الجمهورية الجزائرية الديمقراطية الشعبية

People's Democratic Republic of Algeria

وزارة التعـليـم العالي والـبحث الـعلـمي

Ministry of Higher Education and Scientific Research

جامعة الشهيد حمة لخضر الوادي

Martyr Hamma Lakhdar University of El Oued

كلية العلوم الطبيعة والحياة

Faculty of Natural and Life Sciences

قسم البيولوجيا الخلوية والجزيئية

Department of Cellular and Molecular Biology

MASTER'S THESIS

Submitted in Partial Fulfilment of the Requirements for the Degree of Academic Master in Biological Sciences

Specialty: Biodiversity and plant physiology

In accordance with the provisions of Algerian Ministerial Decree No. 1275

THESIS

Formulation of a Corn Starch and Thyme Extract–Based Natural Spray for Postharvest Preservation and Insect Control, Applied to Tomato Fruits and Aphis gossypii

Presented by:
BELILA Meriem

President	Dr. SENIGRA Moussa	**University of El Oued**
Examiner	Dr. LAICHE Khaled	**University of El Oued**
Supervisor	Dr. MOUANE Aicha	**University of El Oued**
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Academic Year: 2025/2026

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بسم الله الرحمن الرحيم

كلك ١٤١٧

إهداء

﴿وَمَا تَوْفِيقِي إِلَّا بِاللَّهِ عَلَيْهِ تَوَكَّلْتُ وَإِلَيْهِ أُنِيبُ﴾ [هود: 88]

إلى نفسي، التي خاضت هذه الرحلة بكل ما حملته من تعب وأمل، وآمنت أن الأحلام لا تتحقق إلا بالإصرار والعمل، فصبرت واجتهدت حتى أصبح هذا الإنجاز حقيقة أعتز بها، وأسأل الله أن يجعل فيه الخير والبركة.

إلى والدي العزيز **عثمان** ووالدتي الغالية **هدى**، اللذين كانا سندًا ودعمًا لي في كل مراحل حياتي، وكان دعاؤهما وتشجيعهما سببًا في وصولي إلى هذه المرحلة.

إلى إخوتي وأختي الأعزاء: **أسيا، عائشة، إبراهيم، زيد، يحيى، وعيسى،** الذين كانوا خير سند وعون، وشاركوا معي لحظات التعب والفرح، فكان وجودهم مصدر قوة وسكينة.

إلى جدتي الغالية زينة، التي كان لحنانها ودعواتها أثر كبير في مسيرتي، وكانت دائمًا مصدر دفء ومحبة.

إلى صديقاتي وكل من وقف إلى جانبي بكلمة طيبة أو دعاء صادق، فكان لهم أثر جميل في هذه الرحلة.

وأخيرًا، إلى كل من ساهم في نجاحي، أهدي هذا العمل بكل حب وامتنان.

الشكر والتقدير

﴿لَئِن شَكَرْتُمْ لَأَزِيدَنَّكُمْ﴾ [إبراهيم: 7]

الحمد لله رب العالمين، الذي بنعمته تتم الصالحات، وبفضله تتحقق الغايات، وله الحمد على توفيقه وإعانته لي لإتمام هذا العمل.

أتقدم بخالص الشكر والتقدير إلى مشرفتي الفاضلة الدكتورة عائشة موان، على توجيهاتها العلمية القيّمة، ودعمها المستمر، ونصائحها السديدة طوال فترة إنجاز هذا العمل.

كما أتقدم بالشكر إلى أعضاء لجنة المناقشة الموقرين، لتفضلهم بقبول مناقشة هذه المذكرة، ولما سيقدمونه من ملاحظات علمية قيّمة.

وأشكر جميع أساتذتي الأفاضل الذين ساهموا في تكويني العلمي، وطاقم المخابر والتقنيين على مساعدتهم وتسهيلاتهم خلال الجانب التطبيقي من الدراسة.

Abstract

This study aimed to develop a natural bio-spray for postharvest fruit preservation with dual functionality, combining postharvest preservation and insecticidal activity, and to evaluate its effectiveness under room-temperature storage conditions as a natural alternative to conventional chemical products. The bio-spray was formulated using the hydroethanolic extract of *Thymus vulgaris* and corn starch, together with other auxiliary ingredients to obtain a stable formulation. The plant extract was prepared by cold maceration using a hydroethanolic solvent (80:20, v/v), yielding an extraction efficiency of 9.96%. Three bio-spray formulations containing 0.375 g, 0.750 g, and 1.125 g of thyme extract per 250 mL were prepared while maintaining the same proportions of the other formulation components. The insecticidal activity of the extract and the formulated sprays was evaluated using a direct contact bioassay against the cotton aphid (*Aphis gossypii*). In addition, the efficacy of the bio-spray in preserving tomato fruits was assessed over a 15-day storage period. The results showed that aphid mortality increased progressively with increasing extract concentration and exposure time. The highest concentration (1.125 g/250 mL) achieved 100% mortality after 15 min, whereas the same mortality rate was reached after 20 and 25 min with the 0.750 g and 0.375 g formulations, respectively. Regarding tomato preservation, the untreated control fruits exhibited the first signs of deterioration from the fifth day, with pronounced deterioration on days 10 and 15. In contrast, all treatments containing thyme extract delayed fruit deterioration and maintained fruit quality throughout the storage period. Among the tested formulations, T2 showed the best performance in preserving fruit firmness, external appearance, and overall quality, followed by T1 and T3. These findings indicate that combining the hydroethanolic extract of *Thymus vulgaris* with corn starch represents a promising strategy for developing a natural bio-spray or edible coating capable of extending the postharvest shelf life of fruits while controlling certain agricultural pests, with strong potential for future commercialization as an environmentally friendly postharvest preservation product.

Keywords: Bio-spray; Postharvest preservation; *Thymus vulgaris*; Hydroethanolic extract; Corn starch; Tomato; *Aphis gossypii*.

الملخص

هدفت هذه الدراسة إلى تطوير بخاخ حيوي طبيعي لحفظ الثمار بعد الحصاد يتميز بفعالية مزدوجة تتمثل في إطالة العمر التخزيني للثمار ومكافحة الحشرات، وتقييم كفاءته تحت ظروف التخزين في درجة حرارة الغرفة، بوصفه بديلًا طبيعيًا للمواد الكيميائية التقليدية. وقد تم تطوير هذا البخاخ بالاعتماد على المستخلص الهيدروإيثانولي لنبات الزعتر (*Thymus vulgaris*) ونشا الذرة، مع إضافة مجموعة من المواد المساعدة للحصول على تركيبة مستقرة. حُضِّر المستخلص النباتي بطريقة النقع البارد باستخدام مذيب هيدروإيثانولي بنسبة (80:20، حجم/حجم)، حيث بلغ مردود الاستخلاص 9.96%. كما تم تحضير ثلاث صيغ من البخاخ الحيوي احتوت على 0.375 غ و0.750 غ و1.125 غ من مستخلص الزعتر لكل 250 مل، مع تثبيت باقي مكونات التركيبة. وتم تقييم النشاط الإبادي للمستخلص والصيغ المحضرة باستخدام اختبار السمية بالملامسة المباشرة ضد حشرة المن القطني(*Aphis gossypii*) ، إضافة إلى دراسة كفاءة البخاخ في حفظ ثمار الطماطم لمدة 15 يومًا. وأظهرت النتائج أن نسبة نفوق حشرة المن القطني ازدادت تدريجيًا بزيادة تركيز المستخلص وزمن التعرض، حيث حقق أعلى تركيز (1.125 غ/250 مل) نسبة نفوق بلغت 100% بعد 15 دقيقة، بينما تحققت نسبة النفوق نفسها بعد 20 و25 دقيقة عند التركيزين 0.750 غ و0.375 غ على التوالي. كما أظهرت ثمار الشاهد علامات التدهور ابتداءً من اليوم الخامس، مع تدهور واضح خلال اليومين العاشر والخامس عشر، في حين ساهمت جميع المعاملات المحتوية على مستخلص الزعتر في تأخير مظاهر التلف والمحافظة على جودة الثمار طوال فترة التخزين. وقد سجلت المعاملة T2 أفضل النتائج من حيث الحفاظ على الصلابة والمظهر الخارجي والجودة العامة للثمار، تلتها المعاملتان T1 ثم T3. وتخلص هذه الدراسة إلى أن دمج المستخلص الهيدروإيثانولي للزعتر مع نشا الذرة يمثل استراتيجية واعدة لتطوير بخاخ حيوي أو طلاء غذائي طبيعي قادر على إطالة العمر التخزيني للثمار والحد من الإصابة ببعض الآفات الزراعية، مما يعزز إمكاناته للتطوير مستقبلًا كمنتج تجاري صديق للبيئة وقابل للتطبيق في مجال حفظ المنتجات الزراعية بعد الحصاد.

الكلمات المفتاحية : بخاخ حيوي، حفظ ما بعد الحصاد، الزعتر(*Thymus vulgaris*) ، المستخلص الهيدروإيثانولي، نشا الذرة، الطماطم، *Aphis gossypii*.

Résumé:

Cette étude avait pour objectif de développer un biopulvérisateur naturel destiné à la conservation des fruits après récolte, doté d'une double fonction consistant à prolonger leur durée de conservation et à lutter contre les insectes ravageurs, puis d'évaluer son efficacité dans des conditions de stockage à température ambiante en tant qu'alternative naturelle aux produits chimiques conventionnels. Le biopulvérisateur a été formulé à partir d'un extrait hydroéthanolique de *Thymus vulgaris*, d'amidon de maïs et d'autres ingrédients auxiliaires afin d'obtenir une formulation stable. L'extrait végétal a été obtenu par macération à froid à l'aide d'un solvant hydroéthanolique (80:20, v/v), avec un rendement d'extraction de 9,96 %. Trois formulations du biopulvérisateur contenant respectivement 0,375 g, 0,750 g et 1,125 g d'extrait de thym pour 250 mL ont été préparées, tout en maintenant constantes les proportions des autres composants de la formulation. L'activité insecticide de l'extrait et des formulations a été évaluée par un test de toxicité par contact direct contre le puceron du cotonnier (*Aphis gossypii*). Par ailleurs, l'efficacité du biopulvérisateur pour la conservation des tomates a été étudiée pendant une période de stockage de 15 jours. Les résultats ont montré que la mortalité de *Aphis gossypii* augmentait progressivement avec l'augmentation de la concentration de l'extrait et du temps d'exposition. La concentration la plus élevée (1,125 g/250 mL) a entraîné une mortalité de 100 % après 15 minutes, tandis que le même taux de mortalité a été atteint après 20 et 25 minutes avec les formulations contenant respectivement 0,750 g et 0,375 g d'extrait. Concernant la conservation des tomates, les fruits témoins ont présenté les premiers signes de détérioration à partir du cinquième jour, avec une dégradation marquée aux dixième et quinzième jours. En revanche, toutes les formulations contenant l'extrait de thym ont retardé la détérioration des fruits et ont permis de préserver leur qualité tout au long de la période de stockage. Parmi les traitements testés, la formulation T2 a obtenu les meilleurs résultats en termes de maintien de la fermeté, de l'aspect externe et de la qualité globale des fruits, suivie des formulations T1 et T3. Cette étude montre que l'association de l'extrait hydroéthanolique de *Thymus vulgaris* et de l'amidon de maïs constitue une stratégie prometteuse pour développer un biopulvérisateur ou un enrobage comestible naturel capable de prolonger la durée de conservation des fruits après récolte tout en contrôlant certains ravageurs agricoles, avec un fort potentiel de développement en tant que produit commercial respectueux de l'environnement.

Mots-clés : Biopulvérisateur ; Conservation post-récolte ; *Thymus vulgaris* ; Extrait hydroéthanolique ; Amidon de maïs ; Tomate ; *Aphis gossypii*.

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INTRODUCTION

Introduction:

Fresh fruits are considered one of the most important components of a healthy human diet due to their high nutritional value. They are rich sources of vitamins, minerals, dietary fibers, antioxidants, and a wide range of bioactive compounds that significantly contribute to human health and help prevent several chronic diseases, including cardiovascular diseases, diabetes, obesity, and certain types of cancer **(Slavin & Lloyd, 2012; FAO, 2021).** In addition to their nutritional importance, horticultural crops play a key economic role by providing income for farmers, creating job opportunities, and contributing to food security and agricultural trade. With increasing awareness of healthy nutrition, the global demand for fresh fruits continues to rise.

