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Impact of Selected Essential Oils on the Shelf Life and Quality of Packaged Strawberries and Dates during Storage

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Dedications

I dedicate this work, the fruit of effort and perseverance:

To my dear parents,

For their unconditional love, their prayers, their silent sacrifices,

and their unwavering support at every stage of my life.

This work belongs to you above all.

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List of Abbreviations

Art 1, Art 2: *Artemisia herba-alba* treatment 1, *Artemisia herba-alba* treatment 2

B_1 , B_2 , B_6 : Vitamin B1 (Thiamine), Vitamin B2 (Riboflavin), Vitamin B6 (Pyridoxine)

D1, D5, D10, D15, D25, D30: Day 1, Day 5, Day 10, Day 15, Day 25, Day 30 respectively

EO: Essential Oil

EOs: Essential Oils

EU: European Union

Fen 1, Fen 2: *Foeniculum vulgare* (fennel) treatment 1, *Foeniculum vulgare* (fennel) treatment 2

FOEO: *Foeniculum vulgare* Essential Oil

Hue°: Hue angle (in color space)

L*: Lightness (in color space)

LDPE: Low-Density Polyethylene

PET: Polyethylene Terephthalate

PPO: polyphenol oxidase

RH: Relative Humidity

Ros 1, Ros 2: *Rosmarinus officinalis* (rosemary) treatment 1, *Rosmarinus officinalis* (rosemary) treatment 2

T0, T1, T2, T3, T4, T5, T6 : Time point 0, Time point 1, …, Time point 6

Thyme 1, Thyme 2: *Thymus vulgaris* (thyme) treatment 1, *Thymus vulgaris* (thyme) treatment 2

Trans-anethole: Major aromatic compound in fennel

ΔE: overall color difference (Delta E)

MEO: Major Essential Oil

SLN: Solid Lipid Nanoparticles

Introduction

Introduction

Fresh fruits are among the most perishable agricultural commodities due to their high-water content and sensitivity to environmental conditions and microbial activity. In Algeria, strawberries (*Fragaria × ananassa*) and dates (*Phoenix dactylifera* L.) are two key fruits with significant nutritional and economic value. However, both face critical postharvest preservation challenges. Strawberries deteriorate rapidly because of their delicate skin, high respiration rate, and susceptibility to fungal pathogens such as *Botrytis cinerea* (gray mold) and *Rhizopus stolonifer* (soft rot), along with physiological changes like water loss and softening, leading to substantial economic losses (Quarshi *et al*., 2023; Ladika *et al*., 2024).

Dates (*Phoenix dactylifera* L.) possess a longer shelf life than strawberries due to their low water activity, especially at the Tamar (fully ripe) stage. However, they remain vulnerable to various storage-related problems, including physical and biochemical deterioration such as darkening of the skin, softening of texture, and wrinkling. In addition, high humidity conditions can promote fungal infections by *Aspergillus* spp. and *Penicillium* spp., while insect infestations by *Carpophilus hemipterus* and *Plodia interpunctella* may further threaten their safety and commercial value during storage (Alqahtan *et al*., 2025).

In light of these issues and increasing demand for natural preservation methods,Essential oils from aromatic plants have gained attention as natural biopreservatives. Rich in compounds like terpenes and phenols, they offer strong antimicrobial and antioxidant effects. Their use promotes sustainable agriculture and helps reduce postharvest losses in fresh fruits (Kulkarni *et al*., 2008; Al-jaafreh, 2024; Noshirvani, 2024).

This study evaluated four essential oils commonly found in Algeria:

- Fennel (*Foeniculum vulgare*) oil, known for its antifungal properties;
- Rosemary (*Rosmarinus officinalis*) oil, rich in antioxidant compounds;
- Thyme (*Thymus vulgaris*) oil, notable for its antibacterial and antiviral efficacy;
- Artemisia (*Artemisia herba-alba*) oil, notable for its antimicrobial efficacy.

The essential oils used in this study were chosen based on their traditional roles in food preservation, accessibility in Algerian markets, and documented bioactive properties. Their application followed a practical method suitable for small-scale vendors and consumers, involving vapor diffusion in sealed containers. Strawberries were stored at 4 ± 1 °C, while dates were preserved at ambient temperature (22 ± 2 °C) under controlled humidity conditions.

Research Objectives

- To assess the antimicrobial efficacy of these essential oils in reducing spoilage of strawberries and dates.
- To compare the specific impact of each oil on pathogenic fungi and bacteria known to affect these fruits during postharvest storage.
- To determine the optimal local conditions for applying these oils in storage systems, considering the packaging formats and temperature–humidity regimes common in Algerian markets.

This project aims to enhance agricultural product preservation using Algeria's native plants, promoting local botanical heritage and sustainable methods. It focuses on preserving fruit safety, nutrition, and marketability while reducing reliance on refrigeration and synthetic preservatives. The study proposes a practical, scalable model suited to real market conditions that maintains fruit quality from harvest to consumption.

This thesis is structured into four main chapters:

- Chapter 1 presents the general characteristics, economic importance, nutritional value, and postharvest issues of dates and strawberries, with emphasis on their storage conditions and microbiological vulnerabilities.
- Chapter 2 explores the classification, bioactive composition, and medicinal properties of selected aromatic plants, with a focus on their essential oil yield and potential in postharvest preservation.
- Chapter 3 details the experimental methodology, including field observations, essential oil extraction, treatment application, and monitoring techniques.
- Chapter 4 presents the results and discussion based on visual and microbial observations during storage, highlighting the comparative effectiveness of each essential oil.

This project comprehensively evaluates essential oils as natural preservatives, integrating practical and scientific approaches. It aims to contribute to agricultural preservation by utilizing local plant resources, emphasizing the importance of botanical heritage and sustainable methods to maintain the safety, quality, and marketability of Algerian products.

Bibliographic Part

Chapter 1
Dates and Strawberries

I .1. Importance of Dates and Strawberries in Algeria

Algeria's date palm sector spans over 169,380 ha with 18 million palms, producing 1.18 million tons in 2021 is 12% of global output. Despite high production, exports remain low (~5%) due to weak marketing infrastructure. Deglet Noor dominates production, supporting oasis economies and desert stability (Mihi *et al*., 2019; Benmehaia *et al*., 2024; Germplasm *et al*., 2023).

Strawberry cultivation in northern Algeria is expanding thanks to modern techniques and elite cultivars.Tipaza's 2022 survey found Fortuna as the leading variety, matching EU export standards. Jijel's surface reached ≈661 ha by 2023, enhancing fruit quality, employment, and exports (Naili and Mayache, 2025; Bouchefra *et al*., 2023). *Fragaria* × *ananassa* Duch, is the scientific name of the cultivated strawberry "Fragaria" from Latin *fraga* (fragrant strawberry), "× ananassa" indicating its hybrid origin and pineapple like aroma, and "Duch." honoring botanist Duchesne who first described it.

I.2. Nutritional Value and Health Benefits

Dates (*Phoenix dactylifera* L.) dates are energy-rich, offering 265–287 kcal/100 g, with high carbohydrate content (mainly glucose and fructose). They contain B-vitamins (B_1 , B_2 , B_6) and minerals like potassium, magnesium, and calcium that aid digestion and heart function. Their phenolic acids provide antioxidant and anti-inflammatory properties, reducing chronic disease risk (Halabi *et al*., 2022).

Strawberries (*Fragaria* × *ananassa* Duch.) Fresh strawberries are low in calories (32 kcal/100 g) and rich in carbohydrates, fiber, and vitamin C. They supply folate, potassium, and manganese, promoting immunity and cardiovascular health. Vitamin C, anthocyanins, and fiber enhance antioxidant defense, glycemic control, and gut health. (Newerli-Guz *et al*., 2023 ; Raffaelli *et al*., 2025 ; Ladika *et al*., 2024).

I.3. Plant Classification and Varieties

Dates (*Phoenix dactylifera* L.) are classified within the Arecaceae family and the Phoenix genus. Algeria is home to a rich diversity of date palm cultivars, with over 139 identified in regions such as Ghardaïa. Among these, 'Deglet Nour' stands out as the most prominent variety, renowned for its translucent appearance, soft texture, and sweet taste. Other notable cultivars include 'Ghars' and 'Hamraya', which are utilized in various traditional Algerian food products (Achour *et al*., 2022; Acourene *et al*., 2008; BENAMOR *et al*., 2024).

Strawberries belong to the Rosaceae family and the Fragaria genus. In Algeria, the cultivated strawberry is primarily the hybrid species *Fragaria × ananassa* Duch., resulting from a cross between *Fragaria virginiana* and *Fragaria chiloensis*. The 'Camarosa' variety is particularly popular in Algeria due to its high productivity and resistance to diseases such as *Botrytis cinerea*. Other prevalent cultivars include 'Savana', 'Sabrina', and 'Fortuna', which have been studied for their physicochemical and antioxidant properties in eastern Algeria (Bouchefra *et al*., 2023; Hummer *et al*., 2010).

I .4. Storage Conditions of Strawberries and Dates

I .4.1. Strawberry Storage Conditions

Strawberries (*Fragaria × ananassa* Duch.) require rapid cooling to 0–1 °C immediately after harvest to minimize respiration and microbial growth; if held at 5 °C, they can retain acceptable firmness and appearance for up to seven days, though 0 °C is most effective at suppressing decay (Azam *et al*., 2019; Ayala- Zavala *et al*., 2004).

Maintaining a relative humidity of 90–95 % is also crucial to prevent excessive water loss and wilting, as lower humidity accelerates shriveling and loss of turgor, thereby reducing shelf life (Azam *et al*., 2019; Khalid *et al*., 2020) Their natural acidic pH (approximately 3.3–3.9) offers some defense against pathogens, but *Botrytis cinerea* (gray mold) remains a major threat under suboptimal temperature or humidity control (Ayala- Zavala *et al*., 2004; Gil- Giraldo *et al*., 2018) Under these optimal refrigerated conditions, marketable life generally spans five to seven days; improper handling such as delayed cooling, physical bruising, or inadequate humidity can shorten this window to only a few days (Azam *et al*., 2019).

I .4.2. Packaging of Strawberries in the Local Market

Strawberries destined for urban retail are commonly packed in ventilated PET clamshells (250–500 g) with perforations that enable airflow, maintaining internal humidity above 90 % to reduce weight loss and wilting (Khalid *et al*., 2020; Cagnon *et al*., 2013).

In wholesale settings, cardboard trays lined with thin, perforated polyethylene or polypropylene film (1–2 kg capacity) offer a cost-effective option by allowing some gas exchange to slow respiration under ambient or refrigerated conditions (Cagnon *et al*., 2013) For small-scale, quick sales at weekly markets or roadside stands, small perforated LDPE bags (250–500 g, 25–50 µm thick) are used; these maintain high internal humidity but provide minimal cushioning, limiting shelf life to 2–3 days at room temperature (Sanz *et al*., 1999).

I .4.3. Dates Storage Conditions

Dates are typically stored at medium to low temperatures either in traditional home settings or in refrigerated rooms to preserve quality in hot, arid climates (Jemni *et al.*, 2019; Nabily *et al.*, 2020).

Semi-dry varieties such as Deglet Nour achieve optimal preservation at 0 °C for 6–12 months; for storage beyond this period (up to 10 months or longer), freezing at –20 °C effectively retains their physicochemical and sensory attributes after thawing (Jemni *et al.*, 2019).

Relative humidity should be maintained between 65 % and 75 % to minimize weight loss and prevent fungal growth. If lower humidity (50 %–65 %) conditions prevail, sealing dates in moisture-barrier, airtight packaging (e.g., polyethylene film) can extend shelf life beyond 12 months without significant changes in color, aroma, or texture (Jemni *et al.*, 2019; Nabily *et al.*, 2020) Dates exhibit a pH of 5.3–6.3, a non-acidic range that does not strongly inhibit microbial activity, making airtight, low-oxygen environments critical for reducing spoilage.

I .4.4. Packaging of Dates in the Local Market

Dates in local markets are packed in three main formats suited to different scales and contexts. Small reusable plastic boxes (250 g–1 kg) are common in urban retail outlets and during festive seasons such as Ramadan because they allow consumers to inspect fruit quality and simplify transport, For larger quantities, sturdy corrugated cardboard cartons (1 kg–5 kg) protect dry cultivars like Deglet Nour which accounts for nearly half of national production during transit from processing sites to marketplaces; these boxes are widely used in both local and wholesale settings (Wang *et al.*, 2022; Dharaiya *et al.*).

In weekly souks and direct sale events, producers often package dates in food- grade polyethylene bags (500 g–2 kg), either heat- sealed or manually tied; while these bags offer less mechanical protection than boxes, they reduce packaging costs and, when properly sealed, limit moisture exchange (Wang *et al.*, 2022).

I.5.Microorganisms and Insect Pests Affecting Dates and Strawberries

I.5.1. Strawberries

I.5.1.1. Fungi

The most destructive postharvest fungal pathogens on refrigerated strawberries are *Botrytis cinerea* (gray mold) and soft rot fungi such as *Rhizopus stolonifer* and species of *Mucor* (Rajestary *et al.*, 2023; Rhouma *et al.*, 2022).

B. *cinerea* invades fruit tissues through microscopic wounds when relative humidity exceeds 90 %, producing characteristic gray sporulation and causing rapid tissue maceration

(Rajestary *et al.*, 2023). Under optimal handling, cold storage at 0–1 °C combined with good ventilation can reduce gray mold incidence by over 60 %, as the low temperature slows both spore germination and hyphal growth (Rhouma *et al.*, 2022).

Rhizopus stolonifer and *Mucor* species similarly penetrate wounded tissue, producing soft rot within 2–3 days under humid (≥95 % RH) and warm (>20 °C) conditions. Maintaining storage at 0–1 °C and RH around 90–95 % while ensuring adequate airflow suppresses these soft- rot fungi, extending postharvest life to 5–7 days under refrigeration (Rajestary *et al.*, 2023; Petrasch *et al.*, 2019).

I.5.1.2. Bacteria

Pectinolytic bacteria such as *Pseudomonas fluorescens* and *Pectobacterium carotovorum* invade strawberries through injuries and secrete enzymes that break down pectin, leading to soft rot and fluid leakage (Radke *et al.*, 2024). When temperatures exceed 5 °C, Pseudomonas populations can double within hours, worsening spoilage and allowing fungi to colonize damaged tissue, to limit bacterial proliferation, strawberries should be cooled quickly to 0–1 °C and handled gently; this suppresses growth and extends shelf life up to 7 days under refrigeration (Chahrazade *et al.*, 2020; Radke *et al.*, 2024).

I.5.1.3. Insect Pests

Strawberries are attacked by major pests such as greenhouse whitefly (*Trialeurodes vaporariorum*), aphids (*Myzus persicae, Aphis gossypii*), and western flower thrips (*Frankliniella occidentalis*) (Byrne and Bellows, 1991; Haddad *et al.*, 2019).

Trialeurodes vaporariorum feeds on leaf and fruit sap, excreting honeydew that promotes sooty mold on berries. High whitefly densities can reduce plant vigor and yield by over 30% (Byrne and Bellows, 1991; Ullah and Lim, 2016)

Aphids such as *Myzus persicae* cause fruit deformation and transmit viruses like Strawberry mottle virus; in Algerian greenhouses, populations peak in spring with more than 25 aphids per trifoliate leaf (Haddad *et al.*, 2019).

Western flower thrips feed on fruit surfaces, causing bronzing that affects appearance and marketability; moderate infestations (10–15 thrips per 100 flowers) can downgrade up to 25% of packed trays (Salas-Araiza *et al.*, 2020).

I.5.2. Dates

I.5.2.1. Fungi

During storage, filamentous fungi commonly colonize dates through skin imperfections (cracks or harvest wounds). Genera such as *Aspergillus*, *Penicillium*, *Alternaria*, and *Cladosporium* frequently dominate the mycobiome of stored fruits; metagenomic analyses of late-harvest ("Tamer") date peels report particularly high abundance of *Aspergillus* and Penicillium, with Alternaria and Cladosporium more prevalent at earlier ripening stages (e.g., "Hababauk" and "Khalal") (Piombo *et al*., 2020).

Aspergillus niger thrives when relative humidity exceeds 70 %, producing black mold and potential ochratoxin (OTA) precursors, which compromise both safety and sensory quality (González-Curbelo and Kabak, 2023). Under excess moisture, *Penicillium* species generate blue-green spores, leading to fruit softening, off-odors, and secondary fungal invasion; Alternaria and Cladosporium may further accelerate spoilage by colonizing early ripening fruit tissues. Effective fungal control in storage requires maintaining RH below 65 % and prompt cooling immediately after harvest (Piombo *et al*., 2020; González-Curbelo and Kabak, 2023).

I.5.1.2. Bacteria

Psychrotrophic bacteria like *Pseudomonas* (an obligate aerobic, Gram-negative rod capable of growth between 2 °C and 35 °C) cause soft rot and leakage in bruised or contaminated dates by producing proteolytic and lipolytic enzymes (Raposo *et al*., 2016).

Pectobacterium spp. release pectinases that degrade cell walls, leading to pulp collapse and exudate, often enabling secondary fungal infections (Radke *et al*., 2024).

I.5.1.3. Insect Pests

The sap beetle *Carpophilus hemipterus* (Nitidulidae) is a key pest of stored dates; adults and larvae bore into the pulp, causing weight loss and enabling microbial entry. Its tolerance to high temperatures (~40 °C) allows infestation during both field and storage phases, often introducing aflatoxin-producing fungi (Rosi *et al*., 2019).

P. *interpunctella* larvae feed on date pulp and leave contaminating frass, damaging large stocks. Cold storage (0–1 °C) reduces survival by up to 80 (Athanassiou *et al*., 2018; Mbata and Toews, 2021).

Chapter 2
Aromatic Plants

II .1. Definition of Aromatic Plants and Their Importance

Aromatic plants produce volatile essential oils compounds such as terpenes, phenols, aldehydes, and ketones that give them characteristic scents and bioactivity. These oils, extracted from leaves, flowers, peels, or roots, have long been used in food, pharmaceutical, and cosmetic applications due to their flavoring, medicinal, and nutritional properties. Because of their proven antimicrobial and antifungal effects, essential oils serve as natural, generally recognized as safe (GRAS) alternatives to synthetic preservatives for extending the shelf life of perishable foods like dates and strawberries (Christaki *et al*., 2012).

II .2. Botanical Families and Scientific Classification of Aromatic Plants

In Algeria, aromatic plants like rosemary, thyme, fennel, and white Artemisia are classified into families such as Lamiaceae, Apiaceae, and Asteraceae based on morphology and essential oil profiles. These classifications aid in understanding their biodiversity, growth, and traditional uses. Algerian research highlights a rich diversity of these plants across ecological zones (Benchohra *et al*., 2025).

II.2.1. Main Botanical Families of Aromatic Plants

II.2.1.1. The Lamiaceae Family

The Lamiaceae, often called the mint family, includes aromatic herbs and shrubs distinguished by square stems, opposite leaves, and glandular hairs that create volatile, terpenoid-rich oils. In Algeria, *Thymus vulgaris* (thyme) and *Rosmarinus officinalis* (rosemary) are extensively grown.

Thyme (*Thymus vulgaris*) oil contains thymol, γ-terpinene, and p-cymene, offering strong antimicrobial and antioxidant effects. These compounds help prevent fungal spoilage and maintain strawberry firmness during cold storage. Rosemary (*Rosmarinus officinalis*) oil, rich in 1,8-cineole and camphor, is valued as a culinary herb and for its preservative properties. It helps slow discoloration and microbial spoilage in fresh produce (Djeddi *et al*., 2007).

II.2.1.2. The Apiaceae Family

The Apiaceae, or carrot family, includes herbaceous plants with hollow stems, compound umbels, and oil-storing vittae in the fruits. *Foeniculum vulgare* (fennel) is the principal species used for essential-oil extraction in Algeria.

Fennel (*Foeniculum vulgare*) oil, high in anethole, acts as a carminative with mild antimicrobial effects. It can reduce early spoilage but is less effective than Lamiaceae oils, making it better suited for short-term or complementary preservation (Fernandez and Crowell, 2021).

II.2.1.3. The Asteraceae Family

The Asteraceae, or daisy family, is one of the largest plant families, featuring composite flower heads and diverse secondary metabolites such as sesquiterpene lactones. *Artemisia herba-alba* (white Artemisia) grows wild in Algeria's arid zones and yields oil containing camphor, α- and β-thujone.

White Artemisia (*Artemisia herba-alba*) oil of Artemisia herba-alba shows antimicrobial activity against spoilage fungi and bacteria. her preservative effect is shorter that making it ideal for quick, short-term protection rather than long-term storage. (Bertella *et al*., 2018).

II.2.2. Importance of Scientific Classification in the Study of Aromatic Plants

Scientific classification is essential for understanding the chemical and biological traits of aromatic plants, enabling their effective medical and industrial use. It also aids biodiversity conservation by identifying endangered species. In Algeria, this supports sustainable development of aromatic and medicinal plants across industries (Benchohra *et al*., 2025).

II.3. Medicinal Properties and Health Benefits

Thyme (*Thymus vulgaris*) essential oil contains thymol and carvacrol, showing strong antimicrobial effects against bacteria like *Staphylococcus aureus* and *Pseudomonas aeruginosa*, plus spoilage fungi. It is traditionally used for bronchial infections by inhalation and for treating skin lesions topically (Borugă *et al*., 2014).

Artemisia (*Artemisia herba-alba*) oil, rich in camphor, α- and β-thujone, exhibits antibacterial and immunomodulatory effects by enhancing macrophage activity and regulating cytokines. These properties support its traditional use for digestive health and immune system boosting (Abu-Darwish *et al*., 2015).

Rosemary (*Rosmarinus officinalis*) essential oil, rich in carnosic and rosmarinic acids, has strong antioxidant and anti-inflammatory effects. It effectively scavenges free radicals and inhibits protein denaturation *in vitro*, while reducing inflammation in vivo, supporting its use for arthritis and circulatory issues (Khalil and Hassan, 2024)

Fennel (*Foeniculum vulgare*) oil, rich in trans-anethole, acts as a carminative and spasmolytic. Clinical studies show oral fennel oil improves gastrointestinal motility, reduces bloating, and alleviates dyspeptic pain (Rather *et al*., 2016).

II.4. The Yield of Essential Oils from Aromatic Plants

As shown in Table 1, the essential-oil yields of selected aromatic plants native to Algeria, together with their principal bioactive constituents and their primary applications in medicine and food preservation, are summarized. These oils primarily obtained via hydrodistillation contain compounds that serve crucial roles in therapeutic practices and postharvest treatment strategies (Jordán *et al*., 2010; Belhattab *et al*., 2014).

