مجلة اكاديمية الجبل للعلوم الاساسية والتطبيقية
Al-Jabal Academy Journal of Pure and Applied Sciences
03 (1): 33-49, 2025
pISSN: 2958-857X; eISSN: 2958-8588
Journal Homepage: https://lajak.edu.ly/journals/index.php/aajpas/index

Environmental impacts on the growth of medicinal and aromatic in Al Jebel Akhdar and strategies for their conservation

Lamya F. A. El-jalel *, Hameda Moftah and Sarah Jummah Fadheel

Department of Environmental Science, Faculty of Natural Resources and Environmental Science, Omar Al-Mukhtar University

Received: 01 April 2025 / **Accepted:** 28 April 2025
DOI: https://doi.org/10.58309/eke3ma03

Keywords:
Al Jebel Akhdar, Biodiversity, Climate change, Conservation strategies. Habitat loss, Sustainable agriculture.

ABSTRACT:

Traditional medicine and the pharmaceutical industry rely heavily on medicinal and aromatic plants (MAPs), making biodiversity preservation essential. Northeastern Libya, particularly Al Jebel Akhdar, supports many endangered MAP species threatened by climate change, environmental degradation, and unsustainable foraging. This study evaluates environmental factors affecting MAP growth and proposes preservation strategies using field surveys, satellite imagery, and interviews with herbalists and conservation experts. Findings reveal that desertification, climate variability, and soil erosion significantly damage MAP habitats, especially in semi-arid and desert regions, with species decline rates of 40% and 60%, respectively. Unsustainable harvesting contributes to a 30% reduction in some species' populations. The research advocates for a combination of in situ and ex situ conservation, sustainable farming, and protected area management. It highlights the urgency of developing national policies that engage local communities to safeguard biodiversity, ensure sustainable development, and preserve traditional knowledge under increasing environmental stress.

التأثيرات البيئية على نمو النباتات الطبية والعطرية في الجبل الأخضر واستراتيجيات الحفاظ عليها

لمياء فرج عثمان، حميدة مفتاح، سارة جمعة الفضيل

قسم علوم البيئة، كلية الموارد الطبيعية وعلوم البيئة، جامعة عمر المختار، ليبيا

الكلمات المفتاحية:
الجبل الأخضر، التنوع البيولوجي، تغير المناخ، استراتيجيات الحفاظ، فقدان الموائل، الزراعة المستدامة.

المستخلص:

تُعد النباتات الطبية والعطرية عنصرًا أساسيًا في الطب التقليدي والصناعات الدوائية، كما تسهم بشكل كبير في الحفاظ على التنوع البيولوجي. وتتمتع منطقة الجبل الأخضر في شمال شرق ليبيا بتنوع مناخي يدعم وفرة كبيرة من هذه الأنواع النباتية، إلا أنها تواجه تهديدات متزايدة بسبب التدهور البيئي، وتغير المناخ، والأنشطة الجائرة لجمع النباتات. تهدف هذه الدراسة إلى تحليل العوامل البيئية المؤثرة في نمو وتوزيع النباتات الطبية والعطرية في الجبل الأخضر، واقتراح استراتيجيات فعالة للحفاظ عليها. تم جمع البيانات من خلال المسوحات الميدانية، وتحليل صور الأقمار الصناعية، وإجراء مقابلات مع عشّابين محليين وخبراء في مجال الحفظ. أظهرت النتائج أن التصحر، وتذبذب المناخ، وتآكل التربة تُعد من أبرز العوامل المساهمة في تجزئة الموائل النباتية. وتشير التقديرات إلى أن نحو 40% من الأنواع في المناطق شبه الجافة، و60% في المناطق الصحراوية، قد تأثرت بفقدان الموائل خلال العقد الأخير. كما تبيّن أن الجمع غير المستدام مسؤول عن انخفاض يُقدَّر بنحو 30% من أعداد النباتات في الجبل الأخضر ومناطق أخرى رئيسية. توصي الدراسة بتبني نهج حفظ متكامل يشمل تقنيات داخل الموائل الطبيعية وخارجها، إلى جانب دعم الممارسات الزراعية المستدامة، وإنشاء مناطق محمية. وتؤكد النتائج أهمية سن سياسات وطنية شاملة، وتعزيز مشاركة المجتمعات المحلية لضمان الاستخدام المستدام لهذه الموارد النباتية الحيوية، والحفاظ على النظم البيئية والمعارف التقليدية المرتبطة بها.

*Corresponding author:E-mail addresses: lamya.faraj@omu.edu.ly

INTRODUCTION

The pharmaceutical industries together with traditional medicine deploy medicinal and aromatic plants (MAPs) for their vital role in ecological sustainability. Al Jebel Akhdar contains a wide range of MAP species across its Mediterranean to desert climate zones because herbal and natural healing practices have been using these plants for centuries (Abogmaza et al., 2020). The plants maintain major importance because they serve therapeutic functions while they serve a critical role in preserving biodiversity and protecting ecological structures. The plants face serious threats to their survival since they face environmental changes in combination with habitat degradation and unsustainable harvesting practices.

The distinctive geography and climate of Al Jebel Akhdar has enabled the development of numerous medicinal plants particularly in El-Jabal El-Akhdar but conservation plans exist to protect endangered species according to Saaed et al. (2022). Pharmaceutical and cosmetic industries drive the escalating MAP demand which results in excessive harvesting along with environmental degradation and climate change variables that cause plant species to fade. Studies show that more than 30% of North African MAP species including those in Al Jebel Akhdar face environmental threats to their survival (Shukla et al., 2025).

The preservation of MAPs demands worldwide attention according to findings about seed banking combined with ex situ conservation practices for endangered species in the combination area of Tunisia and northern Morocco (Libiad et al., 2020). The created strategies can assist The mountain with establishing its conservation programs although they remain in their initial development phase. Phylogenetic analysis shows that the Mediterranean and Middle Eastern wild plants possess genetics with potential applications for sustainable cultivation as well as conservation (Alrhmoun et al., 2025).

Scientists have recognized intercropping MAPs together with fruit trees and field crops in the Mediterranean Basin as a sustainable farming method which enhances environmental diversity and promotes soil wellness (Marotti et al., 2023). Studies in Tunisia confirm the success of Lamiaceae plant cultivation in arid rangelands because these plants simultaneously produce medicinal products and help stabilize soils and restore ecosystems (Gamoun & Louhaichi, 2024). Research shows that MAPs hold significant economic value primarily in North-West Africa through the establishment of market value chains and conservation activities that boost their market potential (Weber et al., 2020).