Despite their importance, fresh fruits are highly perishable products due to their continued metabolic activity after harvest. Physiological and biochemical processes such as respiration, transpiration, ethylene production, enzymatic activity, and water loss continue postharvest, leading to rapid quality deterioration and reduced shelf life. In addition, microbial contamination and insect infestation accelerate spoilage, causing significant quantitative and qualitative losses. According to the Food and Agriculture Organization (FAO), approximately one-third of food produced for human consumption is lost or wasted annually, with fruits representing a major share due to their short postharvest life, and losses may exceed 40% in developing countries due to inadequate handling, storage, and preservation practices **(FAO, 2021).**

In this context, edible coatings have emerged as a promising technology to reduce postharvest losses and improve the quality of fresh produce. These coatings consist of thin edible layers applied to the surface of fruits, forming a semi-permeable barrier that reduces moisture loss, regulates gas exchange, delays ripening, and limits microbial growth. As a result, edible coatings help maintain fruit quality, preserve nutritional value, and extend shelf life without compromising food safety **(Falguera et al., 2011; Baldwin et al., 2012).** They can also act as carriers of natural antioxidant, antimicrobial, and insecticidal compounds, enhancing their functional effectiveness.

The composition of coating solutions plays a crucial role in determining their physical properties and performance on fruit surfaces. Wettability, adhesion, and spreading ability depend not only on the main polymer but also on additives such as Tween 80 and glycerol, which reduce surface tension and improve uniform distribution on the fruit surface. Starch is one of the most widely used natural polymers in edible coatings due to its availability, low cost, biodegradability, and good film-forming ability. Starch-based coatings have been successfully applied to extend the shelf life of several fruits by reducing weight loss and delaying deterioration. Their performance can be further improved by plasticizers such as glycerol or hydrophobic additives, which enhance flexibility and reduce film brittleness, making the coating more suitable for irregular fruit surfaces **(Valencia-Chamorro et al., 2018).**

Thymus vulgaris L. (common thyme) is a medicinal and aromatic plant rich in bioactive compounds, particularly thymol and carvacrol, which exhibit strong antioxidant, antibacterial, antifungal, and insecticidal activities. Many studies have highlighted thyme extract as a natural alternative to synthetic pesticides and preservatives, making it a promising candidate for sustainable agriculture and food preservation applications **(Baser et al., 2022; Nazzaro et al., 2019).**

Based on these considerations, the main research question of this study is:

Can a bio-based spray formulated from corn starch and hydroethanolic extract of Thymus vulgaris L. achieve a dual function in improving postharvest preservation of fruits and exhibiting effective insecticidal activity against agricultural pests?

The study is based on a single main hypothesis stating that the starch-based bio-spray enriched with hydroethanolic thyme extract exhibits dual functionality, improving postharvest fruit preservation and extending shelf life, while also demonstrating insecticidal activity that makes it a potential natural alternative to conventional chemical treatments.

The objective of this study is to formulate a natural bio-spray based on corn starch and hydroethanolic Thymus vulgaris extract, and to evaluate its effectiveness in postharvest fruit preservation and shelf-life extension, as well as its insecticidal activity to its potentialas an eco-friendly alternative in agricultural protection.

Tomato fruits were used as an experimental model in this study to evaluate the effectiveness of the proposed spray, due to their high perishability and wide consumption, making them an appropriate model for postharvest treatment assessment.

To achieve these objectives, the thesis is organized into two main parts. The first part, the theoretical framework, includes three chapters: Chapter One covers postharvest fruit preservation and factors affecting quality and shelf life; Chapter Two discusses edible coatings in terms of their concept, properties, mechanisms, and applications; and Chapter Three presents the scientific basis of the proposed spray components.

The second part, the practical framework, also consists of three chapters: Chapter One presents materials and methods, including extract preparation, bio-spray formulation, and experimental procedures; Chapter Two presents the obtained results; and Chapter Three discusses these results in comparison with previous studies. The thesis concludes with a general conclusion summarizing the main findings, along with recommendations and future research perspectives.

Part I:
Theoretical Framework

Chapter I:

PRESERVATION OF FRUITS AND VEGETABLES AFTER HARVEST

1.-Definition of Fresh Fruits and Vegetables and Their Nutritional and Economic Importance

1.1.-_Botanical Definition

Plant science precisely distinguishes between the two concepts of vegetables and fruits. Fruit *(fruit)* is defined as the plant organ resulting from the development of the flower's ovary after fertilization, serving as the vessel that holds the seeds. Vegetables *(légumes/vegetables)*, on the other hand, encompass all other edible plant parts, including roots, leaves, stems, flowers, and tubers. From a strict botanical standpoint, tomatoes, cucumbers, peppers, and zucchini are considered botanical fruits; however, they are classified commercially and nutritionally as vegetables **(Kader, 2002).**

2.2.-Nutritional Definition

From a nutritional perspective, fresh vegetables and fruits are defined as plant-based products with a high-water content ranging between 75% and 95% of their weight, rich in vitamins, minerals, dietary fiber, and protective phytochemicals, with a notably low content of energy and fats.

Regular consumption of fruits and vegetables as plant-based foods is associated with a reduced risk of chronic diseases **(Slavin & Lloyd, 2012).** They are also characterized by their rapid perishability, which makes post-harvest management a critical factor in preserving their nutritional and economic value **(FAO/OMS, 2021).**

2.3.-Nutritional Importance:

Vitamins

Fruits and vegetables are among the richest dietary sources of both water-soluble and fat-soluble vitamins ***(Slavin and Lloyd, 2012)*****:**

Vitamin C: abundant in citrus fruits, strawberries, peppers, and broccoli; plays a critical role in immune function, collagen synthesis, and antioxidant defence.

Vitamin A: (Beta-carotene): found in carrots, sweet potatoes, tomatoes, and leafy greens; essential for vision, skin integrity, and immune response.

Vitamin K: present in dark leafy vegetables such as spinach and kale; necessary for blood coagulation and bone metabolism.

B-group vitamins: (B1, B6, B9/Folate): widely distributed across vegetables and legumes; support neurological function, energy metabolism, and DNA synthesis ***(Slavin and Lloyd, 2012; FAO, 2021).***

Minerals:

Fruits and vegetables supply a wide range of essential minerals (Tab.1) that regulate vital physiological processes. ***(Slavin and Lloyd, 2012)*:**

Table 1: Types of minerals *(Slavin and Lloyd, 2012)*

Mineral	Main Sources	Key Function
Potassium	Banana, dates, tomatoes	Blood pressure regulation
Calcium	Spinach, broccoli, orange	Bone and muscle health
Iron	Lentils, spinach, berries	Oxygen transport
Magnesium	Leafy greens, legumes	Enzyme activation
Manganese	Pineapple, spinach	Antioxidant enzyme support

Dietary Fiber:

Dietary fiber, present in high concentrations in most fruits and vegetables, promotes healthy gut microbiota, regulates bowel function, lowers blood cholesterol, and reduces the glycemic response after meals **(Slavin and Lloyd, 2012).** A diet rich in fiber from plant sources has been consistently associated with a lower incidence of colorectal cancer and metabolic syndrome **(FAO, 2021).**

Water Content and Energy Density:

Most fresh fruits and vegetables have a high water content ranging from 85% to 95%, and a naturally low energy density, making them ideal components of weight-management diets and contributing to daily hydration needs **(FAO, 2021; Slavin and Lloyd, 2012).**

2.4.-Economic Importance

The global fruits and vegetables sector exceeds 2 billion metric tons in annual production **(FAO, 2022),** with a market size of $875 billion in 2025 and 6.68% growth until 2030 **([Statista, 2025][Market Data Forecast, 2024).**

In developing countries, the sector is essential for income and food security; improving post-harvest management increases farmers' income by 15–25% **(FAO, 2021).**

Post-harvest losses reach 25–50% in developing countries versus 15–20% in developed ones, causing billions in annual losses **(Kader, 2002).**

2.- Postharvest Deterioration of Fresh Fruits and Vegetables

Postharvest is considered one of the most critical stages during which fruits and vegetables are exposed to deterioration and loss. In developing countries, postharvest losses are estimated at 20% to 55% of total production, which reduces profit due to the shortened storage life. This loss affects both quantity and quality and may also result from disease infection **(Kader, 2002; Wills et al., 2007).**

2.1.-Physiological Symptoms

Water Loss and Wilting

Water loss is one of the most important physiological signs of deterioration in fresh fruits and vegetables after harvest, occurring mainly as a result of continued transpiration and, to a lesser extent, respiration **(Lufu et al., 2020; Saltveit, 2016).** It leads to wilting, shrinkage, loss of firmness, and reduced glossiness, which negatively affects the sensory and market quality of the product **(Lufu et al., 2020).** Even a relatively small loss of fresh weight may accelerate physiological senescence and shorten the storage life of fruits and vegetables **(Saltveit, 2016).** The severity of this phenomenon increases under unfavorable storage conditions, especially when temperature is high and relative humidity is low **(Lufu et al., 2020; Li et al., 2025).**

Continuous Respiration

Continuous respiration after harvest is one of the most significant physiological processes in which plant tissues maintain oxygen consumption and break down stored organic compounds including sugars, organic acids, and lipids to generate energy through two main stages: glycolysis in the cytoplasm, followed by the Krebs cycle in the mitochondria(fig.1) **(Saltveit, 2016; Almerja, 2024).** An elevated respiration rate accelerates the depletion of reserve substrates, increases heat and CO_2 production, and promotes moisture loss, all of which contribute to rapid quality deterioration and a shortened postharvest shelf life **(Saltveit, 2016; ARC Egypt, 2024).**

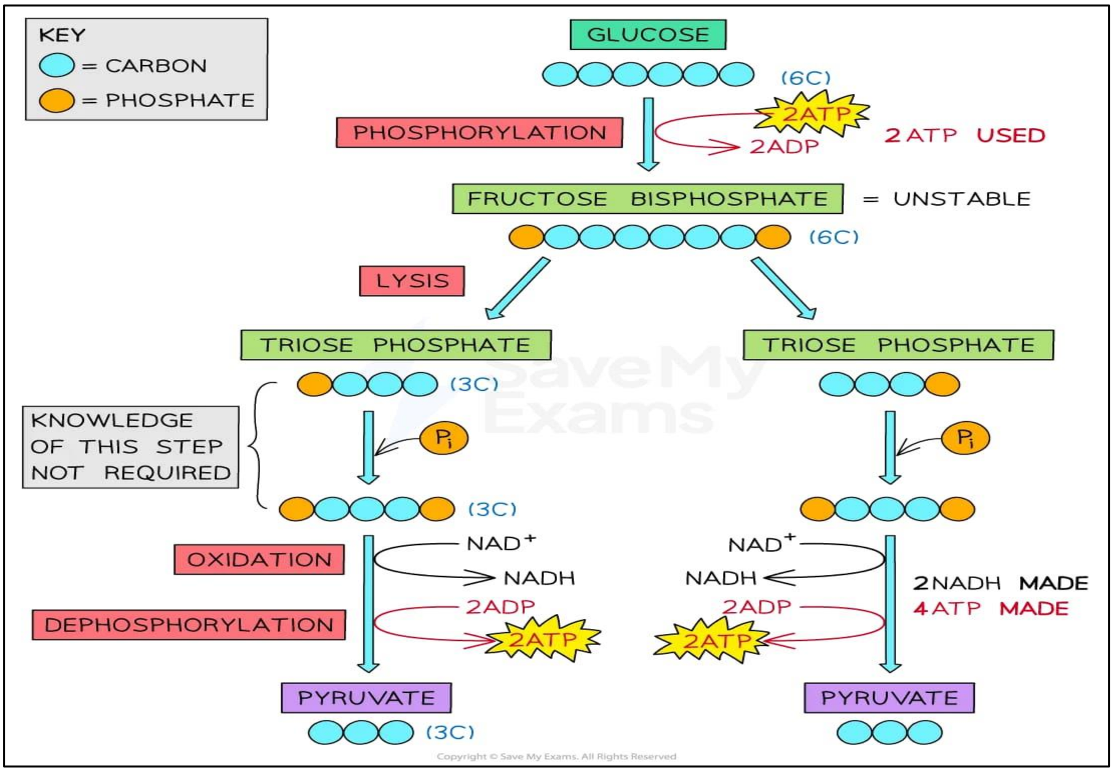


Figure 1: Conversion of glucose to pyruvate through 10 enzymatic steps, yielding 2 ATP and 2 NADH net (OpenOregon, 2024; Khan Academy, 2025).