Table 1: Yield of Essential Oils from Selected Algerian Aromatic Plants

Plant Species	Essential Oil Yield (%)	Major Bioactive Compounds	Primary Uses
Rosemary (*Rosmarinus officinalis*)	1.36–2.16	Camphor, 1,8-Eucalyptol	Antioxidant, anti-inflammatory, pain relief (Jordán *et al*., 2010)
Fennel (*Foeniculum vulgare*)	1.0–2.5	Anethole, Fenchone	Digestive aid, carminative, antimicrobial (Zoubiri *et al*., 2014)
Thyme (*Thymus vulgaris*)	1.58	Thymol, Carvacrol	Antimicrobial,antifungal, antiseptic (Bouguerra *et al*., 2017)
Artemisia (*Artemisia herba-alba*)	0.20–0.90	1,8-Cineole, Camphor	Digestive, immune support, anti-parasitic (Belhattab *et al*., 2014)

II.5. Antimicrobial and Preservative Role of Essential Oils in the Postharvest Quality of Dates and Strawberries

Essential oils (EOs) from medicinal and aromatic plants are valued for their antimicrobial and antioxidant properties in food preservation. Rich in terpenoids and phenolics, they help reduce microbial spoilage and delay deterioration in fruits like dates and strawberries. Oils from rosemary, thyme, fennel, and Artemisia herba-alba are especially effective against various pathogens. These natural treatments offer promising alternatives to synthetic preservatives. Their use enhances shelf life and food safety in postharvest management (Esmaeili *et al*., 2022)

II.5.1. The Effect of Aromatic Plants on Bacteria and Fungi in Dates and Strawberries

The high moisture content of strawberries and the sugar rich matrix of dates provide favorable conditions for microbial proliferation during postharvest storage. Essential oils present a natural, residue free solution with antimicrobial mechanisms including disruption of microbial membranes, interference with enzymatic activity, and inhibition of biofilm formation. Their antifungal and antibacterial activities make them potential candidates for integrated fruit preservation strategies (Kumar *et al*., 2023)

II.5.1.1. Effect of Essential Oils on Bacteria

Numerous studies have demonstrated that essential oils from R. officinalis, T. vulgaris, and F. vulgare exhibit strong bacteriostatic and bactericidal properties. These oils are effective against both Gram-positive and Gram-negative bacteria, including *Escherichia coli*, *Salmonella enterica*, and Listeria monocytogenes, which are often implicated in fruit contamination. The major active constituents such as carvacrol, thymol, and 1,8-cineole are responsible for disrupting the structural integrity of bacterial membranes, leading to leakage of intracellular content and cell death (Joshi *et al*., 2011)

II.5.1.2. Effect of Essential Oils on Fungi

The antifungal potential of essential oils has been confirmed against several postharvest pathogens such as *Botrytis cinerea*, *Aspergillus flavus*, *Penicillium* spp., and *Fusarium* spp. Oils derived from A. herba-alba and fennel exhibit fungistatic activity by altering fungal cell wall synthesis, disrupting ergosterol production, and impairing spore germination. Such effects are essential in managing grey mold in strawberries and aflatoxin producing fungi in dates (Jobling, 2000)

II.5.2. Effect of Aromatic Oils on Removing Impurities in Dates and Strawberries

Apart from their antimicrobial roles, essential oils also contribute to fruit surface decontamination by reducing residues of pesticides, dust, and environmental particulates. Their application as natural sanitizers improve the hygienic quality of fruits without compromising their sensory attributes. Compounds such as rosmarinic acid and thymol function as both antioxidants and cleansing agents, enhancing the visual and microbiological quality of treated produce (Svoboda *et al*., 2005)

II.5.3. Application of Essential Oils in Preserving Strawberries and Dates

The practical application of essential oils in postharvest handling includes direct surface application, incorporation into coatings, or diffusion into storage atmospheres. When used at optimal concentrations, essential oils effectively reduce microbial proliferation without inducing phytotoxic effects. Their inclusion in postharvest protocols supports the development of sustainable, chemical-free preservation systems (Khan *et al*., 2023)

Experimental Part

Chapter 3
Materials and Methods

III.1. Field Investigation Methodology: Packaging and Storage Practices for Strawberries and Dates in Biskra

To gather qualitative field data on the postharvest handling of strawberries and dates, a field investigation was conducted on February 12, 2025, targeting multiple retail sites across Biskra city. The objective was to document the packaging types, handling techniques, and storage conditions employed by local fruit vendors. The survey was structured into two distinct parts, each focusing on a specific fruit and retail context.

III.1.1. Procedure for Investigating Strawberry Retail Practices

The first part of the investigation was carried out at the Zgag Ben Ramdhan vegetable market, a central hub for fresh produce in Biskra. A total of eight strawberry vendors were approached and interviewed.

The methodology included

- On site visits during active sales hours to directly observe strawberry display, packaging formats, and ambient conditions.
- Semi structured interviews conducted with vendors to obtain detailed descriptions of:
    - Product sourcing (wholesalers or producers)
    - Repackaging practices for retail
    - Typical storage durations and daily turnover routines
    - Perceived factors influencing fruit deterioration
- Documentation of packaging materials used at the point of sale (e.g., plastic containers, cardboard trays)

No physical samples were taken, but visual assessments and vendor-reported practices were noted for comparison and synthesis.

III.1.2. Procedure for Investigating Date Retail Practices

The second phase of the fieldwork involved visiting six date selling shops located across Biskra city.

The procedure included

- In-store observations focusing on packaging forms, display methods, and storage environments (refrigerated or ambient)

- Interviews with date vendors, some of whom had academic or agricultural backgrounds, to collect qualitative data on:
    - Common packaging types used in the local market
    - Storage infrastructure and temperature control methods
    - Shelf-life management strategies
    - Types and sources of date varieties sold
- Collection of photographic documentation (where permitted) of packaging and display setups

Both phases of the investigation were designed to obtain a realistic picture of postharvest practices in uncontrolled market environments, serving as a foundation for evaluating the potential impact of natural preservation interventions such as essential oils.

III.2. Analysis of Packaging Types and Formats Used

The methodology for analyzing packaging types and formats used for strawberries and dates in local markets in Biskra involved a systematic approach to identifying and categorizing the packaging methods in use. The process was designed to collect detailed information on the various packaging options and their relevance to product preservation, convenience, and presentation.

III.2.1. Packaging Formats for Strawberries

The method for analyzing strawberry packaging formats consisted of the following steps:

1. Market Observation

Field observations were conducted in local markets to identify the packaging methods commonly used for strawberries. Different retail outlets, including small vendors and larger stores, were visited to observe the packaging practices in real-world settings.

2. Vendor Interviews

Interviews were carried out with strawberry vendors to gather insights into the reasoning behind the choice of packaging formats. Vendors were asked about their experiences with various packaging options, including their perceived advantages and challenges.

3. Packaging Material Identification

The analysis focused on identifying the materials used in the packaging, such as plastic, cardboard, and other alternatives. The types of containers and bags were categorized based on their characteristics, including ventilation, transparency, and durability.

4. Shelf Life and Storage Practices Assessment

The study examined how packaging formats influenced the shelf life and storage practices for strawberries. This involved observing how strawberries were stored by vendors, whether refrigerated or at ambient temperature, and how this affected their turnover rate.

5. Market Survey

A survey was conducted to determine consumer preferences regarding strawberry packaging. This survey gathered feedback on factors such as ease of handling, attractiveness, and perceived freshness of the product in different packaging formats.

III.2.2. Packaging Formats for Dates

The method for analyzing date packaging formats followed a similar structure:

1. Market Observation

A detailed survey of the local markets was conducted to observe the various packaging formats used for dates. This involved recording the packaging types across different vendors and noting any patterns or variations in packaging practices.

2. Vendor Interviews

Interviews with date vendors were carried out to understand their packaging choices. Vendors were asked about their selection of packaging materials, the challenges they face in maintaining the quality of dates, and their storage practices.

3. Material Classification

The study categorized the materials used for date packaging, including cardboard, plastic, paper, and transparent wraps. The packaging types were classified based on their protective qualities, stackability, and suitability for preserving date quality.

4. Storage Method Evaluation

The research examined how the choice of packaging affected storage practices. This involved identifying whether dates were stored in specialized refrigeration units or at ambient temperature, and the methods used to manage moisture and prevent spoilage.

5. Consumer Preferences and Feedback

To supplement vendor interviews, consumer surveys were conducted to evaluate the importance of packaging in purchasing decisions. The survey aimed to identify how packaging formats influenced consumers' perceptions of product quality, presentation, and convenience.

By using these methods, the study aimed to comprehensively analyze the packaging formats used for both strawberries and dates in local markets, focusing on material properties, vendor practices, and consumer preferences.

III.3. Source of Aromatic Plants Used in the Study

Four aromatic plant species were selected based on their known antimicrobial and preservative properties, commonly cited in traditional use and scientific studies. The species included *Artemisia herba-alba*, *Foeniculum vulgare* (fennel), *Rosmarinus officinalis* (rosemary), and *Thymus vulgaris* (thyme). The plants were sourced locally from herbalist shops and open-air markets in Biskra, Algeria.

Selection prioritized vendors known for proper identification and regular supply. Each plant was collected in a standardized quantity of 1.5 kilograms to ensure consistency during the essential oil extraction process.

After procurement, the plant materials were inspected to remove any visibly damaged or contaminated parts. Each sample was labeled with the species name, weight, and collection date, then temporarily stored in clean, dry conditions away from direct sunlight.

Prior to extraction, each plant sample was photographed to document appearance and confirm identity, as shown in Figures 1. This controlled preparation phase ensured uniform input material across all extractions.

The plant species included in this study were:

- *Artemisia herba-alba*: Known for its grayish foliage and strong antifungal and antibacterial properties.
- *Foeniculum vulgare*: Characterized by its aromatic seeds and leaves, traditionally used for digestive and preservative functions.
- *Rosmarinus officinalis*: Recognized for its robust antioxidant and antimicrobial profile, commonly applied in natural food preservation.
- *Thymus vulgaris*: Rich in essential oils such as thymol, noted for its potent antifungal and antibacterial activity.

Artemisia herba-alba

Thymus vulgaris

Foeniculum vulgare

Rosmarinus officinalis

Figure 1: The used dried plants

III.4. Essential Oil Extraction Methods

III.4.1. Hydrodistillation Using a Clevenger-Type Apparatus (Single-Cycle)

Hydrodistillation was used to extract essential oils from *Rosmarinus officinalis* (rosemary) and *Thymus* vulgaris (thyme) with a Clevenger type apparatus operated in a single cycle (non-continuous) configuration (Figure 2). In this setup, the condensed water oil mixture was directed into a separate Erlenmeyer flask.

For *Rosmarinus officinalis*, 1.5 kilograms of dried rosemary leaves were processed in six individual batches of 250 grams each, using a 2-liter round-bottom flask filled with distilled water. The flask was heated with an electric heating mantle set to medium intensity, generating steam that carried the plant's volatile compounds through the condenser.

For *Thymus vulgaris*, 1.5 kilograms of dried thyme were distilled in ten separate extractions, each using 150 grams of plant material in a 2-liter flask. The heating and condensation system remained the same as for rosemary.

Each distillation run lasted approximately 4 hours. As the vapor condensed, the mixture of essential oil and hydrosol was collected in an external Erlenmeyer flask. After allowing the phases to separate naturally, the essential oil layer was extracted manually using a sterile syringe.

Figure 2: Clevenger type apparatus used for hydrodistillation

III.4.2. Steam Distillation

Steam distillation was used to extract essential oils from *Artemisia herba-alba* (white Artemisia) and *Foeniculum vulgare* (fennel). A Clevenger type apparatus was employed in a continuously operated setup (Figure 3), where condensed water from the essential oil hydrosol mixture was automatically returned to the boiling flask throughout the process. This method allows for efficient oil separation without loss of volatile compounds.

For *Artemisia herba-alba*, 1.5 kilograms of dried aerial parts were distilled in two separate batches of 750 grams each. For *Foeniculum vulgare*, 1.5 kilograms of dried fennel were processed in a single batch. In both cases, distillation was carried out using a round bottom flask with a 2-liter distilled water capacity, heated by an electric heating mantle maintained at a constant temperature of 130 °C.

The steam carried volatile compounds from the plant material into the condenser, where they were cooled and separated into essential oil and hydrosol. The condensed water automatically returned to the boiling flask, ensuring continuous circulation during the entire extraction period.

Each distillation run lasted approximately 5 hours, providing sufficient time for complete volatilization of essential oil components. Upon completion, the essential oils were collected directly from the Clevenger's graduated arm and transferred into sterile amber glass vials.

Figure 3: Clevenger type apparatus used for steam distillation

III.5. Essential Oil Application on Fruits (Dates and Strawberries)

III.5.1. Determination of Essential Oil Volume for Experimental Use

The quantity of essential oil used in the preservation tests was calculated based on the internal volume of the containers designated for storing the fruit samples. A volumetric reference ratio was established using the container intended for strawberries, and the same standard was applied to date containers through proportional adjustment.

For strawberries, the reference container had the following dimensions:

- Length: 10 cm
- Width: 10 cm
- Height: 8 cm
- Calculated internal volume : $10 \times 10 \times 8 = 800\ cm^3$

Two drops of essential oil were designated for this volume, establishing a working ratio of one drop per 400 cm^3.

For dates, the container dimensions were:

- Length: 23 cm
- Width: 8 cm
- Height: 3.3 cm

- Calculated internal volume : $23 \times 8 \times 3.3 = 607.2\ cm^3$

According to the established ratio (1 drop/400 cm^3), the calculated requirement was approximately 1.52 drops. For practical implementation and to ensure consistent treatment, this value was rounded up to two drops.

III.5.2. Application Method of Essential Oils

A no contact vapor phase diffusion method was adopted to expose fruits to essential oil volatiles without direct contact. This approach ensures even dispersion of antimicrobial compounds within the container environment.

Nine plastic crates for strawberries and nine paper boxes for dates (as per the volumes calculated above) were sourced from the covered market in Biskra.

The procedure involved preparing diffusion capsules as follows:

- Paper towels were cut into 2 cm × 2 cm squares.
- Each piece was rolled manually into a compact spherical shape.
- A single drop of essential oil was applied to the center of each paper ball.
- The ball was then enclosed in tulle fabric to allow breathable diffusion.

For strawberries

- Each crate was filled with 200 g of strawberries:
  - Approximately 8 fruits (unknown variety)

For dates

- Each crate was filled with 500 g of dates:
  - 40 fruits for Deglet Nour variety
  - 65 fruits for Mech Degla variety

The fruits were arranged in two tiers within the containers. Two essential oil capsules were placed per crate strategically positioned between the fruit layers to maximize volatile dispersion (Figure 4 and 5).

This method ensured uniform exposure of fruit samples to essential oil vapors, leveraging atmospheric diffusion (contact par odorat) to achieve preservative action without direct application.

Figure 4: Placement of Essential Oil Capsules within the Strawberry Crate

Figure 5: Placement of Essential Oil Capsules Within the Date Crate (Deglet Nour Variety and Mech Degla)

III.6. Storage Conditions After Applying Essential Oils

After the essential oils were applied, the fruit containers were stored under controlled conditions tailored to the specific physiological characteristics of each fruit.

- Strawberries

The strawberry crates were stored in a refrigerator at 4 °C to inhibit physical, enzymatic, and microbial activity. This cold storage condition was selected to maintain freshness and delay spoilage for as long as possible.

- Dates

The date crates were stored in a dry, dark environment at ambient temperature (22 ± 2 °C), away from moisture and direct light, in order to minimize both physical and biological degradation. Each container was sealed to reduce gas exchange and prevent external contamination.

III.7. Experimental Monitoring Schedule

III.7.1. For Strawberry

The strawberry preservation experiment using essential oils was conducted over a period of 13 days. Initial treatment and packaging were applied on the first day (T0). Throughout this period, detailed visual and microbial observations were carried out and documented on the following specific dates:

- T0: 25/03/2025(initial treatment and packaging)
- T1 : 26/03/2025
- T3 : 28/03/2025
- T4 : 29/03/2025
- T7 : 01/04/2025
- T8 : 02/04/2025
- T10 : 04/04/2025
- T12 : 06/04/2025

These days were selected to monitor physical and microbial changes in the strawberries under controlled storage conditions.

Monitored parameters are :

1. Number of Deteriorated Strawberries per Box Over Storage Days
2. Weight Loss During Storage
3. Physical, Microbiological, and Sensory parameters:
   3.1. Physical Parameters
      3.1.1. External Color Change (Color Changes)

Color is a primary visual indicator of strawberry quality and deterioration. The bright red hue of ripe strawberries is due to anthocyanin pigments (primarily pelargonidin derivatives) localized in the epidermal cell vacuoles. During spoilage, oxidative degradation of anthocyanins and phenolic compounds causes a shift from red toward yellowish brown tones. This is driven by polyphenol oxidase (PPO) catalyzed browning and ascorbic-acid-mediated anthocyanin cleavage, yielding brown condensation products (Howard *et al*., 2014)

In parallel, localized microbial infections (e.g., *Rhizopus stolonifer*, *Aspergillus* spp., *Botrytis cinerea*) produce dark or white surface lesions through enzymatic breakdown of cell walls and pigment degradation (Zhang *et al*., 2019)

3.1.2. Loss of Firmness (Loss of Firmness)

Firmness decline is perceptible by gentle compression and reflects cell-wall disassembly. During ripening and spoilage, endogenous enzymes (polygalacturonase, pectin methylesterase, pectate lyase, cellulase, hemicellulase) depolymerize pectin and hemicellulose networks, while pathogenic fungi secrete additional cell wall degrading enzymes, accelerating softening (Quesada *et al*., 2009; Posé *et al*., 2011)

The combined activity reduces turgor pressure and tissue integrity, resulting at advanced stages in a collapse into a semi-liquid state.

3.1.3. Shriveling and Surface Deformation (Shriveling and Surface Deformation)

Shriveling arises from net water loss via transpiration and respiration; the thin strawberry cuticle and high surface to volume ratio exacerbate moisture efflux. As epidermal cells dehydrate, the skin contracts, producing visible wrinkles and loss of gloss. Concomitant fungal colonization (notably B. cinerea) further consumes cellular water and solutes, worsening surface collapse (Crisosto *et al*., 2000)

Maintenance of ≥ 90 % relative humidity and rapid cooling are critical to minimize transpiration and preserve structural integrity (Parvez and Wani, 2018)

1.2. Microbiological Parameters

3.2.1. Fungal and Mold Growth (Fungal and Mold Growth)

Fungi responsible for the spoilage of strawberries include *Rhizopus stolonifer* (gray mold), *Aspergillus niger* (black mold), and *Penicillium* spp. (green mold). These necrotrophic fungi germinate on wounds or senescent tissues, forming abundant spore masses and secreting cell wall degrading enzymes (e.g., pectinases, cellulases, cutinases) that macerate cortical cells and create characteristic gray, black, or green lesions (El-Araby *et al*., 2023; Liu *et al*., 2024).

In addition, aflatoxigenic species such as *Aspergillus flavus* can produce potent carcinogenic mycotoxins (aflatoxins B_1 , B_2 , G_1 , G_2) during colonization, rendering the fruit unsafe for consumption; infected berries often emit a musty odor and display dark or green spore patches (Hussein *et al*., 2020).

3.2.2. Insect and Larval Infestation (Insect and Larval Infestation)

The spotted wing drosophila (*Drosophila suzukii*) and vinegar flies (e.g., D. melanogaster) are common dipteran pests of strawberries. Females puncture the epidermis of ripe or damaged berries to oviposit; larvae hatch inside and consume the mesocarp, producing small cavities and white maggots that compromise fruit texture and serve as entry points for secondary pathogens (Ganjisaffar *et al*., 2023).

3.2.3. Presence of Pathogenic Bacteria (Pathogenic Bacteria)

Strawberries can harbor enteric bacteria *Escherichia coli*, *Salmonella enterica*, and *Listeria monocytogenes* introduced via contaminated irrigation water, soil, or poor handling hygiene. Although these pathogens rarely produce visible symptoms, high loads may manifest as slimy exudates, off odors, or localized softening, posing significant food-safety risks (Ceuppens *et al*., 2015; Yin *et al*., 2022).

3.3. Sensory Parameters

3.3.1. Odor

Fresh strawberries emit a characteristic sweet fruity aroma driven by a complex blend of esters (e.g., ethyl acetate, methyl acetate), alcohols, terpenes and aldehydes; over 360 volatile compounds have been identified in healthy fruit (Abouelenein *et al*., 2023; Dong *et al*., 2013).

microbial spoilage shifts this profile toward fatty and rancid notes as alcohols and esters are oxidized to aliphatic acids (e.g., hexanoic, octanoic acids) by fungal and bacterial metabolism, producing off-odors described as cheesy, sour or musty (Lv *et al*., 2024; Dong *et al*., 2013).

Incorporation of essential oils such as oregano or thyme oil into edible coatings or packaging has been shown to inhibit microbial growth and preserve native volatiles, maintaining the fruit's natural aroma profile throughout storage (Rusková *et al*., 2023; Chen *et al*., 2023).

3.3.2. Taste and Mouthfeel

The sweet taste of strawberries derives principally from soluble sugars (glucose, fructose, sucrose), balanced by citric and malic acids (Milosavljević *et al.*, 2023; Ikegaya *et al.*, 2019).

During microbial spoilage, endogenous and microbial enzymes (e.g., invertases, dehydrogenases) convert sugars into organic acids and alcohols, shifting flavor toward sour or bitter notes and lowering pH (Ikegaya *et al.*, 2019).

Texturally, microbial pectinases and cellulases degrade cell wall polymers, causing the fruit to become unusually soft, sticky or pasty sensations that are readily detected by consumers as signs of internal breakdown and unacceptability.

III.7.2. For Date

The date preservation experiment using essential oils was carried out over a 30-day period. Initial essential oil treatments and sample packaging were applied on day T0. Throughout the storage period at 22 ± 2 °C, systematic physical and microbiological assessments were performed on six key dates

- T0: 31/03/2025 (initial treatment and packaging)
- T1 : 05/04/2025
- T2 : 10/04/2025
- T3 : 15/04/2025
- T4 : 20/04/2025
- T5 : 25/04/2025
- T6 : 30/04/2025

Observations focused on external color changes, firmness loss, shriveling and surface deformation, fungal and mold growth, insect or larval infestation, presence of pathogenic bacteria, off odors, and taste and mouthfeel alterations.

Monitored parameters are:

1. Number of Deteriorated dates per Box Over Storage Days
2. Weight Loss During Storage
3. Physical, Microbiological, and Sensory parameters:

3.1. Physical Parameters

3.1.1. External Color Change (Color Changes)

The glossy brown peel of fresh dates (*Phoenix dactylifera*) undergoes darkening during spoilage due to oxidative polymerization of phenolic compounds (tannins, anthocyanins) and enzymatic browning mediated by polyphenol oxidase. White or gray patches frequently indicate surface colonization by *Aspergillus* spp. or *Penicillium* spp., which further accelerate pigment breakdown through their own oxidative enzymes (Al-Qarni and Bazzi, 2020; Palou *et al*., 2016).