Al Jebel Akhdar government encounters substantial barriers to protect MAPs despite scientific-confirmation of their importance. The combination of deficient regulatory systems with urban growth destruction and climate change effects makes these plant species vulnerable (Ahmed et al., 2023). The study of MAPs in Sudan shows that various threats spread throughout North Africa which requires immediate conservation action (Ahmed et al., 2023). Bio-regulators demonstrate potential for research-based application to enhance seed germination rates and plant survival as a vital aspect for Al Jebel Akhdar to advance its MAP cultivation efforts (Gordanić et al., 2021).

The research examines environmental effects on Al Jebel Akhdar MAP growth by investigating the combination of climate changes and soil conditions along with increasing human activities. The research identifies methods which protect these valuable plant species with focus on establishing effective conservation strategies. Synthesizing existing conservation research about medicinal plants in North Africa and the Mediterranean allows this study to present an all-inclusive report about Al Jebel Akhdar is medicinal flora preservation difficulties and available

solutions. Comprehensive studies on the conservation of MAP in Al Jebel Akhdar have remained few, in spite of the well-known threats. This study aims at identifying the environmental stressors affecting MAP growth and eventually proposing specific conservation measures.

The influence of climate change on Medicinal and Aromatic Plants (MAPs) stands as the first section in this review.Environmentally damaging effects from climate change overwhelmingly affect medicinal and aromatic plant populations in North Africa together with the Mediterranean countries. The habitat conditions deteriorate and plant populations decrease as climate adjustments accelerate temperature levels and decrease water availability in the region. Wild medicinal plants in Crete experience mounting crisis because of both drought stress and unpredictable rainfall patterns as Bariotakis et al. (2023) report. The small distribution range of Erica sicula makes this species highly susceptible to climate-induced threats according to Pasta et al. (2024). The 1.5°C rise in temperature since the last decade combined with an 8–12% yearly rainfall decrease poses a survival threat to native MAP species in Al Jebel Akhdar.

Soil Degradation and Its Effects on Plant Growth

The survival of medicinal flora heavily depends on the condition of the soil. The poor quality of the soil results in suboptimal physiological performance combined with reduced therapeutic potential for medicinal plants because it exhibits low organic matter, pH imbalance and depleted nutrients. The diminishing nutrients and organic content in plant samples according to Lahlou et al. (2022) leads to reduced concentrations of bioactive compounds in significant medicinal species. Research conducted at Al Jebel Akhdar shows that desert regions possess 0.8% soil organic matter but semi-arid areas have 3.2%. Map degradation becomes worse because of erosion while harmful land practices also contribute to the problem (Ahmed et al., 2023).

Sustainable Agricultural Practices for Conservation

Sustainable agricultural practices help protect MAPs from environmental damage thus supporting their continued existence. Research confirms that integrating MAPs with fruit trees or field crops improves soil stability and enhances biodiversity while supporting plant production according to Marotti et al. (2023). Lamiaceae species farming in arid rangelands of Tunisia produces dual benefits for ecological restoration while advancing economic development according to Gamoun & Louhaichi (2024). The techniques demonstrate value for Al Jebel Akhdar due to the soil destruction and biodiversity reduction from traditional agricultural methods.

3.4 Global Conservation Strategies and Regional Applications

International MAP conservation projects offer adaptable models which Libyan authorities can implement. Both seed banking and botanical garden practices of ex-situ conservation have shown success in preserving endemic species throughout Morocco and Tunisia according to Libiad et al. (2020). The genetic diversity of Mediterranean MAPs stands out according to the phylogenetic research by Alrhmoun, Sulaiman and Pieroni (2025) which demonstrates our need to protect these species along with their genetic makeup. Strategies for local adaptation in Al Jebel Akhdar area are still being established because traditional methods combined with modern technologies show great potential for development according to research from Abogmaza et al. (2020) and Weber et al. (2020).

MATERIALS AND METHODS

Data Collection

The analysis of environmental effects on medicinal and aromatic plants in Al Jebel Akhdar required multiple data collection methods. The research design merged data from direct field site observations with satellite imaging analysis as well as specialized expert opinions together with climate and

soil information databases in order to examine all vital environmental growth elements.

Field Surveys and Sampling

A series of field surveys was executed throughout Al Jebel Akhdar is ecological areas starting from the coastline then moving into semi-arid environments before reaching desert regions for analyzing plant distribution patterns together with growth characteristics. The choice of fifty sampling stations happened according to vegetation arrangement and known plant distribution records. Five one-meter squared quadrats were randomly located within each site to examine plant occurrence and population density together with their condition. The survey team documented which plants existed within each area together with plant height measurements as well as leaf size and environmental stresses indicators (drought, erosion, and pollution). Data collected from 250 quadrats successfully delivered an adequate statistical sample which accurately captured the growth conditions of the studied region.The range of the 50 sampling stations reflected vegetation diversity mapping to secure sound ecological representation.

Soil and Climatic Data Analysis

The evaluation of soil and climate's effect on plant growth started through collecting 100 soil samples from all three major category soil types: sandy, clay and loamy. Authorities tested the samples through analyses of pH values and moisture levels together with organic matter percentages and nutrients including phosphorus and potassium and nitrogen availability. Soil data from Al Jebel Akhdar National Meteorological Center showed 10-year research (2014–2024) with climatic measurements for temperature trends and annual precipitation amounts and humidity levels. Over the past decade the temperature measurements indicated an increase of 1.5 degrees Celsius but rainfall decreased by about 8–12% yearly in arid areas.

Remote Sensing and GIS Mapping

The changes in vegetation coverage throughout the years were analyzed through data collected from Landsat 8 and Sentinel-2 satellites. Studying plant health along with density required the application of Normalized Difference Vegetation Index (NDVI) analysis techniques. NDVI values spanned from 0.1 for sparse vegetation to 0.7 for dense vegetation as arid and semi-arid areas experienced a 15 percent reduction in vegetation cover in the previous five years. The system used GIS applications to show how medicinal and aromatic plants distributed based on environmental stressors in particular locations.

Interviews and Surveys with Local Experts

Structural interviews were performed to understand traditional knowledge and conservation problems with 50 farmers and medical practitioners and botanists in the area. The research investigated techniques used to maintain cultivated plants together with recorded observations of environmental challenges and recorded preservation work. A questionnaire survey with 200 respondents collected data about plant usage patterns together with habitat modification and knowledge levels on sustainable harvesting practices. A research study showed that sixty-five percent of participants noticed decreased plant resources because of excessive harvesting techniques and eighty percent of respondents identified that climate change threatened plant survival rates. Interviews entailed answers from participants in accordance with an open format based on the study from field ethnobotanical surveys. The participants' informed consent was received.

