenumber of 3319 cm−1 with the incorporation of beeswax at varying concentrations, from 2.5% to 15%. This shift indicates that

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beeswax influences the film's network by weakening hydrogen bonds within the matrix, a finding consistent with earlier studies (Zhang et al., 2019). The increased content of beeswax may have impeded the reformation of hydrogen bonds during the film-drying process (Z.N. Diyana et al., 2021).

4.4 Thermal stability

Thermogravimetric analysis provides critical information about the thermal stability of biobased films, which is essential for determining how these materials will perform under heat. This is particularly important for applications that involve exposure to elevated temperatures, such as in packaging.

4.4.1Thermogravimetric analysis

Thermogravimetric analysis traces of weight loss (%) and derivative weight (% /°C) as a function of degradation temperature (°C) for BW0%, BW2.5%, BW5%, BW10% and BW15% are shown in the fig below.

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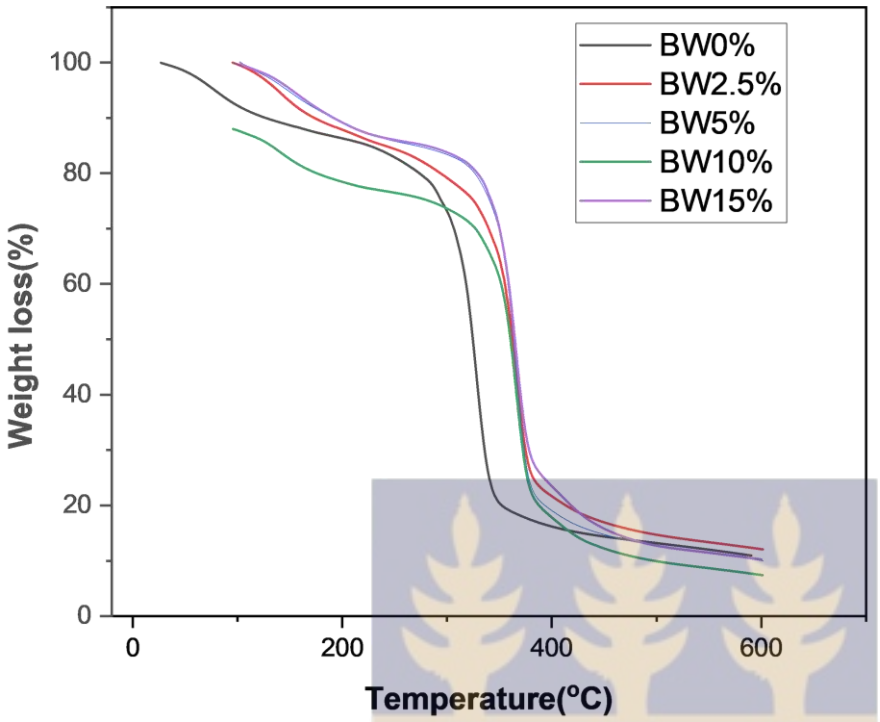


Figure ~~8~~9 : TGA Graphical representation of Films with various beeswax inclusion.

For the BW0% sample, three primary stages of weight loss were identified. The initial stage, occurring between 74.2°C and 106°C, manifested a weight loss of 13.4%, which is likely attributed to the loss of free water. In contrast, this initial weight loss was diminished in the films with beeswax concentrations (BW2.5%, BW5%, BW10%, and BW15%), where weight losses were recorded at 10.2%, 8.92%, 9.65%, and 9.38%, respectively. This observation corroborate with the steeper slope displayed in Figure 9, implying a relationship between beeswax's hydrophobic nature and the reduced moisture content in the films. This finding is consistent with prior studies by Fratini et al. (2016) and Santos et al. (2017), who noted decreased water absorption in beeswax-enhanced films compared to those devoid of wax. These outcomes are also in line with the results concerning water solubility and moisture content.

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The second stage of weight loss, extending from 13.4% to 69.04% for BW0%, occurred between 266°C and 407°C. This stage likely corresponds to the loss of bound water and degradation of the cornstarch polymer chains, as discussed by Wu et al. (2013). The devolatilization temperature range for beeswax-containing films (BW2.5%–BW15%) was higher than that of BW0%, with BW2.5%–BW15% spanning approximately 238°C–372°C, while BW0% occurred over a lower range of approximately 218°C–281°C.These temperature variations indicate that interactions within the emulsions of wax, cornstarch, and glycerol are primarily driven by hydrogen bonds, electrostatic forces, van der Waals interactions, and steric repulsions (McClements, 2015). As the temperature reached 180°C to 360°C, the second stage of weight loss was attributed to the decomposition of volatile components from starch. For BW0%, the weight loss reached 69.04%, likely due to the release of volatile matter from carbohydrates, loss of bound water, and glycerol degradation (Y. Cheng, W. Wang, 2021). However, the analysis did not permit assessment of glycerol volatilization peaks regarding melting or crystallinity.

In the second stage, the BW2.5%, BW5%, BW10%, and BW15% samples all exhibited lower weight losses compared to BW0%. Specifically, the recorded weight losses were 67.3%, 65.43%, 68.3%, and 68.1%, respectively, with a summary provided in Table 3. The degradation point for the CS-BW0% sample at 179°C represents the temperature at which the sample begins to deviate from the baseline, indicating impending weight loss. Additionally, Table 3 illustrates the maximum decomposition rates for CS-BW0%, CS-BW2.5%, CS-BW5%, CS-BW10%, and CS-BW15% as 5.8%, 9.87%, 7.76%, 9.85%, and 9.64%, respectively. This outcome aligns with findings by Zhang et al., indicating that the maximum decomposition rate for wax-free gelatin films is lower than that of films incorporating beeswax. The tabulated results, together with the

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TGA plot, indicate that incorporating beeswax into the CS formulation shifts the onset of thermal degradation to a higher temperature, reflecting delayed initial mass loss and improved resistance to thermal activation. This upward shift in onset temperature, and the corresponding behavior near the temperature of maximum decomposition, supports the conclusion that beeswax enhances the thermal stability of the bio-based cornstarch films by retarding the onset of degradation and moderating decomposition over the heating range.

Table 3: TGA values of weight loss.

Variants	Weight loss (%) first stage 1	Weight loss (%) stage 2	Decomposition (%) stage 3
BW0%	13.34	69.04	5.80
BW2.5%	10.21	67.03	9.87
BW5%	8.92	65.43	7.76
BW10%	9.65	68.30	11.85
BW15%	9.38	68.10	9.64

4 Mechanical Properties of Cornstarch films with Beeswax blends

Since the fabricated films are designed with the intended purpose of food packaging, mechanical properties such as tensile strength, Young's modulus and elongation at break are essential. In fig 9 below, the tensile stress and strain values are plotted against each other and slope values of selected sections of the graph are calculated to determine Young's Modulus

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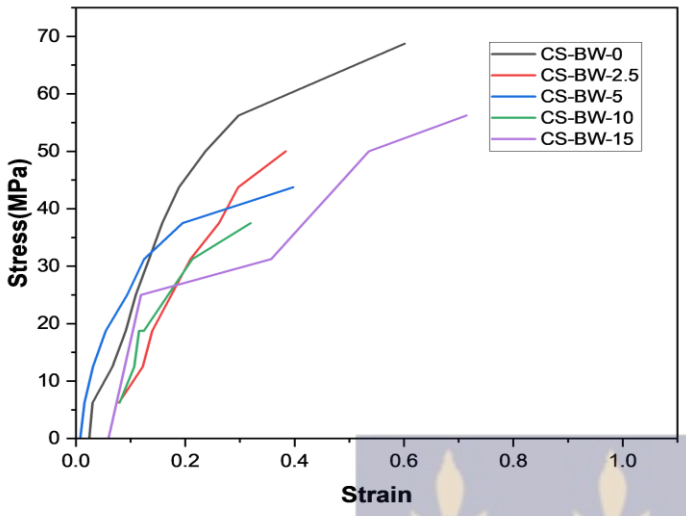


Figure ~~9~~10: A plot of Stress against Strain

The table 4 consists of specific values of tensile strength (MPa), Young's Modulus and Elongation (%) values

Table 4 contains Tensile strength and Elongation Values

Samples	Elongation (%)	Young Modulus	Tensile strength (MPa)
CS-BW0%	60.0	117.7	68.75
CS-2.5%	38.0	148.88	50.00
CS-5%	39.7	103.79	43.96
CS-10%	31.4	122.3	37.5
CS-15%	95.0	63.71	62.5

As shown in table (4), incorporation of varying concentrations of beeswax into cornstarch films significantly affects their tensile properties. Specifically, the tensile strength (TS) of the biofilm blends demonstrated a notable decrease as the beeswax content increased from 2.5% to 15%. Concurrently, elongation at break (EAB) decreased from 60% to 34.4%. Initially, the addition of beeswax resulted in an improvement in tensile modulus, which increased from 117 to 148 MPa

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at a 2.5% beeswax concentration. However, a decline in tensile modulus was observed at 5% beeswax, followed by a slight recovery to 122.5 MPa at 10%. Nonetheless, a drastic reduction to 63.71 MPa occurred at the 15% beeswax level.

These findings align with those reported by Zhang et al. (2018), who studied gelatin matrices augmented with both beeswax and carnauba wax. Their research indicated a similar trend where the addition of these waxes resulted in decreased tensile strength and elongation, while tensile modulus improved. Notably, the gelatin-biofilm produced with beeswax exhibited higher mechanical strength compared to the gelatin-carnauba wax film.