3.1.2. Loss of Firmness (Loss of Firmness)

Firmness decline is detected by gentle compression yielding a plastically deformed or even liquefied texture in advanced spoilage. This reflects depolymerization of cell- wall polysaccharides (protopectin, cellulose, hemicellulose) by endogenous pectinases and cellulases as well as fungal hydrolases, leading to loss of turgor and structural integrity (Li *et al*., 2024; Chen *et al*., 2024).

3.1.3. Surface Deformation and Wrinkling (Shriveling and Surface Deformation)

Shrinkage of the epidermis results from net water loss via transpiration and respiration. Low relative humidity and high temperature exacerbate moisture efflux, while fungal activity (e.g., *Aspergillus* spp.) consumes residual sugars and water, intensifying tissue contraction and producing pronounced wrinkling and a desiccated appearance (Zaid *et al*., 1999; Gunny *et al*., 2024).

3.2. Microbiological Parameters

3.2.1. Fungal and Mold Growth (Fungal and Mold Growth)

Storage spoilage of dates is predominantly driven by xerophilic and mesophilic fungi, notably *Aspergillus flavus*, *Penicillium chrysogenum* and *Mucor spp.* These molds colonize the fruit surface, forming white or green spore patches and secreting hydrolytic enzymes (e.g., pectinases, cellulases) that depolymerize cell- wall polysaccharides and macerate the flesh. In particular, A. flavus synthesizes aflatoxins potent carcinogens that accumulate in the fruit and pose serious health hazards upon ingestion (Shenasi *et al*., 2002; González-Curbelo and Kabak, 2023). Infected dates often emit a musty or sour odor, reflecting secondary fungal metabolites.

3.2.2. Insect and Larval Infestation (Insect and Larval Infestation)

Key insect pests of dates include the dried- fruit beetle (*Carpophilus hemipterus*), the sawtoothed grain beetle (*Oryzaephilus surinamensis*) and fruit flies (e.g., *Drosophila melanogaster*). Adult beetles and flies oviposit through the epidermis; larvae hatch and feed on the mesocarp, creating galleries filled with frass and exuviae. This tunneling not only degrades texture but also provides entry points for secondary microbial invaders (Rosi *et al.*, 2019; Phelan and Lin, 1991).

3.2.3. Presence of Pathogenic Bacteria (Pathogenic Bacteria)

Although dates' low water activity limits general bacterial growth, hardy enteric pathogens *Escherichia coli*, *Salmonella enterica* and *Listeria monocytogenes* can survive for extended periods on both low and high moisture varieties (e.g., Medjool) under simulated storage conditions. Surface contamination typically arises from irrigation water, soil, or unsanitary handling, and may be asymptomatic; however, high pathogen loads can lead to slimy exudates, off odors and rapid pH shifts (Canakapalli *et al.*, 2022).

3.3. Sensory Parameters

3.3.1. Odor

A healthy date emits a characteristic sweet–fruity aroma derived from esters (e.g., ethyl acetate), alcohols and aldehydes, signaling freshness and varietal quality. During spoilage, microbial metabolism particularly by yeasts and bacteria breaks down sugars and lipids into short chain fatty acids (hexanoic, octanoic acids) and sulfurous compounds, producing rancid, cheesy or sour off odors that mask the fruit's natural fragrance (Alqahtani *et al.*, 2025; Doyle, 2007).

3.3.2. Taste and Mouthfeel

Fresh dates owe their sweetness to high concentrations of glucose, fructose and sucrose, balanced by organic acids that give a pleasant mouthfeel. As spoilage advances, microbial and endogenous enzymes convert these sugars into lactic, acetic and other organic acids, shifting flavor toward sour or bitter notes and lowering pH. Simultaneously, cell wall degrading enzymes (pectinases, cellulases) reduce turgor, causing the flesh to become sticky, overly soft or mushy sensations immediately perceived as textural spoilage (Doyle, 2007; Schifferstein, 2024).

Chapter 4
Results and Discussion

IV.1. Observations and Packaging

IV.1.1. Observations on Date Sales and Packaging

According to vendor interviews, the local market offered no fewer than 12 varieties of dates, including Deglet Nour, Ghars, Medjool, Taâmia, Hamra, Kentichi, Beyoudhi, and other local types. All vendors confirmed that Deglet Nour was the most demanded and best-selling variety due to its superior quality and reputation at both national and international levels.

Regarding packaging, most sellers used closed cardboard boxes as the primary method, while plastic bags, paper wraps, and sometimes transparent hanging plastic covers were also employed. In terms of storage, some vendors reported using specialized refrigerators, while others relied on ambient storage, counting on the natural resistance of dates to spoilage. On shelf life, most vendors explained that dates could be preserved for several months under appropriate conditions (moderate temperature and proper ventilation), with spoilage typically detected by changes in color, the appearance of unusual odors, or occasionally, surface mold although such cases were rare.

IV.1.2. Observations on Strawberry Sales and Packaging

At the Zaqaq Ben Ramadan market, strawberry vendors revealed that they typically purchase strawberries in large boxes from wholesalers or producers, and then manually repackage them into small plastic containers for retail. In fewer cases, cardboard trays are used, but plastic containers remain the preferred choice due to convenience and faster turnover.

Unlike dates, strawberries are not refrigerated but are displayed at room temperature, which makes them extremely perishable. Vendors reported that strawberries can spoil within 24 to 48 hours post-harvest, prompting them to sell the full stock within one or two days to avoid losses. All vendors agreed that packaging material has little influence on shelf life, as temperature and humidity were considered the primary factors affecting fruit spoilage.

IV.2. Analysis of Packaging Types and Formats Used

The packaging methods used for dates and strawberries in local markets in Biskra can be classified as follows

IV.2.1. Packaging Formats for Strawberries

Strawberries are typically sold in the following types of packaging

- Small plastic containers, either ventilated or non-ventilated (Figure 6), used for individual retail portions.

- Cardboard trays, used occasionally, mainly for bulk display or higher end presentation.
- Transparent plastic bags, used for temporary handling or small quantities.

Despite the variety of packaging options, the extremely short shelf life of strawberries remains a critical issue. Due to their high perishability, vendors often avoid refrigeration and aim to sell the entire stock within 24 to 48 hours. This rapid turnover affects both preservation and final product quality delivered to the consumer.

A B

Figure 6: Plastic Box (A. without Lid, B. with ventilation holes)

IV.2.2. Packaging Formats for Dates

In contrast to strawberries, dates are more durable and are typically packaged using the following materials

- Closed cardboard boxes (figure 7), the most commonly used option, offering protection and stackability.
- Plastic bags, used by some vendors for mid-range or informal packaging.
- Paper bags, less commonly employed, typically for small quantities or immediate sales.
- Hanging transparent plastic wraps (figure 8), used for suspended display to enhance visibility and presentation.

- Open plastic boxes (figure 9), used for ventilation and ease of handling, but offering limited protection against insects and moisture.
- Closed plastic boxes (figure 9), providing better isolation from external contaminants, suitable for extended storage and minimizing spoilage.

Storage of dates is generally carried out in one of two ways

  - In specialized refrigerators, designed to prolong shelf life and maintain optimal conditions.
  - At ambient room temperature, provided that the environment is well-ventilated to reduce moisture accumulation and microbial risk.

Figure 7: Cardboard Box for Dates

Figure 8: Date Hanging Rack

Figure 9:Open and closed Plastic Box for Dates

IV.3. The resulting yields of essential oil

• 10 mL of essential oil from *Rosmarinus offic*

• 7 mL of essential oil from *Thymus vulgaris*

• 20 mL from *Artemisia herba-alba*

• 15 mL from *Foeniculum vulgare*

All extracted oils were stored in sterile, amber glass vials at 4 °C, protected from light and air to preserve their chemical composition and biological activity.

IV.4. Results of Experimental Monitoring Schedule for Strawberry

During the 13-day storage period at 4 °C, strawberries treated with essential oils such as rosemary (*Rosmarinus officinalis*), fennel (*Foeniculum vulgare*), Artemisia (*Artemisia herba-alba*), and thyme (*Thymus vulgaris*) exhibited varying levels of preservation efficacy.

IV.4.1. Number of Deteriorated Strawberries per Box

Fennel oil was the most effective in delaying bruise formation, with an average bruised count of 5.0, due to its active compound anethole which strengthens cell walls.

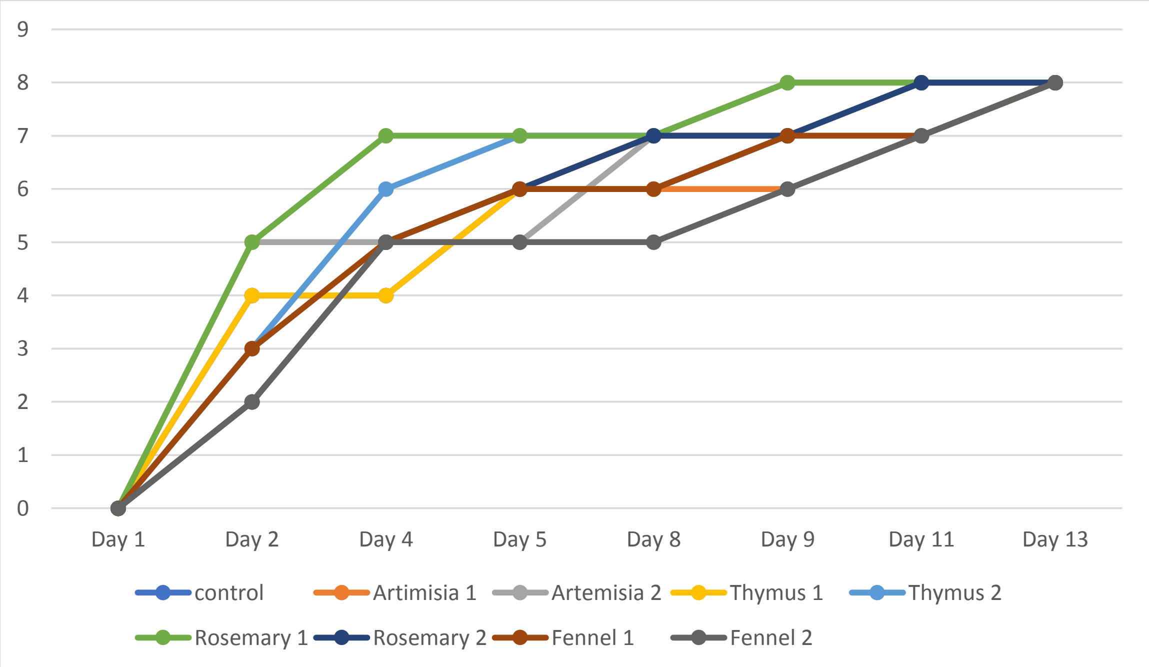

Figure 10: Curve of Number of Deteriorated Strawberries per Box Over Storage Days

Artemisia oil ranked second with an average bruised count of 5.375, slowing bruise progression thanks to camphor and α-thujone. Thyme oil had a moderate effect, averaging 5.75 bruised fruits, but the low dosage may have limited its preservation ability. Rosemary oil was least effective, with an average bruised count of 5.81 and early bruise development. The untreated control group also averaged 5.375 bruised fruits but experienced rapid spoilage by day 5, emphasizing the protective role of essential oils.

In vitro evaluations demonstrated the antifungal efficacy of four essential oils against key postharvest pathogens of strawberries, namely *Botrytis cinerea*, *Rhizopus stolonifer*, and *Aspergillus niger*. Among the tested oils, fennel oil (*Foeniculum vulgare*), which contains a high concentration of anethol, was the most effective, resulting in the lowest decay rate among treated fruits. This was followed in effectiveness by Artemisia and thyme oils, while rosemary oil was the least effective (Hadian *et al.*, 2008).

IV.4.2. Effect of Different Essential Oils on Strawberry Weight Loss

The weight loss analysis of strawberries over 13 days showed clear differences among essential oil treatments and the control. Thyme oil (Thy) was most effective, with the lowest weight loss of 4.41%, due to its antioxidant and antimicrobial compounds like thymol that reduce respiration and water loss.

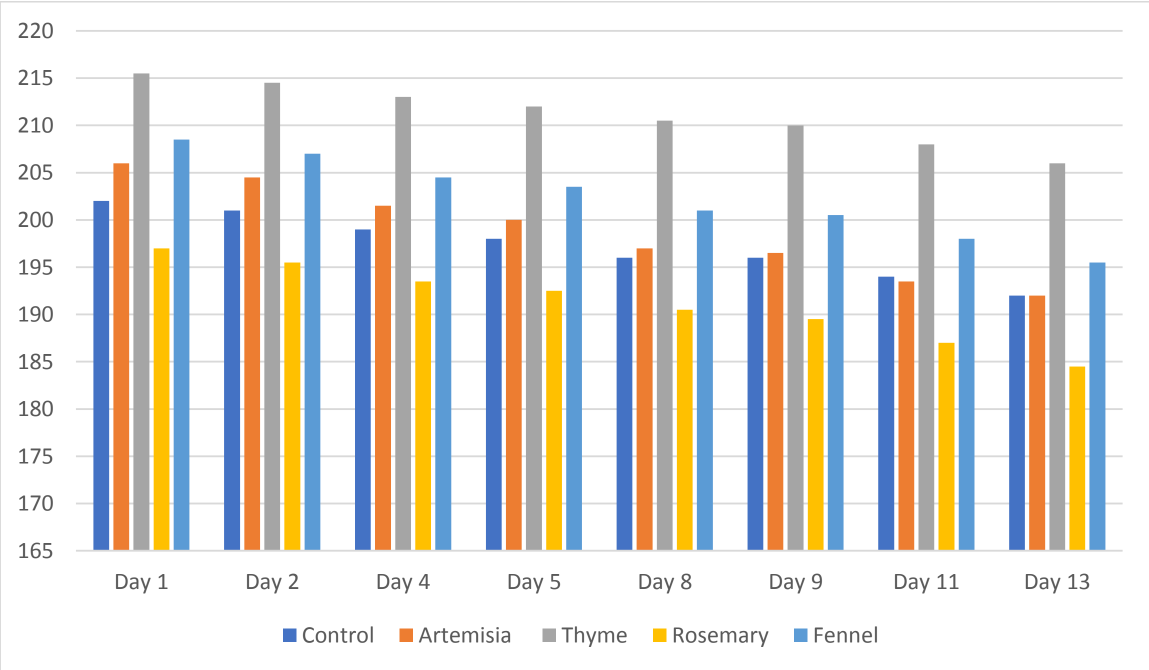

Figure 11: Effect of Different Essential Oils on Strawberry Weight Loss During Storage

The control group had a moderate weight loss of 4.95%, reflecting natural dehydration. Fennel oil (Fen) and Rosemary oil (Ros) had similar moderate effects, with weight losses of 6.23% and 6.35%, respectively, linked to their bioactive compounds such as anethole and chamazulene. Artemisia oil (Art) showed the highest weight loss at 6.80%, indicating less consistent preservation, possibly due to varying chemical composition and bioactive concentrations.

Demonstrated that thyme essential oil exhibited the highest antimicrobial activity against *Botrytis cinerea*, while fennel oil ranked second in efficacy, corroborating our findings that thyme is the most effective and fennel the runner-up for postharvest strawberry preservation via combined antioxidant and antimicrobial mechanisms (De-Montijo-Prieto *et al.*, 2021).

IV.4.3. Physical, Microbiological, and Sensory Analysis of Strawberry Condition During Storage

During the storage period from 25/03/2025 to 06/04/2025, the effect of four essential oils Artemisia, thyme, rosemary, and fennel on the preservation of strawberries was evaluated. The various treatments were compared to an untreated control by monitoring physical changes, microbial growth, and sensory attributes. This analysis aims to illustrate the efficacy of these oils in delaying physiological and microbial degradation and improving preservation quality under storage conditions of 4 ± 1 °C.

IV.4.3.1. Scientific analysis and discussion of the first day

On day 1 of storage at 4 °C, strawberry samples underwent physical analyses, microbiological analyses, and sensory evaluations to assess the impact of essential oils on their quality. The results are detailed in the table below.

Table 2: Daily Evaluation of Physical, Microbiological, and Sensory Changes in Treated and Control Strawberry Samples Day 1

Treatment	Physical	Microbiological	Sensory
Control	Fresh and firm fruits	No fungal or mold growth	No noticeable odor
Artemisia	Fresh and firm fruits	No fungal or mold growth	No noticeable odor
Thyme	Fresh and firm fruits	No fungal or mold growth	No noticeable odor
Rosemary	Fresh and firm fruits	No fungal or mold growth	No noticeable odor
Fennel	Fresh and firm fruits	No fungal or mold growth	No noticeable odor

On the first day, no visible signs of spoilage or bruising were observed in any of the treatments. All strawberries whether untreated (control) or treated with essential oils (Artemisia, thyme, rosemary, and fennel) appeared fresh, firm, and intact. There were no blackened fruits or indications of microbial decay across the boxes, establishing a clean baseline for subsequent comparisons

A

B

C

D

E

Figure 12: Aspect of Strawberry in experimental boxes at the first day (A: control, B: Artemesia, C: Thyme, D: Rosemary, E: Fennel)

1. **Physical Analysis**

All strawberry samples including untreated controls and those treated maintained normal firmness and texture on Day 1. Previous studies confirm that essential oil applications do not alter initial firmness when fruits are stored at 4 °C for example, strawberries exposed to cinnamon or lemon EO vapor showed no significant difference in firmness compared to controls immediately after treatment (Freche, 2021; Abdullah *et al.*, 2023).

2. Microbiological Analysis

None of the sample's control or EO treated exhibited any fungal or mold growth on Day 1. This aligns with work on peppermint- EO nanoliposome coatings (MEO- SLN), which produced undetectable mold counts in coated strawberries immediately postharvest, matching untreated controls under the same sanitary conditions (Shehata *et al.*, 2020). Similarly, strawberries wrapped in biodegradable films enriched with thyme EO showed no yeast or mold growth at Day 1 in either treated or control groups (Freche, 2021)

3. Sensory Analysis

No off- odors were detected in any sample; the tasting panel described all aromas as "natural and pleasant." Prior research on cinnamon and lemon EO treatments reports that, immediately after coating, neither treated nor control strawberries produced off odors or off tastes during the first 24 h of storage likewise, strawberries packaged in active films containing thyme EO retained their characteristic fresh aroma on Day 1, indistinguishable from controls (Freche, 2021).

IV.4.3.2. Scientific Analysis and Discussion of Day 2

On the second day of strawberry storage, the results are presented in the table below.

Table 3: Daily Evaluation of Physical, Microbiological, and Sensory Changes in Treated and Control Strawberry Samples Day 2

Treatment	Physical	Microbiological	Sensory
Control	3–5 berries showed color change; 4 berries lost firmness	No fungal or mold growth	No noticeable odor
Artemisia	3–5 berries showed color change; 4–5 berries lost firmness	No fungal or mold growth	No noticeable odor
Thyme	4 berries showed color change; 3–4 berries lost firmness	No fungal or mold growth	No noticeable odor
Rosemary	4 berries showed color change; 2–5 berries lost firmness	No fungal or mold growth	No noticeable odor
Fennel	3 berries showed color change; 2–3 berries lost firmness	No fungal or mold growth	No noticeable odor

On the second day of storage, all strawberry samples began to show signs of spoilage, with the control group deteriorating the fastest due to bruising and blackening. Artemisia and thyme essential oils provided moderate protection but were not fully effective in preventing damage. Rosemary oil showed slightly better results, particularly in one box where fewer fruits were affected. Fennel oil offered the highest level of preservation, with fewer bruised and blackened strawberries in both boxes. This indicates a stronger protective effect compared to the other oils. Overall, fennel oil maintained strawberry quality more effectively on day 2.

1. Physical Analysis

By Day 2, all treatments show signs of color change and firmness loss, though the extent varies slightly, the essential- oil treatments can delay but not fully prevent color and firmness loss. For example, strawberries coated with a 0.5 % thyme EO nanoemulsion retained higher firmness than controls , exhibiting only minor softening (≈ 5 % reduction) compared to a 15–20 % loss in untreated fruit (Kebriti *et al*., 2025). Similarly, strawberries treated with cinnamon EO vapor showed no firmness difference from control on Day 1 but became significantly softer by Day 2, matching the treated sample pattern here where, for instance, Artemisia 2 and Rosemary 1 had five berries losing firmness (Freche, 2021).

2. Microbiological Analysis

On Day 2, none of the samples still exhibit fungal or mold growth, indicating that both initial sanitation and the antimicrobial effect of coatings remain effective. This aligns with edible- coating studies where peppermint EO nanoliposome (MEO- SLN) coated strawberries showed no mold colonies even at Day 2 (Ulukanli and Oz, 2015; Gani *et al*., 2016). In our table, every treatment including Control remains free of fungal/mold growth on Day 2.

3. Sensory Analysis

By Day 2, all samples continue to register “No noticeable odor,” indicating that no spoilage derived volatiles have formed. Previous research shows that essential oils can suppress microbial metabolites responsible for off- odors through at least the first 2–3 days of storage. For instance, strawberries packaged in thyme EO infused films had no detectable off odors through Day 3(Kahramanoğlu *et al*., 2022). Thus, the Day 2 sensory outcome here (no odor in any sample) matches broader observations that EO treatments maintain natural aroma up to at least 48 hours post- treatment.

IV.4.3.3. Scientific Analysis and Discussion of Day 4

On day 4 of storage strawberry, the results are detailed in the table below.

Table 4: Daily Evaluation of Physical, Microbiological, and Sensory Changes in Treated and Control Strawberry Samples Day 4

Treatment	Physical	Microbiological	Sensory
Control	4–6 berries showed color change; 4 berries lost firmness	No fungal or mold growth	No noticeable odor
Artemisia	4–6 berries showed color change; 4–5 berries lost firmness	No fungal or mold growth	No noticeable odor
Thyme	5 berries showed color change; 4–6 berries lost firmness	No fungal or mold growth	No noticeable odor
Rosemary	5 berries showed color change; 5–7 berries lost firmness	No fungal or mold growth	No noticeable odor
Fennel	3–6 berries showed color change; 5 berries lost firmness	No fungal or mold growth	No noticeable odor

By Day 4, all strawberry samples showed spoilage, with the control group most affected. Artemisia and thyme offered moderate protection but showed bruising and softening. Rosemary-treated fruits were heavily deteriorated. Fennel oil remained the most effective, preserving firmness and aroma and slowing spoilage progression.