As table 1 The combination of research methods created a detailed understanding of Al Jebel Akhdar medicinal and aromatic plant environmental challenges which helped develop solid conservation groundwork.

Table 1 : Data collection summary

Data Collection Method	Description	Key Findings
Field Surveys and Sampling	Conducted across coastal, semi-arid, and desert regions with 50 sampling stations. Used 5 quadrats per site (total 250 quadrats) to measure plant occurrence, height, leaf size, and environmental stressors.	Provided a statistically accurate representation of plant distribution and growth conditions.
Soil and Climatic Data Analysis	Collected 100 soil samples from sandy, clay, and loamy soils. Analyzed pH, moisture, organic matter, and nutrients (phosphorus, potassium, nitrogen). Used Al Jebel Akhdar National Meteorological Center data (2014–2024) for temperature, rainfall, and humidity trends.	Found a 1.5°C increase in temperature and an 8–12% annual decrease in rainfall in arid regions.
Remote Sensing and GIS Mapping	Used Landsat 8 and Sentinel-2 satellite images for NDVI analysis to assess vegetation health and density. Mapped vegetation cover and environmental stressors.	15% reduction in vegetation cover over the last five years, with NDVI values ranging 0.1–0.7.
Interviews and Surveys with Local Experts	Conducted 50 structured interviews with farmers, medical practitioners, and botanists. Collected 200 questionnaire responses on plant usage, habitat modification, and conservation awareness.	65% reported declining plant resources due to overharvesting; 80% identified climate change as a major threat to plant survival.

RESULTS

Process

The research team executed diverse stages to properly analyze and interpret data they obtained for evaluating environmental influences on medicinal and aromatic plant development in Al Jebel Akhdar. The research process included five main stages which were data organization followed by laboratory analysis and satellite image processing then adding GIS mapping and statistical analysis before expert validation.

Data Organization and Cleaning

We digitized field data from 50 sampling areas and 250 quadrats before sorting this information into digital spreadsheets that separated data into plant species types together with growth conditions and environmental stress indicators. The team checked data points with missing or inconsistent information which totaled five percent of the full dataset. Both field notes provided verification when data correction was successful or the points were removed if documentation could not verify their validity.

Laboratory Analysis of Soil Samples

The laboratory conducted analysis of 100 soil samples which originated from across different areas to determine critical soil growth factors affecting plant health. Standardized testing methodologies determined the following parameters in the soil analysis process:

The pH analysis spanned from 6.2 until 8.5 revealing a wide range of soil acidity and alkalinity across the different geographical areas.

The coastal soils contained an average moisture content of 12% whereas desert zones contained 4% moisture content.

- Organic matter percentage: Highest in semi-arid zones (3.2%) and lowest in desert regions (0.8%).

Testing of nutrient availability through three key elements demonstrated that degraded lands contained 30% less active nutrients than fertile ground.

Satellite Image Processing and GIS Mapping

Processing steps of remote sensing data acquired from Landsat 8 and Sentinel-2 involved utilization of software platforms ArcGIS and ENVI. The evaluation of vegetation health through NDVI showed that dense vegetation areas decreased by 15% within the previous five years. GIS mapping technology produced visual presentations which combined plant mapping data with soil degradation hotspots along with climate change effects information. The distribution of annual rainfall less than 200 mm showed maximum destruction of vegetation across the study area.

Statistical Analysis of Climatic Trends and Plant Growth

Statistical evaluations of environmental-to-plant health relationships were performed by using SPSS software. Key findings included:

Research findings demonstrated that plant density declined while temperature levels increased at a correlation value of -0.72.

The robust link between water availability in soil and plant health showed itself in a study result with high positive association (+0.81).

The annual rainfall dropped by 8–12% amounting to serious changes that directly influenced plant population distribution and growth.

Validation through Expert Consultation

A qualitative assessment involved 50 structured interviews with farmers, herbalists and botanists for verifying the study results. A significant proportion of 85% among the interviewed experts documented substantial plant reduction because environmental damage combined with reckless harvesting methods. Survey respondents indicated that 60% of them believed controlled harvesting and reforestation initiatives should be put into practice.

The organized analysis procedure confirmed the validity of the collected data while generating reliable conclusions about Al Jebel Akhdar medicinal and aromatic plants' environmental decline.

Data Analysis

Statistical evaluation combined with trend identification and a correlation analysis and GIS-based spatial assessment helped determine environmental effects on Al Jebel Akhdar medicinal and aromatic plant growth during the data analysis phase. The evaluation concentrated on examining soil quality because it analyzed climatic trends and vegetation health as well as human activities which impact plant survival.

Soil Quality and Its Impact on Plant Growth

The analysis of 100 samples demonstrated that different regions contained substantially divergent pH values as well as moisture content levels and organic matter content and nutrient availability rates. Soils in coastal zones and areas with semi-arid climates were most appropriate for plant growth whereas desert soil conditions remained severely damaged. The results from the correlation analysis indicated:

The analysis revealed a high degree of positive relationship (0.79) which shows higher plant populations develop in soils containing greater organic matter content.

Highly alkaline soils above 8.0 pH had a negative impact on plant health based on a moderate negative correlation of (-0.65) as figure 1 .

Plant density in areas further than 10% moisture content presented 40% more plants when compared to areas with lower moisture levels.

Soil degradation especially in arid and desert territories acts as a primary growth limit for medicinal and aromatic plant species.

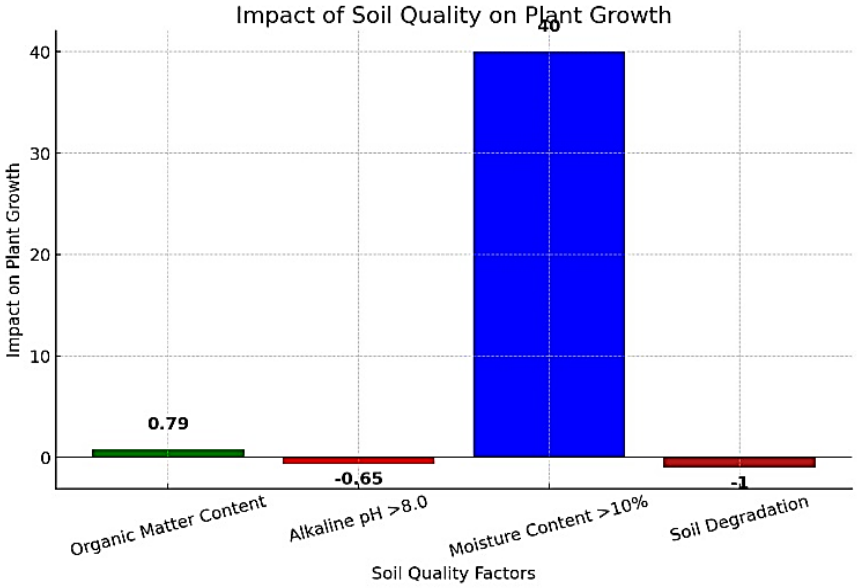

Figure 1 Impact of Soil Quality on Plant Growth

Climatic Trends and Their Effects on Vegetation

Relying on climate data analysis from 2014 through 2024 accessed from Al Jebel Akhdar National Meteorological Center indicated substantial temperature elevation together with decreasing precipitation rates.