The observed reductions in tensile strength and elongation in the bio-composite films could be attributed to several factors. First, the mechanical resistance of the lipid matrix is relatively poor, leading to the formation of a heterogeneous film structure that introduces discontinuities within the polymer network. This, in turn, diminishes the mechanical integrity of the starch polymer matrix (Cifuentes et al, 2020). Second, the influence of lipid concentration on the mechanical properties of bio-composites is structurally dependent on the polymer matrix composition, as suggested by previous studies (Massa et al, 2011). Also the recovery of tensile strength at 15% beeswax inclusion in cornstarch films can be explained by morphological transitions, wax crystallinity, reduced moisture plasticization, and improved stress redistribution. These mechanisms are well-documented in starch–lipid composite literature, where strength decreases at intermediate loadings but partially recovers at higher wax fractions due to co-continuity and crystalline reinforcement.(Nasir et al, 2021; Ibrahim et al 2019).

Furthermore, the hydrophilic nature of starch, which has a high affinity for water, contrasts with the hydrophobic characteristics of beeswax, indicating a potential incompatibility between the

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two components. However, the similar chemical properties of beeswax and starch both containing hydroxyl functional groups in their structures may account for the observed increase in tensile modulus (Afif et al., 2020). This observation is supported by Fourier-transform infrared spectroscopy (FTIR) results, which showed characteristic peaks at 3299 and 3294 cm^{-1} corresponding to the hydroxyl region.

Moreover, the reduction in elongation following the addition of beeswax could be attributed to the bonding interactions between beeswax and starch, which consequently restrict the material's ability to stretch. Also As a result, the composite becomes less ductile compared to the thermoplastic cornstarch (TPCS) matrix.

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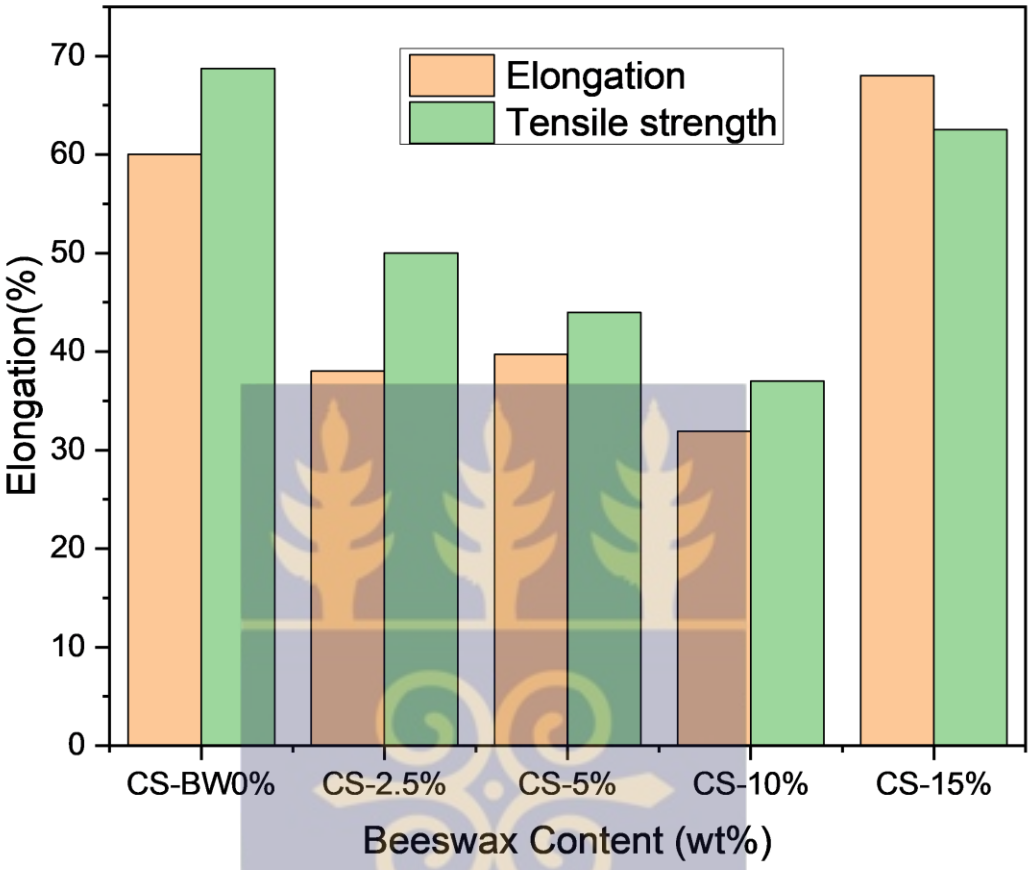


Figure 10~~11~~: Graphical representation of Elongation and TS values

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4.6 Moisture Content, Swelling Degree, Water Solubility, and Test of Film Stability in Water

4.6.1 Moisture content test (mc).

Table 5 contains recordings of values of moisture content for individual variants of beeswax percentage inclusion in corn-starch films. Values were repeated twice and average found for consistency.

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Table 5: Moisture Content Data

Films	Mc	StD ±
B0%	15.70	0.050
B2.5%	14.34	0.045
B5%	13.83	0.025
B10%	14.35	0.045
B15%	15.10	0.050

To examine the impact of different levels of beeswax on the moisture content of cornstarch films, the data was analyzed for various percentages of beeswax, represented in table 5.

The initial decrease in moisture content from 15.7% to 13.83% (up to 5% beeswax) can be attributed to the hydrophobic nature of beeswax. Beeswax creates a physical barrier in the cornstarch matrix, thereby reducing the water absorption capacity of the film. This finding is consistent with research by Pavez et al. (2019), where the incorporation of hydrophobic agents significantly reduced moisture uptake in biopolymer films. This suggests that adding beeswax to cornstarch films improves their hydrophobic properties. Other studies have also shown that beeswax is effective in enhancing the hydrophobicity of starch films. [Dumont et al,2018].

However, the stability seen at 10% beeswax incorporation (14.35%) suggests that an optimal concentration exists where the hydrophobic interactions enhance the film structure without compromising its integrity. This point reflects a balance between the hydrophilic nature of cornstarch and the hydrophobic properties of beeswax, allowing controlled moisture retention conducive for many applications (Prata et al., 2020).

Also, the increase in moisture content at the 15% beeswax incorporation level (15.1%) indicates a shift in film characteristics. This hike could be due to several factors. Higher concentrations of beeswax can lead to phase separation, which may create microvoids within the film structure.

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These voids can serve as capillaries for moisture ingress, leading to an increased moisture content (Mao et al., 2021).

Excess beeswax can saturate the binding sites within the starch matrix, disrupting the network that holds moisture in place, hence allowing more water to be absorbed. At higher concentrations, insufficient dispersion of beeswax could result in uneven distribution, impacting the film's barrier properties (Gu et al., 2018).

4.6.2 Solubility test (ST).

A solubility test for a film is a method to determine how much of the film dissolves in a given solvent or medium. This can help to evaluate the water barrier properties, biodegradability, and stability of the film.

Table 6 Solubility Data for different Beeswax Percentages

Variations	Values	StD(±)
BW0%	0.3200	0.0130
BW2.5%	0.2985	0.0085
BW5%	0.2085	0.0085
BW10%	0.2400	0.0100
BW15%	0.2651	0.0050

Table 6 represents solubility of cornstarch films with varying concentrations of beeswax. The data indicates an initial drop from 0.32 to 0.20 as beeswax incorporation increases from 0% to 5%. Furthermore, a slight increase in solubility is observed at both 10% (0.24) and 15% (0.26) beeswax concentrations. This suggests a non-linear relationship between the beeswax content and the solubility of the films. This trend suggests that beeswax enhances water resistance and reduces solubility in cornstarch films. Beeswax's hydrophobic nature forms a water-resistant barrier,

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reducing the film's solubility. Other studies have reported similar results, showing that the addition of beeswax reduces the solubility of gelatin films and cassava films. (Diyana, 2021).

The presence of lipophilic components and long-chain alkyl esters in beeswax contribute to its low solubility in water-based solvents. Incorporating higher concentrations of beeswax improves water resistance and decreases solubility, resulting in films with enhanced durability and stability. The initial decrease in solubility can be attributed to the formation of a more hydrophobic network due to the incorporation of beeswax. Beeswax, being a lipid, has hydrophobic properties that can reduce the interaction between water molecules and the cornstarch matrix. This aligns with findings by Anguiano-Azuara et al. (2020), who noted that lipid incorporation can enhance the hydrophobicity of starch-based films, subsequently decreasing their solubility in aqueous environments. The slight increase in solubility at 10% and 15% beeswax can be explained through two potential mechanisms.

At higher concentrations of beeswax, phase separation may occur, leading to zones with reduced starch content. Such regions can become more susceptible to solubility in water. A higher level of lipids can lead to poor emulsification and phase separation within the polymer matrix, allowing water to penetrate those areas more easily. The presence of excessive beeswax could disrupt the continuity of the starch-glucose network, weakening the interaction between starch molecules. Consequently, the barrier properties of the film might be compromised, allowing for greater water infiltration and dissolution (Zhang et al., 2019).

In comparison, previous studies indicate that the solubility of hydrophilic biopolymer films can be significantly altered by the addition of hydrophobic compounds. For instance, Fakhouri et al.

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(2021) reported that the solubility of gelatin films decreased with incremental lipid addition, but at specific higher concentrations, the solubility exhibited a rising trend, a finding consistent with the data gathered in this study.

4.6.3 Swelling degree (SD)

The essence of measuring the swelling degree of a film is to understand its water absorption properties and how it may behave in different environments. By measuring the swelling degree, researchers can assess the film's ability to absorb and retain water, which is important for various applications such as packaging, coatings, and biomedical materials. This information helps in determining the film's stability, durability, and performance under different conditions. It also aids in optimizing the formulation and processing of the film to meet specific requirements.

Table 7: Data for Swelling Degree

Films	SD	StD ±
B0%	0.725	0.025
B2.5%	0.425	0.034
B5%	0.292	0.037
B10%	0.616	0.033
B15%	0.664	0.024

The measured swelling degrees for cornstarch films with varying beeswax contents are represented in table 7

The swelling degree showed an initial decrease from 0.72 for the control (0% beeswax) to 0.29 at 5% beeswax incorporation, indicating a significant reduction in water uptake. Conversely, swelling increased at 10% (0.61) and again at 15% (0.66), suggesting a non-linear relationship between beeswax concentration and the swelling behavior of the films.