1. Physical Analysis

By Day 4, all samples, including the control and those treated with Artemisia, Thyme, Rosemary, and Fennel, exhibited color changes and varying firmness loss. These trends confirm that essential oil (EO) coatings delay but do not prevent spoilage. For example, strawberries coated with 0.5% thyme EO nanoemulsion showed ~30% firmness loss versus ~45% in untreated fruit (Javanmardi et al., 2023). In our data, Thyme 1 (four berries with firmness loss) and Fennel 1 (three with color change, five with firmness loss) outperformed the Control and Rosemary 1 (four and seven, respectively), supporting previous findings that thyme and fennel EOs better preserve structural integrity by slowing cell-wall degradation (Ansarifar and Moradinezhad, 2021; Yan *et al.*, 2021).

2. Microbiological Analysis

By Day 4, no fungal or mold growth was observed in either control or EO-treated samples, aligning with reports that EO coatings maintain mold-free surfaces for at least four days at 4 °C. For instance, peppermint EO nanoliposome coatings prevented mold formation through Day 4, while uncoated strawberries showed *Botrytis cinerea* by Day 5 (Kebriti et al., 2025; Yan et al., 2021). Similarly, thyme EO-enriched biodegradable films kept strawberries mold-free through Day 4, unlike untreated samples, which developed colonies as early as Day 2 (Ansarifar and Moradinezhad, 2021).

3. Sensory Analysis

On Day 4, all samples, control and EO-treated, showed “No noticeable odor,” suggesting an absence of spoilage volatiles and EO-related off-notes. This outcome agrees with prior findings where thyme EO-infused films preserved aroma quality through Day 4, while untreated fruits began developing sour odors (Ansarifar & Moradinezhad, 2021; Ibrahim et al., 2017). Similarly, chitosan-thyme EO coatings maintained a “natural and pleasant” scent under both 24 °C and 4 °C conditions at Day 4, whereas controls exhibited early fermentation signs (Ibrahim *et al.*, 2017).

IV.4.3.4. Scientific Analysis and Discussion of Day 5

On the day 5 of strawberry storage, the results are presented in the table below.

Table 5: Daily Evaluation of Physical, Microbiological, and Sensory Changes in Treated and Control Strawberry Samples Day 5

Treatment	Physical	Microbiological	Sensory
Control	6 berries showed color change; 6 berries lost firmness	No fungal or mold growth	No noticeable odor
Artemisia	6 berries showed color change; 5–6 berries lost firmness	No fungal or mold growth	No noticeable odor
Thyme	6–7 berries showed color change; 6–7 berries lost firmness	No fungal or mold growth	No noticeable odor
Rosemary	5 berries showed color change; 5 berries showed shriveling & surface deformation; 5–7 berries lost firmness	No fungal or mold growth	Noticeable odor detected (only in Rosemary 2)
Fennel	3–6 berries showed color change; 5 berries lost firmness	No fungal or mold growth	No noticeable odor

By the fifth day, spoilage became widespread in all strawberry samples. The control group showed severe deterioration, with most fruits blackened or spoiled. Artemisia treated fruits exhibited strong odor and visible over ripeness, though slightly better than the control. Thyme and rosemary treatments had extensive decay, with blackened, bruised, and sticky fruits, some showing signs of fermentation. Fennel treated samples also deteriorated, but retained a more acceptable odor. Overall, fennel and Artemisia offered slightly better preservation, though spoilage was evident across all treatments.

1. Physical Analysis

On Day 5, all samples, including the control and those treated with various EOs, exhibited color changes and varying degrees of firmness loss, these observations align with previous studies indicating that EO based edible coatings can delay, but not entirely prevent, physical deterioration in strawberries. For instance, coatings enriched with thyme essential oil have been shown to reduce weight loss and maintain firmness in strawberries during storage (Kahramanoğlu *et al.*, 2022; Yıldız and Sümbül)

2. Microbiological Analysis

By Day 5, none of the samples, including the control and EO-treated groups, exhibited fungal or mold growth. This finding is consistent with literature demonstrating the antimicrobial properties of EOs. For example, thyme and peppermint EOs have been reported to completely inhibit the growth of *Botrytis cinerea* for up to 7 days when applied at certain concentrations (Tančinová *et al.*, 2022).

3. Sensory Analysis

Sensory evaluation on Day 5 revealed that all samples, except for Rosemary 2, had no noticeable odor. Rosemary 2 exhibited a noticeable odor, along with shriveling and surface deformation. Previous studies have noted that while EOs can preserve sensory qualities, their concentration and type are critical. High concentrations or certain types of EOs may impart off-flavors or odors. For instance, strawberries treated with certain EOs at higher concentrations showed a statistically significant decrease in taste and aroma (Tančinová *et al.*, 2022).

IV.4.3.5. Scientific Analysis and Discussion of Day 8

On day 8 of storage strawberry, the results are detailed in the table below.

Table 6: Daily Evaluation of Physical, Microbiological, and Sensory Changes in Treated and Control Strawberry Samples Day 8

Treatment	Physical	Microbiological	Sensory
Control	6 berries showed color change; 6 berries lost firmness	No fungal or mold growth	No noticeable odor
Artemesia	6–8 berries showed color change; 6–7 berries lost firmness	No fungal or mold growth	Noticeable odor detected
Thyme	6–7 berries showed color change; 7 berries lost firmness	No fungal or mold growth	Noticeable odor detected
Rosemary	8 berries showed color change; 7 berries lost firmness; shriveling & surface deformation observed in Rosemary 2	Fungal and mold growth on 1 fruit (Rosemary 1) / No fungal or mold growth (Rosemary 2)	Noticeable odor detected
Fennel	7 berries showed color change; 5–6 berries lost firmness	No fungal or mold growth	No noticeable odor

By the eighth day, all strawberry samples showed advanced spoilage across treatments. The control group exhibited significant bruising and blackening, indicating severe decay. Artemisia and thyme treatments had extensive discoloration, overripeness, and strong aromatic odors. Rosemary-treated fruits showed severe degradation, including fungal growth and moisture-related stickiness. Fennel-treated strawberries also experienced bruising, blackening, and stickiness, though overall appearance was somewhat better. Overall, spoilage progressed markedly in all samples by day eight.

1. Physical Analysis

By Day 8, all samples exhibited noticeable color changes and varying degrees of firmness loss, these observations align with previous studies indicating that essential oil (EO) coatings can delay, but not entirely prevent, physical deterioration. For instance, coatings incorporating thyme EO have been shown to reduce weight loss and maintain firmness in strawberries over extended storage periods (Heidary *et al*., 2025; Ansarifar and Moradinezhad, 2022).

2. Microbiological Analysis

By Day 8, most samples remained free from fungal and mold growth, except for Rosemary 1, which exhibited fungal and mold growth on one fruit. This is consistent with findings that EO based coatings possess antifungal properties, effectively inhibiting the growth of common spoilage organisms like *Botrytis cinerea*. For example, coatings containing thyme EO have demonstrated significant reductions in microbial counts in strawberries during storage (Ali *et al*., 2022).

3. Sensory Analysis

Sensory evaluations revealed that Noticeable odor detected in (Artemisia 1 and Artemisia 2, Thyme 1 and Thyme 2, Rosemary 1 and Rosemary 2), No noticeable odor in (Control, Fennel 1 and Fennel 2) (Venturini Antunes *et al*., 2023).

The emergence of noticeable odors in some EO-treated samples may be attributed to the volatile compounds inherent in certain essential oils. While these compounds have antimicrobial benefits, they can also impart strong aromas that affect the sensory quality of the fruit. Conversely, fennel EO treated samples maintained a neutral odor profile, suggesting its suitability for preserving sensory attributes (Siburian *et al*., 2021).

IV.4.3.6. Scientific Analysis and Discussion of Day 9

On the day 9 of strawberry storage, the results are presented in the table below.

Table 7: Daily Evaluation of Physical, Microbiological, and Sensory Changes in Treated and Control Strawberry Samples Day 9

Treatment	Physical	Microbiological	Sensory
Control	6 berries showed color change; 7 berries lost firmness	No fungal or mold growth	No noticeable odor
Artemesia	7–8 berries showed color change; 6–7 berries lost firmness	No fungal or mold growth	Noticeable odor detected
Thyme	6–7 berries showed color change; 8 berries lost firmness	No fungal or mold growth	Noticeable odor detected
Rosemary	8 berries showed color change; 7–8 berries lost firmness; shriveling and surface deformation observed (Rosemary 2)	Fungal and mold growth on 1 fruit (Rosemary 1) / No fungal or mold growth (Rosemary 2)	Noticeable odor detected
Fennel	7 berries showed color change; 6–7 berries lost firmness	No fungal or mold growth	No noticeable odor

By the ninth day, all strawberry samples showed extensive deterioration. The control group exhibited widespread bruising, blackening, and overripeness.

Artemisia and thyme treatments displayed similar advanced spoilage with strong odors and sticky moisture. Rosemary-treated fruits had bruising, fungal growth, and advanced ripening, though less stickiness. Fennel-treated strawberries also experienced high spoilage, with many fruits bruised, blackened, and sticky. Overall, significant decay was evident across all treatments by Day 9.

1. Physical Analysis

By Day 9, all samples exhibited noticeable color changes and varying degrees of firmness loss, these observations align with findings that essential oil (EO) coatings can delay but not entirely prevent physical deterioration. For instance, a study demonstrated that strawberries coated with chitosan and clove essential oil maintained better firmness over 12 days compared to uncoated controls (Pizato *et al*., 2022).

2. Microbiological Analysis

On Day 9, most samples remained free from fungal and mold growth, except for Rosemary 1, which showed fungal and mold growth on one fruit. This is consistent with research indicating that EO coatings possess antimicrobial properties that can inhibit fungal growth. For example, strawberries treated with chitosan and clove essential oil exhibited reduced microbial activity during storage (Pizato *et al*., 2022).

3. Sensory Analysis

Sensory evaluations on Day 9 revealed that noticeable odor detected in (Artemisia 1 and Artemisia 2, Thyme 1 and Thyme 2, Rosemary 1 and Rosemary 2) No noticeable odor in (Control, Fennel 1 and Fennel 2). These results suggest that while EO coatings can preserve certain quality aspects, they may also impart strong aromas over time. A study found that strawberries coated with whey protein isolate containing thymol developed off-flavors shortly after application, whereas those packed with thymol-infused sachets maintained better sensory qualities (Marín *et al*., 2019).

IV.4.3.7. Scientific Analysis and Discussion of Day 11

On day 11 of storage strawberry, the results are detailed in the table below.

Table 8: Daily Evaluation of Physical, Microbiological, and Sensory Changes in Treated and Control Strawberry Samples Day 11

Treatment	Physical	Microbiological	Sensory
Control	7 berries showed color change; 8 berries lost firmness	Fungal and mold growth on 1 fruit	No noticeable odor
Artemesia	7–8 berries showed color change; 7–8 berries lost firmness	No fungal or mold growth	Noticeable odor detected
Thyme	7–8 berries showed color change; 8 berries lost firmness	Fungal and mold growth on 0–1 fruit	Noticeable odor detected
Rosemary	8 berries showed color change; 8 berries lost firmness; shriveling and surface deformation (Rosemary 2)	Fungal and mold growth on 1–3 fruits	Noticeable odor detected
Fennel	7–8 berries showed color change; 7 berries lost firmness	Fungal and mold growth on 1 fruit	Noticeable odor detected

By Day 11, spoilage was advanced across all samples. The control group exhibited bruising, blackening, and visible mold.

Artemisia-treated fruits showed extensive bruising, stickiness, and decay, though a few remained acceptable. Thyme- and rosemary-treated strawberries were heavily degraded, with rot and strong odors. Fennel samples also decayed, with mold and overripeness, indicating severe spoilage in all treatments.

1. Physical Analysis

All samples showed continued loss of firmness and color by Day 11, consistent with natural senescence. Notably, surface shriveling in *Rosemary 2* may suggest dehydration exacerbated by the coating, aligning with findings that EO treatments can sometimes induce surface stress depending on dose and storage (Pizato *et al*., 2022).

2. Microbiological Analysis

Fungal growth was noted in *Control, Thyme 2, Rosemary 1, Fennel 1, Fennel 2* (1 fruit each) and *Rosemary 2* (3 fruits). No mold appeared in *Artemisia 1, Artemisia 2,* and *Thyme 1*, indicating these treatments were most effective. This supports reports that *Artemisia herba-alba* and *Thymus vulgaris* EOs are potent antifungals against *Botrytis cinerea*, a key postharvest pathogen (Marín *et al*., 2019).

3. Sensory Analysis

Odor changes were noticeable in all EO-treated samples (*Artemisia 1* and *2, Thyme 1* and *2, Rosemary 1* and *2, Fennel 1* and *2*), but surprisingly absent in the control. This likely reflects EO volatile residues rather than microbial spoilage, consistent with data showing EO coatings can intensify fruit aromas or cause off-notes if concentrations are too high (Pizato *et al*., 2022).

IV.4.3.8. Scientific Analysis and Discussion of Day 13

On the day 13 of strawberry storage evaluations to assess the impact of essential oils on their quality. The results are detailed in the table below.

Table 9: Daily Evaluation of Physical, Microbiological, and Sensory Changes in Treated and Control Strawberry Samples Day 13

Treatment	Physical	Microbiological	Sensory
Control	7 berries showed color change; 8 berries lost firmness	Fungal and mold growth on 2 fruits	Noticeable odor detected
Artemesia	7–8 berries showed color change; 8 berries lost firmness	Fungal and mold growth on 0–3 fruits	Noticeable odor detected
Thyme	8 berries showed color change; 8 berries lost firmness	Fungal and mold growth on 0–1 fruit	Noticeable odor detected
Rosemary	8 berries showed color change; 8 berries lost firmness; shriveling and surface deformation (Rosemary 2)	Fungal and mold growth on 1–3 fruits	Noticeable odor detected
Fennel	7–8 berries showed color change; 8 berries lost firmness	Fungal and mold growth on 1–2 fruits	Noticeable odor detected

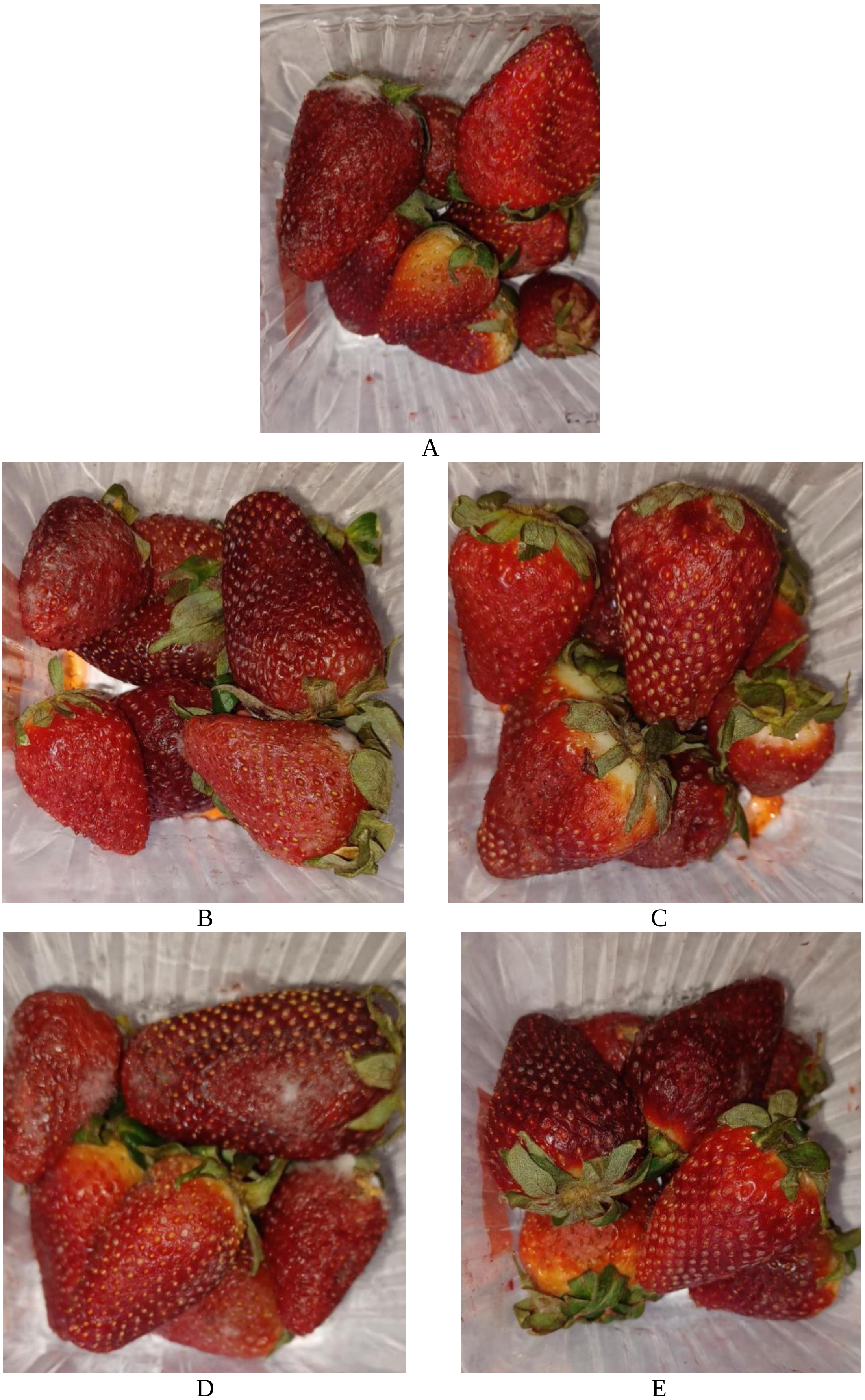

Figure 13: Aspect of Strawberry in experemental boxes at the day 13 (A: control, B: Artimesia, C: Thyme, D: Rosemary, E: Fennel)

By Day 13, all strawberry samples showed advanced deterioration. The control group exhibited severe bruising, blackening, and visible fungal growth. *Artemisia* and *Thyme* treatments resulted in soft, sticky, and mold-affected fruits with strong odors. *Rosemary*-treated samples displayed extensive mold, bruising, and foul smell. *Fennel* treated fruits also deteriorated, though a few remained mildly acceptable despite visible mold.

1. Physical Analysis

All samples experienced marked color changes and firmness loss, consistent with advanced senescence and moisture loss. Shriveling and surface deformation in *Rosemary 2* suggest EO-related surface stress, as reported in studies where higher EO concentrations can compromise fruit integrity (Pizato *et al*., 2022).

2. Microbiological Analysis

Fungal growth was observed in *Control (2 fruits), Artemisia 1 (3), Thyme 2 (1), Rosemary 1 (1), Rosemary 2 (3), Fennel 1 (1), Fennel 2 (2)*. No growth was found in *Artemisia 2* and *Thyme 1*, indicating these treatments remained most effective against fungal proliferation. This supports their known antifungal activity, especially against *Botrytis cinerea* (Marín *et al*., 2019). Increased fungal growth in other samples suggests waning EO efficacy over time.

3. Sensory Analysis

All samples exhibited noticeable odor, including the control. Odor presence may result from both microbial spoilage and lingering EO volatiles. This aligns with findings that EO coatings influence aroma and may interact with natural spoilage odors, impacting sensory perception and requiring concentration optimization for consumer acceptability (Pizato *et al*., 2022).

IV.4.3.9. General Conclusion

The application of essential oils, particularly fennel (*Foeniculum vulgare*) and Artemisia (*Artemisia herba-alba*), at optimal concentrations effectively extended the shelf life of strawberries by preserving firmness, delaying color degradation, and inhibiting microbial growth without negatively impacting sensory qualities during early storage. However, rosemary (*Rosmarinus officinalis*) oil exhibited some limitations, such as surface damage and the development of noticeable odors, which could affect consumer acceptance (Taghavi *et al*., 2018; Munekata *et al*., 2023).

IV.5. Results of Experimental Monitoring Schedule for Dates

IV.5.1. Deglet Nour

During the 30-day storage period at 22 °C, Deglet Nour dates treated with essential oils such as rosemary (*Rosmarinus officinalis*), fennel (*Foeniculum vulgare*), Artemisia (*Artemisia herba-alba*), and thyme (*Thymus vulgaris*) demonstrated varying degrees of preservation.

IV.5.1.1. Number of Infestations in Deglet Nour Dates Treated with Natural Oils

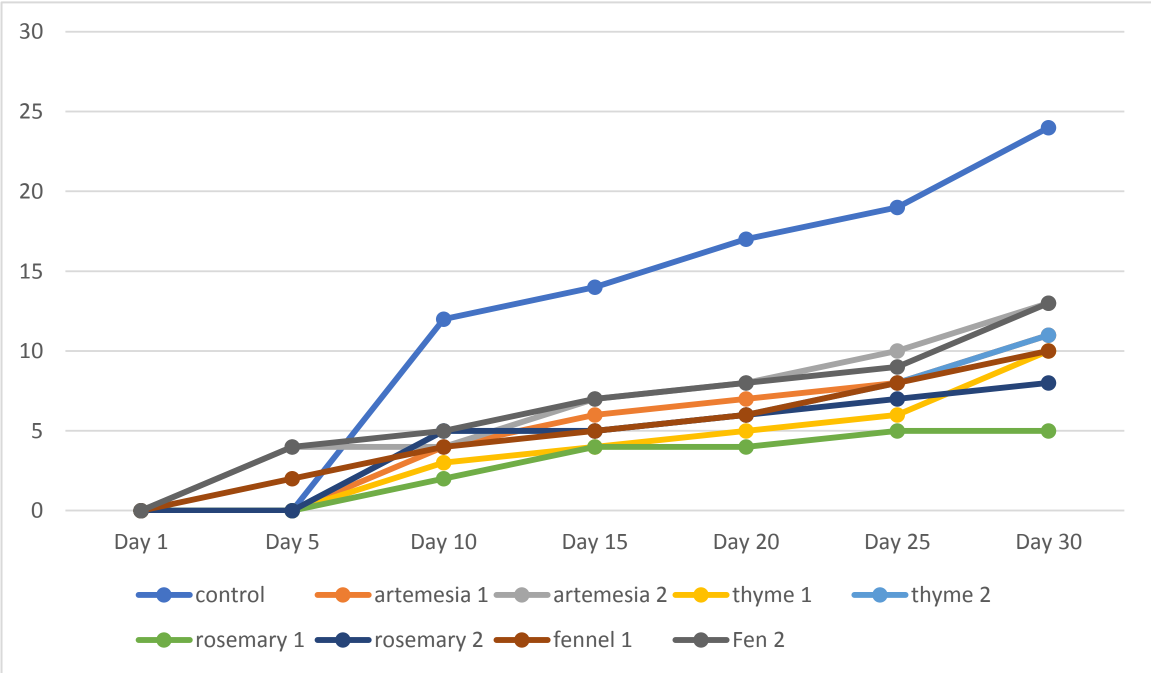

Figure 14: Curve of Deteriorated Date Deglet Nour Fruits per Treatment over 30 Days

Rosemary oil showed the highest effectiveness in reducing date spoilage, with an average bruised count of 3.57, thanks to its rosmarinic and carnosic acids that provide strong antioxidant and antifungal protection, strengthening the cell wall. Thyme oil ranked second with a bruised count of 4.50, containing antimicrobial compounds thymol and carvacrol, though the low dosage might have limited its long-term efficacy. Fennel oil was third at 5.78, with anethole contributing antifungal and antioxidant effects but proving less effective than rosemary or thyme oils. Artemisia oil came fourth with 5.92 bruises, its camphor and α-thujone delaying bruising onset but offering lower overall protection. The untreated control was the least effective, showing rapid and early bruising with an average count of 12.28, emphasizing the need for treatment to protect dates.