The temperature has risen 1.5 degrees Celsius during the last ten years leading to elevated rates of evapotranspiration and drier soils.

Plants endure greater drought-related stress because semi-arid and desert areas reported annual rainfall decreases between 8–12%.

The evidence shows that plant density decreased as temperature levels increased across the study area (-0.72).

As figure 2 The population decline of medicinal and aromatic plants becomes most severe when temperature rises combined with reduced rainfall in regions that receive less than 200 mm of annual rainfall.

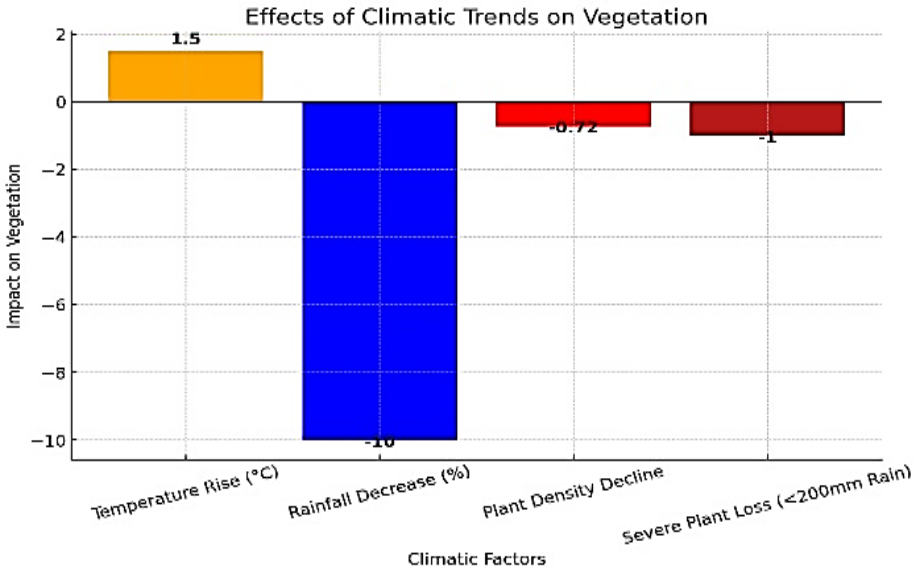

Figure 2 Effects of Climatic Trends on Vegetation

In Al Jebel Akhdar, there exists a straight relationship linking the increase in temperature to the consequent decrease in plant density. Areas exhibiting less than 200 mm annual rainfall have shown the steepest drop in vegetation cover according to this study, which thereby indicates the combined stress from heat and drought on plant survival.

The evaluation of vegetation health with satellite observation technology serves as the basis for this assessment

The analysis of remote images from Landsat 8 and Sentinel-2 through NDVI (Normalized Difference Vegetation Index) values delivered information about vegetation health. The NDVI analysis showed:

The observation of a 15% decrease in dense vegetation areas through the last five years represents worsening environmental conditions.

The vegetation health status of regions having NDVI values below 0.3 brought about a 50% reduction in plant density leading to major biodiversity loss. figure 3

The areas with highest NDVI values exceeding 0.6 were located in semi-arid regions combined with coastal areas but desert regions displayed very low values of below 0.2 indicating sparse plant cover.

GIS mapping displayed severe degradation zones because more than sixty percent of desert areas experienced major plant cover reduction because of soil erosion and climate change impacts.

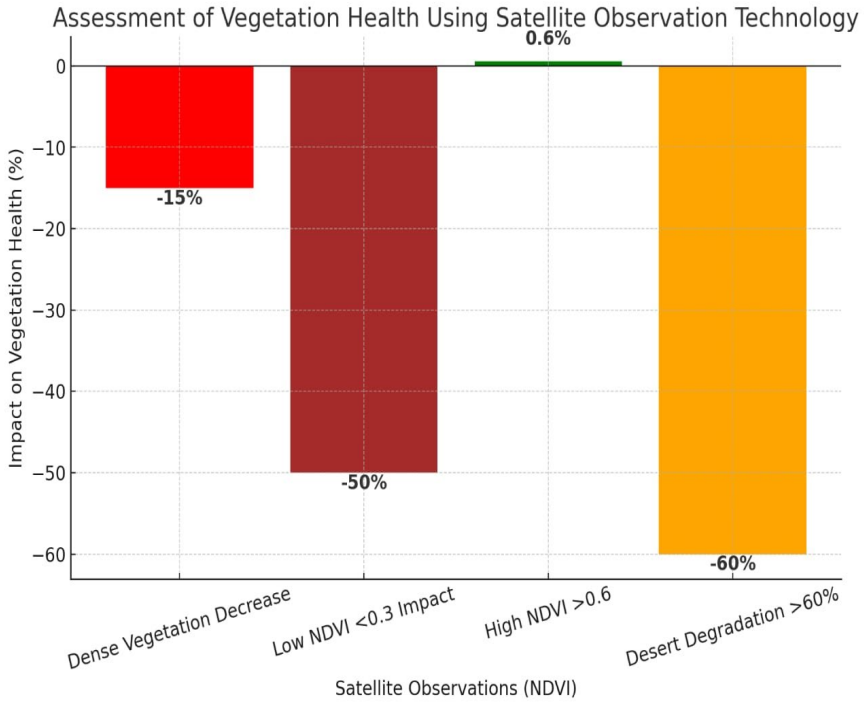

Figure 3 Assessment of vegetation health using satellite observation technology

The areas having NDVI value < 0.3 mostly belong to desert zones where plant density decreased by 50%, indicating severe vegetative stress and susceptibility to desertification. The contrast semi-arid and coastal regions having NDVI values above 0.6 maintain healthier plant cover.