Initial decrease in Swelling Degree with Beeswax Incorporation: The initial significant decrease in swelling degree can be attributed to the hydrophobic nature of beeswax, which creates a barrier

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against water absorption. As noted in studies by Zhai et al. (2021), the incorporation of hydrophobic lipids significantly reduces the swelling capacity of starch matrices by minimizing the interactions between water molecules and starch granules. This hydrophobic barrier effectively limits water mobility and infiltration, leading to decreased swelling.

The subsequent increase in swelling degree at the 10% and 15% beeswax incorporation levels may be explained through several key factors. At higher concentrations, beeswax can exhibit poor emulsification within the cornstarch matrix, leading to phase separation. The formation of discrete hydrophobic domains can create localized regions where water can more readily penetrate the film, thereby increasing its swelling degree. Research by Wang et al. (2022) supports this observation, suggesting that lipid-rich films may experience phase segregation that enhances water uptake in certain areas. Excess beeswax can interfere with the continuity of the starch polymer network. A compromised network may exhibit increased susceptibility to water penetration as the cohesive force amongst starch molecules weakens, facilitating greater swelling (Mao et al., 2021). It is also possible that, at higher beeswax contents, certain hydrophilic sites may remain exposed or become more accessible due to partial disruption of the starch matrix, which can promote water absorption (Ali et al., 2020).

Previous literature indicates that the swelling behavior of biopolymeric films is highly sensitive to the balance between hydrophilic and hydrophobic components. For instance, research by Megan et al. (2019) found that excessive lipid incorporation altered the polymer structure, affecting its water retention capacity. Their studies highlighted that both hydrophilic segments within the biopolymer and the structural integrity of the network were crucial for determining swelling behavior.

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4.7 To determine the effect of GEO incorporation on the Physiochemical Properties and Moisture Sensitivity of the Films.

4.7.1 FT-IR results and analysis for films with GEO incorporation.

FT-IR is a technique used to obtain an infrared spectrum of absorption or emission of a solid, liquid. In the context of testing bio-based cornstarch films with beeswax and ginger essential oil, FT-IR allows for the identification of the chemical functional groups present in the cornstarch films, as well as the incorporated beeswax and ginger essential oil and helps to analyze the interaction between the bonds of the films.

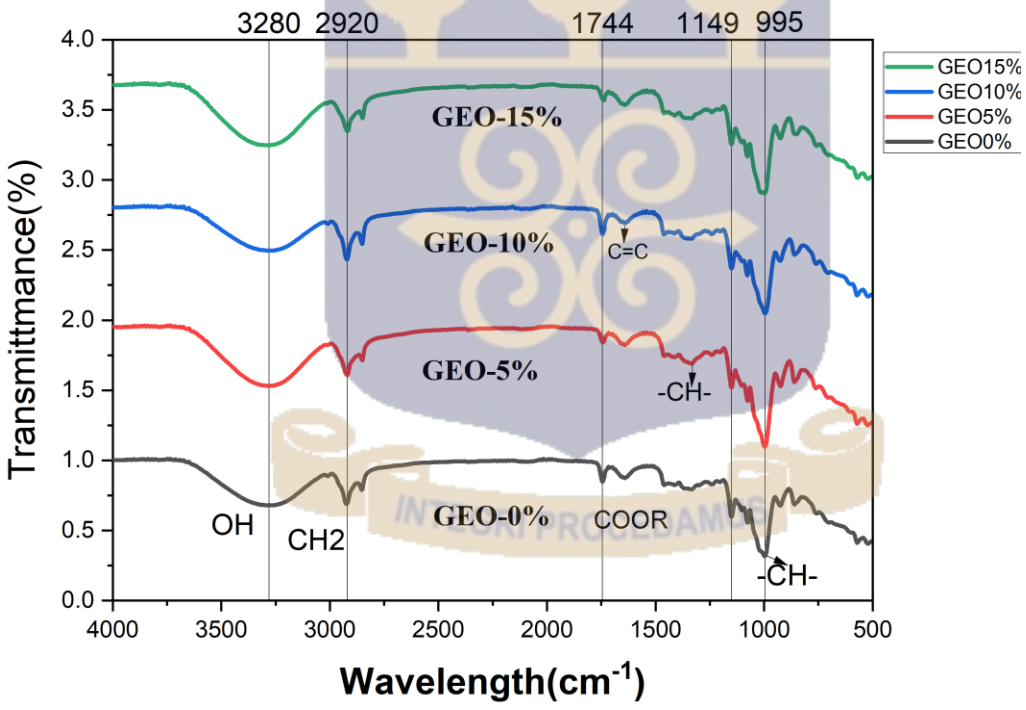


Figure 1112: FTIR Representation of Films with GEO incorporations

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The FTIR analysis identified various peaks in the spectrum:O-H stretching is a wide band peak that typically occurs in compounds such as alcohols and carboxylic acids, and it appears at 3280 cm^{-1}. A peak at 2920 cm^{-1} indicates C-H stretching in organic compounds, particularly in alkanes and alkyl groups. A peak at 1744 cm^{-1} indicates C=O stretching, which is seen in ketones, carboxylic acids, and aldehydes. A peak at 1149 cm^{-1} indicates the presence of C-O stretching vibrations, which are known to be present in alcohols, esters, and ethers. A peak at 995 cm^{-1} indicates C-H bending vibrations and is indicative of aliphatic molecules, such as alkanes or alkyl groups (Salman et al., 2019)

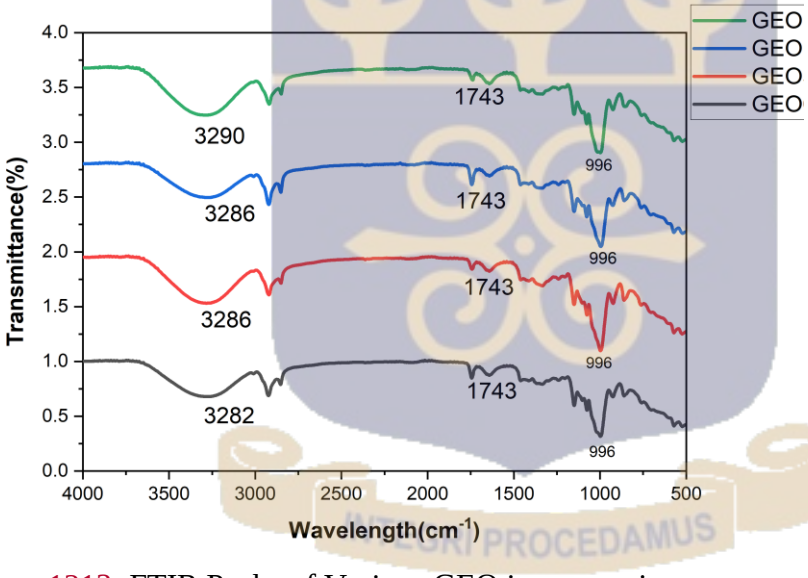


Figure 12~~13~~: FTIR Peaks of Various GEO incorporations

The Fourier-transform infrared (FTIR) analysis of cornstarch-beeswax blends incorporating ginger essential oil (GEO) at concentrations of 5%, 10%, and 15% reveals vital information regarding the molecular interactions occurring within the polymeric matrices. The observed FTIR peaks, particularly in the range of 3282 to 3290 cm^{-1}, correspond to O–H stretching vibrations,

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indicating that hydrogen-bonding interactions are prevalent in the films. This observation aligns with findings from previous research, such as that by Al-Harrasi and Bhatia (2022), which similarly reported broad peaks in the 3000-3500 cm^{-1} region, attributing them to O–H group vibrations present in various biopolymeric systems.

In our study, all samples from the GEO-0 to GEO-15 series exhibited comparable FTIR spectra, primarily characteristic of cornstarch-beeswax films. The consistency in these spectra suggests that the incorporation of GEO does not substantially alter the fundamental chemical structure of the matrix. However, an interesting detail was noted: the broad peaks associated with O–H stretching was retained even after the addition of GEO in the 5% formulation, indicating that the interaction between cornstarch and the functional groups in GEO is strong enough to maintain these spectral characteristics.

The intensity of the O–H stretching peaks was generally greater in the blends without essential oil compared to those with GEO. This discrepancy may be attributed to the enhanced interactions of the hydroxyl groups in GEO with the cornstarch matrix, as evidenced by previous studies indicating that essential oils can interfere with the fundamental interactions in polymeric matrices due to their varying polarities (Sun et al., 2017).

Additionally, the presence of key peaks at 1743 cm^{-1}, which signifies C=O stretching from ester groups, could suggest the formation of ester linkages due to the interaction between the hydroxyl groups of cornstarch and the carbonyl groups in beeswax and GEO. This is corroborated by the literature that discusses the esterification process between fatty acids and alcohols, indicating potential enhancements in the mechanical properties of the films (Bhatia et al., 2014).

Furthermore, peaks around 996 cm^{-1} may indicate C–O stretching, reflecting the presence of different polysaccharides and possibly signaling the formation of hydrogen bonds between GEO

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and the cornstarch-beeswax matrix. The modifications in peak positions and intensities observed across the film formulations suggest that the incorporation of GEO fosters new chemical interactions. Notably, studies on polymer blends have indicated that physical and chemical compatibility often leads to shifts in absorption bands, demonstrating new covalent or hydrogen bonds formed between the components.

Overall, while the addition of GEO at varying concentrations did not drastically change the core spectral peaks of the cornstarch-beeswax blends, there were discernible implications of enhanced interactions between the components. These interactions, evidenced by the noted shifts and the preservation of characteristic peaks, imply that the blend's physical properties may benefit from the inclusion of GEO, promoting a compact and uniform film structure through covalent and hydrogen bonding. Such insights underline the potential of using GEO to enhance the functionality of biopolymeric films for various applications, particularly in the food packaging industry.