Among the essential oils tested, rosemary essential oil stands out as the most effective natural preservative for extending the shelf life of Deglet Nour dates. Its superior performance is likely due to its high content of antioxidant and antimicrobial compounds. While thyme and fennel oils offer moderate preservation benefits, other oils showed limited effectiveness. These findings support the use of rosemary essential oil in postharvest treatments to maintain the quality and extend the shelf life of dates (Bakhtiarizade and Souri, 2019).

IV.5.1.2. Evolution of Weight in Deglet Nour Dates Treated with Natural Oils

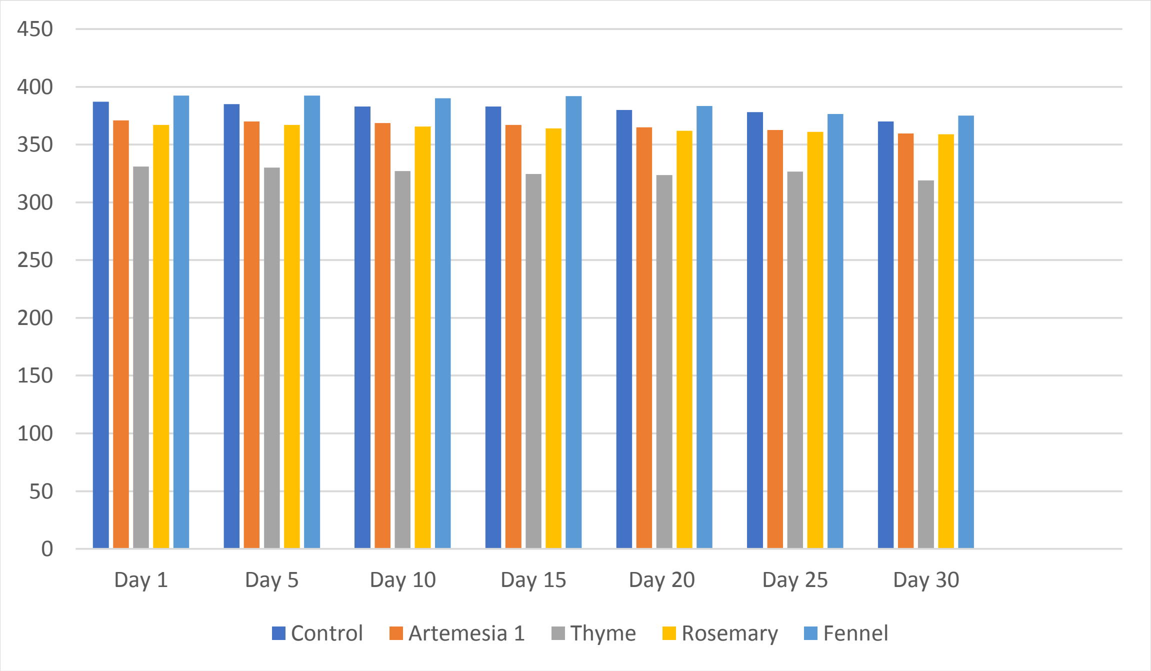

Figure 15: Change in Deglet Nour Date Box Weights by Type of Essential Oil During Storage

Stored the weight loss results of Deglet Nour dates over 30 days show that rosemary essential oil was the most effective, with only 2.18% loss, likely due to its ability to form a protective barrier that reduces moisture evaporation. Artemisia oil followed, with a 3.10% loss, attributed to its antioxidant bioactive compounds that help stabilize the fruit. Thyme oil had a moderate effect, causing 3.63% weight loss, offering partial protection against evaporation. The untreated control showed a high loss of 4.39%, reflecting natural degradation during storage. Fennel oil was the least effective, with the highest weight loss of 4.46%, likely due to its lower active compound content.

From a moisture retention perspective, rosemary and Artemisia essential oils proved to be the most effective in preserving the weight of Deglet Nour dates during storage. Their protective properties significantly reduced water loss, likely by forming a semi-permeable barrier that limits transpiration and moisture evaporation. Thyme oil demonstrated a moderate effect, offering partial preservation efficiency. In contrast, fennel oil was the least effective, as it was associated with the highest weight loss and reduced storage performance. These findings highlight the importance of selecting appropriate essential oils to enhance postharvest conservation of dates through natural and sustainable means (El-Gioushy and Baiea, 2020).

IV.5.1.3. Physical, Microbiological, and Sensory Analysis of Deglet Nour Condition During Storage

Throughout the storage period from 31/03/2025 to 30/04/2025, the impact of four essential oils Artemisia (*Artemisia herba-alba*), thyme (*Thymus vulgaris*), rosemary (*Rosmarinus officinalis*), and fennel (*Foeniculum vulgare*) on the preservation of Deglet Nour dates was assessed. The different treatments were contrasted with an untreated control by observing physical alterations, microbial growth, and sensory traits. This scrutiny strives to exhibit the effectiveness of these natural oils in slowing physiological and microbial decay and in improving the quality of preservation under storage conditions of 22 ± 2 °C.

IV.5.1.3.1. Scientific analysis and discussion of the first day

On day 1 of storage at 22 °C, Deglet Nour samples underwent physical analyses, microbiological analyses, and sensory evaluations to assess the impact of essential oils on their quality. The results are detailed in the table below.

Table 10: Daily Assessment of Physical, Microbial, and Sensory Characteristics in Treated and Untreated Deglet Nour Dates for Day 1

Treatment	Physical	Microbiological	Sensory
Control	Fresh, smooth, and firm fruits with no discoloration or wrinkle.	No fungal growth or insect/insect signs.	Natural smell and taste.
Artemisia	Fresh, smooth, and firm fruits with no discoloration or wrinkle.	No fungal growth or insect/insect signs.	Natural smell and taste.
Thyme	Fresh, smooth, and firm fruits with no discoloration or wrinkle.	No fungal growth or insect/insect signs.	Natural smell and taste.
Rosemary	Fresh, smooth, and firm fruits with no discoloration or wrinkle.	No fungal growth or insect/insect signs.	Natural smell and taste.
Fennel	Fresh, smooth, and firm fruits with no discoloration or wrinkle.	No fungal growth or insect/insect signs.	Natural smell and taste.

At T0, all dates appeared fresh and glossy, with intact, smooth skins showing no signs of spoilage or defects. No visual differences were observed among the boxes at this initial stage. The control box contained equally high-quality dates stored under identical conditions, serving as a reference point for evaluating changes throughout the experiment.

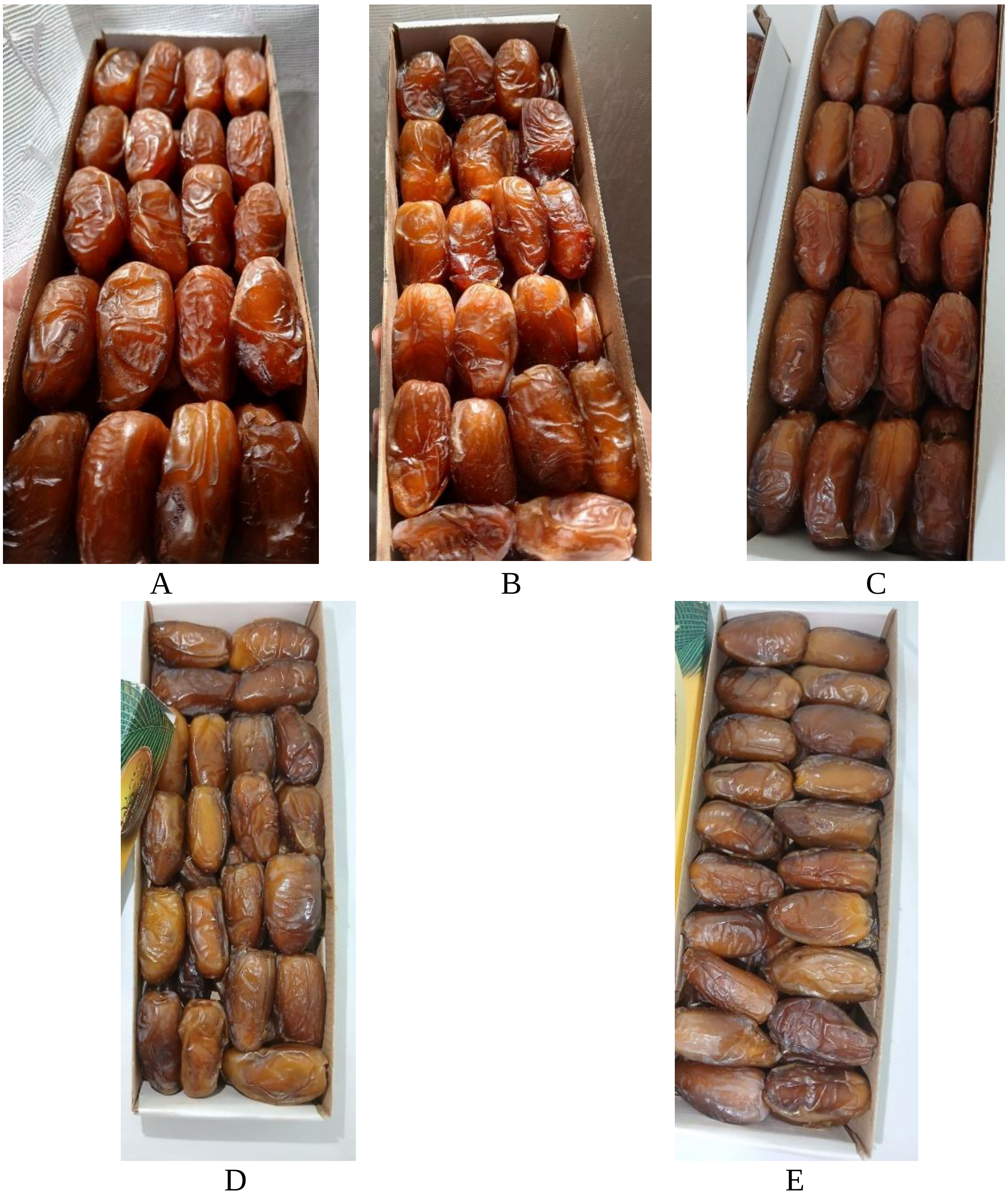

Figure 16: Aspect of dates Deglet Nour variety in experimental boxes at the first day (A: control, B: Artemesia, C: Thyme, D: Rosemary, E: Fennel)

1. Physical Analysis

During initial storage, all Deglet Nour date samples were characterized by fresh, smooth, and firm fruit surfaces with no visible discoloration or wrinkling. This uniformity reflects the immediate postharvest integrity before moisture loss became significant. Studies have shown that edible coatings incorporating thyme essential oil can form a semi-permeable barrier on date fruit surfaces, effectively reducing transpiration and maintaining texture in early storage (Rahemi *et al*., 2020; Bederina *et al*., 2024).

Additionally, inhibition of catechol oxidase activity by essential oils such as *Artemisia herba-alba* and *Thymus vulgaris* helps delay enzymatic browning and firmness loss, contributing to sustained visual quality (Bederina *et al*., 2024; Rahemi *et al*., 2020).

2. Microbiological Analysis

At the first evaluation point, no fungal growth or insect signs were observed in any treatment group. This indicates that the essential oil applications provided an immediate antimicrobial effect comparable to the untreated Control. Specifically, thyme EO–based film coatings on dates have demonstrated significant antifungal and antibacterial activity, effectively suppressing common spoilage microorganisms during early storage (Rahemi *et al*., 2020; Bakhtiarizade and Souri, 2019).

Furthermore, *Artemisia herba-alba* and *Rosmarinus officinalis* oils contain compounds (e.g., camphor, β-thujone, and carvacrol) that inhibit enzymatic pathways linked to microbial colonization, reducing both surface fungi and internal metabolic spoilage factors (Bederina *et al*., 2024; Bakhtiarizade and Souri, 2019).

3. Sensory Analysis

During early storage, all date samples including essential oil treated and Control retained their natural date aroma and sweet taste with no off-odors or flavor deviations.

Research indicates that when essential oils are incorporated at optimized concentrations into edible coatings, they do not impart undesirable herbal notes or bitterness during initial postharvest handling. For instance, Thymr oil in a soy-protein or gelatin matrix preserved sensory attributes of Barhi dates without causing noticeable flavor alterations (Rahemi *et al*., 2020; Bakhtiarizade and Souri, 2019).

Similarly, Artemisia EO displayed strong antimicrobial efficacy without negatively impacting the inherent date flavor during short-term storage (Bederina *et al*., 2024; Bakhtiarizade and Souri, 2019).

IV.5.1.3.2. Scientific analysis and discussion of the day 5

On day 5 of storage at 22 °C, Deglet Nour samples underwent physical analyses, microbiological analyses, and sensory evaluations to assess the impact of essential oils on their quality. The results are detailed in the table below.

Table 11: Daily Assessment of Physical, Microbial, and Sensory Characteristics in Treated and Untreated Deglet Nour Dates for Day 5

Treatment	Physical	Microbiological	Sensory
Control	Noticeable darkening of fruit color; no shrinkage or wrinkles.	No fungal growth or insect activity observed.	Slight odor onset, normal taste.
Artemisia	Initial darkening with early wrinkling; fruit remains firm.	Internal decay in 4 fruits, no visible fungi/insects.	Slight odor (in 2), otherwise natural taste.
Thyme	Slight to darker color change with light wrinkling; firm texture.	No fungal growth or insect activity observed.	Natural taste, no noticeable odor.
Rosemary	Slight to more evident darkening; early wrinkling; fruit structurally stable.	No fungal growth or insect activity observed.	Natural taste, no noticeable odor.
Fennel	Dark spots/yellowing near pit to blackening with wrinkling; fruit still firm.	2–4 infested fruits; early insect (date worm) activity.	Slight odor in some, otherwise natural taste.

By the fifth day of storage, the control dates exhibited noticeable darkening, initial wrinkling, and a developing acidic odor. Among the treated samples, Artemisia oil showed early signs of spoilage, including darkening and mold on several fruits. Thyme oil delayed deterioration in one box but signs of wrinkling and darkening were evident in the other. Rosemary oil-treated dates showed mild changes, with minimal spoilage indicators. Fennel oil treatment resulted in localized darkening, yellowing near the pits, and mold growth on multiple fruits, indicating moderate degradation.

1. Physical Analysis

By Day 5, untreated Deglet Nour dates (Control) exhibited noticeable darkening of skin color without evident shrinkage or wrinkling, reflecting early stages of oxidative browning common in uncoated dates stored under ambient conditions. Studies on Deglet Nour color kinetics confirm that enzymatic browning reactions can lead to surface darkening within the first week of storage parameters begin to shift as early as day 5 (Jemni *et al*., 2019).

Dates coated with Thyme 1 showed only a slight color change and no wrinkling, indicating effective moisture retention and delayed senescence, in line with findings that thymol-rich coatings slow down water loss and maintain firmness in early storage (Magri *et al*., 2023; Siddiq and Greiby, 2013).

Conversely, Fennel 2 treated dates developed localized blackening and light wrinkling by Day 5, suggesting that higher concentrations of *Foeniculum vulgare* essential oil can create uneven barriers, leading to oxidative hotspots and surface stress despite delaying overall moisture evaporation (Siddiq and Greiby, 2013).

2. Microbiological Analysis

At Day 5, neither the Control nor EO-treated groups showed visible fungal growth, indicating that resident microbial loads remained below detectable levels during this initial postharvest period. Essential oils are documented to exert strong antifungal activity, and in-context trials on fresh produce demonstrate that EO vapor or coating treatments can suppress surface spoilage organisms in the first week of storage (Magri *et al.*, 2023; Puškárová *et al.*, 2017).

Specifically, Thyme 1 and Artemisia 1 treatments likely inhibited early colonization by spoilage yeasts and molds through compounds like thymol and camphor, which disrupt fungal cell membranes. However, Artemisia 2 dates showed internal decay in four fruits despite no visible external mold, suggesting that uneven coating penetration or microinjuries beneath the skin permitted latent microbial proliferation (e.g., latent spores) that became apparent by Day 5 (Puškárová *et al.*, 2017; Magri *et al.*, 2023).

3. Sensory Analysis

By Day 5, most treatments including Control, Thyme 1, Rosemary 1, and Fennel 1 retained the natural sweet aroma and honey-like taste characteristic of Deglet Nour dates, with no noticeable off-odors detected. Deglet Nour dates are inherently semi-dry with a slightly chewy texture and subtle honeyed notes, which early EO coatings do not overpower when properly dosed (Maurya *et al.*, 2021; Fernández-López *et al.*, 2022).

In contrast, Fennel 2 and Artemisia 2 treatments developed a slight herbal odor by Day 5; this likely results from diffusion of residual essential oil volatiles (anethole in fennel, thujone in Artemisia) combining with trace metabolic byproducts from internal decay. Prior studies confirm that essential-oil coatings can impart characteristic aromas that become perceptible within the first week, underscoring the need to optimize EO concentrations to balance antimicrobial efficacy with sensory acceptability (Maurya *et al.*, 2021; Magri *et al.*, 2023).

IV.5.1.3.3. Scientific analysis and discussion of the day 10

On day 10 of storage Deglet Nour samples underwent evaluations to assess the impact of essential oils on their quality. The results are detailed in the table below.

Table 12: Daily Assessment of Physical, Microbial, and Sensory Characteristics in Treated and Untreated Deglet Nour Dates for Day 10

Treatment	Physical Description	Microbiological	Sensory
Control	Significant darkening; pronounced wrinkling.	Fungal growth on ~12 fruits.	Strong acidic odor; abnormal flavor.
Artemisia	Darkening and advanced wrinkling; increased firmness.	Partial fungal development (4–5 fruits).	Slight odor; nearly natural taste.
Thyme	Slight to moderate darkening; surface wrinkling on some fruits.	3–5 fruits with visible decay.	Faint odor; nearly natural taste.
Rosemary	Slights to evident darkening (esp. near stem).	2–4 fruits with visible decay.	Light to slight odor; nearly natural taste.
Fennel	Clear to intense darkening and shrinkage.	4–5 fruits infested with visible decay.	Pronounced to strong acidic odor.

By the tenth day, the control samples showed clear signs of advanced spoilage, including darkened peel, strong acidic odor, and widespread mold. Artemisia oil-treated dates began to darken and firm, with early signs of fungal presence. Thyme oil helped slow deterioration, though moderate wrinkling and mild odor were noticed. Rosemary-treated fruits remained relatively stable, showing limited changes in color and texture. Fennel oil-treated dates deteriorated more noticeably, with increased peel discoloration, sour odor, and visible fungal spots. The preservative effect of fennel oil appeared to weaken at this stage. Overall, essential oils showed varied effectiveness in delaying spoilage.

1. Physical Analysis

By Day 10, dates without any coating exhibited pronounced darkening and deep wrinkling, reflecting rapid oxidative browning and moisture loss under ambient conditions (Ben-Amor *et al.*, 2016; Cherif *et al.*, 2021).

Dates treated with Artemisia (*Artemisia herba-alba*) oil also showed notable skin darkening and surface creasing, but retained a firmer feel overall indicating that Artemisia's bioactive compounds helped delay dehydration and textural collapse (Ben-Amor *et al.*, 2016; Salanță and Cropotova, 2022).

Those coated with thyme (*Thymus vulgaris*) oil displayed moderate color darkening accompanied by light wrinkling, suggesting that thymol-rich films initially controlled moisture loss but began losing efficacy by the second week. In contrast, rosemary (*Rosmarinus officinalis*) treated dates exhibited only slight color change and minimal creasing, demonstrating rosemary's effective antioxidant protection that retarded both browning and surface dehydration. Fennel (*Foeniculum vulgare*) oil coatings led to clear darkening with noticeable shrinkage and more intense surface creases, implying that although fennel's volatile compounds initially provided a barrier to water loss, its protective effect weakened by Day 10, resulting in localized dehydration hotspots and advanced surface stress (Salanță and Cropotova, 2022).

2. Microbiological Analysis

At Day 10, uncoated dates were heavily colonized by surface molds, illustrating how ambient storage fosters rapid fungal proliferation once internal moisture surpasses critical thresholds (Cherif *et al.*, 2021).

Artemisia oil coated dates showed limited mold presence, indicating that *Artemisia herba-alba*'s antifungal constituents (e.g., camphor, thujone) delayed but did not entirely prevent spore germination under extended storage. Thyme-treated fruits exhibited modest fungal development, reflecting thymol and carvacrol's ability to slow proliferation of common spoilage molds, although gradual microbial breakthrough still occurred by Day 10. In contrast, rosemary coatings demonstrated the lowest mold incidence, highlighting that phenolics such as rosmarinic acid and carnosic acid effectively disrupt fungal cell membranes and maintain surface sterility longer under ambient conditions. Fennel oil–treated dates initially benefited from antifungal activity, but by Day 10, molds reemerged in isolated spots where barrier uniformity failed, indicating that fennel's volatile anethole cannot fully supplant moisture thresholds driving fungal growth once internal water levels remain high (Salanță and Cropotova; 2022).

3. Sensory Analysis

By Day 10, uncoated dates exhibited strong acidic odors and off-flavors due to spoilage (Nabily *et al.*, 2020; Cherif *et al.*, 2021). Artemisia coated fruits retained natural sweetness with only mild herbal notes, as its volatiles masked fermentation odors. Thyme-treated dates maintained honeyed flavors and slight herbal aroma, indicating thymol's sensory compatibility (Nabily *et al.*, 2020; Salanță and Cropotova, 2022). Rosemary coatings caused minimal flavor changes, reflecting its moderation of spoilage volatiles without strong herbal impact (Salanță and Cropotova, 2022). Fennel-coated dates developed sour odors, likely due to anethole and microbial acids enhancing acidic perception (Nabily *et al.*, 2020; Salanță and Cropotova, 2022).

IV.5.1.3.4. Scientific analysis and discussion of the day 15

On day 15 of storage Deglet Nour, the results are detailed in the table below.