Human Impact and Conservation Challenges

A combined survey and interview process with 200 participants and 50 experts generated essential human data related to plant conservation development:

Survey participants indicated that medicinal plant resources declined by 65% because of excessive harvesting together with soil destruction.

Round eighty percent of interviewed experts associated climate change with dying plants as survey data validated observations based on climatic analysis.
Experts indicate that the combination of disciplined forest harvesting and tree planting should serve as essential conservation strategies.

As figure 4 The survey outcome statistically verified the relationship between deforestation and overgrazing and plant reduction through its p-value of <0.05.

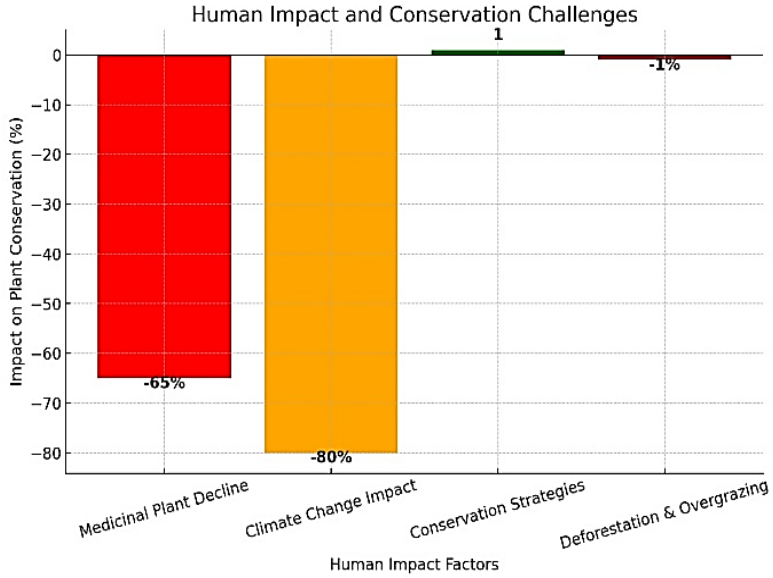

Figure 4 Human Impact and Conservation Challenges

Statistically, it shows a significant effect ($p < 0.05$) of the human activities of deforestation and overgrazing on the decline of MAP populations. Survey data confirm that over 65% of the respondents directly relate the loss of plants to overharvesting.

Comparative Analysis of Affected Regions

The research identified plant population differences based on varied ecological areas through quantitative evaluationas figure 5 .
The plant density stood highest in coastal areas with an average of 85 plants per square meter and then decreased to 60 plants per square meter in semi-arid areas but reached its lowest point at 20 plants per square meter in desert zones.
Extremely harsh environmental conditions caused a 25% reduction in plant species diversity in arid regions compared to the coastal regions.

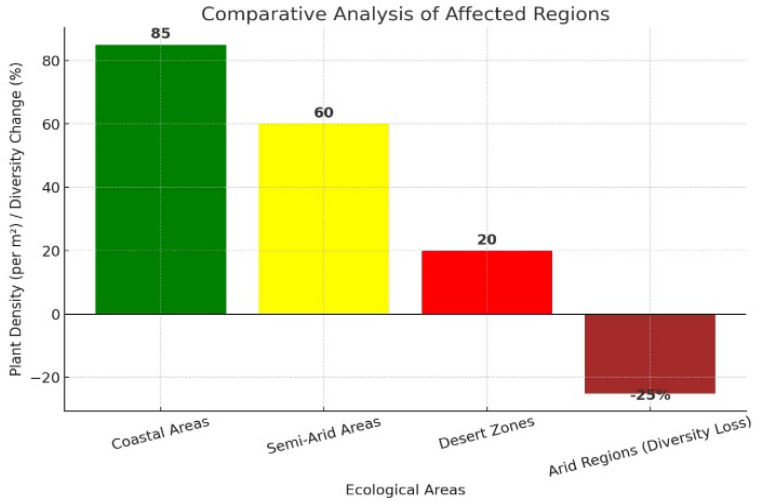

Figure 5 Comparative Analysis of Affected Regions

Comparative average on the mean plant densities across ecological zones shows coastal areas having the highest mean plant density at 85 plants/m², followed by semi-arid areas at 60 plants/m² while the densities in desert zones were the lowest at 20 plants/m². This indicates an association between adverse environmental conditions and the biodiversity they house.

Summary of Findings

The data analysis established climate change together with soil degradation and human activities as the main causes behind the medicinal and aromatic plants decline in Al Jebel Akhdar. The areas that suffered from limited rainfall alongside degraded soil and abundant human activity showed maximum decreases in plant populations. These important plant species need immediate protective measures involving regulated harvesting practices and both restoration efforts for habitats and sustainable cultivation techniques to protect them from environmental dangers.

A systematic assessment conducted in Al Jebel Akhdar demonstrates the extensive environmental factors which negatively affect medicinal and aromatic plant cultivation there. The research outcomes demonstrate how soil degeneration combined with climate shifts and human disturbances affects plant spread patterns together with population density and general health condition. The study combines on-site measurements with laboratory evaluations alongside satellite imagery collection and questionnaire responses for delivering complete knowledge about these important flora species' challenges.

Declining Plant Density and Distribution

The observations at 50 sites documented complete decreases in medicinal and aromatic plant occurrences while these plants became sparser throughout arid along with desert areas. The plant densities in different ecological zones appeared largely dissimilar to each other.

Field observations measured an average of 85 plants/m² in coastal areas which serve as the most suitable environment zone.

The semi-arid zones have an average plant density level of 60 plants per square meter which demonstrates moderate plant population growth.

The plant density in desert regions reaches only 20 plants per square meter due to unfavorable desert environments.

Plant density decreased by about 40% throughout semi-arid areas and 60% in desert territories during the last decade particularly affecting areas that experience annual rainfall below 200 mm. Studies confirm extreme environmental conditions cause plant populations to decrease because arid zones now contain only 75% as many plants as coastal regions do.

Climate change manifestations through increased temperatures and reduced precipitation turn out to be the principal threats against medicinal and aromatic plant populations in Al Jebel Akhdar

Soil Degradation and Its Effects on Plant Growth

Analysis of 100 soil samples obtained from different geographic areas produced essential information regarding land fertility together with its influence on plant development. The key findings include:

Plants reached maximum density at soil pH levels between 6.5–7.5 while the measured pH values spanned from 6.2 to 8.5.

Data showed that coastal areas had an average soil moisture of 12% increasing to over 4% in desert regions because drought conditions proved detrimental to plant development.