4.7.2 Tensile test for films with GEO incorporation

Figure 16 shows a plot of stress against strain. The gradients of the plots represented the young modulus of the films. The values of young modulus, elongation percentage and tensile strength where carefully analyzed.

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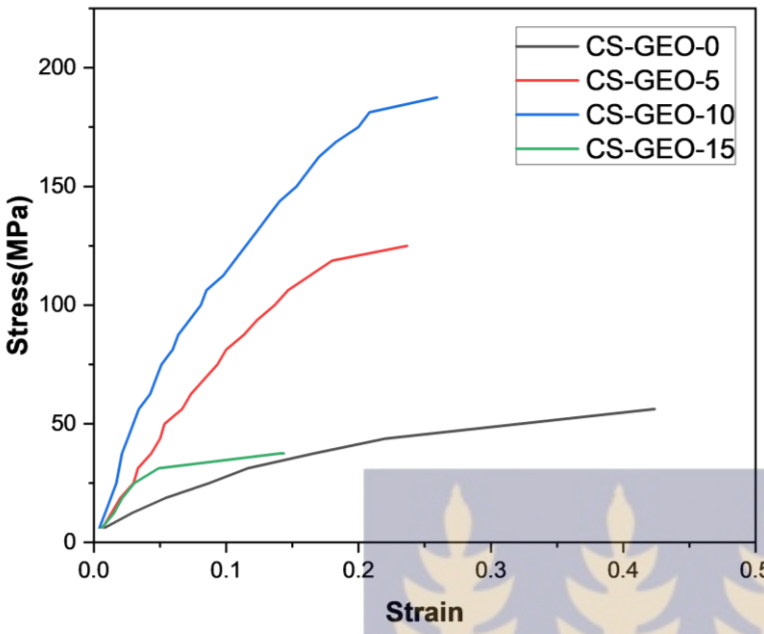


Figure 13~~14~~: Graphical representation of tensile test of films with GEO incorporations.

Table 8 TS Values

Samples	Elongation (%)	Tensile Strength
CS-GEO0%	42.30	56.25
CS-GEO5%	23.00	100.00
CS-GEO10%	25.90	187.50
CS-GEO15%	14.30	37.50

Table 8 summarizes the tensile strength (TS) and elongation percentage of cornstarch (CS) films with various concentrations of ginger essential oil (GEO). The film that did not contain GEO exhibited a TS of 56.25 MPa, which is notably higher than the ranges typically reported in prior literature (22−32 MPa) (Park, H. J., 1996). The introduction of GEO into the cornstarch films led to a substantial increase in TS, rising from 56.25 MPa to 187.5 MPa at a concentration of 10%

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GEO. However, this increase in tensile strength was accompanied by a significant reduction in elongation, which decreased from 42.3% to 14.3%, indicating a concentration-dependent effect. The films without oil demonstrated the lowest tensile strength of 56.25 MPa alongside the highest elongation value of 42.3%. The observed increase in tensile strength upon the incorporation of GEO can be attributed to the presence of low-molecular-weight compounds in the essential oil, including aldehydes, ketones, and phenolic substances. These components are known to enhance crosslinking within the polymeric network, thereby improving interchain interactions (Azizah et al., 2023).

This finding aligns with previous research that showed the beneficial effects of adding polyphenol-rich P. maackii juice to kappa carrageenan and hydroxypropyl methylcellulose films, resulting in improved tensile strength. Similarly, the addition of Satureja hortensis essential oil to kappa carrageenan films led to analogous results, demonstrating both decreased tensile strength and elongation at break (EAB) (Shojaee-Aliabadi et al., 2013).

The significant decrease in elongation, from 42% to 14%, can likely be explained by the partial replacement of strong polymer–polymer interactions with weaker polymer–oil interactions within the film matrix, a finding corroborated by previous studies (Bharti et al., 2022). The dynamics of essential oil incorporation into polymeric matrices often produce variable outcomes that are contingent upon the type and proportion of ingredients used, as well as the specific conditions under which the films are prepared (Atarés & Chiralt, 2016).

In summary, while the addition of ginger essential oil notably enhances the tensile strength of cornstarch films, it concurrently reduces their elasticity, illustrating a trade-off between these mechanical properties based on the concentration of essential oil incorporated.

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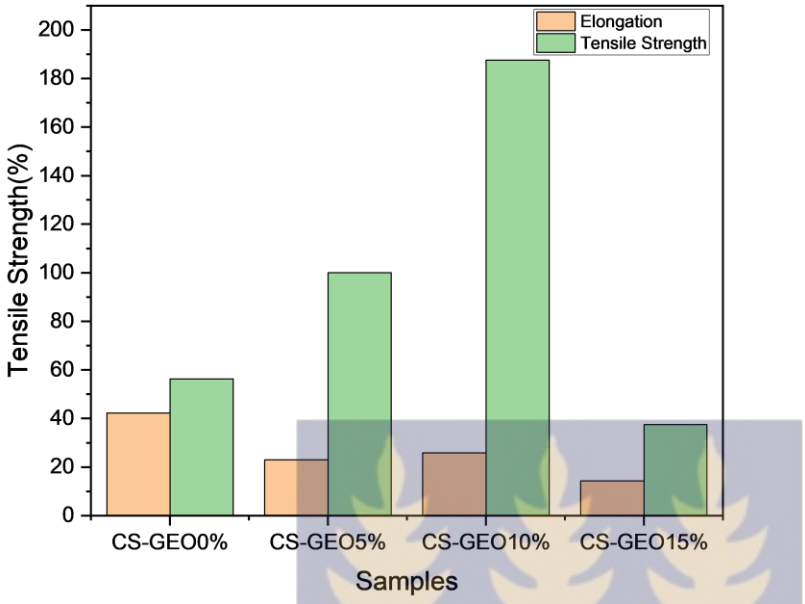


Figure 14~~15~~: Tensile Strength Plot

4.7.3Moisture Content, Swelling Degree and Solubility GEO Films

4.7.3.1 Swelling degree and solubility of films with GEO incorporations

The table 9 represents data of solubility and swelling degree. The solubility values of the cornstarch-beeswax films with ginger essential oil incorporation were measured as represented in table 9

Table 9 Data for Solubility with GEO incorporations

Films	Sol	StD ±
GEO0%	0.302	0.01
GEO5%	0.215	0.015
GEO10%	0.275	0.015
GEO15%	0.306	0.01

Notably, the solubility decreased from 0% to 5% ginger essential oil, then increased marginally at both 10% and 15%

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The initial decrease in solubility from 0% to 5% ginger essential oil may indicate enhanced hydrophobic interactions due to the combined effects of beeswax and ginger essential oil. The hydrophobic characteristics of both the beeswax and ginger essential oil limit the water accessibility to the starch matrix, thus reducing solubility. Research by Zha et al. (2019) supports this notion, demonstrating that lipid incorporation in starch films decreases solubility by creating a hydrophobic barrier against water.

Previous studies have shown that essential oils with high hydrophobicity tend to reduce the permeability of packaging materials, resulting in improved barrier properties (Yue Zhou et al., 2021). In line with these findings, the solubility trend observed in this study suggests that ginger oil enhances the hydrophobicity and resistance to dissolution of the cornstarch beeswax films.

However, the observed increase in solubility at 10% ginger essential oil (0.275) and further at 15% (0.306) can be attributed to several potential mechanisms:

At higher concentrations of ginger essential oil, it is possible that the interactions among the starch, beeswax, and the essential oil contribute to microphase separation within the film matrix. Such phase separation might create pockets or channels that allow for increased water penetration, leading to higher solubility values. This correlates with findings from Payo et al. (2021), which noted that excessive oil concentrations could disrupt the polymer network, facilitating water absorption.

The chemical nature of ginger essential oil, which contains various bioactive compounds such as phenolics and terpenes, might impart some degree of hydrophilicity at higher concentrations. The presence of these compounds can create sites for hydrogen bonding, enhancing affinity for water and possibly contributing to water mobility within the starch matrix (Lu et al., 2020).

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Hydrophobicity Improvement with Ginger Essential Oil: Despite the initial increase in solubility at higher ginger essential oil concentrations, the addition of ginger essential oil improves the overall hydrophobicity of the cornstarch-beeswax films. The essential oil acts synergistically with beeswax, reinforcing the hydrophobic properties while simultaneously imparting antioxidant and antimicrobial characteristics to the films, which are beneficial for food applications (Jain et al., 2022). The hydrophobicity is further enhanced through the formation of a continuous lipid phase, which creates barriers to moisture absorption and can prevent swelling, leading to better surface characteristics against water attacks, as observed in films researched by Gupta et al. (2019).

Related studies highlight that the incorporation of essential oils into starch-based biopolymers significantly affects their physical properties. For example, Santos et al. (2020) noted that films with increased essential oil content exhibited reduced water solubility due to prolonged interactions between the polymer chains and the oil phase, thus achieving improved barrier properties.

4.7.3.2 Solubility in acetic acid

The solubility values of the cornstarch-beeswax films with varying concentrations of ginger essential oil 0%,5%,10%,15% in acetic acid are represented in Figure 10 below.

Table 10: Table showing solubility in Acid

Films	**Sol**	**StD ±**
GEO0%	0.287	0.015
GEO5%	0.17	0.010
GEO10%	0.195	0.020
GEO15%	0.203	0.0250

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The values indicate a significant decrease in solubility from 0% to 5%, followed by a slight recovery at 10% and 15%.