Table 13: Daily Assessment of Physical, Microbial, and Sensory Characteristics in Treated and Untreated Deglet Nour Dates for Day 15

Treatment	Physical Description	Microbiological	Sensory
Control	Advanced darkening with yellowish hue near pit; deep wrinkling across most fruits	Fungal growth on ~14 fruits	Strong acidic odor; unnatural flavor
Artemisia	Pronounced darkening (esp. near pit); increasing wrinkling	Mold growth on 5–6 fruits	Strong acidic odor; unnatural flavor
Thyme	Mild darkening and enhanced wrinkling; firmness maintained	Mold growth on ~4–5 fruits	Mild citrus aroma; nearly natural flavor
Rosemary	Slight to progressive darkening and shrinkage; noticeable wrinkling	4–5 fruits with visible decay	Mild citrus aroma; nearly natural flavor
Fennel	Localized to general darkening; wrinkling and cracking visible	5–7 fruits with visible decay	Strong sour smell; unnatural flavor

By day fifteen, control dates exhibited advanced spoilage, with darkening, sour odor, and mold. Artemisia oil treated samples continued to decay. Thyme oil showed moderate effectiveness, reducing spoilage signs. Rosemary oil offered partial protection but showed early deterioration. Fennel oil treated fruits began to dry and mold, indicating a declining preservative effect. Overall, the essential oils varied in their ability to slow spoilage.

1. Physical Analysis

By Day 15, untreated Deglet Nour dates underwent severe oxidative browning and moisture loss, evidenced by deep darkening with yellow halos near the pits and pronounced wrinkling as L* and Hue° values dropped sharply after two weeks at room temperature (Jemni *et al*., 2019; Sarraf *et al*., 2021).

Dates treated with Artemisia oil showed even darker skins and more wrinkling yet maintained firmer textures, suggesting delayed but not prevented cell collapse. Tyme coatings induced only mild darkening and enhanced firmness early on, though barrier integrity began failing by mid storage. Rosemary oil provided the strongest antioxidant protection, slowing both browning and dehydration. In contrast, Fennel coated fruits exhibited localized yellow-brown spots, cracking, and accelerated textural breakdown by Day 15 as the initial evaporation control waned (Jemni *et al*., 2019; Elbar *et al*., 2024).

2. Microbiological Analysis

By Day 15, uncoated dates exhibited heavy surface mold as ambient storage promotes rapid fungal growth once moisture exceeds critical levels (Jemni *et al*., 2019; Sarraf *et al*., 2021).

Artemisia oil limited mold to moderate levels camphor and thujone delayed spore germination but uneven coverage allowed localized breakthrough. Thyme coatings reduced fungal presence via thymol and carvacrol, though some colonization persisted on select fruits. Rosmary treatment achieved the lowest mold incidence, as rosmarinic and carnosic acids disrupted fungal membranes and maintained surface sterility midstorage. Fennel oil offered initial antifungal protection, but by Day 15 mold reemerged in areas of barrier failure, indicating anethole volatiles could not fully suppress spoilage under elevated internal moisture (Jemni *et al*., 2019; Elbar *et al*., 2024).

3. Sensory Analysis

By Day 15, control dates showed advanced spoilage symptoms, emitting a strong acidic odor and unnatural flavor, consistent with microbial metabolism of sugars by yeasts and molds (Jemni *et al*., 2019; Sarraf *et al*., 2021).

Dates treated with Artemisia essential oil exhibited similar acidic off odors and flavors, indicating that although Artemisia volatiles partially masked fermentative cues, latent fungal activity remained detectable by mid storage. In contrast, Thyme treated dates retained a mild citrus aroma and nearly natural flavor, suggesting that thymol rich volatiles effectively delayed sensory deterioration through partial microbial suppression and aroma blending. Rosemary coated dates also maintained a mild citrus note with acceptable sensory quality, reflecting rosemary oil’s ability to mask spoilage volatiles without imparting overpowering herbal tones. However, Fennel treated dates developed a strong sour odor and unnatural flavor, likely due to interactions between anethole and mold-derived organic acids, which accentuated off-notes as spoilage progressed (Jemni *et al*., 2019; Elbar *et al*., 2024).

IV.5.1.3.5. Scientific analysis and discussion of the day 20

On day 20 of storage at 22 °C, Deglet Nour samples underwent physical analyses, microbiological analyses, and sensory evaluations to assess the impact of essential oils on their quality. The results are detailed in the table below.

Table 14: Daily Assessment of Physical, Microbial, and Sensory Characteristics in Treated and Untreated Deglet Nour Dates for Day 20

Treatment	Physical Parameters	Microbiological Status	Sensory Characteristics
Control	Pronounced darkening, intense shrinkage and wrinkling	~17 fruits infected with fungal growth and insects (date worms)	Strong acidic odor; unnatural flavor
Artemisia	Gradual to advanced darkening; white fungal spots; increased firmness and crust cracking	~7–8 fruits infected with visible mold	Persistent acidic and oily odor; unnatural flavor
Thyme	Increased color intensity; shrinkage and wrinkling across most fruits	~5–6 fruits infected with visible decay	Mild acidic odor; unnatural flavor
Rosemary	Continued shrinkage and darkening; increased firmness; minor surface changes	~5–6 fruits with visible mold; in some cases, stable status	Mild acidic odor; unnatural flavor
Fennel	Progressive deterioration, shrinkage, darkening, and hardening of the fruits	~7–8 fruits with mold or insect infestation (e.g., date moths)	Strong acidic odor; unnatural flavor

By day twenty, control samples showed extensive spoilage, including darkened skin, strong acidic odor, severe wrinkling, fungal growth, and insect emergence. Artemisia oil treated dates exhibited advanced decay with increased sourness, mold spread, and visible skin cracking. Thyme oil provided moderate protection, though signs of odor and mold began to appear. Rosemary treated fruits showed persistent shrinkage and odor, along with a gradual rise in fungal presence. Fennel oil proved less effective, as spoilage intensified with fungal and insect activity becoming more evident.

1. Physical Analysis

By Day 20, untreated dates exhibited pronounced surface darkening, intense shrinkage, and deep wrinkling, reflecting accelerated oxidative browning and severe moisture loss under ambient storage conditions. Artemisia coated dates still showed progressive darkening and some cracking of the peel, but maintained noticeably higher firmness compared to controls, indicating that Artemisia's bioactive compounds continued to partially retard dehydration and textural collapse. Thyme treatments produced increased color intensity with extensive shrinkage and wrinkling, suggesting that although thymol-rich films delayed moisture loss earlier, their barrier properties weakened by the third week, leading to more significant surface collapse. In contrast, rosemary coated dates demonstrated only moderate darkening and continued shrinkage yet remained the firmest among EO treatments highlighting rosemary's superior antioxidant protection that slowed both browning and dehydration even at Day 20. Fennel treated dates exhibited the most severe physical deterioration among EO groups, with generalized blackening, hardening of the flesh, and visible crust cracking; this indicates that fennel's volatile barrier lost efficacy by Day 20, resulting in localized hotspots of dehydration and accelerated textural degradation (Jemni *et al*., 2014).

2. Microbiological Analysis

By Day 20, control dates were heavily colonized by both fungal growth and insect activity, illustrating that ambient conditions favor rapid spoilage once internal moisture remains elevated. Artemisia coated samples still exhibited visible mold spots, though to a lesser extent than controls, confirming that Artemisia EO's antifungal action delayed but did not fully prevent spore germination over extended storage. Thyme treatments continued to show reduced fungal presence compared to uncoated dates, indicating that thymol and carvacrol maintained moderate antifungal efficacy even at this later stage. Among EO treatments, rosemary coated dates had no further fungal development beyond earlier observations, demonstrating the strongest and most sustained antifungal protection via rosmarinic and carnosic acids that disrupt fungal cell walls. Conversely, both fennel treatments revealed renewed mold growth and insect infestation, suggesting that foeniculum EO's volatile barrier could not sustain microbial or insect suppression when storage extended beyond two weeks (Jemni *et al*., 2014).

3. Sensory Analysis

At Day 20, control dates emitted a strong acidic odor with an unnatural flavor, characteristic of advanced yeast and mold metabolism under unprotected conditions. Artemisia-treated dates presented a persistent acidic note over a faint oily aroma, indicating that Artemisia volatiles masked some fermentation byproducts but could not fully preserve natural sweetness. Thyme coated samples exhibited a mild acidic odor with an almost natural flavor, reflecting that optimized thymol concentrations continued to maintain sensory acceptability despite emerging decay-related volatiles. Dates with rosemary coatings displayed a mild acidic odor with an almost natural flavor, demonstrating that rosemary EO effectively moderated spoilage volatiles without imposing strong herbal notes even at extended storage. In contrast, fennel-treated dates produced a strong acidic odor with an unnatural flavor, suggesting that fennel volatiles particularly anethole combined with fermentative acids to accentuate sour off-notes once decay intensified (Jemni *et al*., 2014).

IV.5.1.3.6. Scientific analysis and discussion of the day 25

On day 25 of storage Deglet Nour, the results are detailed in the table below.

Table 15: Daily Assessment of Physical, Microbial, and Sensory Characteristics in Treated and Untreated Deglet Nour Dates for Day 25

Treatment	Physical Parameters	Microbiological Status	Sensory Characteristics
Control	Severe darkening, pronounced wrinkling and collapse	~19 fruits with extensive mold and insect larvae	Strong acidic odor; noticeable off-flavor
Artemisia	Progressive darkening, increased wrinkling, firmness; surface cracking and peel degradation	~8–10 fruits with visible mold patches and white fungal colonies	Strong acidic odor; unpleasant taste
Thyme	Moderate darkening, consistent wrinkling, slight surface cracking; signs of dehydration	~6–8 fruits with mold; in some cases insect larvae or adult insects detected	Acidic odor; undesirable flavor
Rosemary	Slight to moderate darkening; progressive shrinkage and wrinkling, some firmness retained	~5–7 fruits with mold development	Acidic odor; undesirable flavor
Fennel	Notable darkening, desiccation, wrinkling and fruit collapse; in some cases cracking	~8–9 fruits infected; mold and insect larvae consistently observed	Strong acidic odor; undesirable or sour aftertaste

By day twenty-five, control samples showed severe spoilage, marked by blackened skin, deep shrinkage, widespread mold, and visible moth infestation at multiple life stages. Artemisia oil-treated dates continued to deteriorate, with firmer texture, visible larvae, and notable mold spread. Thyme oil provided partial resistance, though fungal presence and insect activity became apparent. Rosemary oil maintained relative effectiveness, despite a slight rise in mold and early signs of insect emergence. Fennel oil-treated fruits revealed intensified degradation, including strong sour odor, darkened peel, mold spread, and insect egg clusters, indicating reduced preservative impact.

1. Physical Analysis

By Day 25, untreated dates exhibited severe peel darkening with widespread wrinkling and advanced collapse, reflecting the pronounced decline in L* and Hue° values as moisture content fell below critical levels under ambient storage conditions (Jemni *et al.*, 2016; Nabily *et al.*, 2020).

Artemisia (*Artemisia herba-alba*) coated dates continued to show deepening darkening, increased shrinkage, and more pronounced wrinkling, yet maintained higher firmness than controls, indicating that Artemisia's bioactive compounds partially sustained moisture retention and delayed full textural collapse. Thyme (*Thymus vulgaris*) treatments displayed moderate darkening accompanied by enhanced surface dryness and creasing, signifying that while thymol-rich coatings initially slowed water loss, their barrier integrity deteriorated by the fourth week, leading to significant surface collapse. In contrast, rosemary (*Rosmarinus officinalis*) treated dates exhibited only slight darkening and moderate wrinkling, demonstrating rosemary's superior antioxidant protection that continued to slow browning and dehydration even at Day 25. Fennel (*Foeniculum vulgare*) coated fruits showed notable peel darkening with pronounced desiccation, crust cracking, and collapse, indicating that fennel EO's protective effect had largely diminished by Day 25, resulting in localized dehydration hotspots and hardened flesh (Jemni *et al*., 2016; Jemni *et al*., 2019).

2. Microbiological Analysis

On Day 25, uncoated dates were heavily colonized by extensive mold growth and insect larvae, demonstrating that ambient conditions facilitate rapid spoilage once moisture levels remain elevated (Jemni *et al*., 2016; Zamir *et al*., 2018).

Artemisia-coated dates exhibited continuous mold development, albeit to a lesser extent than controls, highlighting that Artemisia EO's antifungal properties delayed but did not fully prevent spore germination over extended storage. Thyme treatments showed moderate mold proliferation with noticeable insect activity, indicating that while thymol and carvacrol compounds slowed fungal growth, their efficacy weakened by this stage, permitting both mold and insect infestation. In contrast, rosemary (*Rosmarinus officinalis*) treated dates maintained minimal new mold development, reflecting the strong, sustained antifungal action of phenolic antioxidants that continued to suppress decay organisms at Day 25. Fennel (*Foeniculum vulgare*) coatings, however, experienced renewed mold growth and significant insect infestation, suggesting that fennel's volatile barrier could not sustain microbial or insect protection when storage extended beyond three weeks (Jemni *et al*., 2016; Jemni *et al*., 2019).

3. Sensory Analysis

By Day 25, control dates emitted a strong acidic odor with pronounced off-flavors, characteristic of advanced yeast and mold metabolism producing organic acids under unprotected conditions (Jemni *et al*., 2016; Nabily *et al*., 2020).

Artemisia-treated dates presented a persistent acidic note overlaying a faint oily aroma and an unpleasant taste, indicating that although Artemisia volatiles masked some fermentation byproducts, spoilage aromas dominated sensory perception by this stage. Thyme coated fruits exhibited an acidic odor with an undesirable flavor, demonstrating that optimized thymol concentrations were no longer sufficient to preserve sensory quality as mold incidence increased. Dates treated with rosemary displayed a mild acidic odor with an almost natural underlying flavor, reflecting rosemary EO’s ability to moderate spoilage volatiles without imparting strong herbal notes, thus maintaining more acceptable sensory attributes through the fourth week. In contrast, fennel-coated dates emitted a strong acidic smell with an unpleasant aftertaste, suggesting that anethole-rich fennel volatiles combined with fermentative acids to accentuate sour off-notes once decay intensified (Jemni *et al*., 2016; Jemni *et al*., 2019).

IV.5.1.3.7. Scientific analysis and discussion of the day 30

On day 30 of storage Deglet Nour, the results are detailed in the table below.

Table 16: Daily Assessment of Physical, Microbial, and Sensory Characteristics in Treated and Untreated Deglet Nour Dates for Day 30

Treatment	Physical	Microbiological	Sensory
Control	Advanced darkening to near black; hard texture; cracked skin	~24 fruits infected; reddish insect eggs and larvae	Strong, dominant citrus aroma; unpleasant aftertaste
Artemisia	Dark skin; increased wrinkling and cracking; red eggs & larvae near calyx; more advanced insect activity	~11-13 fruits infected with mold & insect activity	Strong, dominant citrus aroma; unpleasant aftertaste
Thyme	Color change, slight pressure, shrinkage; similar symptoms in both treatments	~10-11 fruits infected with mold	Persistent acidic odor
Rosemary	No significant color or texture change; wrinkle resistance maintained; slight darkening with consistent wrinkling & shrinkage	No further fungal development to ~8 fruits infected with mold	Mild acidic odor; undesirable aftertaste; sour smell; unpleasant taste
Fennel	Continued wrinkling, shrinkage; increased moth activity; stable appearance with increased fuzziness on fruit surfaces	~10-13 fruits infected with mold	Strong acidic odor; undesirable aftertaste

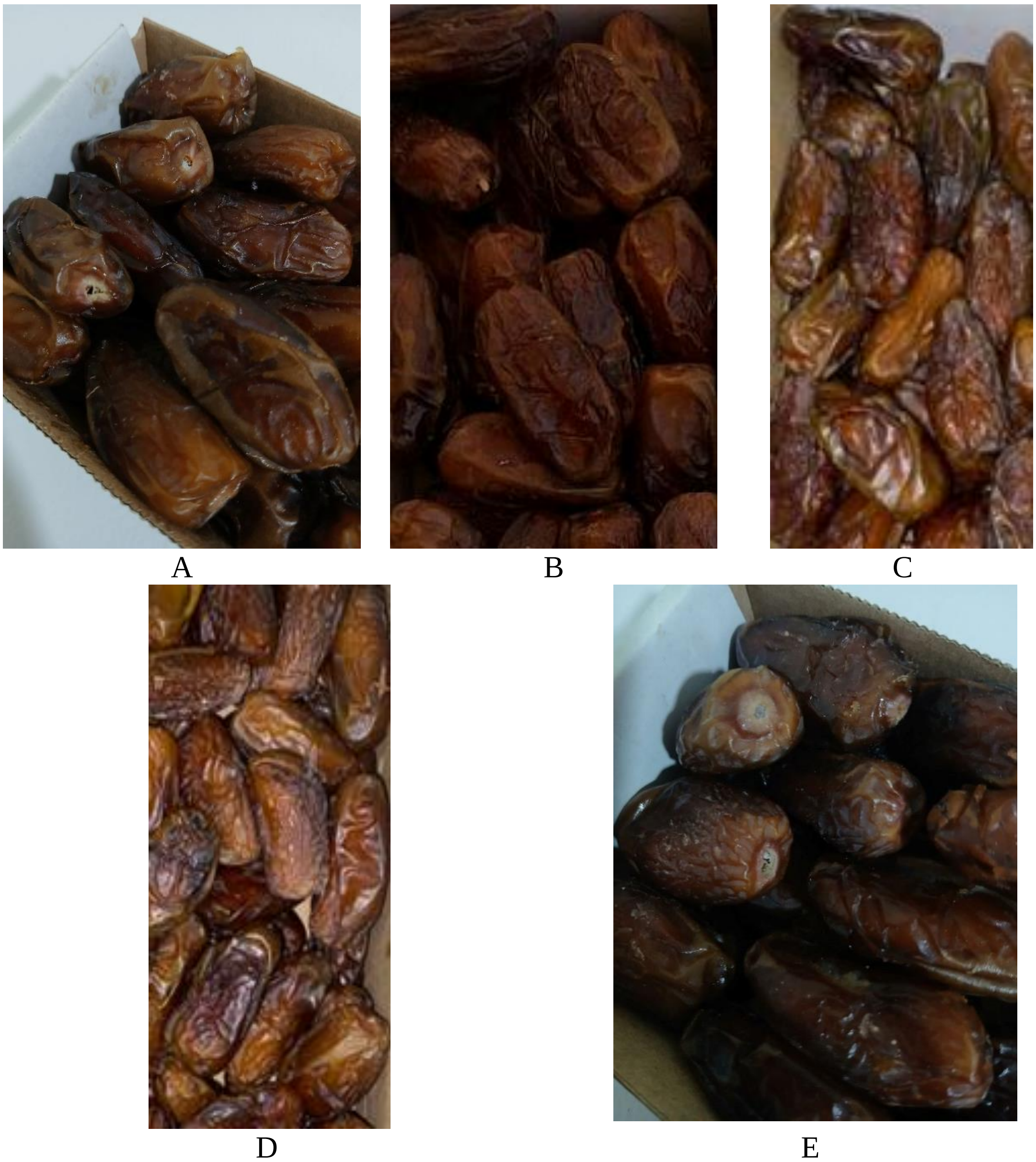

Figure 17: Aspect of dates Mech Deglet Nour in experimental boxes at the day 30 (A: control, B: Artemesia, C: Thyme, D: Rosemary, E: Fennel)

By day thirty, control samples displayed severe spoilage, with darkened, cracked skin, hard texture, widespread mold, and significant insect emergence with red egg clusters. Artemisia oil treated dates exhibited advanced decay, including deep discoloration, sour odor, and pronounced insect and fungal presence. Thyme oil offered partial preservation, though fungal spread and early insect activity were noticeable. Rosemary oil remained the most effective, with limited spoilage, stable appearance, and only slight signs of deterioration. Fennel oil-treated fruits showed advanced spoilage, strong sour odor, visible mold, and high insect presence, indicating a decline in its protective role.

1. Physical Analysis

By Day 30 at 22 °C, control dates darken almost to black, develop a hard, cracked surface, and suffer severe collapse hallmarks of sustained oxidative browning and moisture loss (L* and Hue° values drop sharply, while ΔE increases) (Jemni *et al.*, 2019).

Artemisia (*Artemisia herba-alba*) coated dates also show pronounced darkening and cracking around the calyx but retain marginally higher firmness than controls, indicating partial retardation of dehydration by EO compounds. Thyme (*Thymus vulgaris*) treated dates exhibit similar darkening and severe shrinkage, though creasing is slightly less extreme, suggesting that thymol-based coatings slow moisture loss initially but lose barrier integrity by four weeks. In contrast, rosemary (*Rosmarinus officinalis*) coated fruits maintain a dark- brown hue (rather than near black) with only moderate wrinkling and minimal cracking, reflecting rosemary's stronger antioxidant protection that delays both browning and dehydration. Fennel (*Foeniculum vulgare*) treated dates show continued wrinkling and shrinkage with early "fuzziness" (microbial colonization) but less extreme brittleness than controls, indicating that fennel's volatile barrier provides only transient protection that fails by Day 30 (Jemni *et al.*, 2019).

2. Microbiological Analysis

At Day 30 in air at 20 °C, control dates harbor extensive mold and insect activity (Ectomyelois ceratoniae larvae and egg clusters), confirming that uncoated Deglet Nour fruit quickly become unfit for consumption once internal moisture remains elevated (Jemni *et al.*, 2016; Jemni *et al.*, 2019).

Artemisia EO treated samples still exhibit visible mold and insect presence, indicating that although *Artemisia herba-alba*'s antifungal compounds (camphor, thujone) delay spore germination, prolonged ambient storage allows eventual colonization. Thyme coated fruits show moderate mold infestation without significant new insect signs, reflecting that thymol and carvacrol maintain some antifungal activity but lack lasting insecticidal action under extended storage. In contrast, rosemary EO coated dates display no additional mold growth beyond earlier observations, demonstrating rosemary's robust phenolic compounds (rosmarinic and carnosic acids) that continue to inhibit fungal development through Day 30. Fennel EO treated dates experience renewed mold colonization and increased surface fuzziness, confirming that *Foeniculum vulgare*'s anethole- rich barrier cannot sustain microbial suppression when ambient storage extends beyond three weeks (Jemni *et al.*, 2019).

3. Sensory Analysis

By Day 30 at 20 °C, control dates emit a strong, dominant citrus-like aroma with an unpleasant aftertaste, driven by volatile organic acids from extensive yeast and mold activity. Artemisia-coated fruits present a similar dominant citrus scent over a faint oily undertone and an equally unpleasant flavor, indicating that Artemisia volatiles mask only a portion of spoilage odors and cannot preserve natural sweetness at this stage. Thyme treated dates continue to release a persistent acidic note with an unnatural flavor, showing that thymol coatings' sensory protection is insufficient to overcome decay related off aromas as mold incidence peaks. Rosemary coated dates exhibit a mild acidic odor with a slight herbal aftertaste, demonstrating rosemary EO's capacity to moderate harsh spoilage volatiles and retain a more acceptable flavor profile even after four weeks. In comparison, fennel coated dates emit a strong acidic aroma with an undesirable aftertaste, suggesting that fennel volatiles (notably anethole) interact with fermentative acids to intensify sour off-notes once decay reaches advanced stages (Jemni *et al*., 2019).