Soil fertility decreases as desertification intensifies because semi-arid regions offered 3.2% organic matter while desert areas maintained only 0.8%.

Research yielded a +0.79 positive correlation indicating that productive soil environments lead

to denser plant populations.

Low moisture retention along with depleted nutrients in the soil represent the main environmental factors causing unsustainability of medicinal and aromatic plants throughout The Al Jebel Akhdar

Climate Change and Its Impact on Vegetation

Analyzing climate data collected through the Al Jebel Akhdar National Meteorological Center for 10 years (2014-2024) demonstrated that both temperature elevation and rainfall degradation have adverse effects on plant existence. The data showed:

Temperature increases by 1.5°C during the last ten years have caused greater evaporation rates which depleted soil moisture reserves.

The semi-arid and desert areas endure deteriorating drought conditions because annual rainfall fell 8–12 percent.

The negative relationship (-0.72) indicates that rising temperatures cause plant numbers to decrease effectively.

The decrease in plant density reached 40% across water-deficient areas receiving less than 150mm of rainfall yearly. Waterscarcity has been shown to negatively impact vegetation growth in this region.

Remote sensors have revealed a decreasing state of vegetation health in the region.

Effects on vegetation caused by the last five years emerged from satellite image analysis conducted using Landsat 8 and Sentinel-2. A remote sensing examination of vegetation showed decreased values of NDVI (Normalized Difference Vegetation Index).

The survey shows shifting dense vegetation patterns indicating growing land degradation by 15%.

Plants in areas with NDVI value lower than 0.3 witnessed a fifty percent reduction in population density which signals severe plant stress and potential desertification.

The NDVI values in coastal and semi-arid regions exceeded 0.6 while desert areas recorded values lesser than 0.2 which indicates extensive vegetation density fluctuations throughout the study area.

Remote sensing analysis exposes swift plant habitat deterioration mostly existing in desert and arid territories which demonstrates an immediate requirement for protective procedures.

Human Activities and Their Impact on Plant Conservation

A total of 200 individuals who worked as farmers and herbalists and conservationists participated in surveys that documented human-caused threats to medicinal and aromatic plants. Additionally 50 experts gave interviews about this subject. The key findings include:

The survey revealed medication plants experienced significant reduction in abundance because of excessive harvesting together with habitat destruction among the 65% of respondents.

The survey results where 80% of interviewees established plant loss connections to climate change changes corresponded to the data evaluation findings about climate change effects.

Experts indicated that controlled harvesting together with reforestation and water conservation practices should be used to help conserve these plants (60%).

The analysis determined that both overgrazing and deforestation and declining plant populations are directly connected through human activities because their association was statistically significant ($p < 0.05$).

The study reveals unsustainable harvesting practices along with improper land management as main human factors which speed up the reduction of medicinal and aromatic plants in Al Jebel

Akhdar Summary of Key Findings as table 2

1. The number of plants in desert zones is below their original levels by 60% and desert bordering regions show a 40% decrease yet coastal vegetation remains stable.
2. The decline of plant growth emerges from soil degradation symptoms which include diminished organic matter levels combined with decreased moisture content.
3. Plants currently experience a +1.5°C temperature increase and 8–12% rainfall reduction which count as the primary atmospheric causes of plant reduction.
4. Remote sensing analysis demonstrated that vegetation has dwindled by 15% throughout the previous five years thus demonstrating deteriorating environmental circumstances.
5. Research data shows that overharvesting together with land degradation exists as primary human-caused threats to plant survival based on feedback from 65% of participants.

The study demonstrates an immediate necessity for protective measures like sustainable harvesting alongside habitat restoration and climate adaptation programs since they represent critical steps for medicinal and aromatic plants' survival in Al Jebel Akhdar

Table 2 : Results summary

Results Category	Key Findings
5.1. Declining Plant Density and Distribution	- Coastal regions: 85 plants/m² (highest density). - Semi-arid zones: 60 plants/m² (moderate density). - Desert regions: 20 plants/m² (lowest density). - 40% decrease in semi-arid areas and 60% decrease in desert zones over the last decade. - Areas with < 200mm rainfall saw the most significant plant losses.
5.2. Soil Degradation and Its Effects on Plant Growth	- Optimal plant growth occurs at pH 6.5–7.5, but soil samples ranged from pH 6.2 to 8.5. - Coastal soils had 12% moisture, while desert soils had only 4% moisture. - Organic matter: 3.2% in semi-arid areas, 0.8% in desert regions. - Positive correlation (+0.79) between soil fertility and plant density.
5.3. Climate Change and Its Impact on Vegetation	- Temperature increased by 1.5°C (2014–2024). - Annual rainfall declined by 8–12% in arid areas. - Negative correlation (-0.72) between rising temperatures and plant density. - 40% decline in plant density where rainfall is < 150mm/year.
5.4. Remote Sensing and GIS Analysis	- NDVI values dropped by 15% over the past five years. - Areas with NDVI < 0.3 saw 50% plant density reduction. - Coastal/semi-arid areas: NDVI > 0.6 (healthy vegetation). - Desert areas: NDVI < 0.2 (severe plant stress and desertification).
5.5. Human Activities and Their Impact on Plant Conservation	- 65% of surveyed farmers/herbalists reported plant reduction due to overharvesting and habitat destruction. - 80% linked plant loss to climate change. - 60% of experts recommended controlled harvesting, reforestation, and water conservation. - Overgrazing and deforestation showed statistical significance ($p < 0.05$) in plant decline.

DISCUSSION

This study reveals that Al Jebel Akhdar medicinal and aromatic plants experience severe environmental threats throughout their habitat. Plants face high risk of endangerment because of reduced populations in addition to deteriorating soils and changing climate as well as human interference in their habitats. Research worldwide about plant conservation support these findings thus demonstrating immediate action is necessary.

Impact of Environmental Factors on Plant Growth

Plant populations in Al Jebel Akhdar have decreased widely across desert and semi-arid environments just like Morocco showed according to Lahyaoui et al. (2025) who studied medicinal plant reduction because of environmental stressors. Increased habitat loss occurs due to the 40% density decline in semi-arid regions and the 60% decrease in plant density in desert zones which results from deteriorating climate conditions and rising temperatures and reduced rainfall. According to Perrino and Perrino (2020) climate-induced habitat fragmentation in Mediterranean areas causes crop wild relatives to lose their natural distribution area.