The marked decrease in solubility from 0% to 5% ginger essential oil (from 0.28 to 0.17) suggests a strong interaction between the biopolymers (cornstarch and beeswax) and the essential oil. The low solubility at 5% may reflect the effectiveness of the beeswax in creating a hydrophobic barrier, which subsequently limits the interactions between acetic acid and the water affinity of starch. Research by Grygorieva et al. (2021) indicates that lipid incorporation generally enhances hydrophobicity in starch-based films, thereby decreasing solubility in polar solvents like acetic acid.

Also, the slight increase in solubility at both 10% (0.19) and 15% (0.203) may be due to several interrelated factors. At these higher levels of ginger essential oil, there is potential for partial phase separation, which could create localized pockets within the film that are more prone to dissolution in acetic acid. Wong et al. (2020) demonstrated similar trends in composite films, wherein higher oil concentrations led to phase demarcation, allowing for more solvent penetration.

The chemical constituents of ginger essential oil may interact in complex ways with starch and beeswax, leading to modifications in the structural integrity of the film matrix, allowing for slight increases in solubility. The presence of phenolic compounds in ginger essential oil has been reported to influence molecular interactions, potentially enhancing solvent accessibility (Bhairo et al., 2021).

The combination of beeswax and ginger essential oil in the cornstarch films improves hydrophobicity, an important attribute considering the use of these films in environments with moisture or acidic conditions. The incorporation of ginger essential oil provides additional

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hydrophobic characteristics that complement those contributed by beeswax (Dahmash et al., 2022).

Ginger essential oil, while having a hydrophilic nature due to the presence of hydroxyl groups, can create a more complex barrier when integrated into the lipid-rich beeswax matrix. This complexity leads to improved overall resistance to solubility in acetic acid. Studies have indicated that essential oils can contribute to film hydrophobicity when adequately dispersed, creating a network that limits hydrophilic interactions with solvents (Gonzalez-Tejero et al., 2020).

Literature indicates that the addition of lipids or essential oils can modulate the solubility characteristics of biopolymer films. Previous studies have found that essential oils can reduce the solubility of starch-based films in polar solvents owing to modifications in network structure and solvent interactions (Mao et al., 2016). This aligns with the findings of the present study, especially in terms of the initial drop in solubility upon essential oil incorporation.

Table 11**Table of Solubility in Ammonia**

Films	**Sol**	**StD±**
GEO0%	0.295	0.015
GEO5%	0.218	0.01
GEO10%	0.282	0.01
GEO15%	0.337	0.05

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Table 11 represents solubility values of the cornstarch-beeswax with varying concentration of GEO 0%, 5%,10% 15% films in ammonia solution. The data suggest decreased solubility from the control to 5%, with a rebound observed at 10% and 15% ginger essential oil concentrations. The significant drop in solubility from 0% to 5% ginger essential oil (from 0.29 to 0.21) can be attributed to the combination of hydrophobic and intermolecular interactions facilitated by the beeswax and the essential oil. As a hydrophobic component, beeswax can effectively create a barrier that inhibits the interaction between the starch matrix and ammonia, leading to a muted

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solubility performance. Research by Zhang et al. (2020) supports this, indicating that the incorporation of hydrophobic materials in starch films typically results in decreased solubility due to a reduction in polymer-solvent affinity.

The apparent increase in solubility at 10% (0.28) and particularly at 15% (0.34) ginger essential oil may be explained by. At higher concentrations, the essential oil may disrupt the continuous matrix formed by starch and beeswax, leading to phase separation. This could create zones within the film that are more susceptible to ammonia penetration, thereby increasing solubility (Youssef et al., 2019).

The increase could also be a result of the influence of ginger essential oil, which includes various hydrophilic compounds, potentially promoting increased water affinity in the film. This interaction may partially counter the hydrophobic effects of both beeswax and the starch matrix, facilitating more interaction with the ammonia solvent (Cheng et al., 2021)

The incorporation of ginger essential oil enhances the hydrophobic characteristics of the cornstarch-beeswax films, which is particularly pressing for applications related to meat preservation. The hydrophobicity is crucial since it helps to mitigate moisture ingress, thus extending the shelf life by reducing microbial proliferation a significant factor considering that meat can emit ammonia and other volatile compounds as it spoils (Lemos et al., 2020).

Ginger essential oil, known for its antimicrobial properties, can add another layer of protection against spoilage by reducing microbial growth on the film surface, further protecting the meat underneath. Additionally, it constitutes a natural preservative, improving the films' functionality by combining moisture barrier properties with antioxidant properties to counteract spoilage indicators (Gonzalez-Tejero et al., 2020).

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The solubility and hydrophobicity aspects of cornstarch-beeswax films infused with ginger essential oil are especially pertinent, given that ammonia is a common byproduct of meat spoilage. Enhanced hydrophobic properties allow for better resistance to ammonia absorption, thereby sustaining the integrity of the films and their performance in food packaging applications (Meghla et al., 2021). Therefore, films exhibiting low solubility while maintaining robust hydrophobic characteristics are likely more beneficial in minimizing the impact of spoilage and extending the shelf life of perishable items such as meat.

4.7.3.3 Swelling Degree

Table 12 represents swelling of GEO films.

Table 12 Data for swelling degree of films with GEO incorporations

Films	SD	StD
GEO-0%	2.167	0.037
GEO-5%	1.425	0.045
GEO-10%	0.741	0.053
GEO-15%	1.822	0.055

Table 12 represents swelling degree values of cornstarch-beeswax films with varying GEO concentrations. It shows an initial Decrease in Swelling Degree, the substantial decrease in swelling degree from 0% to 5% ginger essential oil (from 2.17 to 1.43) may be attributed to the hydrophobic properties imparted by both beeswax and ginger essential oil. Beeswax acts as a hydrophobic barrier, reducing the interaction of the film matrix with water, leading to decreased swelling. Research by Wang et al. (2021) noted that the incorporation of lipids into starch-based films can significantly diminish their water absorption capacities, thereby lowering swelling degrees.

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Significant Reduction at 10% Ginger Essential Oil: The marked drop in swelling degree at 10% ginger essential oil (0.74) indicates that this level may represent an optimal incorporation point where the hydrophobic lipid phase becomes predominant. At this concentration, the film's structural integrity is reinforced by the continual formation of a hydrophobic network, creating a barrier that restricts water penetration (Mohammed et al., 2022). The presence of both beeswax and a sufficient amount of ginger essential oil enhance the intermolecular forces within the film, effectively minimizing swelling.

Increase in Swelling Degree at 15% Ginger Essential Oil. The increase in swelling degree observed at 15% ginger essential oil (1.80) can be attributed to several factors:

Excessive concentrations of ginger essential oil could induce phase separation, disrupting the continuous structure formed by the starch and beeswax network. This disruption could create voids or channels within the film matrix, making it more susceptible to water absorption (Pérez et al., 2020).

The constituents of ginger essential oil, comprising various bioactive compounds, may interact differently at higher concentrations, potentially influencing the absorption dynamics and overall stability of the starch matrix. Certain components might lead to reduced intermolecular interactions, allowing more water ingress and an increase in swelling (Santos et al., 2021).

Incorporating ginger essential oil significantly enhances the hydrophobicity of cornstarch-beeswax films. The hydrophobic nature of beeswax is complemented by ginger essential oil, which not only improves moisture barrier properties but also imparts antimicrobial properties due to the bioactive compounds found in the essential oil (Singh et al., 2020).

The overall hydrophobic character of the films is crucial for their application in food packaging, particularly in moisture-rich environments. Enhanced hydrophobicity reduces the potential for

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microbial growth, prolonging the shelf life of food products. Ginger essential oil's bioactive components can improve resistance against moisture absorption, effectively enhancing the functionality of the films (Zhao et al., 2021).

Previous studies indicate that the addition of essential oils to biopolymer films has a profound effect on swelling behavior. For example, Fakhouri et al. (2020) reported that the incorporation of essential oils led to improved barrier properties and swelling behavior, confirming that the interactions between oil and polymer significantly influence the physical properties of the resultant films.

4.8 To determine the effect of GEO on extending the shelf life of meat.

4.8.1 Microbiology analysis

Figure 22 and Figure 23 are graphical representations of different microbial analyses conducted on films utilized to package fresh beef for 8 days. Tests were performed every two days, and the results were documented to form the basis for these plots. The importance of microbial analysis in film packaging for fresh meat during an 8-day duration is crucial for upholding food safety and quality standards. Through assessing the microbial composition present on the packaging, it becomes feasible to supervise and manage the proliferation of harmful bacteria, which could otherwise result in spoilage or foodborne diseases. This examination enables the timely identification of any contamination, facilitating an extension of the meat's shelf life and preservation of its freshness. Furthermore, it contributes to adherence to food safety protocols and guidelines, ultimately benefiting both consumers and producers by ensuring the safety of the meat for consumption.