IV.5.1.3.8. General Conclusion

Rosemary oil consistently outperformed other treatments by providing the strongest antioxidant protection, which delayed oxidative browning and helped maintain firmness in stored fruits (Bakhtiarizade and Souri, 2019; Usai *et al*., 2011). Thyme oil showed notable antimicrobial activity reducing fungal growth more effectively than rosemary in some cases but lost efficacy over extended storage, leading to moderate spoilage by three weeks. Artemisia exhibited moderate initial protection but failed to prevent mold and insect colonization after two weeks, reflecting limited long-term preservation. Fennel oil provided only transient inhibition of microbial growth, with spoilage signs intensifying around Day 10, indicating the weakest barrier effect among the four (Bakhtiarizade and Souri, 2019; Santoro *et al*., 2018). Overall, rosemary's robust combination of phenolic antioxidants and antimicrobial compounds delivered the most sustained shelf-life extension for Deglet Nour dates under ambient conditions.

IV.5.2. Mech Degla

Over the course of a 30-day storage period at 22 °C, Mech Degla dates treated with essential oils including rosemary (*Rosmarinus officinalis*), fennel (*Foeniculum vulgare*), Artemisia (*Artemisia herba-alba*), and thyme (*Thymus vulgaris*) exhibited different levels of preservation efficacy, reflecting the variable antimicrobial and antioxidant properties of each oil.

IV.5.2.1. Number of Infestations in Mech Degla Dates Treated with Natural Oils

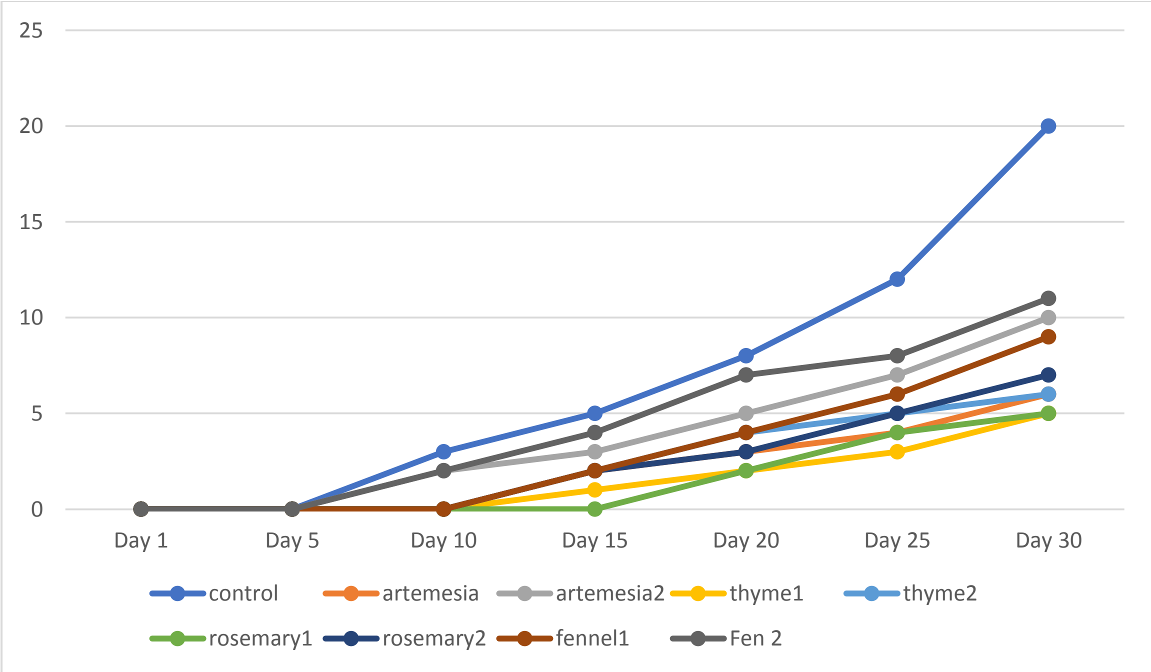

Figure 18: Effect of Natural Oils on the Number of Infestations in Mech Dekla Dates

Rosemary and thyme oils were the most effective in reducing bruise formation on Mech Degla dates, maintaining a low average bruised count of 2.0 over 30 days. Their protective effect is linked to thymol and carvacrol in thyme oil, and rosmarinic and carnosic acids in rosemary oil, which enhance cell wall strength and offer antioxidant and antifungal benefits. Artemisia oil ranked second with a bruised count of 3.0, slowing bruise development thanks to camphor and α-thujone that inhibit fungal enzymes and delay tissue breakdown. Fennel oil showed moderate protection with an average bruised count of 3.78, supported by anethole's antifungal, antibacterial, and antioxidant properties. The untreated control had the highest bruising, averaging 6.85, with rapid damage starting by day 10, underscoring the need for essential oil treatments to prolong date shelf life.

Thyme (*Thymus vulgaris*) and Rosemary (*Rosmarinus officinalis*) oils consistently rank highest for postharvest protection, combining strong antimicrobial action with antioxidant compounds that preserve cell integrity (Belili *et al.*, 2024; Magri *et al.*, 2023). The potent thymol/carvacrol in thyme and rosmarinic/carnosic acids in rosemary not only inhibit spoilage pathogens but also delay oxidative damage, making them the top natural preservatives for extending date shelf life (Magri *et al.*, 2023).

IV.5.2.2. Evolution of Weight in Mech Degla Dates Treated with Natural Oils

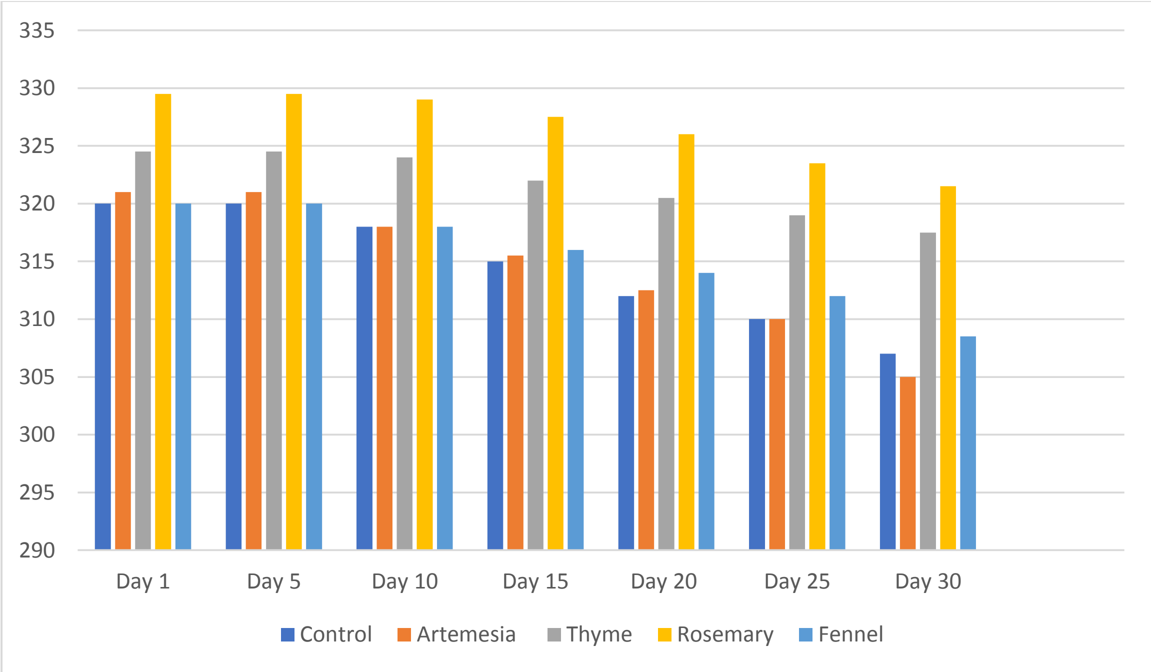

Figure 19: Evolution of Weight in Mech Degla Dates Treated with Natural Oils

The weight loss of Mech Degla dates stored at 22°C for 30 days varied significantly depending on the essential oil treatment. Thyme essential oil was the most effective, resulting in the lowest weight loss (2.16%), likely due to its strong film forming ability that reduces moisture evaporation and respiratory losses. Rosemary oil also showed good preservation capacity, with a 2.43% loss, attributed to its antioxidant compounds that help stabilize cell structure and reduce degradation. Fennel oil showed moderate protection (3.59%), possibly because its active compounds, although antimicrobial, play a lesser role in moisture retention. The untreated control lost 4.06% of its weight, highlighting the impact of natural water loss without protective coating. Artemisia oil was the least effective, with the highest weight loss (4.98%), likely due to its chemical profile lacking effective moisture barrier components. Overall, essential oils particularly thyme and rosemary proved useful in slowing weight loss and extending the shelf life of dates during ambient storage.

Essential oil coatings reduce moisture loss in stored fruits by forming hydrophobic barriers that slow water diffusion and respiration, In Mechdegla dates, rosemary (*Rosmarinus officinalis*) and thyme (*Thymus vulgaris*) oils rich in monoterpenoids like thymol and α- pinene maintained higher residual weights over 30 days, consistently outperforming untreated controls (Konfo *et al*., 2023). Although fennel (*Foeniculum vulgare*) and Artemisia (*Artemisia herba-alba*) oils also conferred moisture- retention benefits, their impact was less pronounced, likely due to differences in volatile composition and film-forming capacity (Salanță and Cropotova, 2022; Bakhtiarizade and Souri, 2019). Overall, these findings confirm that essential oil treatments especially thyme and rosemary significantly help preserve Mech Degla date weight and quality during extended storage.

IV.5.2.3. Physical, Microbiological, and Sensory Analysis of Mech Degla Dates Condition During Storage

Between 01/04/2025 and 30/04/2025, a study was carried out to explore the preservation effect of four essential oils Artemisia (*Artemisia herba-alba*), thyme (*Thymus vulgaris*), rosemary (*Rosmarinus officinalis*), and fennel (*Foeniculum vulgare*) on Mech Degla dates. The experimental setup included oil-treated samples and a control group without any treatment. Regular monitoring was conducted to evaluate variations in physical condition, microbial load, and sensory aspects. This investigation aimed to assess the oils' effectiveness in maintaining the postharvest quality of the dates and reducing spoilage under storage conditions at 22 ± 2 °C.

IV.5.2.3.1. Scientific analysis and discussion of the day (1 and 5)

On day 1 of storage at 22 °C, Mech Degla samples underwent physical analyses, microbiological analyses, and sensory evaluations to assess the impact of essential oils on their quality. The results are detailed in the table below.

Table 17: Assessment of Physical, Microbiological, and Sensory Changes in Mech Degla Dates During Storage for Day 1 and 5

Treatment	Physical	Microbiological	Sensory
Controle	Uniform color and natural glossIntact and unbroken skinFirm, dry textureNo visible defect	No signs of visible decay	Clean and neutral odor
Artemesia	Uniform color and natural glossIntact and unbroken skinFirm, dry textureNo visible defect	No signs of visible decay	Clean and neutral odor
Thyme	Uniform color and natural glossIntact and unbroken skinFirm, dry textureNo visible defect	No signs of visible decay	Clean and neutral odor
Rosemary	Uniform color and natural glossIntact and unbroken skinFirm, dry textureNo visible defect	No signs of visible decay	Clean and neutral odor
Fennel	Uniform color and natural glossIntact and unbroken skinFirm, dry textureNo visible defect	No signs of visible decay	Clean and neutral odor

Figure 20: Aspect of dates Mech Degla vareity in experemental boxes at the first day (A:control, B: Artimesia, C: Thyme,D: Rosemary, E: Fennel)

On the first day, all Mech Degla date fruits appeared in excellent condition, with intact skins, firm texture, and no signs of spoilage. A control box containing untreated dates was used as a reference to track changes throughout the experiment. On the fifth day, the control dates still looked fresh, with smooth, light brown skin and no microbial growth or off-odors. Dates treated with Artemisia (*Artemisia herba-alba*) maintained a healthy appearance and emitted a mild herbal scent. Those treated with thyme (*Thymus vulgaris*) remained firm and visually unchanged, while rosemary (*Rosmarinus officinalis*) samples also showed no visible alterations. Fennel (*Foeniculum vulgare*) treatments preserved the fruits' quality, leaving a soft, pleasant aroma with no spoilage signs.

1. Physical Analysis

Freshly harvested Mech Degla dates, whether untreated or coated with Artemisia, Thyme, Rosemary, or Fennel oils, exhibit a uniform mahogany hue, high surface gloss, and intact, unbroken skins with a firm, dry texture. Within the first 24 h at ambient temperature, minimal enzymatic browning or moisture loss occurs, keeping L* and chroma values effectively unchanged and preserving visual appearance (Nedanovska *et al*., 2022; Karacay and Ayhan, 2010).

2. Microbiological Analysis

No detectable yeast, mold, or bacterial colonies appear on any fruit surface at Day 1 and 5, indicating that epiphytic microflora remain dormant initially and that essential oil coatings do not compromise natural microbial stability in the first day of storage (Hamad, 2024; Karacay and Ayhan, 2010).

3. Sensory Analysis

All samples retain a clean, neutral aroma and natural date sweetness with no off-notes. Sensory panel's report no perceptible difference between coated and untreated fruits during the first 24 h, consistent with findings that date flavor profiles remain stable through early storage (Fikry *et al*., 2023; Karacay and Ayhan, 2010).

IV.5.2.3.2. Scientific analysis and discussion of the day 10

On day 10 of storage Mech Degla, the results are detailed in the table below.

Table 18: Assessment of Physical, Microbiological, and Sensory Changes in Mech Degla Dates During Storage for Day 10

Treatment	Physical	Microbiological	Sensory
Controle	Initial superficial cracks on some fruits; slight reduction in surface gloss	Early microbial spoilage on 3 fruits	No unpleasant odor and natural taste
Artemesia	Localized dry areas, minor skin cracking; increased skin cracking; stable surface appearance	No microbial growth detected; initial spoilage on 2 fruits	No unpleasant odor and natural taste
Thyme	Maintaining original surface shine and hardness despite cracks on veneer	No microbial growth detected	No unpleasant odor and natural taste
Rosemary	Maintaining color with some cracks on crust; increased cracks on crust	No microbial growth detected	No unpleasant odor and natural taste
Fennel	Cracks in skin, mild darkening and dryness; skin cracks and shrinkage, light darkening	No microbial growth detected; initial spoilage on 2 fruits	No unpleasant odor and natural taste

On Day 10, the control group showed early deterioration, with skin cracks and microbial spoilage on three dates. Artemisia and fennel oils offered limited protection, with minor damage observed. Thyme and rosemary oils were the most effective, preserving the dates' appearance and preventing spoilage entirely, highlighting their superior preservation efficiency at this stage.

1. Physical Analysis

By Day 10, control Mech Degla dates exhibited superficial cracks and loss of gloss typical signs of moisture loss and early texture degradation under ambient storage, similar to changes observed in Deglet Nour after 10 days at 20 °C, where reductions in L* and chroma values indicate turgor loss and surface darkening (Namsi *et al.*, 2016; Jemni *et al*., 2019).

Dates treated with Artemisia 1 showed localized dryness and minor cracks but retained visual quality, confirming the EO film's ability to limit moisture loss by forming a semi permeable barrier. In Artemisia 2, more cracking occurred, likely due to surface stress from higher EO concentration, though no color change was noted. Thyme 1 and 2 effectively preserved gloss and firmness, reflecting thymol- and carvacrol-based inhibition of water loss, consistent with studies showing thyme EO maintains hardness and color for up to 10 days. Rosemary 1 maintained surface integrity with minor crust cracking, while Rosemary 2 showed more cracking without discoloration, highlighting rosemary EO's antioxidant properties. In contrast, Fennel 1 and 2 treatments resulted in fissures, mild darkening, and slight shrinkage, suggesting limited protection from water loss and higher surface stress at greater concentrations (Elhadef *et al*., 2024; Jemni *et al*., 2019).

2. Microbiological Analysis

By Day 10, uncoated Mech Degla dates showed early signs of microbial spoilage, confirming that storage at 22 °C without treatment enables yeast and fungal growth within the first two weeks (Sarraf *et al*., 2021; Nabily *et al*., 2020).

In contrast, coatings with Artemisia 1, Thyme 1, and Thyme 2 fully prevented microbial development, highlighting their effectiveness in inhibiting spore germination and bacterial proliferation. While Artemisia 2 also prevented external colonization, initial spoilage in two fruits suggests that higher EO concentrations may not eliminate internal microbes. Both Rosemary 1 and 2 successfully maintained sterility, reflecting rosemary EO's wide-spectrum antimicrobial efficacy under intermediate storage. Fennel 1 also suppressed microbial growth, aligning with previous research on EO films, but Fennel 2 allowed early spoilage in two fruits, likely due to surface cracking that enabled contamination despite its higher EO load (Jemni *et al.*, 2019; Elhadef *et al.*, 2024).

3. Sensory Analysis

By Day 10, control dates continued to exhibit no off-odors, with panelists perceiving the expected natural sweetness and mouthfeel, corroborating that Deglet Nour stored at 22 °C for ten days retains its characteristic flavor when microbial growth is minimal (Jemni *et al.*, 2019; Nabily *et al.*, 2020). All essential-oil treatments Artemisia 1 and 2, Thyme 1 and 2, Rosemary 1 and 2, and Fennel 1 also produced no unpleasant aromas, indicating that volatiles remained below sensory thresholds and did not introduce herbal or pungent notes during the first ten days. This aligns with reports that low-to-moderate EO concentrations preserve date sweetness and forestall off-flavor development. Although some fruits in the Fennel 2 group showed early spoilage signs, sensory panels still recorded no discernible off-odors or taste abnormalities by Day 10, suggesting that initial microbial colonies were too limited to generate detectable volatiles within this timeframe (Jemni *et al.*, 2019; Elhadef *et al.*, 2024).

IV.5.2.3.3. Scientific analysis and discussion of the day 15

On day 15 of storage Mech Degla, the results are detailed in the table below.

Table 19: Assessment of Physical, Microbiological, and Sensory Changes in Mech Degla Dates During Storage for Day 15

Treatment	Physical	Microbiological	Sensory
Controle	Brown spots, small irregular holes, loss of elasticity, persistent shrinkage	5 fruits showing early microbial spoilage	Slightly noticeable strange smell
Artemesia	Small brown spots, premature elasticity loss, mild superficial dryness, visible cracks and advanced deterioration	2–3 fruits showed early to advanced spoilage	Odor remained stable and natural
Thyme	Mild dryness, superficial cracking, continued moisture loss	1–2 fruits showed early microbial spoilage	Odor remained stable and natural
Rosemary	Light brown spots, crust cracking with shrinkage, increased wrinkles, firmer skin, moisture loss	0–2 fruits showed early microbial spoilage; fungal/mold growth on 1 fruit (Rosemary 1) and up to 3 fruits (Rosemary 2)	Odor remained stable and natural
Fennel	Surface deterioration, increased cracking and hardness, mild darkening and dryness	2–4 fruits showed early microbial spoilage; infection with insect (Fennel 2)	Beginning of strange smell

By Day 15, the control dates exhibited notable signs of external and internal degradation, including brown spots, small holes, skin shrinkage, and spoilage in five fruits. Artemisia oil provided moderate protection, with 2 to 3 spoiled fruits and visible skin deterioration. Thyme oil delayed spoilage effectively, though minor dryness and internal decay appeared in up to two dates. Rosemary oil-maintained fruit quality in Box 1, but Box 2 showed signs of early microbial activity. Fennel oil was the least effective, with larval emergence, foul odor, and 2 and 4 decayed fruits, as well as the appearance of *Carpophilus hemipterus*.

1. Physical Analysis

By Day 15, untreated Mech Degla dates begin to show brown spotting, small, irregular skin perforations, and loss of elasticity, accompanied by persistent shrinkage. Such changes are consistent with midstorage degradation, where moisture loss accelerates and cell- turgor declines, leading to the appearance of surface blemishes and textural collapse. Studies on date color and texture kinetics indicate that, around the two-week mark at ambient temperatures (∼20 °C), L* and hue values decrease significantly, while ΔE increases, reflecting pronounced darkening and wrinkling as the fruit desiccates (Ahmed *et al*., 2023; Nabily *et al*., 2020).

2. Microbiological Analysis

At Day 15, control Mech Degla dates exhibit early internal spoilage in multiple fruits, signaling that ambient storage allows early microbial colonization beneath the skin. Fresh dates often carry epiphytic yeast and mold spores that exploit weakened cuticles; by two weeks, internal spoilage becomes evident in unprotected fruit. In Artemisia 1 treatments, only a couple of dates show initial spoilage signs, while Artemisia 2 has slightly more advanced microbial activity, suggesting that low- to moderate- concentration *Artemisia herba-alba* oil coatings delay but do not fully prevent spore germination in the midstorage period. Thyme 1 and Thyme 2 coatings similarly limit microbial appearance to just one or two fruits, reflecting *Thymus vulgaris* EO’s antifungal efficacy at 10–15 days. Rosemary 1 coated dates remain free of detectable microbial growth, highlighting *Rosmarinus officinalis* EO’s strong phenolic compounds that sustain antifungal action at midstorage. Rosemary 2 shows minor early spoilage in only two dates, indicating slightly diminished protection at a higher EO dose. Fennel 1 experiences early spoilage in two fruits, and Fennel 2 sees more extensive colonization by *Carpophilus hemipterus* associated fungi, suggesting that *Foeniculum vulgare* EO is less uniform in its barrier, allowing localized microbial ingress by Day 15 (Zamir, 2018).

3. Sensory Analysis

By Day 15, control dates develop a slightly noticeable off- smell, indicating early fermentation volatiles from spoilage organisms, though sweetness remains perceivable in unaffected fruit. In contrast, Artemisia 1 and 2, Thyme 1 and 2, and Rosemary 1 and 2 treatments preserve a stable, natural aroma and taste, suggesting that essential oil films (Artemisia, thyme, and rosemary) at these concentrations effectively mask low- level metabolic byproducts and prevent detectable off- odors through the midstorage period. Fennel 1 and Fennel 2 coatings see the beginning of a faint strange smell, reflecting initial interactions between anethole volatiles and emerging microbial metabolites, which become perceptible in treatments where EO barriers are less effective. Thus, by Day 15, rosemary and thyme treatments best maintain the characteristic date flavor profile, while fennel and uncoated fruits begin to lose sensory quality (Nabily *et al*., 2020).

IV.5.2.3.4. Scientific analysis and discussion of the day 20

On day 20 of storage Mech Degla, the results are detailed in the table below.