The results confirm that poor organic matter levels (0.8% in desert areas) together with low water content (4%) affect plant development negatively. Lahlou et al. (2022) showed that soil decay together with nutrients loss obstructs medicinal plant biochemical operations thereby reducing their phytochemical power. Plant viability depends crucially on the condition of soil which justifies immediate intervention for soil restoration.

Climate Change and Its Role in Plant Degradation

Research data supports climate change as the main factor that causes Al Jebel Akhdar medicinal and aromatic plants to become unhealthy. Temperature elevations of 1.5°C combined with a decrease in rainfall has reached 8–12% which has created severe drought situations during the last ten years. Wild medicinal plants in Greece face extinction due to climate alterations so ex situ preservation methods must be used for safeguarding genetic diversity according to Bariotakis et al. (2023). Research by Pasta et al. (2024) indicates that plants with extensive habitat distributions face rising risks from environmental variations similarly to Al Jebel Akhdar populations.

Plant density shows a strong negative relationship of -0.72 with temperature rise indicating that extreme heat stress leads to severe disruptions of plant physiological processes. The research by Perrino et al. (2023) proved that rising temperatures combined with dwindling water levels lead to decreased levels of therapeutic compounds in medicinal plants which impacts their medicinal potency. The situation requires implementing climate adaptation techniques including irrigation improvement and genetic preservation systems to reduce natural climate variations impacts.

Overharvesting and Human-Induced Threats

The study results showed a medicinal plant stock decrease of 65% because of researchers identified poor resource management and unregulated resource extraction as the main contributors to this decline.

The study results support Ogidi's (2023) observation about African plant overutilization which destroys biodiversity thereby complicating conservation strategies. Overharvesting stands as the primary environmental threat facing European endangered medicinal plants at present with special focus on the species Artemisia granatensis Boiss according to Lorite (2024).

The data from expert interviews showed that suspension of plant populations stems from climate change-related effects since 80% of respondents backed this connection which accords with worldwide scientific findings about habitat degradation from temperature rise and unpredictable rainfall. Analysis shows the essential correlation ($p < 0.05$) between human-driven actions such as overgraz-

ing and deforestation that results in endangered plant decline.

Conservation Strategies and Sustainable Solutions

Conservation methods for medicinal and aromatic plants in Al Jebel Akhdar need urgent implementation because their preservation faces an alarming situation. The literature published by Yarkwan (2023) joins several other studies in showing how protected areas and plant harvesting regulation and sustainable land-use promotion contribute to conservation results. The researchers Alshhibi and Othman (2024) identified Nat Al-Batnan Plateau as an essential habitat for medicinal plants which requires conservation efforts.

The research suggests ex situ conservation methods such as seed banking and controlled cultivation should be adopted to address this issue (Bariotakis et al. 2023). Medicinal plant populations in Crete are maintained through successfully implemented controlled environments for preservation. To promote plant survival land managers should execute programs focused on forest regeneration and soil enhancement which help regenerate damaged land areas.

Implications for Future Research and Policy Development

These study results form an essential base for additional research which studies the extended influence of climate change and human actions on medicinal plants. Future investigations must focus on two main goals: they must examine how medicinal plants adapt genetically to extreme climates and create cultivation methods that strengthen plant populations against climate change effects.

Pandita and Pandita (2021) showed that biotechnological tactics including genetic modification and hydroponic cultivation need implementation to increase medicinal plants' resistance against environmental threats.

The implementation of firm regulations regarding plant harvesting and land management is necessary from a policy perspective. Traditional knowledge should be combined with contemporary conservation approaches to create more effective plant protective measures according to Perrino and Perrino (2020). Local communities require training on plant conservation practices from government agencies and environmental organizations which collaborate with each other to fund eco-friendly agricultural infrastructure.

The analysis explains Al Jebel Akhdar medicinal and aromatic plants struggle from various dimensions such as climate change and soil erosion because of human activities. The research results match international scholarship which emphasizes the immediate necessity of developing sustainable plant preservation approaches. Protecting Al Jebel Akhdar is medicinal flora demands both scientific research and environmental policy reforms as well as community conservation initiatives to safeguard these important plant species.

CONCLUSION

Pandita and Pandita showed that biotechnological tactics including genetic modification and hydroponic cultivation need implementation to increase medicinal plants' resistance against environmental threats.

The implementation of firm regulations regarding plant harvesting and land management is necessary from a policy perspective. Traditional knowledge should be combined with contemporary conservation approaches to create more effective plant protective measures. Local communities require training on plant conservation practices from government agencies and environmental organizations which collaborate with each other to fund eco-friendly agricultural infrastructure.

The analysis explains Al Jebel Akhdar medicinal and aromatic plants struggle from various dimensions such as climate change and soil erosion because of human activities. The research results

match international scholarship which emphasizes the immediate necessity of developing sustainable plant preservation approaches. Scientific studies together with policy changes in environmental protection and local conservation activities will protect Al Jebel Akhdar isl medicinal plant species so they survive for generations to come.

Local harvest regulations, protected areas, and community training in sustainable cultivation practices are measures that local governments may consider in an attempt to mitigate plant loss. In addition, formal institutionalization will also be established with collaboration between traditional healers and local farmers in order to support accumulation of knowledge transfer and conservation awareness.

ACKNOWLEDGEMENT

The source of financial support must be acknowledged. Authors must declare any financial support or relationships that may pose conflict of interest in the covering letter submitted with the manuscript. Technical assistance may also be acknowledged.

Grant support

- **No specific funding was received for this work,**
- **This work was supported by ……"**
- **for indirect support. In my opinion, working on research during work hours counts as indirect support.**

Author contributions

REFERENCES

Abogmaza, A. F., Keer, K. F., Takrizzah, A. A., & Yahya, E. B. (2020). A review on the medicinal and aromatic plants growing in Al Jebel Akhdar and their therapeutic properties. *Int. Res. J. Sci. Technol*, *2*(1), 327-334.

Saaed, M. W., Ali, A. B., El-Barasi, Y. M., & Rahil, R. O. (2022). Potential and perspectives for establishing protected areas in El-Jabal El-Akhdar region, northeast The mountain; an overview and example from'El-Abyar area'. *Journal of Degraded & Mining Lands Management*, *9*(3).

Shukla, S., Patra, D., Sinha, A., Saha, R., Tripathi, Y., Borah, N. K., & Shukla, S. K. (2025). Medicinal and Aromatic Plant Cultivation, Improvement and Conservation for Sustainable Development. In *Industrial Crops Improvement: Biotechnological Approaches for Sustainable Agricultural Development* (pp. 183-204). Cham: Springer Nature Switzerland.