Ethylene Production

Ethylene (C_2H_4) is the only gaseous hormone in plants a simple unsaturated hydrocarbon naturally produced in plant tissues during ripening and senescence. It is biosynthesized primarily from the amino acid methionine via a well-established enzymatic pathway: Methionine → SAM → ACC → Ethylene, in the presence of oxygen **(Liebermann et al., 1966; Yang et al., 1967, cited in Agronomie.info).** This hormone triggers a cascade of physiological and biochemical changes in harvested fruits, including cell wall degradation, starch-to-sugar conversion, color change, and tissue softening all of which accelerate ripening and shorten postharvest shelf life **(Salk Institute, 2016; JoVE, 2020).** Climacteric fruits such as banana, tomato, and apple exhibit a sudden surge in ethylene production accompanied by a respiratory climacteric at the onset of ripening, whereas non-climacteric fruits such as grapes and citrus produce minimal ethylene without such a peak, making them inherently more storable **(Agronomie.info; Huafan Smart, 2024)**

Senescence in Fruits and Vegetables after Harvest

Postharvest senescence represents the terminal stage of the shelf life of fruits and vegetables an irreversible, genetically programmed physiological process that is triggered immediately upon separation of the produce from the parent plant, marking the transition from productive metabolism to progressive tissue deterioration **(Saltveit, 2016; Bashaier, 2024).** Its manifestations in harvested fruits and vegetables include chlorophyll degradation and yellowing of tissues, cell wall pectin breakdown leading to softening and loss of firmness, decline in nutritional value, and increased susceptibility to fungal and bacterial pathogens **(Uobasrah Postharvest Lectures; Elaard, 2021).** The rate of postharvest senescence is primarily governed by ethylene concentration, storage temperature, relative humidity, and O_2/CO_2 ratios in the storage atmosphere making the precise management of these factors the cornerstone strategy for extending the postharvest life and marketability of fresh produce **(Uobasrah Postharvest Lectures; Agro-lib, 2022).**

2.2.-Chemical and Biochemical Symptoms

Conversion of glucose to pyruvate through 10 enzymatic steps, yielding 2 ATP and 2 NADH net **(OpenOregon, 2024; Khan Academy, 2025).**

Microbiological Symptoms

Microbiological symptoms in harvested fruits and vegetables refer to deterioration caused by the growth of microorganisms, mainly fungi, yeasts, and bacteria, which leads to decay, soft rot, mold development, and loss of marketable quality **(University of Babylon, 2019; Agro-lib, 2025).** In many cases, these pathogens enter through wounds, cuts, bruises, or natural openings in the produce surface, and their development is favored by high humidity, warm storage conditions, and weakened tissue integrity after harvest **(University of Babylon, 2019; FAO, 2000).** Common visible signs include softening, watery breakdown, surface mold, discoloration, and offensive odors, all of which indicate active microbial spoilage during storage and transport **(Agro-lib, 2025; Postharvest Biology and Technology sources).**

2.3.-Physical and Visible Symptoms

Water Loss and Wilting

Water loss through transpiration reduces cell turgor pressure(fig.2), resulting in wilting, shrinkage, and loss of fresh weight **(Wills et al., 2016).**

Figure 2: Postharvest wilting and water loss symptoms observed in vegetables (Adapted from Kader, 2002)

- **Color Changes**

Color alterations occur due to chlorophyll degradation and changes in the concentration of natural pigments such as carotenoids and anthocyanins during storage **(Kader, 2002).**

- **Softening**

Tissue firmness decreases as a result of cell wall degradation, particularly the breakdown of pectic substances by hydrolytic enzymes **(Paliyath et al., 2008).**

- **Microbial Decay**

The growth of fungi and bacteria is one of the major causes of postharvest spoilage, leading to the appearance of lesions, rots, and tissue breakdown **(Wills et al., 2016).**

- **Mechanical Injuries**

Cuts, bruises, and abrasions caused during harvesting, handling, and transportation accelerate water loss and increase susceptibility to microbial infection **(Kader, 2002).**

3.-Factors Affecting Storage Life

The storage life of fresh fruits and vegetables is influenced by a combination of intrinsic and extrinsic factors that interact to determine the rate of deterioration and the duration of marketable quality **(Kader, 2002; FAO, 2021).**

3.1.- Temperature

Temperature is the single most important factor affecting storage life. High temperatures accelerate respiration rate, ethylene production, water loss, and microbial growth, all of which lead to rapid deterioration. For every 10°C rise in temperature, the rate of biological reactions approximately doubles *(Q10 law)*. Conversely, low temperatures close to 0°C significantly slow down metabolic processes and extend storage life. However, chilling-sensitive crops such as bananas, tomatoes, and cucumbers suffer chilling injury when stored below their critical threshold temperatures **(Wills et al., 2007; Kader, 2002).**

3.2.- Relative Humidity

Relative humidity (RH) directly affects the rate of water loss from fruits and vegetables. Low RH promotes transpiration, leading to weight loss, wilting, and shriveling, while excessively high RH encourages the growth of fungi and bacteria on the surface of produce. The optimal RH for most fresh produce ranges between 90% and 95%, which minimizes water loss while limiting microbial proliferation **(Wills et al., 2007; Snowdon, 1990).**

3.3.- Nature of the Plant Product

The nature of the plant product is an important factor influencing its postharvest storage life. Fruits and vegetables differ in their physiological characteristics, including respiration rate, water content, surface structure, and sensitivity to environmental conditions. Products with high respiration rates generally deteriorate more rapidly than those with lower respiration rates. Similarly, commodities with high moisture content are more susceptible to water loss, wilting, and microbial spoilage. Therefore, the effectiveness of postharvest preservation techniques largely depends on the biological and physiological properties of the plant product **(Kader, 2002; Wills et al., 2016).**

3.4.- Initial Microbial Load

The initial microbial load at harvest is a critical determinant of storage life. Produce harvested under poor hygiene conditions, or exposed to soil, contaminated water, or damaged surfaces, carries a higher load of bacteria, yeasts, and molds. Even under ideal storage conditions, a high initial microbial load accelerates spoilage and significantly shortens shelf life. Good Agricultural Practices (GAP) and proper sanitation during and after harvest are therefore essential to reduce this load **(Snowdon, 1990; FAO/OMS, 2021).**

3.5.- Ethylene Concentration

Ethylene gas, produced naturally by the produce itself, accelerates ripening, softening, and s enescence. Storing ethylene-sensitive crops near ethylene-producing crops *(e.g., apples near leafy vegetables)* dramatically shortens their shelf life **(Wills et al., 2007).**

3.6.- Atmospheric Composition

The levels of oxygen (O_2) and carbon dioxide (CO_2) in the storage environment directly affect respiration rate and microbial activity. Modified Atmosphere Packaging (MAP) and Controlled Atmosphere (CA) storage reduce O_2 and increase CO_2 levels to slow down metabolism and extend storage life **(Kader, 2002).**

Chapter II:

EDIBLE COATINGS

1.-Concept and Classification of Edible Coatings

Edible coatings are defined as thin, transparent layers applied directly to the surface of food products. They are made from natural, edible materials such as proteins, polysaccharides, and lipids, with the aim of forming a protective barrier that limits the transfer of moisture and gases, thereby extending shelf life while maintaining product safety and edibility(tab.1) **(Falguera et al., 2011; Baldwin et al., 2015).**

Edible coatings contribute to postharvest food preservation by reducing water loss, slowing respiration processes, and inhibiting the growth of microorganisms. They can also serve as carriers for active compounds with antioxidant or antimicrobial properties **(Bourtoom, 2008; Otoni et al., 2016).**

Studies indicate that agricultural products are subject to considerable microbial spoilage after harvest, and these losses are higher in developing countries due to limited storage and transport infrastructure, as well as poor handling conditions **(Kader, 2002; FAO, 2021).**

Table 2: Classification of Edible Coatings According to Base Material

Type	Base material	Examples
Polysaccharide-based coatings	Polysaccharides	Starch, chitosan, pectin, carrageenan **(Falguera et al., 2011)**
Protein-based coatings	Plant or animal proteins	Soy protein, albumin, casein **(Bourtoom, 2008)**
Lipid-based coatings	Fats and waxes	Beeswax, carnauba wax **(Baldwin et al., 2015)**
Composite coatings	Combination of two or more types	Starch + lipids, protein + polysaccharides **(Otoni et al., 2016)**

Polysaccharide-based coatings are among the most commonly used in food applications because of their good ability to form cohesive and transparent films. Protein-based coatings are relatively better in mechanical properties, whereas lipid-based coatings are characterized by their high ability to reduce water vapor permeability **(Falguera et al., 2011; Bourtoom, 2008).**

2.-Mechanism of Action of Edible Coatings

- **Formation of a protective layer**

Creates a protective coating on the surface resembling "artificial skin" that protects against mechanical and microbial damage **(Falguera et al., 2011; Bourtoom, 2008).**

- **Reduced water loss**

Limits vapor transfer, maintaining moisture and firmness while reducing wilting and shrinkage **(Baldwin et al., 2015; Otoni et al., 2016).**

- **Gas exchange regulation**

Slows oxygen entry and carbon dioxide exit, reducing cellular respiration and delaying over-ripening and senescence **(Falguera et al., 2011; Kader, 2002).**

- **Prevention of enzymatic reactions**

Limits enzymatic browning that occurs when enzymes react with phenolic compounds upon oxygen exposure **(Varela & Fiszman, 2011; Falguera et al., 2011).**

- **Enhancement with active compounds**

Antimicrobial and antioxidant agents (such as plant extracts) can be added to increase preservative effectiveness and extend storage life **(Otoni et al., 2016; Bourtoom, 2008).**

3.- Advantages and Limitations of Edible Coatings

Environmental Benefits

Reduce postharvest losses by extending storage life, lowering economic losses and reducing resource/energy consumption in production, storage, and transport **(Kader, 2002; Otoni et al., 2016).**

Plant-based coatings delay spoilage and preserve quality longer, supporting use in modern distribution chains **(Falguera et al., 2011).**

Health Benefits

Allow incorporation of active compounds like antioxidants and antimicrobials into the coating, enhancing spoilage inhibition and maintaining product safety and quality **(Bourtoom, 2008; Otoni et al., 2016).**

Align with modern food safety principles that reduce contamination and improve natural preservation **(SFDA, 2020; WHO, 2020).**

Practical Limitations

Effectiveness is influenced by temperature, humidity, and plant product type, potentially reducing barrier properties or preservative efficiency if application/storage conditions are not controlled **(Falguera et al., 2011; Baldwin et al., 2015).**

Starch-based or protein-based coatings may have poor water resistance or limited mechanical strength, requiring formulation improvement or additive reinforcement **(Bourtoom, 2008; Otoni et al., 2016).**

Sensory Limitations

Plant extracts or essential oils may affect taste, odor, and appearance, reduce consumer acceptance if exceed acceptable sensory thresholds **(Falguera et al., 2011; Baldwin et al., 2015).**

Effectiveness should be assessed not only by shelf-life extension but also by preservation of sensory quality and commercial acceptability **(Kader, 2002; Otoni et al., 2016).**

Chapter III:

SCIENTIFIC BASIS OF THE PROPOSED FORMULATION COMPONENTS

1.- Corn starch extracted from *(Zea mays L.)*

Corn starch is a plant-derived polysaccharide extracted from the endosperm of the maize kernel, and it is one of the most widely used biopolymers in food applications due to its abundance, biodegradability, and food-grade safety **(Vamadevan and Bertoft, 2022).**

Chemical Structure:

- **Consists of two main components:** amylose and amylopectin, both built from glucose units linked by α-1,4 glycosidic bonds, with α-1,6 bonds at amylopectin branching points **(Pérez and Bertoft, 2010).**
- **Amylose**: Less branched, semi-linear structure contributes to cohesive film formation after drying **(Seung, 2020).**
- **Amylopectin**: Branched structure gives corn starch higher viscosity and important gelatinization properties when heated in water, directly affecting starch behavior during preparation and application **(Vamadevan and Bertoft, 2022).**

Functional Properties:

- **Gelatinization**: Upon heating, granules absorb water, swell, and partially disintegrate to form a homogeneous viscous paste suitable for coating and film preparation **(Wang et al., 2024).**
- **Film-forming:** Polymer chains rearrange during cooling and drying to produce a cohesive thin layer that evenly covers the food surface **(Chen et al., 2024).**
- **Viscosity:** Helps distribute the starch solution over the coating surface without excessive flow or undesired thinning **(Mua and Jackson, 1997).**
- **Edible, non-toxic, biodegradable:** Makes it suitable for edible packaging systems **(Abotbina et al., 2025).**

Role as Protective Coating:

- Forms a semipermeable barrier on fruit/vegetable surfaces, allowing limited gas and vapor passage, reducing moisture loss and limiting rapid internal environment changes **(Chen et al., 2024).**

- Reduces cellular respiration intensity and delays ripening by creating a naturally modified atmosphere around the fruit through reduced oxygen transfer and increased carbon dioxide retention **(Riva et al., 2023).**

- Acts as a carrier matrix that can be combined with natural antioxidants or antimicrobial agents, forming a protective layer with both physical and biological functions simultaneously **(Abotbina et al., 2025)**.