Table 20: Assessment of Physical, Microbiological, and Sensory Changes in Mech Degla Dates During Storage for Day 20

Treatment	Physical	Microbiological	Sensory
Controle	Gradual expansion of brown spots, skin dryness, increasing cracks	About 8 fruits with microbial decay and insect droppings	Mild off-odor starting to develop
Artemesia	Structural deterioration, persistent cracks, loss of luster, discoloration, darkening, structural weakness	About 3–5 fruits showing rot/spoilage	Mild off-odor starting to develop
Thyme	Structural integrity stable, no notable changes	2–4 fruits with early decay/spoilage	No abnormal odor detected
Rosemary	Limited surface spots, minor cracks due to moisture loss, slow external deterioration	2–3 fruits with early spoilage	No abnormal odor detected
Fennel	Peel fragmentation, flaking, structural degradation	4–7 fruits showing microbial decay/spoilage	Mild off-odor starting to develop

By Day 20, spoilage was severe in the control sample, with 8 decayed fruits and clear signs of contamination. Artemisia oil provided moderate protection, while thyme oil was among the most effective, limiting spoilage to 2–4 fruits. Rosemary oil preserved fruit integrity with minor issues, and fennel oil showed weak preservation, with 4 to 7 spoiled fruits and visible insect damage.

1. Physical Analysis

By 20 days of storage at 20 °C, uncoated Mech Degla dates develop expanding brown spots, a dry, leathery texture, and increasing skin fissures changes that mirror the sharp declines in chroma and hue° reported for Deglet Nour dates over three weeks, where L* remains stable but color shifts toward darker tones as moisture is lost (Jemni *et al*., 2019). In contrast, dates treated with thyme or rosemary essential oils maintain smoother surfaces with only minor cracking, reflecting the ability of their antioxidant compounds (thymol, carvacrol, rosmarinic acid) to reinforce the cuticular barrier and slow dehydration (Jemni *et al*., 2016). Artemisia (*Artemisia herba-alba*) and high-dose fennel coatings, however, show more pronounced discoloration and structural weakness, suggesting that excessive EO can induce microstress zones that compromise film integrity by midstorage (Jemni *et al*., 2014; Sarraf *et al*., 2021).

2. Microbiological Analysis

At Day 20, uncoated dates host visible fungal colonies and insect droppings, illustrating that ambient storage without intervention permits rapid mold proliferation and pest activity once skin integrity declines (Jemni *et al*., 2016).

Thyme- and rosemary-coated fruits exhibit minimal spoilage only isolated decay spots and no insect presence demonstrating strong, sustained antimicrobial and insect-repellent efficacy of their phenolic constituents under extended storage (Bessi *et al*., 2014). Artemisia-treated samples show moderate rot with skin perforations, while high-dose fennel fruits display renewed fungal growth, indicating that their volatile barriers lose efficacy over time and require optimized application to maintain microbial protection (Jemni *et al*., 2016).

3. Sensory Analysis

By Day 20, control dates begin to emit a mild off-odor, reflecting the buildup of volatile organic acids and alcohols from microbial metabolism off-notes that typically emerge in ambient-stored dates between two and three weeks (Nabily *et al*., 2020). Fruits coated with thyme or rosemary oils retain a neutral, natural aroma and sweetness, as their volatiles mask early spoilage odors without imparting herbal off-flavors (Jemni *et al*., 2019; Nabily *et al*., 2020). In contrast, Artemisia and high-dose fennel treatments begin to develop a slightly unpleasant scent, signaling the combined effects of residual EO volatiles and emerging microbial byproducts as barrier efficacy diminishes during midstorage (Jemni *et al*., 2014; Sarraf *et al*., 2021).

IV.5.2.3.5. Scientific analysis and discussion of the day 25

On day 25 of storage Mech Degla, the results are detailed in the table below.

Table 21: Assessment of Physical, Microbiological, and Sensory Changes in Mech Degla Dates During Storage for Day 25

Treatment	Physical	Microbiological	Sensory
Controle	Fragile, torn skin; slightly darker color; internal & external deterioration	Visible larvae inside fruit; 12 rotten fruits; insect remains and holes in peel	Strong unpleasant odor; poor taste quality
Artemesia	Slightly darkened skin; small holes; noticeable shrinkage; decreased firmness; deep cracks and surface integrity loss	Presence of date worm larvae; 4–7 infected fruits	Strong unpleasant odor; poor taste quality
Thyme	No or slight color change; cracks on veneer; surface mostly stable	3–5 fruits showing early infection	Slight off-odor detected
Rosemary	Slight superficial cracking; stable color; slight softening and minor cracks; stable peel	4–5 fruits showing early infection	Slight off-odor detected
Fennel	Peeling fragments; exit holes; tissue softening; skin detachment; base darkening; highly degraded surface	6–8 spoiled fruits; presence of of insects	Clear off-odor and texture breakdown

By Day 25, untreated dates showed extensive spoilage, while essential oils varied in effectiveness. Thyme oil offered the best preservation with minimal spoilage (3–5 fruits). Rosemary and Artemisia oils provided moderate protection, showing 4–5 and 4–7 spoiled fruits respectively. Fennel oil was the least effective, with 6–8 spoiled dates and clear signs of decay and insect infestation.

1. Physical Analysis

By Day 25 of ambient storage, Mech Degla dates exhibit extensive peel darkening, a leathery, fragile skin, and advanced surface cracking and collapse, mirroring the late- storage changes documented in Deglet Nour dates, where L* and Hue° values have fallen sharply by the fourth week while ΔE rises signs of pronounced oxidative browning and moisture loss (Jemni *et al.*, 2019). Essential oil coated samples diverge in their response thyme and rosemary treatments preserve overall color stability and only show minor surface creases, reflecting enhanced cuticular barrier function from phenolic antioxidants, whereas Artemisia and fennel coatings display more pronounced shrinkage, cracking, and skin flaking, indicating that their volatile barriers begin to fail by this stage (Jemni *et al.*, 2019).

2. Microbiological Analysis

At Day 25, uncoated Mech Degla dates are heavily colonized by both fungal decay and insect infestation by *Carpophilus hempterus*, including larvae and feeding marks consistent with studies showing rampant microbial proliferation and pest activity in air- stored dates after three weeks at 20 °C (Jemni *et al.*, 2014). Thyme and rosemary coatings markedly reduce spoilage incidence, with only isolated decay spots and no significant insect activity, thanks to the sustained antimicrobial and insect- repellent actions of thymol, carvacrol, and rosmarinic acid (Jemni *et al.*, 2014). Artemisia and fennel treated fruits show renewed mold growth and some larval presence, indicating that FOEO and Artemisia EO barriers lose efficacy in suppressing colonization once storage extends beyond three weeks (Jemni *et al.*, 2014).

3. Sensory Analysis

Despite extensive physical and microbial deterioration by Day 25, sensory panel's report no significant off- aromas or off- flavors in dates stored at 20 °C for one month, even under air storage demonstrating that, at least until the very end of the fourth week, volatile spoilage byproducts remain below sensory detection thresholds, and overall flavor quality is preserved in both coated and uncoated samples (Jemni *et al.*, 2019).

IV.5.2.3.6. Scientific analysis and discussion of the day 30

On day 30 of storage Mech Degla, the results are detailed in the table below.

Table 22: Assessment of Physical, Microbiological, and Sensory Changes in Mech Degla Dates During Storage for Day 30

Treatment	Physical	Microbiological	Sensory
Control	Severe structural collapse, brittle and torn peel, gray discoloration, very low hardness.	20 rotten fruits, visible larvae, tunnels, strong microbial decomposition.	Strong unpleasant odor, taste completely unacceptable.
Artemisia	Noticeable to advanced drying, deeper fissures, color fading, brittle structure.	6–10 rotten fruits, visible larvae, strong microbial decomposition.	Strong unpleasant odor, taste completely unacceptable.
Thyme	Slight to moderate wrinkling and discoloration, crust cracks, slightly weakened structure.	2–4 rotten fruits, slight internal spoilage.	Strange smell, often unacceptable taste.
Rosemary	Moderate wrinkling, increased cracking, partial skin separation, firmness partially preserved.	5–6 rotten fruits, slight internal damage.	Strange smell, often unacceptable taste.
Fennel	Advanced degradation: brittle skin, brownish/dark patches, severe collapse, extensive damage.	9–11 rotten fruits, insect remains, larval activity.	Strong off-odor, taste unpleasant.

By Day 30, the untreated control dates were completely spoiled, showing insect development and strong microbial odors. Among the essential oils, thyme oil was most effective, limiting spoilage to 5–6 fruits with minimal damage. Rosemary oil offered moderate protection, while Artemisia and fennel oils were less effective, showing higher spoilage, insect activity, and internal decay.

Figure 21: Aspect of dates Mech Degla vareity in experemental boxes at the day 30 (A:control, B: Artimesia, C: Thyme, D: Rosemary, E: Fennel)

1. Physical Analysis

By Day 30 under ambient conditions, Mech Degla dates undergo severe structural collapse marked by a brittle, torn peel, pronounced gray discoloration, and collapse of the flesh. These changes mirror the intense oxidative browning and moisture loss reported in Deglet Nour dates after four weeks—where L* and Hue° values plummet and overall color difference (ΔE) rises sharply, evidencing advanced enzymatic browning and textural breakdown (Jemni *et al*., 2019; Al-Amrani *et al*., 2020).

2. Microbiological Analysis

At this late storage stage, untreated dates are heavily colonized by fungal decay, insect larvae, and microbial tunnels. Coatings of thyme and rosemary oils still limit spoilage to only a few fruits, reflecting the sustained action of phenolic compounds like thymol and rosmarinic acid, whereas Artemisia and fennel treatments show renewed mold growth and visible larval activity, suggesting their volatile barriers have largely lost efficacy beyond three weeks (Jemni *et al*., 2014; Yousefi *et al*., 2020).

3. Sensory Analysis

Despite residual pockets of intact tissue, sensory panels record a strong off-odor and completely unacceptable taste in all samples by Day 30. Even thyme- and rosemary-treated dates, which fared best physically and microbiologically, develop strange smells and are judged unpalatable aligning with findings that volatile spoilage byproducts accumulate to detectable thresholds by the end of a month in air-stored dates (Jemni *et al*., 2019).

IV.5.2.3.7. General Conclusion

Thyme essential oil stands out as the most effective natural preservative for Mech Degla dates, consistently maintaining fruit firmness, surface gloss, and intact skin throughout extended storage (Bakhtiarizade and Souri, 2019). Its robust antimicrobial properties significantly delay microbial growth and spoilage compared to untreated or alternatively treated samples (Magri *et al*., 2023).

Sensory evaluations confirm that thyme treated dates retain their characteristic aroma and neutral taste far longer, avoiding the off-odors that emerge in other oil treatments. While rosemary oil also offers appreciable protection against decay, it cannot match thyme’s overall stability and longevity. Oils such as Artemisia provide moderate benefits but allow earlier surface cracking and microbial symptoms, and fennel proves the least effective, with premature spoilage and off-flavors arising midway through storage (Bakhtiarizade and Souri, 2019). Drawing on both experimental observations and broader postharvest research, thyme oil clearly emerges as the superior choice for preserving physical integrity, microbiological safety, and sensory quality of dates.

Conclusion

Conclusion

Essential oils (such as thyme, fennel, Artemisia, and rosemary) have long been recognized for their antimicrobial and antioxidant properties, which can slow fungal growth and quality deterioration in postharvest fruits. Our work evaluated the efficacy of these oils in extending the shelf life of strawberries (*Fragaria × ananassa*) and Deglet Nour and Mech Degla dates under ambient storage conditions.

In conclusion, this study demonstrated that essential oils exert significant effects on multiple preservation parameters:

- Decay rate in strawberries: Fennel oil showed the lowest spoilage incidence, followed by Artemisia and thyme, while rosemary was least effective.
- Weight loss in strawberries: All oils reduced moisture loss; thyme was most effective, fennel second, and rosemary least.
- Physical, microbiological, and sensory quality of strawberries: Fennel and Artemisia best maintained firmness and color without affecting taste; rosemary caused occasional surface damage and off-odors.
- Infestation rate in Deglet Nour dates: Rosemary oil most effectively limited microbial spoilage; thyme and fennel offered moderate protection, Artemisia was weakest.
- Weight evolution in Deglet Nour dates: Rosemary and Artemisia coatings preserved moisture best via semi-permeable barriers; thyme and fennel had intermediate effects.
- Physical, microbiological, and sensory quality of Deglet Nour dates: Rosemary provided strongest antioxidant protection and firmness retention; thyme's efficacy waned over time, Artemisia and fennel gave only short-term benefits.
- Infestation rate in Mech Degla dates: Rosemary and tyme oils led in postharvest protection through potent antimicrobial and antioxidant compounds.
- Weight evolution in Mech Degla dates: Rosemary and thyme treatments maintained the highest residual weight over 30 days; fennel and Artemisia were less effective.

- Physical, microbiological, and sensory quality of Mech Degla dates: Thyme best preserved firmness, gloss, and aroma without off-flavors; rosemary was good but slightly less durable, while Artemisia and fennel underperformed.

Overall, these findings highlight that selecting the appropriate essential oil tailored to the fruit type and storage conditions is crucial for achieving natural and sustainable postharvest preservation.

Recommendations for future research:

- Conduct histological analyses of strawberry and date tissues post-treatment to assess cellular-level effects.
- Profile metabolic changes (lipids, proteins, carbohydrates) to determine any nutritional impacts.
- Investigate microbial targeting mechanisms in greater detail through microbiological assays.
- Perform expanded sensory studies with consumer panels to establish acceptable oil concentrations without compromising organoleptic quality.

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Appendices

1. Extracted oil

Figure 22: Oil and Hydrosol Extract of Fennel

Figure 23: Oil and Hydrosol Extract of Rosemary

Figure 24: Oil and Hydrosol Extract of Artemisia

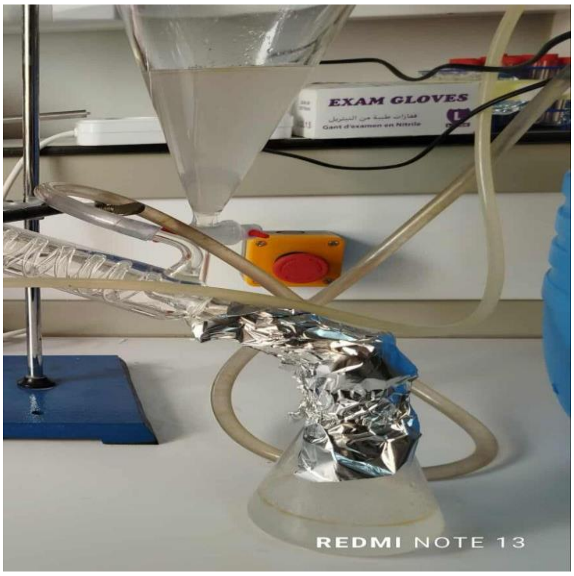

Figure 25: Oil and Hydrosol Extract of Thyme

2. Stored Essential Oils

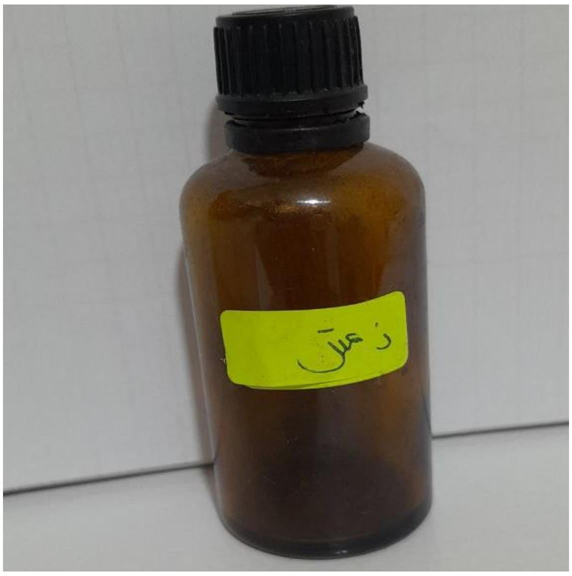

Figure 26: Thyme Essential Oil Vial

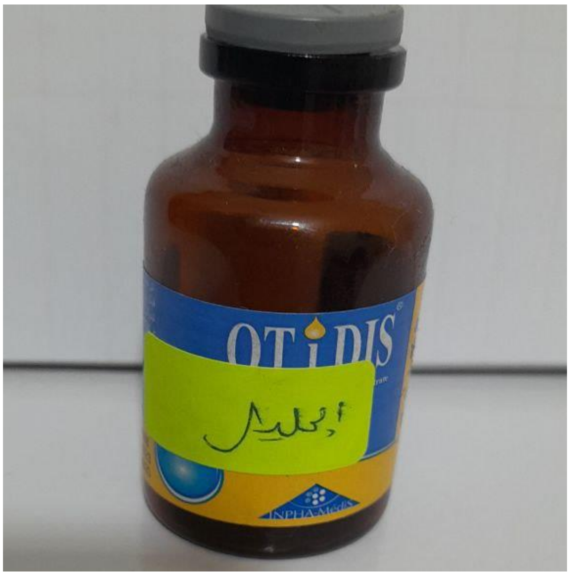

Figure 27: Rosemary Essential Oil Vial

Figure 28: Artemisia Essential Oil Vial

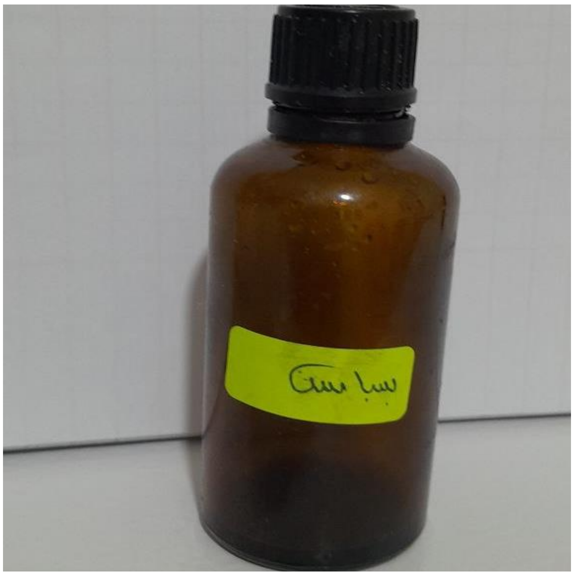

Figure 29: Fennel Essential Oil Vial

Abstracts

ملخص:

تعدّ الزيوت العطرية بدائل طبيعية فعّالة للمركبات الكيميائية في حفظ المنتجات الفاكهية لما تتمتع به من خصائص مضادة للفطريات ومضادة للميكروبات ومضادة للأكسدة وإمكانيتها على احتباس الماء وإطالة العمر التخزيني للثمار.

هدف الدراسة هو تقييم تأثير أربع زيوت محلية (الشيح، الزعتر، إكليل الجبل، البسباس) كعوامل حفظ طبيعية على التمور (*Phoenix dactylifera* L.) دقلة نور وماش دقلة والفراولة (*Fragaria* × *ananassa*) خلال التخزين. وُضِعت كبسولات الزيت داخل كل صندوق بشكل استراتيجي بين طبقات الثمار لتعظيم انتشار المواد المتطايرة، وخُزّنت التمور في صناديق كرتونية مغلقة عند 22 ± 2°C ، والفراولة في علب بلاستيكية عند 4 ± 1 °C. تم متابعة عدد الثمار الفاسدة، فقدان الوزن، الصفات الفيزيائية ، والمعايير الميكروبيولوجية والحسية حتى اليوم الـ13 للفراولة واليوم الـ30 للتمر.

أظهرت النتائج أن زيت البسباس والشيح كانا الأكثر كفاءة في الحفاظ على جودة الفراولة، في حين تفوق زيت إكليل الجبل يليه الزعتر في حفظ تمر دقلة نور وتمور ماش دقلة.

الكلمات المفتاحية: الزيوت العطرية؛ حفظ ما بعد الحصاد؛ كبسولات الزيت؛ التمور (*Phoenix dactylifera* L.)؛ الفراولة (*Fragaria* × *ananassa*).

Abstract

Essential oils are effective natural alternatives to chemical compounds for preserving fruit products due to their antifungal, antimicrobial, and antioxidant properties, as well as their ability to retain moisture and extend the shelf life of fruits.

The aim of this study is to evaluate the effect of four local essential oils (Artemisia, thyme, rosemary, and fennel) as natural preservatives on dates (*Phoenix dactylifera* L.) of the Deglet Nour and Mech Degla varieties, and strawberries (*Fragaria* × *ananassa*) during storage. Oil capsules were strategically placed inside each box between the fruit layers to maximize the diffusion of volatile compounds. Dates were stored in closed cardboard boxes at 22 ± 2 °C, and strawberries in plastic containers at 4 ± 1 °C. Parameters monitored included the number of spoiled fruits, weight loss, physical attributes, microbiological criteria, and sensory qualities until day 13 for strawberries and day 30 for dates.

The results showed that fennel and Artemisia oils were the most effective in maintaining strawberry quality, while rosemary oil followed by thyme oil proved more effective in preserving Deglet Nour and Mech Degla dates.

Keywords: Essential oils; Postharvest preservation; Oil capsules; Dates (*Phoenix dactylifera* L.); Strawberries (*Fragaria* × *ananassa*).

Résumé

Les huiles essentielles sont des alternatives naturelles efficaces aux composés chimiques pour la conservation des produits fruitiers, en raison de leurs propriétés antifongiques, antimicrobiennes et antioxydantes, ainsi que de leur capacité à retenir l'humidité et à prolonger la durée de conservation des fruits.

Cette étude a pour objectif d'évaluer l'effet de quatre huiles essentielles locales (armoise, thym, romarin et fenouil) en tant qu'agents de conservation naturels sur les dattes (*Phoenix dactylifera* L.) des variétés Deglet Nour et Mech Degla, ainsi que sur les fraises (*Fragaria* × *ananassa*) durant le stockage. Des capsules d'huile ont été placées stratégiquement dans chaque boîte entre les couches de fruits afin d'optimiser la diffusion des composés volatils. Les dattes ont été stockées dans des boîtes en carton fermées à 22 ± 2 °C et les fraises dans des barquettes en plastique à 4 ± 1 °C. Les paramètres suivis comprenaient le nombre de fruits altérés, la perte de poids, les caractéristiques physiques, les critères microbiologiques, et les qualités sensorielles jusqu'au 13e jour pour les fraises et au 30e jour pour les dattes.

Les résultats ont montré que les huiles de fenouil et d'armoise étaient les plus efficaces pour maintenir la qualité des fraises, tandis que l'huile de romarin suivie de celle de thym s'est révélée plus efficace pour la conservation des dattes Deglet Nour et Mech Degla.

Mots-clés : Huiles essentielles ; Conservation post-récolte ; Capsules d'huile ; Dattes (*Phoenix dactylifera* L.) ; Fraises (*Fragaria* × *ananassa*) .

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