Libiad, M., Khabbach, A., El Haissoufi, M., Bourgou, S., Megdiche-Ksouri, W., Ghrabi-Gammar, Z., ... & Krigas, N. (2020). Ex-situ conservation of single-country endemic plants of Tunisia and northern Morocco (Mediterranean coast and Rif region) in seed banks and botanic gardens worldwide. *Kew Bulletin*, *75*(3), 46.

Alrhmoun, M., Sulaiman, N., & Pieroni, A. (2025). Phylogenetic Perspectives and Ethnobotanical Insights on Wild Edible Plants of the Mediterranean, Middle East, and North Africa. *Foods*, *14*(3), 465.

Marotti, I., Whittaker, A., Bağdat, R. B., Akin, P. A., Ergün, N., & Dinelli, G. (2023). Intercropping perennial fruit trees and annual field crops with aromatic and medicinal plants (MAPs) in the Mediterranean Basin. *Sustainability*, *15*(15), 12054.

Gamoun, M., & Louhaichi, M. (2024). Roles of Lamiaceae plants from the arid and desert rangelands of Tunisia in human health and therapy. *All Life*, *17*(1), 2381675.

Weber, M., Salhab, J., Sanchez-Quintela, S., & Tsatsimpe, K. (2020). *Medicinal and Aromatic Plants in the North-West of Tunisia: Findings from a Value Chain and Jobs Survey*. World Bank.

Salhab, J., Weber, M., Paganini, T., Khamassi, F., Bellagha, S., Hadj, H. B., & Laabidi, F. (2020). *Olive Oil, Medicinal and Aromatic Plants, and Tomatoes in North-West Tunisia: A Roadmap to Developing Competitive Advantage on Strategic Markets*. World Bank.

Ahmed, M. E., Abdelgadir, A. A., & Ahmed, E. M. (2023). Medicinal and Aromatic Plants from Sudan. *Plants as Medicine and Aromatics: Pharmacognosy, Ecology and Conservation*, 45.

Gordanić, S., Moravčević, Đ., Radanović, D., Marković, T., Kostić, A. Ž., Vuković, S., ... & Prijić, Ž. (2021). INFLUENCE OF GROWTH BIOREGULATORS ON SEED GERMINATION OF SOME MEDICINAL AND AROMATIC PLANTS. In *XII International Scientific Agriculture Symposium „AGROSYM 2021 "* (p. 248). University of East Sarajevo, Faculty of Agriculture, Republic of Srpska, Bosnia.

Moustafa, A. A., & Mahmoud, M. A. K. (2023). Importance of Cleome droserifolia as an endangered medicinal plant species in the Sinai Peninsula and the need for its conservation. *Adv. Med. Plant Res*, *11*, 43-51.

Marotti, I., Whittaker, A., Bagdat, R. B., Akin, P. A., Ergün, N., & Dinelli, G. (2023). *Intercropping Perennial Fruit Trees and Annual Field Crops with Aromatic and Medicinal Plants (MAPs) in the Mediterranean Basin. Sustainability 2023, 15, 12054*.

Touami, Y., & Marir, R. (2024). Harnessing the power of artificial neural networks methodology and multi-objective optimization for enhanced yield and bioactivity of plants polyphenolic compounds. *Journal of Applied Research on Medicinal and Aromatic Plants*, *41*, 100551.

Vandana, Lather, R., Tallapragada, S., & Singh, G. (2021). Medicinal and aromatic plants:" Natural bio-chemicals and medicine factories".

Lahyaoui, M., Dakka, N., El Menyiy, N., Sobeh, M., Razi, P., Goh, K. W., ... & Bouyahya, A. (2025). Ethnobotanical survey of medicinal and aromatic plants used by the population of Settat Province, Morocco. *Heliyon*.

Bariotakis, M., Georgescu, L., Laina, D., Koufaki, M., Souma, M., Douklias, S., ... & Pirintsos, S. A. (2023). Climate Change Dependence in Ex Situ Conservation of Wild Medicinal Plants in Crete, Greece. *Biology*, *12*(10), 1327.

Pasta, S., El Zein, H., Şentürk, O., Gücel, S., de Simone, L., & de Montmollin, B. (2024). Broad-ranged, highly disjunct, locally rare and severely endangered: the challenging risk assessment and a global conservation strategy for Erica sicula Guss. sensu lato (Ericaceae). *ARPHA Preprints*, *5*, e124671.

Perrino, E. V., & Perrino, P. (2020). Crop wild relatives: Know how past and present to improve future research, conservation and utilization strategies, especially in Italy: A review. *Genetic Resources and Crop Evolution*, *67*(5), 1067-1105.

Lahlou, R. A., Samba, N., Soeiro, P., Alves, G., Gonçalves, A. C., Silva, L. R., ... & Ismael, M. I. (2022). Thymus hirtus Willd. ssp. algeriensis Boiss. and Reut: A Comprehensive Review on Phytochemistry, Bioactivities, and Health-Enhancing Effects. *Foods*, *11*(20), 3195.

Perrino, E. V., Mahmoud, Z. N., Valerio, F., Tomaselli, V., Wagensommer, R. P., & Trani, A. (2023). Synecology of Lagoecia cuminoides L. in Italy and evaluation of functional compounds presence in its water or hydroalcoholic extracts. *Scientific Reports*, *13*(1), 20906.

Pandita, D., & Pandita, A. (2021). Secondary metabolites in medicinal and aromatic plants (MAPs): potent molecules in nature's arsenal to fight human diseases. *Medicinal and Aromatic Plants: Healthcare and Industrial Applications*, 41-84.

Pandita, D., & Pandita, A. (2021). Secondary metabolites in medicinal and aromatic plants (MAPs): potent molecules in nature's arsenal to fight human diseases. *Medicinal and Aromatic Plants: Healthcare and Industrial Applications*, 41-84.

Alshhibi, S. M., & Othman, R. M. (2024). THE IMPORTANCE OF ESTABLISHING A NAT AL-BATNAN PLATEAU, MAR.

Ogidi, O. I. (2023). Sustainable utilization of important medicinal plants in Africa. In *Sustainable Utilization and Conservation of Africa's Biological Resources and Environment* (pp. 323-351). Singapore: Springer Nature Singapore.

Yarkwan, B. (2023). Contamination of african water resources: impacts on biodiversity and strategies for conservation and restoration. *Sustainable utilization and conservation of africa's biological resources and environment*, 469-495.

Lorite, J. (2024). Overharvesting Is the Leading Conservation Issue of the Endangered Flagship Species Artemisia granatensis Boiss. *Diversity*, *16*(12), 744.