2.-Thyme (*Thymus vulgaris L.*) and Its Extracts

Thyme (*Thymus vulgaris L.)* is a perennial herbaceous plant belonging to the family Lamiaceae, naturally distributed throughout the Mediterranean region, and classified among medicinal and aromatic plants of nutritional and pharmaceutical importance **(Baser et al., 2022; Jaradat et al., 2021).**

Chemical Composition

- Rich in volatile oils, phenolic compounds, flavonoids, terpenoids, and phenolic acids, directly associated with its biological and applied properties in food and medicine **(Jaradat et al., 2021; Baser et al., 2022).**

- Thymol and carvacrol are the most important active compounds, phenolic monoterpene isomers responsible for most of its antimicrobial activity, along with other compounds like p-cymene, 1,8-cineole, and linalool varying by variety, origin, and extraction method **(Borugă et al., 2014; Pina-Vaz et al., 2007).**

Antibacterial Activity

- Thymol and carvacrol disrupt the bacterial cytoplasmic membrane, increasing permeability, causing ionic imbalance loss, intracellular content leakage, and ultimately cell death **(Xu et al., 2008; Nazzaro et al., 2019).**

- Effective against both Gram-positive and Gram-negative bacteria, giving thyme a broad antimicrobial spectrum **(Nazzaro et al., 2019; Baser et al., 2022).**

Antifungal Activity

- Essential oil and pure thymol inhibit growth of several fungal species and reduce sporulation at relatively low concentrations **(Pina-Vaz et al., 2007; Bouhtit et al., 2017).**

- Affects fungal membrane integrity, interferes with virulence factors, and inhibits fungal biofilm formation **(Bouhtit et al., 2017; Nazzaro et al., 2019).**

Practical Importance

- Thyme and its extracts are promising natural plant sources for food and pharmaceutical applications, especially in formulations for microbial preservation and reducing food spoilage through safer, more sustainable methods **(Baser et al., 2022; Jaradat et al., 2021).**

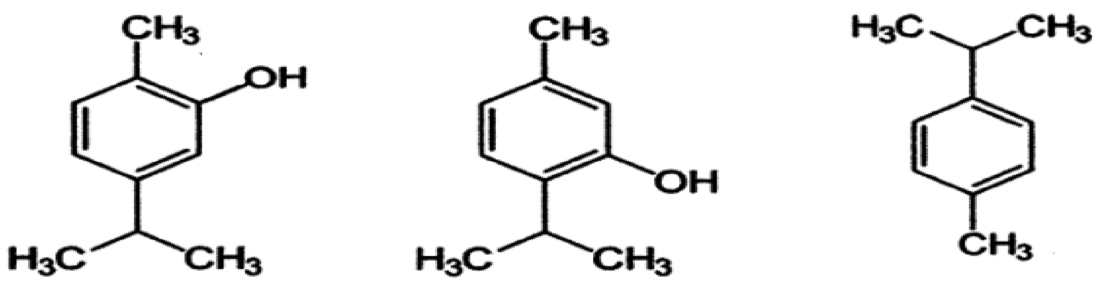


Figure 3: The chemical structure of Thymol, carvacrol and p- cymen (Dauqann&Abdullah;2017)

3.- Auxiliary Components of the Formulation

Auxiliary materials are added to edible coating formulations to improve the physical, chemical, and functional properties of the resulting film, as the base polymeric material alone is insufficient to ensure the flexibility, homogeneity, and microbial stability required during application and storage **(Suput et al., 2021; Gutiérrez and Alvarez, 2023).**

Glycerol (Plasticizer)

- One of the most commonly used plasticizers in starch films, reduces forces between polymer chains and increases their mobility, resulting in greater flexibility and reduced brittleness and cracking after drying **(Müller et al., 2014; Sanyang et al., 2022).**

- Improves formability and elongation, making it suitable for obtaining a homogeneous protective layer with good adhesion to the fruit surface **(Pelissari et al., 2013; Khan et al., 2023).**

Tween 80

- Non-ionic emulsifier that facilitates incorporation of hydrophobic components (such as essential oils or aromatic extracts) into the aqueous phase of the formulation, increasing homogeneity and reducing phase separation **(Tian et al., 2023; Zhang et al., 2020).**
- Improves wettability and spreading on the food surface, helping to form a more uniform layer in thickness and microstructure, especially important in spraying or dipping applications **(Tian et al., 2023; Zhang et al., 2020).**

Citric Acid

- Added mainly to adjust formulation pH, as moderately acidic medium improves stability of some active components and increases microbial preservation efficiency, limits oxidative reactions, and preserves color and sensory properties **(Gurtler et al., 2011; Kaewprachu et al., 2023).**
- Widely used as acidity regulator in food industry, valued for its three pKa values that make it effective in lowering pH and maintaining it within suitable range for food preservation **(Kaewprachu et al., 2023; SFDA, 2014).**

Sodium Benzoate and Potassium Sorbate

- Effective food preservatives against wide range of yeasts, molds, and many bacteria, especially in acidic media where preservative activity is higher **(Pavlovic et al., 2015; Panchal et al., 2019).**
- Applications in edible coatings show that incorporating them into polymer matrix limits microbial growth and delays spoilage of fresh products, while improving shelf life and maintaining sensory properties and overall quality **(Del-Valle et al., 2015; Hassan et al., 2017).**
- Comparative studies show potassium sorbate may be more effective than sodium benzoate against certain yeasts, while combining both can produce better synergistic effect in some acidic food systems **(Smittle, 1995; Romli et al., 2022).**

Part II: Practical framework

Chapter I:

MATERIALS AND METHODE

1.-Materials and Methode

This practical study was carried out in the laboratory of the Faculty of Natural and Life Sciences at Chahid Hamma Lakhdar University – El Oued to evaluate the effectiveness of edible coatings in preserving fruits and vegetables. Tomato fruits were used as the experimental model to assess the ability of these bio-based coatings to improve storage life and maintain fruit quality while reducing weight loss and delaying ripening and spoilage.

1.1.-Materials

1.1.1- Biological Materials

Plant Material

Thyme Plant (*Thymus vulgaris L.*)

Thymus vulgaris L. is a small perennial herbaceous plant from the mint family ***(Lamiaceae),*** ranging 10–30 cm in height, with woody branched stems and a strong aromatic scent produced by essential oils in glandular structures on its leaves **(Dardona et al., 2024; Boskovic et al., 2022).** Its leaves are small, ovate (4–8 mm), gray-green, covered with fine hairs(fig.6), and arranged opposite on the stem. Its flowers are small(fig5), white-pink-purple, in terminal clusters, blooming in spring and summer, bisexual with four stamens **(Dardona et al., 2024).** Its native habitat is the Mediterranean Basin, and it grows naturally in dry limestone soils and sunny semi-arid regions **(Boskovic et al., 2022).** It contains active compounds: thymol and carvacrol (antibacterial, antifungal, antioxidant), flavonoids and tannins (antioxidant and anti-inflammatory), and terpenoids and alkaloids **(Dardona et al., 2024; Al-Khalidi et al., 2026).**

Figure 5: General view of *(Thymus vulgaris L.*) (10–30 cm), woody branched stems, white-pink flowers in terminal clusters, aromatic scent from essential oils (Boskovicl., 2022).

Figure 6: Close-up view of(*Thymus vulgarisL.*) leaves (4–8 mm), gray-green with fine hairs, arranged opposite on stem(Boskovic*l*., 2022).

Classification

According to Plants of the World Online (POWO) – Kew Science, the scientific classification of common thyme(tab.3) ***(Thymus vulgaris L.)*** is:

Table 3 : summarizes the scientific classification of common thyme *(Thymus vulgaris L.)* according to POWO – Kew Science.

Taxonomic Rank	Classification
Kingdom	Plantae
Phylum	Streptophyta
Class	Equisetopsida
Subclass	Magnoliidae
Order	Lamiales
Family	Lamiaceae
Genus	*Thymus*
Species	*Thymus vulgaris L.*

Maize *(Zea mays L.)* : Maize ***(Zea mays L.)*** is an annual herbaceous plant belonging to the family Poaceae (Gramineae). It is one of the world's most important cereal crops due to its high production and significant economic and nutritional value **(Kew Science, 2025; FAO, 2023).**

The plant is characterized by an erect, cylindrical, solid, and generally unbranched stem, with a height ranging from 1 to 4 meters, depending on the cultivar and environmental conditions **(Ritchie, Hanway, & Benson, 1993).**

Maize possesses a well-developed fibrous root system, in addition to brace roots that arise from the lower stem nodes. These roots provide mechanical support and enhance the absorption of water and mineral nutrients(fig.7) **(Ritchie et al., 1993).**

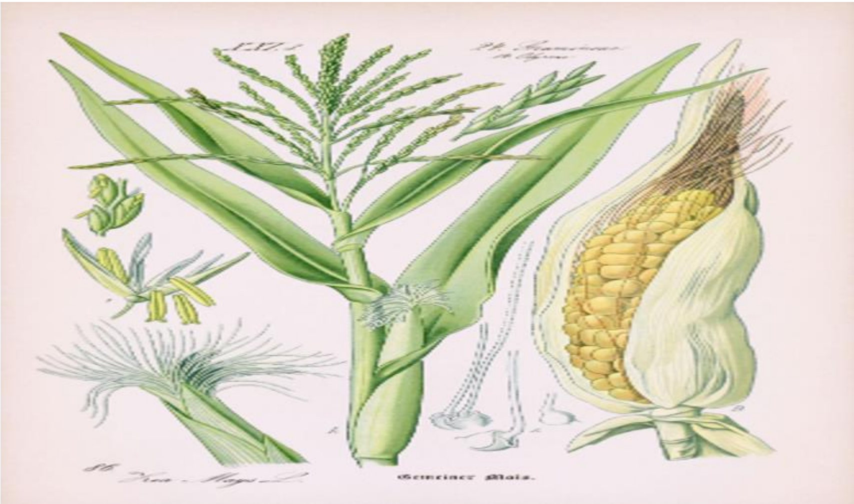


Figure 7: Plant Maize (Zea mays L.) Plants of the World Online (POWO).

Classification

According to Plants of the World Online (POWO) – Kew Science, the scientific classification of common maize (tab.4) ***(Zea mays L.)*** is:

Table4: : summarizes the scientific classification of common maize (*zea maize* L.) according to POWO – Kew Science.

Taxonomic Rank	Classification
Kingdom	Plantae
Phylum	Streptophyta
Class	Liliopsida
Order	Poales

Taxonomic Rank	Classification
Family	Poaceae
Genus	*Zea*
Species	*Zea mays L.*

1.2.-Animal material

Aphis gossypii Glover, 1877 ***(Hemiptera: Aphididae)***

Aphis gossypii Glover, 1877, commonly known as the cotton aphid, is a polyphagous aphid species with a nearly worldwide distribution. It is considered one of the most important pests of cotton and several other cultivated crops(fig.8). This species is also an efficient vector of numerous plant viruses and exhibits considerable variation in color depending on environmental conditions and host plants **(Edde, 2022).**

It colonizes more than 900 plant species and can transmit up to 76 plant viruses, causing substantial economic losses in agricultural production. Furthermore, its populations are highly differentiated and exhibit a complex life history influenced by geographical location, climatic conditions, and host plants **(Liu et al., 2024).**

Figure8: ***Aphis gossypii Glover*** **1877(Original, 2026) .**

Classification

According to the GBIF Backbone Taxonomy **(2026),** the taxonomic classification of ***(Aphis gossypii Glover*, *1877)*** is as follows(tab.5):

Table5: classification of the specie *(Aphis gossypii Glover, 1877)*

Taxonomic Rank	Classification
Kingdom	Animalia
Phylum	Arthropoda
Class	Insecta
Order	Hemiptera
Suborder	Sternorrhyncha
Superfamily	Aphidoidea
Family	Aphididae
Genus	*Aphis*
Species	*Aphis gossypii Glover, 1877*

1.3.- Non-biological materials:

The non-biological materials used in this study included a complete set of laboratory instruments, chemical reagents, and glass and metal tools that contributed to the accurate and efficient execution of the experiments. The equipment included an electronic balance, rotary evaporator, electric heater, drying oven (incubator), pH meter, and laboratory shaker(fig.9). The chemical reagents and compounds used included distilled water, ethanol, Tween 80, citric acid, potassium sorbate, glycerol, sodium bicarbonate, and vegetable oil. To ensure the accuracy of the work, several laboratory tools and glassware were used, namely aluminum foil, filter paper, Petri dishes, beakers, micropipettes, Erlenmeyer flasks, spoons, glass bottles, and magnets. The plant materials used were purified and ground thyme and corn starch(fig.10).