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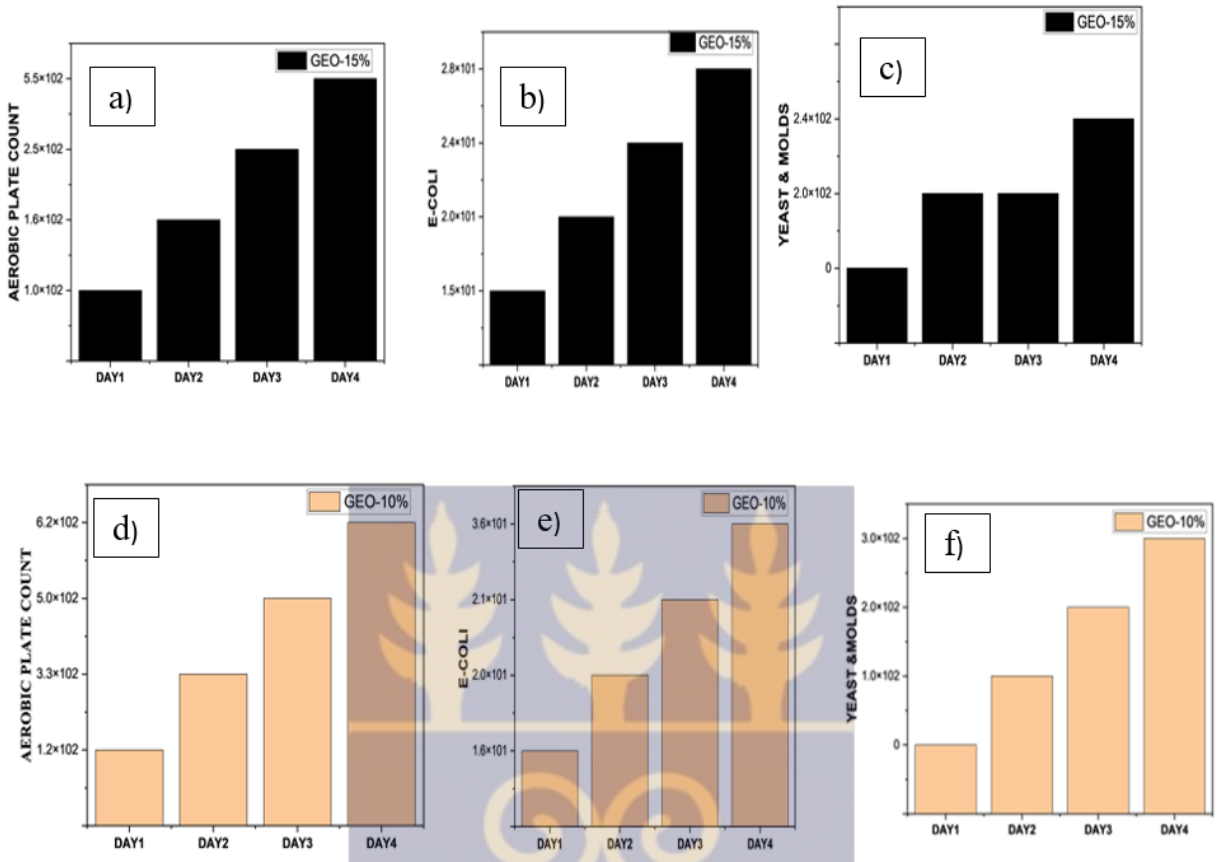


Figure 15~~16~~: Plots of APC, E-COLI & Y&M : (a) APC[GEO-15%] (b) E-COLI [GEO-15%] (c) Y&M [GEO-15%]

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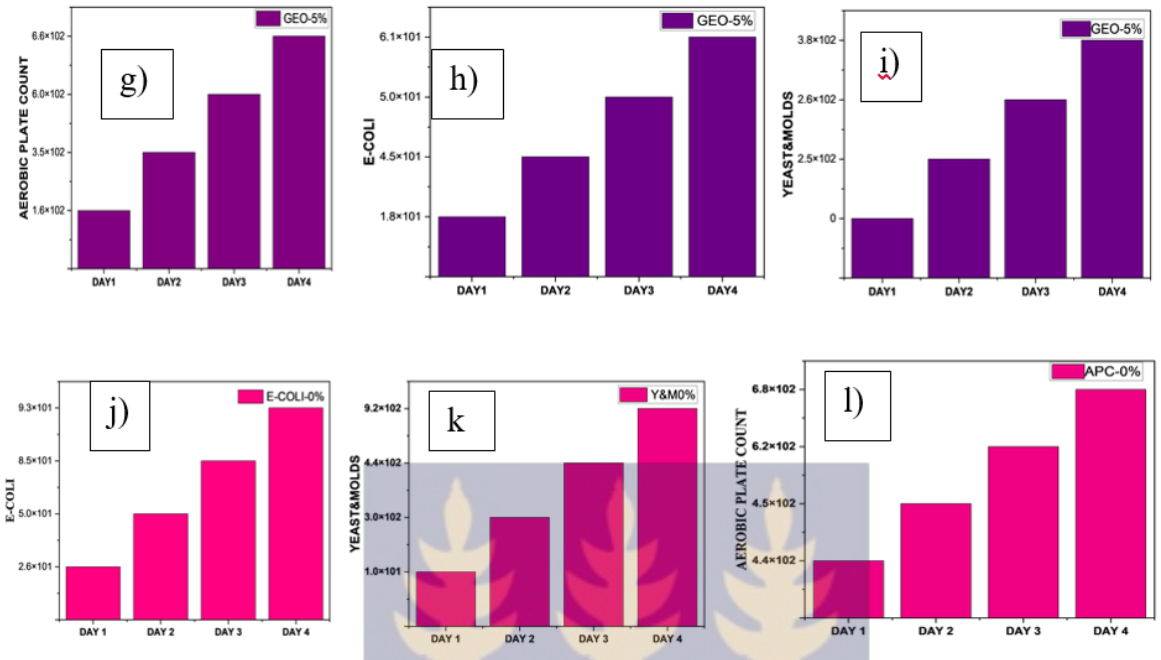


Figure 16~~17~~:APC, E-COLI, Y&M: (g) APC [GEO-5%] (h) E-COLI [GEO-5%] (i) Y&M [GEO-5%] (j) E-COLI [GEO-0%] (k) Y&M [GEO-0%] (l) APC [GEO-0%]

4.8.2 Microbial Analysis

Beef is rich in protein, carbohydrate, water, etc., which serves as a good nutrient matrix for microbial growth, reproduction, and toxic byproduct formation in the storage environment. Therefore, the microbial quantity of meat products under specific storage conditions directly reflects the freshness and overall quality to a large extent.

Aerobic Plate count (APC). The APC is one of the key indicators for evaluating the freshness and overall quality of meat products. The Aerobic Plate Count measures the total number of viable aerobic bacteria (those that grow in the presence of oxygen) in a sample. It is an indicator of overall microbial load. Different countries and organizations may have varying guidelines for APC in fresh beef. For instance**.** The U.S. FDA recommends that fresh beef should have an APC

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of less than 105 colony-forming units (CFU) per gram**.** The UK Food Standards Agency suggests an APC of less than 5 × 10^7 CFU/g for fresh meat.

The incorporation of ginger essential oil (GEO) into cornstarch beeswax blends has been extensively studied, particularly due to its potential antimicrobial properties. This discussion focuses on the observed effects of GEO on microbial colony counts, specifically aerobic plate count (APC), E. coli, and yeast and molds (Y&M), in fresh beef over an eight-day refrigerated storage period, with evaluations conducted every two days.

Initial microbial counts for control (uncoated) beef samples, as reflected in the provided data, indicate a high baseline of microbial growth. At Day 0, the counts were remarkably elevated, with mean counts of 4.7 × 10^5 CFU/g for aerobic plate counts, 1.9 × 10^4 CFU/g for E. coli, and 2.8 × 10^4 CFU/g for yeast and molds. This high microbial load serves as a benchmark against which the effectiveness of the coatings, including those containing GEO, can be measured over the designated storage period.

Research indicates that edible coatings comprising natural ingredients can effectively reduce microbial growth in meat products. For instance, in studies utilizing agar/sodium alginate coatings with GEO, significant reductions in microbial populations were reported. Specifically, at the end of an 18-day storage period, the total viable counts (TVC) and specific pathogens were significantly lower in GEO-coated samples compared to controls (3.90 - 7.50 log CFU/g) (Zhang et al, 2021). Similarly, it is expected that the incorporation of GEO into cornstarch beeswax blends would yield comparable antimicrobial benefits.

According to the data provided, across the four sample groups (0%, 5%, 10%, and 15% GEO concentrations), a consistent pattern of decrease in counts of APC, E. coli, and yeast & molds is observed as the concentration of GEO increases. For instance, the APC count in the 0% sample

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group on Day 4 was 6.8 × 10^2 CFU/g, while counts were significantly lower in higher concentrations by Day 4, with the 15% sample registering a count of 5.5 × 10^2 CFU/g. Similar trends were observed across E. coli and Y&M counts.

The inhibitory effect of GEO has been linked to its bioactive compounds, such as gingerol and shogaol, which have shown antimicrobial activities against various foodborne pathogens. (Fareid et al., 2025; Edo et al., 2025; Akjournals, 2025).The incorporation of such natural preservatives can potentially extend the shelf life of beef products, as seen in studies demonstrating that AS and AS + GEO coatings extended shelf life by 9 days compared to uncoated controls (Bin Zhang et al, 2021).

In the context of this discussion, the gradual reduction in microbial levels throughout the storage period in the GEO-treated samples implies that these treatments could significantly contribute to the shelf-life extension of beef, suggesting an increase in the effective use of such coatings in the meat industry.

Moreover, considering literature that reports enhanced sensory characteristics of coatings containing natural oils (Sudarshan et al,2010), it may be inferred that beef samples treated with cornstarch beeswax blends infused with GEO not only provide better microbial protection but also maintain better sensory qualities, making them more appealing to consumers.

The use of ginger essential oil in cornstarch beeswax blends shows promise as an effective strategy for enhancing the microbiological safety and extending the shelf life of beef during refrigerated storage. The observed reductions in microbial counts for APC, E. coli, and yeasts and molds support the viability of natural coatings in preserving meat quality. Further research should continue to explore optimal concentrations and combinations that maximize antimicrobial activity and sensory quality.

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CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study aimed to improve the water repellence (hydrophobicity) of cornstarch films by incorporating beeswax and adding ginger essential oil to enhance the antimicrobial properties. The goal was to develop an effective packaging material suitable for fresh meat products that could prolong their shelf life. The addition of beeswax at different concentrations notably increased the hydrophobicity of the films, leading to improvements in their strength. Moreover, beeswax inclusion positively impacted film solubility, swelling degree, and moisture content. Thermogravimetric analysis indicated that higher concentrations of beeswax enhanced the thermal stability of the films.