Laboratory Equibment

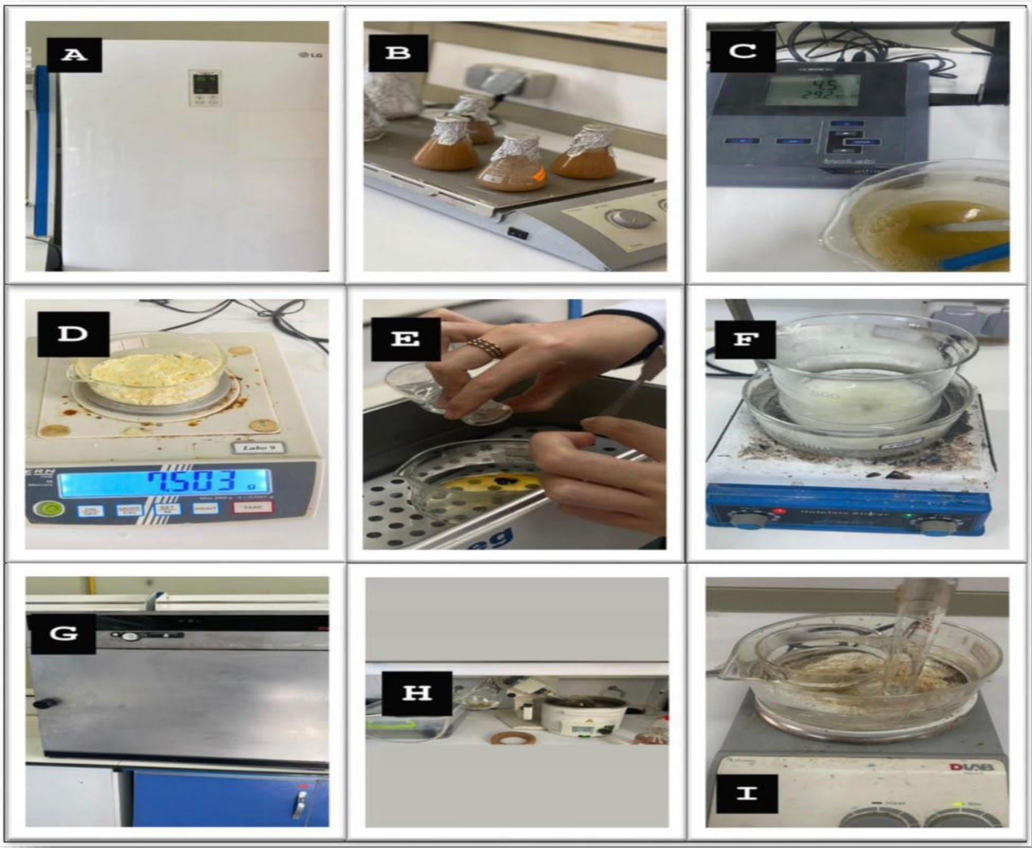


Figure 9 : Laboratory Equipment Used in the Study(original.2026).

(A): Laboratory refrigerator; (B): Magnetic stirrer. ; (C):ph meter ; (D): balance

(E): Centrifuge ; (F): Hot plate magnetic stirrer ; (G): drying oven ; (H):rotavap

(I): Hot plate.

Laboratory materials:

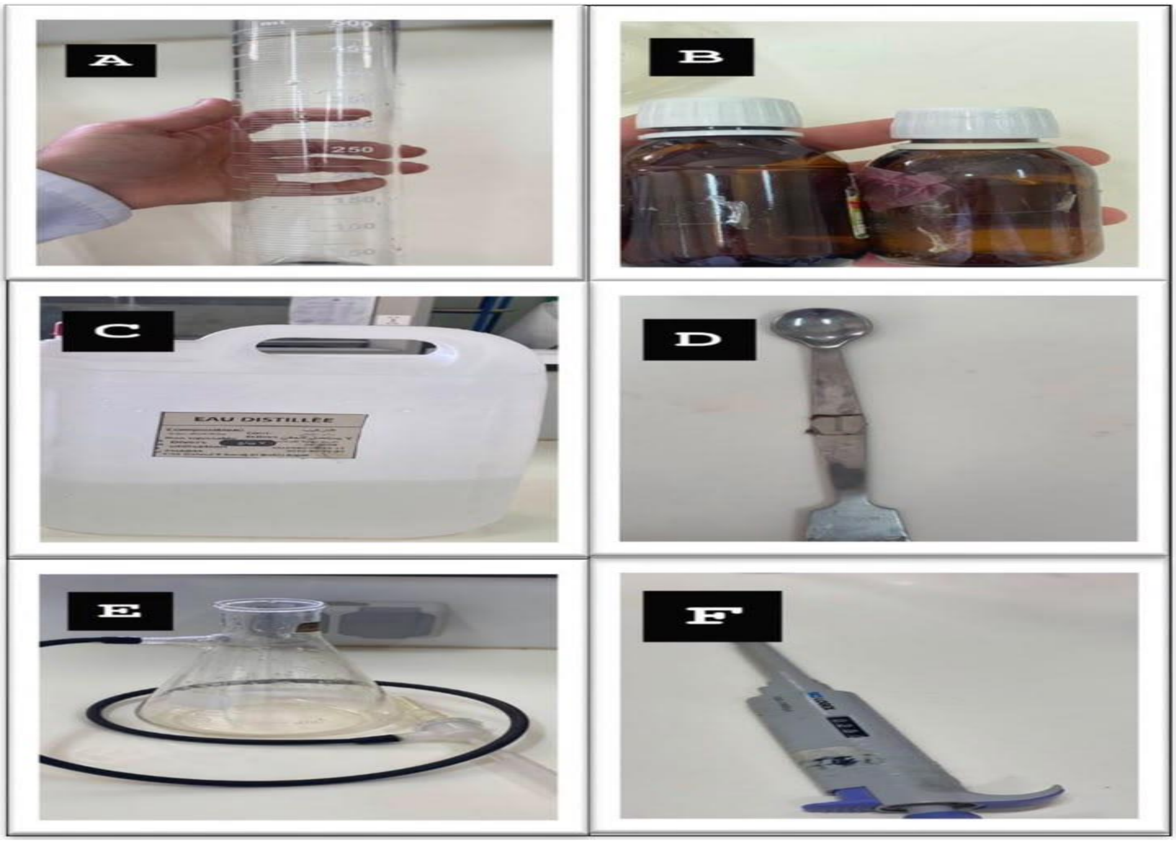


Figure 10: Laboratory Materials Used in the Study(original.2026).

(A): Graduated cylinder ; (B): Glass vials ; (C): Distilled water

(D): Metal spoon ; (E): Filtering flask ; (F): Micropipette

2.methode:

2.1.-Sampling Sites:

The municipality of Hassi Khalifa is located in El Oued Province, approximately 30 km from the provincial capital. It is bordered to the west by the municipality of Debila, to the south by Trifaoui, and to the north by the municipality of Taleb El Arbi (Fig. 11).

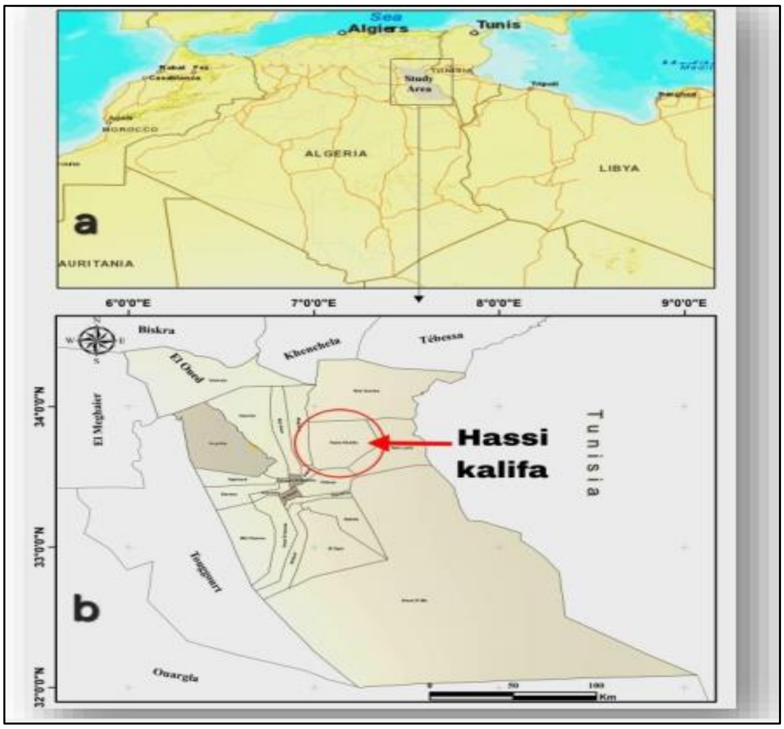


Figure 11 : Location of the sampling sites

(a) El Oued Province, Algeria; (b) Hassi Khalifa Municipality.

2.2. Harvesting of samples:

***(Thymus vulgaris* L)**. was used in this study, and the aerial parts of the plant were collected in March. The samples were cleaned and dried under appropriate conditions before being used for the extraction process.

***(Zea mays* L).** grains were collected in April and used in all experimental procedures.

The cotton aphid, (*Aphis gossypii* Glover), was collected in May and used in the bioassays after ensuring the uniformity and viability of the collected individuals.

2.3. Drying and Storage:

Fresh aerial parts of(*Thymus vulgaris* L.) were dried at room temperature (18–25 °C) in a shaded area, protected from direct light, and spread in thin layers on clean white paper. The samples were turned regularly to ensure uniform drying. This method was used to reduce residual moisture and prevent microbial fermentation as well as mold development.

2.4. Preparation of Plant Powder:

Following the drying process, the dried aerial parts of(*Thymus vulgaris* L.) were cleaned to remove impurities and then ground using an electric grinder to obtain a fine powder(fig.12). The resulting powder was stored in airtight containers at room temperature until further use for extract preparation.

Figure12: Preparation of the thyme plant material *(Thymus vulgaris L)*. after the drying and grinding steps to obtain a fine plant powder(Original,2026)

2.5.- Preparation of corn starch *(Zea mays L.):*

Maize grains were cleaned and soaked in water for 24–48 h to soften the kernels, with periodic water changes to prevent fermentation. The soaked grains were then wet-milled to obtain a slurry(fig.13). The slurry was filtered to remove fibrous material and the germ, and the starch was separated by sedimentation. The obtained starch was washed several times with distilled water, then dried in an oven at 40–50 °C until constant weight. Finally, the dried starch was ground into a fine powder and stored in airtight containers until use.

Figure13: Maize starch powder *(Zea mays L.*)(original2026)

2.6. Preparation of Plant Extracts by Cold Maceration:

The extraction of ***(Thymus vulgaris L.)*** (thyme) was carried out by cold maceration using a hydroalcoholic solvent (ethanol/distilled water). 50 g of dried thyme powder were placed in Erlenmeyer flasks, maintaining a solid-to-liquid ratio of 1:10 (w/v), corresponding to 1 g of plant material per 10 mL of solvent.

The hydroalcoholic solvent consisted of ethanol and distilled water in an 80:20 (v/v) ratio(fig.14). The thyme powder was macerated in this solvent mixture for 24 h at room temperature under continuous stirring using a magnetic stirrer. The extraction process was repeated three times to ensure exhaustive extraction of phytochemical compounds.

After maceration, the extract was filtered through filter paper. The filtrate was then concentrated using a rotary evaporator (Rotavapor) to remove ethanol, followed by oven drying to eliminate the remaining water. The concentrated extract was obtained as a paste-like mass and stored at 4 °C until further use.

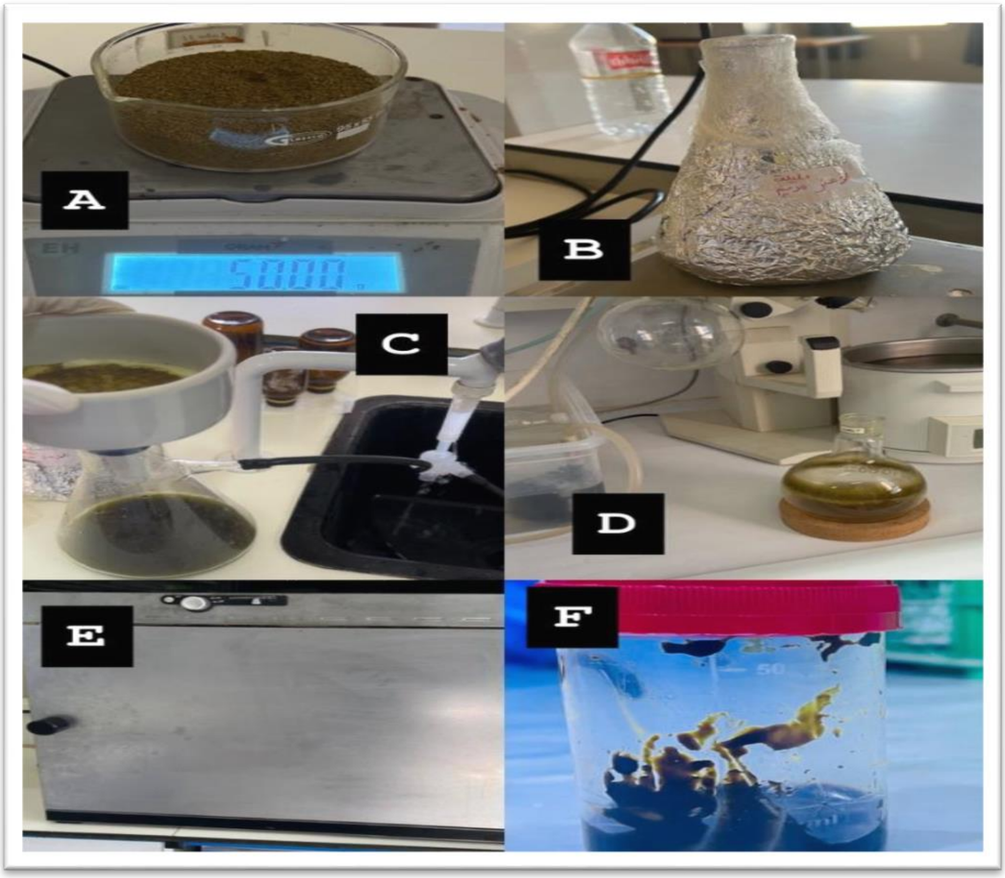


Figure14: Workflow of thyme (*Thymus vulgaris L.*) extract preparation by cold maceration method (original2026)

(A): Thyme *(Thymus vulgaris L.)* powder ;(B) Transfer the ethanolic extract into an orbital shaker (agitator).: ;(C): The extract was filtered.