Using FTIR analysis, it was found that the chemical composition of the films was affected by varying levels of beeswax. Different percentages of beeswax altered hydrogen bonding interactions, with higher concentrations potentially strengthening these bonds and influencing properties such as structural stability and barrier capabilities. Incorporating ginger essential oil further improved the hydrophobicity and strength of the films, while also reducing their solubility and swelling. The FTIR results indicated shifts in the hydroxyl stretching peak due to changes in bond strength and molecular interactions resulting from the ginger oil presence. Microbiological testing conducted over an 8-day period on meat samples revealed that the antimicrobial effect of ginger essential oil varied depending on the concentration, being most effective within the initial four to six days. Although the efficacy lessened over time, the oil still managed to control microbial growth, keeping bacterial counts below spoilage thresholds. Notably, the presence of

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E.coli decreased over time compared to initial levels, further indicating the beneficial impact of ginger oil on extending the meat's shelf life.

5. 2 Recommendations

The findings of this study provide a solid basis for future research endeavors focusing on the intricate interactions between bio-based and biodegradable film blends with beeswax to enhance hydrophobic properties. Several recommendations emerge from this study that can guide further investigations:

1. It is recommended that future research investigates the release mechanisms of essential oils within cornstarch and beeswax films, as this could clarify the release rates of polyphenols in meat and their impact on shelf-life extension.
2. Various methods for incorporating GEO essential oils, including microencapsulation, should be explored to determine the most effective technique for optimizing essential oil integration and ensuring the best release of polyphenols.
3. Additionally, further morphological studies could provide valuable insights into how the films' microstructural characteristics (such as crystallinity, porosity, and phase separation) affect their macroscopic properties, including mechanical strength, barrier performance, and thermal stability.
4. Finally, conducting sensory analysis on meat stored in these films may yield useful information about the influence of GEOs on the sensory attributes of the final products. Expanding these studies will significantly enhance our understanding of the functional properties and applications of cornstarch-beeswax films modified with essential oils.

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REFERENCES

1. Lipiński, B. (2020). Why does animal-based food loss and waste matter? Animal Frontiers, 10, 48–52.

2. Hodges, R. J., Buzby, J. C., & Bennett, B. (2010). Postharvest losses and waste in developed and less developed countries: Opportunities to improve resource use. Journal of Agricultural Science, 149, 37–45.

3. Flanagan, K., Robertson, K., & Hanson, C. (2019). Reducing food loss and waste: Setting a Global Action Agenda. World Resources Institute.

4. Ranganathan, J., Vennard, D., Waite, R., Duman, P., Lipinski, B., Searchinger, T., & GLOBAGRI WRR Model Authors. (2016). Shifting diets for a sustainable food future. In Creating a Sustainable Food Future (Installment 11; Working Paper). World Resources Institute.

5. Buzby, J. C., & Hyman, J. (2012). Total and per capita value of food loss in the United States. Food Policy, 37, 561–570.

6. Abdulla, M., Martin, R. C., Gooch, M., & Jovel, E. (2013). The importance of quantifying food waste in Canada. Journal of Agriculture, Food Systems, and Community Development, 3, 137–151.

7. Gustavsson, J., Cederberg, C., Sonesson, U., & Emanuelsson, A. (2011). The Methodology of the FAO Study: Global Food Losses and Food Waste—Extent, Causes and Prevention. FAO.

8. Enemark, P. S., Lavestekodødelighedtiår. (2015). [Note: Online source with available URL; ensure proper author/title and language corrections if needed]. Available online: http://www.seges.dk/Nyheder/lavestekodoedeligheditiaar.htm (accessed January 16, 2021).

University of Ghana http://ugspace.ug.edu.gh

9. Hartikainen, H., Kisman Pinolehto, M., Räikönen, R., & Kahiluoto, H. (n.d.). Food Waste in Primary Production (Finnish). Retrieved from http://jukuri.mtt.fi/handle/10024/485067 (accessed February 18, 2021).

10. Jaja, I. F., Mushonga, B., Geen, E., & Muchenje, V. (2018). Factors responsible for the post-slaughter loss of carcass and offal's in abattoirs in South Africa. Acta Tropica, 178, 303–310.

11. Falowo, A. B., Fayemi, P. O., & Muchenje, V. (2014). Natural antioxidants against lipid-protein oxidative deterioration in meat and meat products: A review. Food Research International, 64, 171–181.

12. Dora, M., Wesana, J., Gellynck, X., Seth, N., Dey, B., & De Steur, H. (2020). Importance of sustainable operations in food loss: Evidence from the Belgian food processing industry. Annals of Operations Research, 290, 47–72.

13. Kranert, M., Hafner, G., Barabosz, J., Schneider, F., Lebersorger, S., Scherhaufer, S., Schuller, H., & Leverenz, D. (2012). Determination of discarded food and proposals for a minimization of food wastage in Germany: Abridged version. University Stuttgart: Institute for Sanitary Engineering.

14. RASFF: The Rapid Alert System for Food and Feed. (2019). 2018 Annual Report. Health and Consumers Directorate-General of the European Commission: Luxembourg.

15. Bogataj, D., Hudoklin, D., Bogataj, M., Dimovski, V., & Colnar, S. (2020). Risk mitigation in a meat supply chain with options of redirection. Sustainability, 12, 8690.

16. Zhang, H., Hortal, M., Dobon, A., Bermudez, J. M., & Lara-Lledo, M. (2015). The effect of active packaging on minimizing food losses: Life cycle assessment (LCA) of essential oil component-enabled packaging for fresh beef. Packaging Technology and Science, 28, 761–774.

17. Henz, G. P., & Porpino, G. (2017). Food losses and waste: How Brazil is facing this global challenge? Horticultura Brasileira, 35, 472–482.

INTEGRI PROCEDAMUS

University of Ghana http://ugspace.ug.edu.gh

18. Eriksson, M., Strid, I., & Hansson, P. A. (2012). Food losses in six Swedish retail stores: Waste of fruit and vegetables in relation to quantities delivered. Resources, Conservation and Recycling, 68, 14–20.

19. Katajajuuri, J. M., Silvennoinen, K., Hartikainen, H., Heikkila, L., & Reinikainen, A. (2014). Food waste in the Finnish food chain. Journal of Cleaner Production, 73, 322–329.

20. Krajewski, K., Świątkowska, M., Łaba, S., & Szczepański, K. (2018). Losses and waste in meat supply chain, and the needs of product management and market communication. In SUM2018/4th Symposium on Urban Mining and Circular Economy (Proceedings). Bergamo, Italy: Available online: https://www.urbanmining.it/ (accessed February 18, 2021).

21. Magalhães, V. S. M., Ferreira, L. M. D. F., da Silva César, A., Bonfim, R. M., & Silva, C. (2021). Food loss and waste in the Brazilian beef supply chain: An empirical analysis. International Journal of Logistics Management, 32, 214–236.

22. Akhter, M. S., Khatun, H., Hashem, M. A., Rahman, M. M., & Khan, M. (2022). Effect of storage periods on the quality and shelf life of beef liver at refrigerated temperature. Meat Research, 2(2), 17. https://doi.org/10.55002/mr.2.2

23. Akhter, S., Rahman, M. M., Hossain, M. M., & Hashem, M. A. (2009). Effects of drying as a preservation technique on nutrient contents of beef. Journal of Bangladesh Agricultural University, 7, 63–68.

24. Akter, R., Hossain, M. A., Khan, M., Rahman, M. M., Azad, M. A. K., & Hashem, M. A. (2022). Formulation of value-added chicken meatballs by addition of Centella leaf (Centella asiatica) extracts. Meat Research, 2(2), Article.

25. Akter, H., Akhter, S., Rahman, S. M. E., Rahman, M. M., Hossain, M. M., Ra, C. S., Kim, J. M., & Oh, D. H. (2009). Effect of different preservation methods on physicochemical qualities of beef. Journal of Food Hygiene and Safety, 24(3), 217–225.

University of Ghana http://ugspace.ug.edu.gh

26. Alam, M. M., Hashem, M. A., Rahman, M. M., Hossain, M. M., Haque, M. R., Sobhan, Z., & Islam, M. S. (2011). Effect of heat stress on behavior, physiological and blood parameters of goat. Progress in Agriculture, 22, 37–45.

27. Al-Delaimy, K. S., & Ali, S. H. (1970). Antimicrobial action of vegetable extracts on the growth of pathogenic bacteria. Journal of Science and Food Agriculture, 21, 110–112.

28. Ali, M. S., Rahman, M. M., Habib, M., Kabir, M. H., Hashem, M. A., Azad, M. A. K., & Rahman, M. M. (2022). Quality of spent hen sausages incorporated with bee honey. Meat Research, 2(1), Article 9.

29. Anastasio, A., Mercogliano, R., Vollano, L., Pepe, T., & Cortesi, M. L. (2004). Levels of benzopyrene (BaP) in "Mozzarella di bufala Campana" cheese smoked according to different procedures. Journal of Agricultural and Food Chemistry, 52, 4452–4455.

30. Anifantaki, K., Metaxopoulos, J., Kammenou, M., Drosinos, E. H., & Vlassi, M. (2002). The effect of smoking, packaging and storage temperature on the bacterial greening of frankfurters caused by Leuconostoc mesenteroides subsp. mesenteroides. Italian Journal of Food Science, 14, 135–144.

31. Archer, D. L. (2002). Evidence that ingested nitrate and nitrite are beneficial to health. Journal of Food Protection, 65, 872–875. Arvanitoyannis, I. S. (2010). Consumer behavior toward irradiated food. In Irradiation of Food Commodities: Techniques, Applications, Detection, Legislation, Safety and Consumer Opinion.

32. Azad, M. A. K., Rahman, M. M., & Hashem, M. A. (2022). Meat microbiota: A conceptual review. Meat Research, 2(2), Article No. 20. https://doi.org/10.55002/mr.2.3.20

33. Azad, M. A. K., Kikusato, M., Zulkifli, I., Rahman, M. M., Ali, M. S., Hashem, M. A., & Toyomizu, M. (2021). Comparative study of certain antioxidants—electrolyzed reduced water, tocotrienol and vitamin E on heat-induced oxidative damage and performance in broilers. Meat Research, 1(1), Article 7.