(D): Evaporation of the ethanolic solvent ;(E): (E): The extract was dried until a paste-like consistency was obtained ;(F): Thymus vulgaris paste.

Calculation of Extraction Yield (R%):

The extraction yield represents the ratio between the dry mass of the obtained extract and the dry mass of the plant material used for extraction. It was calculated according to the following equation:

$$\boxed{R\% = (Me/Mv) \times 100}$$

Where:

R (%): Extraction yield percentage.

Me: Dry mass of the extract obtained after solvent evaporation.

Mv: Dry mass of the plant material used for extraction.

2.7-The methodology followed in preparing the final product:

Three spray samples were prepared with varying concentrations of thyme extract, while keeping all other formulation components constant, and each sample had a final volume of 250 ml.

The coating solution was prepared following a standardized protocol. Starch (3.75 g) was dispersed in 200 ml of distilled water and heated in a water bath on a magnetic stirrer with continuous stirring. The temperature was gradually increased from 80°C to 95°C over 5 minutes until gelatinization occurred, yielding a glossy, homogeneous gel.

Sodium benzoate and potassium sorbate (0.25 g each), previously dissolved in 5 ml warm water, were added as preservatives. Tween 80 (1.25 ml) was incorporated to promote emulsification. Thyme paste (0.375 g) and glycerol (3.5 ml), pre-dissolved in a water bath, were then added, and stirring was continued for 3 minutes(fig.15).

Citric acid (1.6 g) dissolved in 7.5 ml distilled water was gradually added using a syringe to adjust the pH to 4.5. The final volume was adjusted to 250 ml with distilled water. The solution was filtered through filter paper and stored in a sealed container(tab.6).

Table 6: Thyme Paste Concentrations in the Three Edible Coating Products.

Product	Thyme Paste (g)
1	0.375
2	0.750
3	1.125

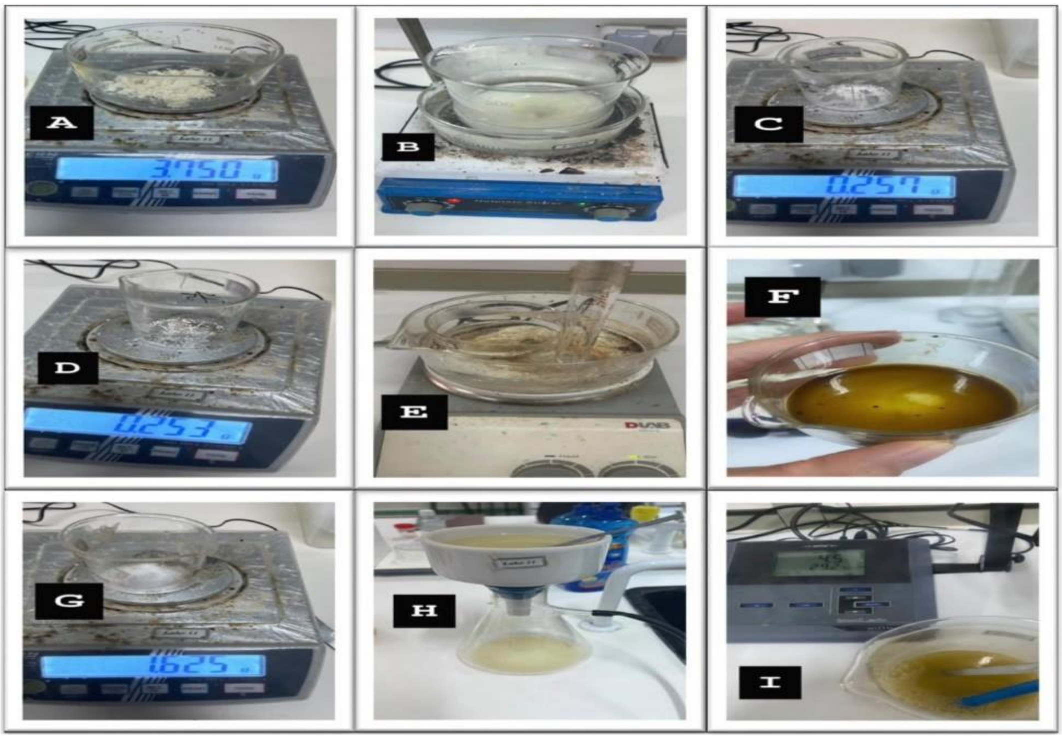


Figure15: Experimental workflow for product formulation and preparation using laboratory equipment(original.2026).

(A): Corn starch weighing ; (B): Heating starch in a water bath using a magnetic stirrer hot plate ; (C): Weighing of potassium sorbate ; (D): Sodium benzoate weighing ; (E) : Glycerol was dissolved in a water bath ; (F) : The thyme paste was dissolved in glycerol ; (G) : Citric acid weighing ; (H) : The final product was filtered (I) : Measurement of pH.

2.8.-Biological Assays of plant Extracts Agaaints the Cotton Aphid *(Aphis gossypii Glover)*

Collection and Maintenance of Adult *Aphis gossypii Glover*

Biological assays were conducted using adult individuals of the cotton aphid, Aphis gossypii Glover, collected from naturally infested host plants and maintained under laboratory conditions. The aphids were reared in Petri dishes lined with dry filter paper under controlled conditions (20-25 °C and suitable relative humidity) .

Adults were gently transferred using a fine brush prior to experimentation to minimize stress and mechanical injury.

2.9.-Direct Contact Toxicity Test:

The experiment consisted of seven treatments divided into two main groups. The first group included four treatments: a control prepared using 0.6 ml of vegetable oil, 0.3 ml of Tween 80, and 2.1 ml of distilled water without the addition of thyme extract, as well as three spray treatments prepared using the same basic components (0.6 ml vegetable oil, 0.3 ml Tween 80, and 2.1 ml distilled water)(fig.16) with different concentrations of Thymus vulgaris paste (0.375 g, 0.750 g, and 1.125 g).

The second group included three final formulations developed in the university laboratory following a standardized protocol. All formulations contained the same concentrations of Thymus vulgaris paste (0.375 g for Product 1, 0.750 g for Product 2, and 1.125 g for Product 3), using the same solvent system.

Each treatment was conducted using three Petri dishes as biological replicates (three replicates per treatment).

After preparation, all emulsions were transferred into sterile glass spray bottles to facilitate application. The treatments were then applied directly onto the insects in Petri dishes. All dishes were maintained under controlled laboratory conditions throughout the experimental period. Mortality was recorded at regular time intervals to evaluate the insecticidal activity of the Thymus vulgaris-based formulations،

(fig.17).

Figure16:Control treatmrnt (original2026).

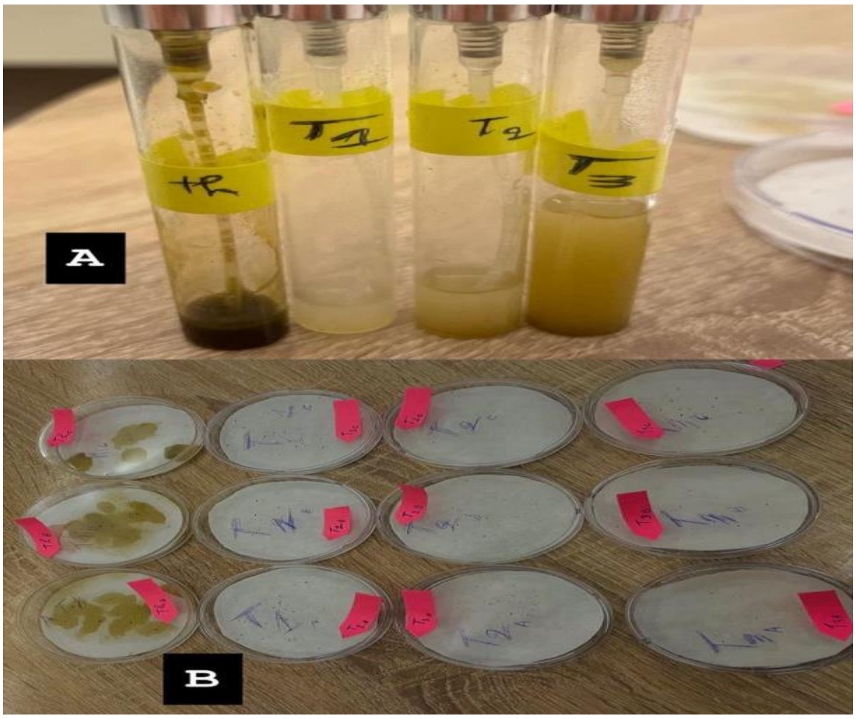


Figure17: Petri Dishes with Insects and (*Thymus vulgaris*) Extract Formulations(original.2026).

(A): Different concentrations of (*Thymus vulgaris*) extract

(B): Petri Dishes with Insects Treated by Direct Spraying of (*Thymus vulgaris*) Extracts

2.10.- Application of the Edible Coating on Tomato Fruits:

Tomato fruits (Solanum lycopersicum) were selected as the experimental model for evaluating the edible coating due to their high susceptibility to post-harvest deterioration, short shelf life (3–7 days under normal conditions), and clear visual indicators of spoilage (color change, softening, fungal growth, and weight loss). Additionally, tomato is an economically important crop in Algeria, particularly in the El Oued region, making this study relevant to local agricultural preservation needs.

The tomatoes were stored at room temperature (without refrigerator) to challenge harsh conditions and monitor the effectiveness of the product(fig.18) in preserving fruits under non-optimal storage conditions(tab.7).

Table 7: Fifteen tomato fruits were divided into five treatment groups (n=3 per group):

Treatment	Code	Description	Thyme Amount	Number of Fruits
Control 2	T0a	No spray	0 g	3 fruits

Treatment	Code	Description	Thyme Amount	Number of Fruits
Control 1	T0b	Sprayed with distilled water only	0 g	3 fruits
Product 1	T1	Spray Product 1	0.375 g	3 fruits
Product 2	T2	Spray Product 2	0.750 g	3 fruits
Product 3	T3	Spray Product 3	1.125 g	3 fruits

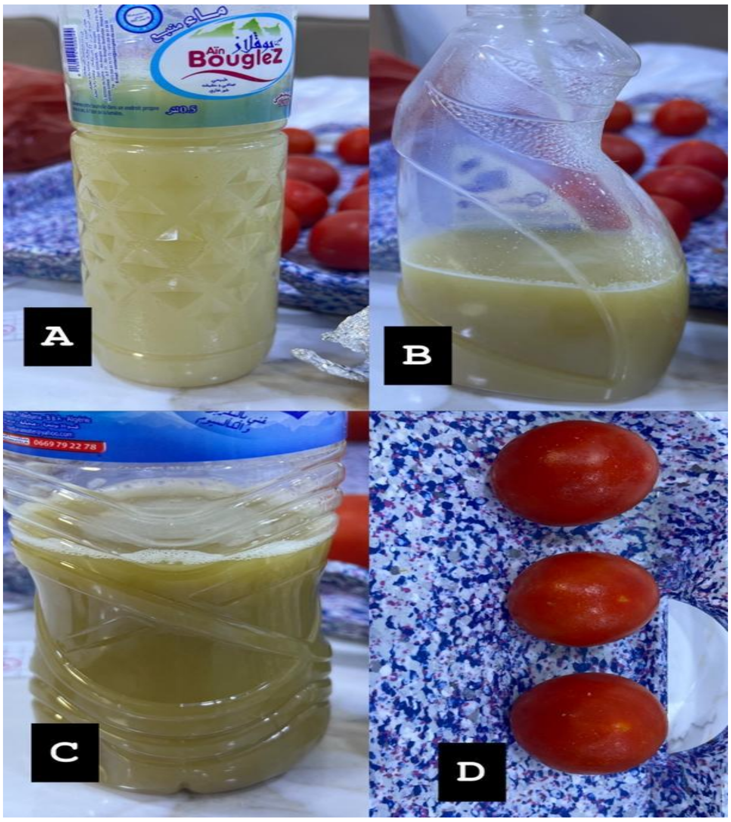


Figure18: Edible coating formulations prepared with different concentrations of thyme extract (original2026)

(A): Product 1 ;(B): Product 2 ;(C): Product 3

(D): Tomatoes treated with the edible coating spray

2.10. Counting of Individuals

The insecticidal efficacy of (*Thymus vulgaris L.*) extract against the cotton aphid (*Aphis gossypii Glover*) was evaluated by monitoring mortality rates at different exposure times and tested concentrations. Aphids were examined using a fine brush to detect .

movement response. Individuals that showed no movement after mechanical stimulation were considered dead.

2.11. Estimation of Observed Mortality

The observed mortality percentage of treated aphids was calculated using the following formula:

$$\mathbf{MO(\%)} = \boldsymbol{Number\ of\ dead\ individuals / Total\ number\ of\ treated\ individuals} \times \mathbf{100}$$

2.12. Estimation of Corrected Mortality

Since natural mortality may occur in the control treatment, mortality percentages were corrected using Abbott's formula (Abbott, 1925):

$$\boxed{\mathbf{MC\ (\%)} = \frac{\boldsymbol{MO - MT}}{\mathbf{100} - \boldsymbol{MT}} \times \mathbf{100}}$$

Where:

- **MC:** Corrected mortality percentage
- **MO:** Observed mortality in the treated groups
- **MT:** Mortality recorded in the control group

2.13. Determination of Lethal Time (LT_{50})

To evaluate the insecticidal efficacy of *Thymus vulgaris L.* extract against the cotton aphid (*Aphis gossypii Glover*), the lethal time (LT_{50}) was determined. This parameter represents the exposure time required to cause 50% mortality of the treated aphid population.

The LT_{50} value was estimated using Probit analysis. Corrected mortality percentages were transformed into Probit units, while exposure times were converted into decimal logarithmic values (Log_{10}) to establish the linear regression equation:

$$Y = bX + a$$

Where:

- **Y:** Probit value of corrected mortality
- **X:** Decimal logarithm of exposure time
- **b:** Slope of the regression line
- **a:** Intercept of the regression line

Finally, the LT_{50} value, together with its 95% confidence limits, was obtained from the statistical analysis results.

Chapter II: RESULTS

1.-Extraction yield results of plant extracts:

Results of the Yield of Thyme Plant Extract (*Thymus vulgaris L.*).

Table 8 : Results of the Yield of Thyme Plant Extract (*Thymus vulgaris* L.).

Plant species	Plant mass (g)	Extract mass (g)	Extraction yield (%)
Thymus vulgaris L	50	4.98	9.96

The table above summarizes the results of the hydroethanolic maceration extraction performed on 50 g of thyme biomass *(Thymus vulgaris L.)*. The data show that this extraction yielded 4.98 g of crude extract, corresponding to an extraction yield of approximately 9.96%.

2.-Evaluation of the insecticidal effect of different concentrations of extracts

➢ ***Thymus vulgaris leaf extract***

The results of the present study demonstrated that the aerial part extract of thyme exhibited a strong insecticidal activity against aphids, with mortality rates increasing with both concentration and exposure time, indicating a positive relationship between these two factors and the biological efficacy of the extract. After 5 min of exposure, mortality rates reached 20%, 23.3%, and 48.3% at concentrations C1, C2, and C3, respectively, compared with only 5% in the control group. After 10 min, these values increased to 35%, 50%, and 85%, whereas the control mortality did not exceed 10%. At 15 min, mortality rates reached 56.7%, 78.3%, and 100%, respectively, with the highest concentration (C3) achieving complete mortality, while the lower concentrations required a longer exposure period to reach the same effect. After 20 min, concentrations C2 and C3 produced 100% mortality, whereas C1 resulted in 95% mortality. Complete mortality (100%) was achieved at all concentrations after 25 min of exposure, compared with a mortality rate that did not exceed 16.65% in the control group (Fig. 19)

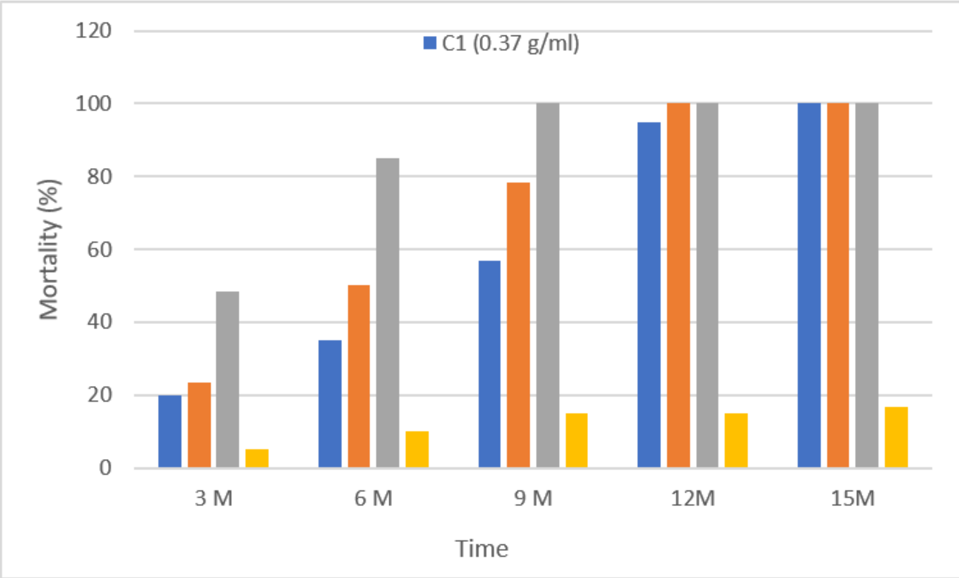
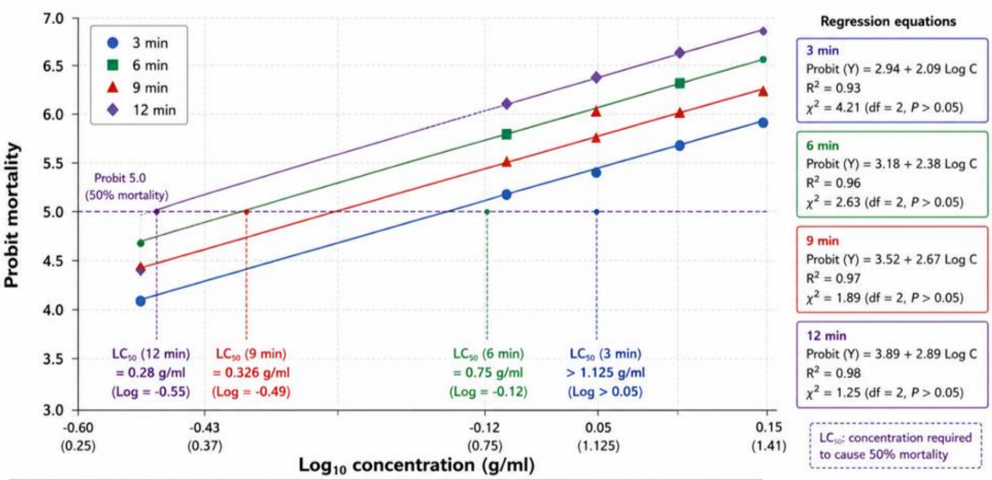


Figure 19: Insecticidal effect of *Thymus vulgaris* leaf extract on Aphids

Determining and TL50 LC50

Different concentrations of thyme extract were evaluated using the Log–Probit regression model to estimate the lethal time and concentration required to induce 50% mortality (LT_{50}). The mortality percentages recorded at different exposure times were transformed into Probit values, and the relationship between mortality response and the logarithm of exposure time was analyzed using a linear regression model for each concentration separately.

Determination of LT_{50} Values



Concentration (g/ml)		0.25	0.37	0.75	1.125	1.41
Log_{10} concentration		-0.60	-0.43	-0.12	0.05	0.15
Mortality (%)	3 min	5	20	85	100	100
	6 min	10	35	50	100	100
	9 min	15	56.7	78.3	100	100
	12 min	15	95	100	100	100

Note: Mortality (%) was transformed to probit values. Regression lines were fitted using the least squares method.

Figure 20: Log–Probit regression of mortality versus log exposure time for three concentrations of the tested extract, with estimation of LT_{50} values.

The analysis revealed a strong linear relationship between exposure time and toxic response for all tested concentrations. For concentration C1 (0.37 g/ml), the regression equation was: Probit (Y) = -1.85 + 2.62 log t, with a coefficient of determination (R^2) of 0.94, indicating a high explanatory capacity of the model. The chi-square value (χ^2) was 3.88 and was not statistically significant ($P > 0.05$), confirming the good fit of the model to the experimental data. For concentration C2 (0.75 g/ml), a stronger relationship was observed, with the regression equation: Probit (Y) = -1.10 + 2.95 log t. The model showed a high coefficient of determination ($R^2 = 0.96$), while the chi-square value was 2.91 ($P > 0.05$), indicating an acceptable fit between the observed and predicted values.

The highest concentration, C3 (1.125 g/ml), showed the best agreement with the Log–Probit regression model. The regression equation was: Probit (Y) = 0.05 + 3.40 log t, with the highest coefficient of determination ($R^2 = 0.98$) and the lowest chi-square value ($\chi^2 = 1.75$; $P > 0.05$). These results demonstrate a strong relationship between exposure time and toxic response at this concentration (Fig. 20).

Determination of LC_{50} Values

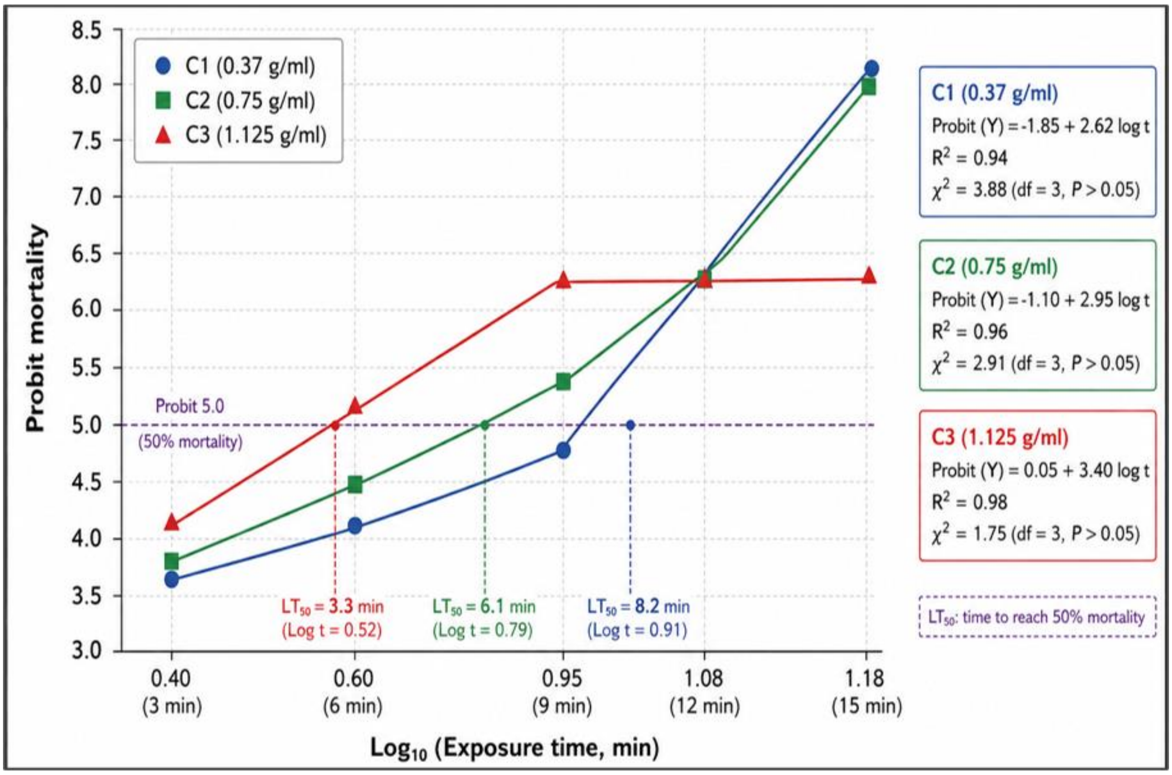


Figure 21: Log–Probit regression of mortality versus log exposure time for three concentrations of the tested extract, with estimation of LC_{50} values.

The analysis revealed a strong linear relationship between increasing extract concentration and increased mortality at all studied exposure times (3, 6, 9, and 12 minutes). The 3-minute exposure time yielded a regression equation of Probit(Y) = 2.94 + 2.09 Log C, with a coefficient of determination (R^2) of 0.93 and a chi-squared value (χ^2) of 4.21 (df = 2, P > 0.05). When the exposure time was increased to 6 minutes, the model's fit improved, with a regression equation of Probit(Y) = 3.18 + 2.38 Log C, an increase in the coefficient of determination (R^2) of 0.96, and a decrease in the chi-squared value (χ^2) of 2.63 (df = 2, P > 0.05). The 9-minute exposure time showed the best statistical agreement, with a regression equation of Probit(Y) = 3.52 + 2.67 Log C, a very high coefficient of determination (R^2) of 0.97, and a chi-squared value (χ^2) of 1.89 (df = 2, P > 0.05). However, at the longest exposure time (12 minutes), the model demonstrated the highest explanatory power, with a regression equation of Probit(Y) = 3.89 + 2.89 Log C, R^2 = 0.98, and a low chi-squared value (χ^2) of 1.25 (df = 2, P > 0.05) (Fig. 21).