University of Ghana http://ugspace.ug.edu.gh

34. Bachir, M. A., & Mehio, A. (2001). Irradiated luncheon meat: Microbiological, chemical and sensory characteristics during storage. Food Chemistry, 75, 169–175.

35. Bahk, J., Yousef, A. E., & Marth, E. H. (1990). Behavior of Listeria monocytogenes in the presence of selected spices. Lebensmittel-Wissenschaft & Technologie, 23, 66–69.

36. Billing, J., & Sherman, P. W. (1998). Antimicrobial functions of spices: Why some like it hot. Quarterly Reviews of Biology, 73, 134–142.

37. Bithi, M. A. A., Hossain, M. A., Rahman, S. M. E., Rahman, M. M., & Hashem, M. A. (2020). Sensory, nutritive, antioxidant and antimicrobial activity of telakucha (Coccnia cordifolia) leaves extract in broiler meatballs. Journal of Meat Science and Technology, 8(2), 23–31.

38. Boby, F., Hossain, M. A., Hossain, M. M., Rahman, M. M., Azad, M. A. K., & Hashem, M. A. (2021). Effect of long coriander leaf (Eryngium foetidum) extract as a natural antioxidant on chicken meatballs during freezing. SAARC Journal of Agriculture, 19(2), 271–272.

39. Sejidov, F. T., Mansoori, Y., & Goodarzi, N. (2005). Esterification reaction using solid heterogeneous acid catalysts under solvent-less condition. Journal of Molecular Catalysis A: Chemical, 240(1–2), 186–190.

40. Cheng, L. H., Karim, A. A., & Seow, C. C. (2006). Effects of water-glycerol and water-sorbitol interactions on the physical properties of Konjac Glucomannan films. Journal of Food Science, 71(2), E62–E67.

41. Bordes, P., Pollet, E., & Avérous, L. (2009). Nano-biocomposites: Biodegradable polyester/nanoclay systems. Prog Polymer Science, 34(2), 125–155.

42. Cuq, B., Gontard, N., Cuq, J., & Guilbert, S. (1997). Selected functional properties of fish myofibrillar protein-based films as affected by hydrophilic plasticizers. Journal of Agricultural and Food Chemistry, 45(3), 622–626.

INTEGRI PROCEDAMUS

University of Ghana http://ugspace.ug.edu.gh

43. Guilbert, S., Gontard, N., & Gorris, L. G. M. (1996). Prolongation of the shelf-life of perishable food products using biodegradable films and coatings. Food Science and Technology, 29(1–2), 10–17.

44. Debeaufort, F., Quezada-Gallo, J. A., & Voilley, A. (1998). Edible films and coatings: Tomorrow's packagings—a review. Critical Reviews in Food Science and Nutrition, 38(4), 299–313. Markarian, J. (2008). Biopolymers present new market opportunities for additives in packaging. Plastics Additives and Compounding, 10(3), 22–25.

45. Silva, M. A., Bierhalz, A. K. C., & Kieckbusch, T. G. (2009). Alginate and pectin composite films crosslinked with Ca2+ ions: Effect of the plasticizer concentration. Carbohydrate Polymers, 77(4), 736–742.

46. Karbowiak, T., Hervet, H., Léger, L., Champion, D., Debeaufort, F., & Voiley, A. (2006). Effect of plasticizers (water and glycerol) on the diffusion of a small molecule in iota-carrageenan biopolymer films for edible coating application. Biomacromolecules, 7(6), 2011–2009.

47. Azizah, F., et al. (2023). Polymers, 15(9), 2075.

48. Bharti, S., Kumar, V., Sharma, K., Nagpal, K., & Bera, T. (2022). Starch-based edible film functionalized with Carum carvi L. essential oil: Antimicrobial, rheological, physic-mechanical and optical attributes. Journal of Food Science and Technology, 59, 456–466.

49. Atarés, L., & Chiralt, A. (2016). Essential oils as additives in biodegradable films and coatings for active food packaging. Trends in Food Science & Technology, 48, 51–62.

50. Sun, L., Sun, J., Chen, L., Niu, P., Yang, X., & Guo, Y. (2017). Preparation and characterization of chitosan film incorporated with thinned young apple polyphenols as an active packaging material. Carbohydrate Polymers, 163, 81–91.

University of Ghana http://ugspace.ug.edu.gh

51. Bhatia, S., Kumar, V., Sharma, K., Nagpal, K., & Bera, T. (2014). Significance of algal polymer in designing amphotericin B nanoparticles. Science of the Total Environment (Sci. World J. 2014). Note: adjust journal title if needed.

52. Maitlo, G. M., Ali, I., et al. (2022). Plastic waste recycling, applications, and future prospects for a sustainable environment. Sustainability, 14(18), Article 11637. https://doi.org/10.3390/su141811637

53. Yang, Lan; Wang, X.-C.; Dai, M.; et al. (2021). Shifting from fossil-based economy to bio-based economy: Status quo, challenges, and prospects. Energy, 228. https://doi.org/10.1016/j.energy.2021.120533

54. Ghoneim, M. M. E. (2018). Meat packaging: Types, materials, and preservation techniques. Food Science & Nutrition, 6(7), 1813–1826.

55. Kumar, R., et al. (2019). Packaging materials for meat and meat products. In Meat Processing and Preservation (pp. 45–70). Springer.

56. Mahmoud, N. A., Yasien, A. M., et al. (2022). Impacts of biodegradable plastic on the environment. In A. Handbook of Biodegradable Materials (pp. 1–27). Springer.

57. Khodaei, N., & Romani, S. (2016). Analyzing the physical properties of beeswax/starch films using response surface methodology. Journal of Polymers and the Environment.

58. Oliveira, J. C., et al. (2018). Characterization of wax-starch films with potential use as an alternative for food conservation. LWT - Food Science and Technology.

59. Robertson, G. L. (2004). Food Packaging: Principles and Practice. CRC Press.

60. Lim, J. H., et al. (2015). Preparation and characterization of composites based on polylactic acid and beeswax with improved water vapor barrier properties. Journal of Food Science, 80(11), E2471–E2477.

INTEGRI PROCEDAMUS

University of Ghana http://ugspace.ug.edu.gh

61. Ruban, S. W. (2009). Biobased packaging – Application in meat industry. Veterinary World, 2(2), 79–82.

62. Baldwin, E. A., Nisperos, N. O., & Baker, R. A. (1995). Use of edible coatings to preserve quality of processed products. Critical Reviews in Food Science and Nutrition, 35, 509–522.

63. Cha, D. S., & Chinnan, M. S. (2004). Biopolymer-based antimicrobial packaging: A review. Critical Reviews in Food Science and Nutrition, 44, 223–227.

64. Xu, L., Niu, M., Fang, Z., & Zhang, R. (2015). Studies on corn starch–beeswax blend films by tuning beeswax contents. Carbohydrate Polymers, 134, 96–101.

65. Peelman, N., Ragaert, P., De Meulenaer, B., Adons, D., & Cardon, L. (2015). Mechanical and barrier properties of thermoplastic starch films derived from different origins supplemented with beeswax or montan wax. Journal of Applied Polymer Science, 132(5), 41460.

66. Sothornvit, R., & Krochta, J. (2001). Plasticizing and water-barrier properties of beeswax-corn starch films. Journal of Food Science, 66(7), 1036–1041.

67. Mao, L., Gao, Y., Cao, T., Li, S., & Zhang, Y. (2017). The effects of beeswax on the tensile and water vapor permeability properties of sodium alginate/corn starch composite films. Food Packaging and Shelf Life, 11, 136–144.

68. Si, W., Chen, Y., Zhang, J., Chen, Z., Chung, H. Y., & Yan, R. (2018). Antioxidant activities of ginger extract and its constituents toward lipids. Food Chemistry, 239, 1117–1125.

69. Tarfaoui, M., Pizzi, A., & Cherki, A. (2022). Antioxidant activity of ginger extracts obtained from different solvents: DPPH assay and ferric reducing power. Journal of Food Measurement and Characterization, 16(2), 917–928.

University of Ghana http://ugspace.ug.edu.gh

70. Sethi, J., Yadav, M., Sood, S., Dahiya, K., Singh, V., & Bhattacharya, A. (2016). Pharmacognostic, phyto-chemical investigation and antioxidant potential of Ginger extract (Zingiber officinale Roscoe). Bulletin of Faculty of Pharmacy, Cairo University, 54(1), 135–143.

71. Wang, Y., Wang, Y., Pang, L., Xu, L., Zhao, H., & Li, Y. (2023). Antioxidant activity of ginger and its relationship with phenolic components. LWT, 149, 112478.

72. Redfearn, E., Warren, W., & Goddard, L. (2023). Environmental factors affecting food preservation. In Food Safety Management (pp. 99–115). John Wiley & Sons.

73. Esmaeili, M., Pournamdari, M., Ghelichpour, M., Fatemi, S. M. R., Shahriari Moghadam, M., Ghazanfari Moghaddam, A., & Jalali, S. M. A. (2021). Chemical food safety issues: Pesticides, heavy metals, and microbial toxins. In Handbook of Environmental Materials Management (pp. 323–341). Springer.

74. Lawal, S. O., Osho, I. B., Oloyede, O. I., & Odeyemi, M. O. (2023). Foodborne pathogens and their associated diseases. In Food Safety and Preservation (pp. 85–105). John Wiley & Sons.

75. Caldeira, C., De Laurentiis, V., Corrado, S., Van Holsteijn, F., & Sala, S. (2019). Quantification of food waste per product group along the food supply chain in the European Union: A mass flow analysis. Resources, Conservation and Recycling, 149, 479–488.

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