- **Plant extract spray**

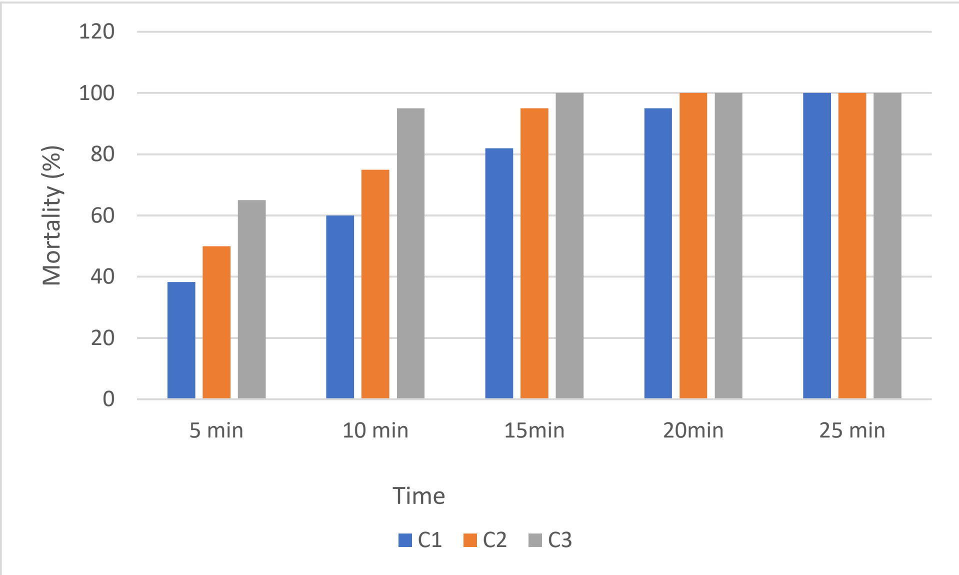


Figure 22:Mortality (%) of aphids exposed to different concentrations of thyme extract applied by spraying at different exposure times.

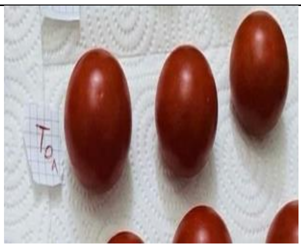
After 5 min of treatment, mortality rates reached 38.3%, 50%, and 65% at concentrations C1, C2, and C3, respectively. With increasing exposure time to 10 min, mortality increased to 60%, 75%, and 95%, indicating a rapid toxic effect of the extract, particularly at the highest concentration (C3). After 15 min, mortality rates reached 82%, 95%, and 100%, respectively, with concentration C3 achieving complete mortality of aphids. The insecticidal effect continued to increase over time, with mortality rates reaching 95%, 100%, and 100% after 20 min, while complete mortality (100%) was achieved at all concentrations after 25 min of exposure.

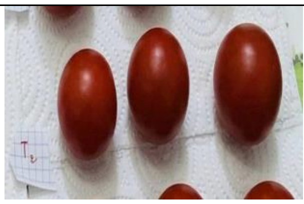
3.-Visual assessment of the effect of the final formulation on tomato fruits during the storage period

Visual changes in tomato fruits were recorded in terms of shriveling, fermentation, softening, color change, and the appearance of decay during the storage period(tab.9).

- **T0a:** Unwashed control.
- **T0b:** Control washed with water.
- **T1:** Sprayed with Spray 1.
- **T2:** Sprayed with Spray 2.
- **T3:** Sprayed with Spray 3.

Table 9: This table shows the visual appearance of tomato fruits during 15 days of storage under different treatments.

Days	0	5	10	15
				
T0a				
T0b				
T1				

T2				
T3				

The visual assessment of tomato fruits stored at room temperature over a 15-day period showed clear differences among the treatments. On day 1, all fruits appeared in very good condition in terms of color, texture, and overall appearance, with no noticeable visual differences among treatments. As storage progressed to day 5, slight visual changes began to appear in the two control treatments,(T0a)and (T0b), mainly in the form of slight shriveling and partial loss of surface gloss, while the sprayed treatments maintained a better appearance, with(T2) retaining fruit quality the best, followed by (T1) and then(T3). By day 10, deterioration became more obvious in the control samples, with noticeable shriveling, surface damage, and early signs of spoilage, whereas the sprayed treatments continued to show a clear delay in deterioration.(T2) remained the best in preserving the overall shape and smooth surface, followed by (T1) and (T3). By day 15, T0a and T0b showed severe deterioration, characterized by strong shriveling, major shrinkage, and obvious decay or mold development.(T1) also showed clear deterioration, but it was less severe than the controls and better than (T3). In contrast, (T3) maintained a relatively good visual appearance with moderate shriveling and limited wrinkling, while(T2) showed the best performance until the end of storage, as the fruits retained their shape better and showed less shriveling and damage than the other treatments. Overall, these results indicate that(T2) was the most effective treatment in slowing the visual deterioration of tomato fruits during storage, followed by (T1) and then(T3), whereas (T0a) and (T0b) were the most affected by quality loss.

4.-Final products:

MB FreshGuard is a natural spray product based on thyme extract and used as an edible coating. It is designed to extend fruit freshness and preserve quality. Shake well before use(fig.23).

Figure23: Natural Spray for Longer Freshness .

- **MB FreshGuard**
- **Natural Spray for Longer Freshness**
- **100% Natural**

- **Eco-Friendly | Food-Safe**
- **Shake well before every use.**

Chapter III: DISCUSSION

1. Discussion of Extraction Yield

The hydroalcoholic extraction of thyme was performed using 80% ethanol and 20% distilled water, resulting in an extraction yield of 9.96% **(Molecules, 2020; Frontiers in Nutrition, 2024).** Hydroalcoholic solvents are well known for their high efficiency in extracting bioactive compounds from thyme and other aromatic plants, particularly phenolic compounds and flavonoids, due to their suitable polarity, which allows the dissolution of a wide range of phytochemicals **(Molecules, 2020; Frontiers in Nutrition, 2024).** This yield reflects a good recovery of soluble plant constituents **(Plants, 2024; IJPPR, 2023).**

In similar studies, hydroalcoholic extraction systems have been reported to provide efficient yields and to recover antioxidant-rich fractions, supporting their suitability for thyme extraction **(Frontiers in Nutrition, 2024).** The three-day extraction period, combined with daily solvent renewal and continuous agitation, likely enhanced extraction efficiency by maintaining a strong concentration gradient between the plant material and the solvent **(Frontiers in Nutrition, 2024).**

Finally, concentration using a rotary evaporator followed by drying under controlled conditions allowed the production of a stable dry extract suitable for further analysis or formulation. These post-extraction steps are standard techniques used to remove solvents and obtain concentrated crude extracts for subsequent characterization and application **(Molecules, 2020; Plants, 2024).**

2.-Discussion of the Insecticidal Effect of Thyme Extract on *(Aphis gossypii)* and the Analysis of LT_{50} and LC_{50}

The present results showed that thyme extract exerted a strong insecticidal effect against Aphis gossypii, with mortality increasing markedly with both concentration and exposure time, indicating a clear dose- and time-dependent relationship **(MDPI Toxins, 2025).** This effect is attributed to the bioactive compounds in thyme, particularly phenolic compounds, thymol, and carvacrol, whose toxic effects accumulate with increasing dose and contact duration **(Frontiers in Nutrition, 2024; Plants, 2024).**

A rapid onset of toxicity was observed, with higher mortality rates recorded in treated groups after 5 minutes compared to the control. Mortality then increased sharply at 10 and 15 minutes, with some concentrations achieving complete mortality within 15 minutes. By 20 to 25 minutes, both medium and high concentrations reached 100% mortality, confirming the strong and rapid insecticidal activity of the extract compared to the control.

The LT_{50} analysis supports these findings, as the Log–Probit model showed a strong linear relationship between exposure time and mortality at all concentrations (R^2 = 0.94–0.98), indicating that exposure time explains a large proportion of the variation in insect response **(Robertson et al., 2017).** Non-significant chi-square values ($P > 0.05$) confirmed the adequacy of the model and the reliability of the estimated lethal time (Finney, 1971). The increase in regression slope with increasing concentration indicates faster and more homogeneous mortality at higher doses, reflecting increased insect susceptibility to the extract.

The LC_{50} analysis further demonstrated a clear concentration–response relationship, with improved model fit over time and a progressive decrease in LC_{50} values, indicating increased toxicity with prolonged exposure. This is explained by the greater absorption and deeper penetration of bioactive compounds into insect tissues over time, enhancing insecticidal efficacy **(Isman, 2020).**

The strong insecticidal activity is mainly attributed to thymol and carvacrol, which act on the insect nervous system, disrupt cell membrane integrity, inhibit acetylcholinesterase activity, and interfere with essential physiological processes, ultimately leading to mortality **(Isman, 2020; Wang et al., 2021).**

Overall, the results confirm that thyme extract exhibits effective insecticidal activity against Aphis gossypii, which is clearly dependent on concentration and exposure time. Increasing exposure duration reduced both LT_{50} and LC_{50} values, thereby enhancing its biological effectiveness. These findings support the potential use of thyme extracts as environmentally friendly botanical alternatives to conventional chemical insecticides.

3.- Discussion Efficacy of Plant Extract Spray and Postharvest Quality of Tomato Fruits

The plant extract spray showed a clear insecticidal effect against *Aphis gossypii*, with mortality increasing with both concentration and exposure time, indicating a dose- and time-dependent response. This effect is attributed to improved direct contact between the active compounds and the insect when applied as a spray, which enhances toxicity and accelerates insect mortality.

Plant-based sprays are known to be effective against sap-sucking insects due to improved contact and better distribution of active compounds on plant surfaces **(Isman, 2006; Pavela, 2015).** In addition, plant compounds may disrupt multiple vital physiological systems in insects, leading to functional disorders and eventual death **(Regnault-Roger et al., 2012).** Overall, these results confirm that plant-based sprays represent an effective and environmentally friendly approach for controlling *Aphis gossypii* under laboratory conditions.

Regarding the postharvest quality of tomato fruits, untreated fruits began to show progressive deterioration from day 5, characterized by shrinkage and loss of gloss, which developed into visible decay by days 10 and 15. This deterioration is attributed to natural postharvest physiological processes such as increased respiration rate and moisture loss **(Kader, 2002).**

In contrast, treated fruits exhibited a slower rate of deterioration, maintaining better quality throughout the storage period compared to the control. Treatment T2 showed the best performance, followed by T1 and T3. This improvement is attributed to the ability of the treatments to reduce water loss and delay ripening and senescence processes **(Baldwin et al., 2012),** as well as their potential to form a protective barrier that reduces gas exchange and slows spoilage development **(Dash et al., 2013).**

Although refrigeration is generally more effective in extending fruit shelf life by reducing respiration, enzymatic activity, and microbial growth, this study was intentionally conducted under room temperature conditions to evaluate treatment effectiveness under more challenging storage conditions, where deterioration occurs more rapidly.

Overall, the results confirm that T2 was the most effective treatment in maintaining the visual quality of tomato fruits and delaying deterioration during storage, supporting the potential of plant extracts as promising natural agents for postharvest preservation.

CONCLUSION

Conclusion

In conclusion, this study shows that thyme plant extract is a promising material with high practical value in post-harvest protection of agricultural products and in pest control through a natural and safe approach. The results demonstrated that hydroalcoholic extraction of thyme yielded a good number of active compounds, confirming that this plant is a rich source of bioactive substances with functional properties.

The study also showed that thyme extract exhibited a clear insecticidal effect against *Aphis gossypii*, as mortality increased with both concentration and exposure time. This reflects the effectiveness of the active compounds, especially phenolic and aromatic constituents, in producing a gradual toxic effect on the insect. The results of the Log-Probit analysis confirmed that the dose-response relationship was strong and scientifically significant, which supports the reliability of the findings and strengthens the potential use of this extract as a plant-based, environmentally friendly alternative to conventional chemical pesticides.

On the other hand, the treatments applied to tomato fruits proved capable of slowing visual deterioration during storage at room temperature. The treated fruits, especially treatment T2, maintained their external appearance, shape, and quality for a longer period compared with the control samples. This may be explained by the ability of the plant coating or spray to reduce water loss, slow respiration rate, and delay ripening, wilting, and tissue breakdown, making this technique highly promising for extending the shelf life of fresh fruits.

Based on these findings, it can be concluded that combining plant extracts with natural carrier materials is not limited to research purposes only, but also provides a foundation for developing a practical product with both economic and environmental value. Such a product can contribute to preserving the quality of agricultural products, reducing post-harvest losses, and decreasing dependence on synthetic chemical compounds. Therefore, this research opens important prospects for the development of natural edible coatings and sprays that may be applied industrially in support of food safety and agricultural sustainability.

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