



Genetic, Ecological, and Chemical Diversity of Artemisia in Al-Jabal Al-Akhdar, Libya

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التنوع الوراثي والبيئي والكيميائي لنبات الشيح في الجبل الأخضر، ليبيا

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Abstract:

This paper presents a structured critical review of the genetic, ecological, and chemical diversity of Artemisia in Al-Jabal Al-Akhdar, Libya, with particular emphasis on Artemisia herba-alba, the species most represented in the available Libyan literature for the region. Evidence was compiled from genetic, morphometric, ecological, chemical, and bioactivity studies, while the bibliographic details of key references were re-examined using publisher records, scientific indexes, and botanical nomenclatural resources. The principal Libyan molecular study published in 2019, which sampled 18 individuals across different elevation classes, reported high proportions of polymorphic bands and notable separation of the higher-elevation group; however, the sample size and marker system do not support extrapolation to broad population-level estimates. Verified Libyan chemical evidence also indicates more than one compositional profile: a 2015 study reported a chrysanthenone- and chrysanthenyl-acetate-rich profile, whereas a 2025 study from Zintan described a camphor-thujone-dominant profile. The current evidence therefore does not justify adoption of a fixed list of Libyan chemotypes without standardized sampling across broader spatial and seasonal scales. Environmental and morphometric studies indicate that elevation, grazing, soil properties, and local conditions are important factors in explaining differences among populations, while rangeland degradation and extreme rainfall events warrant continued monitoring. The review concludes that the key research priority is not simply to increase isolated descriptive studies, but to establish an integrated design combining voucher specimens, population genomics or SNP-based approaches, flow cytometry, standardized analysis of oils and extracts, spatial environmental data, and explicit assessment of the strength of biological and clinical evidence.

Keywords: Artemisia herba-alba; Al-Jabal Al-Akhdar; genetic diversity; ecological variation; essential oils; chemotype.

المخلص:

تقدم هذه الورقة مراجعة نقدية منظمة للتنوع الوراثي والبيئي والكيميائي لنبات الشيح (Artemisia) في منطقة الجبل الأخضر بليبيا، مع التركيز بصفة خاصة على النوع Artemisia herba-alba الذي يحظى بأكبر تمثيل في الأدبيات الليبية المتاحة عن المنطقة. جُمعت الأدلة من الدراسات الوراثية والمورفومترية والبيئية والكيميائية ودراسات الأنشطة الحيوية، مع إعادة فحص البيانات البليوغرافية للمراجع الأساسية بالاستناد إلى سجلات الناشرين والفهارس العلمية.

والمصادر المتخصصة في التسمية النباتية. أظهرت الدراسة الجزيئية الليبية الرئيسية المنشورة عام 2019، والتي شملت 18 فردًا موزعين على فئات ارتفاعية مختلفة، ارتفاعًا في نسب الحزم متعددة الأشكال، إلى جانب تمايز ملحوظ للمجموعة الواقعة على ارتفاع أعلى. ومع ذلك، فإن حجم العينة ونظام الواسمات الجزيئية المستخدم لا يسمحان بتعميم النتائج على نطاق واسع أو اعتمادها لتقدير مؤشرات التنوع على مستوى التجمعات السكانية. كما تشير الأدلة الكيميائية الليبية التي أمكن التحقق منها إلى وجود أكثر من نمط تركيبى؛ إذ أظهرت دراسة منشورة عام 2015 نمطًا غنيًا بمركبي الكريزانتينون وخلات الكريزانتينيل، في حين وصفت دراسة منشورة عام 2025 لعينة من زنتان نمطًا تسود فيه مركبات الكافور والثوجون. وبناءً على ذلك، لا تبرر الأدلة الحالية اعتماد قائمة ثابتة من الأنماط الكيميائية لنبات الشيح في ليبيا قبل إجراء عمليات أخذ عينات موحدة تشمل نطاقًا جغرافيًا أوسع ومواسم مختلفة. وتشير الدراسات البيئية والمورفومترية إلى أهمية الارتفاع والرعي وخصائص التربة والظروف المحلية في تفسير الاختلافات بين التجمعات النباتية، في حين يستدعي تدهور المراعي وأحداث الأمطار الغزيرة المتطرفة استمرار الرصد البيئي. وتخلص المراجعة إلى أن الأولوية البحثية الرئيسية لا تتمثل في زيادة الدراسات الوصفية المنفردة فحسب، بل في إنشاء تصميم بحثي تكاملي يجمع بين العينات النباتية المرجعية المحفوظة في المعاشب، وتقنيات الجينومات السكانية أو الواسمات القائمة على تعدد أشكال النوكليوتيد المفرد (SNPs)، وقياس محتوى الحمض النووي باستخدام قياس التدفق الخلوي، والتحليل المعياري للزيوت والمستخلصات النباتية، والبيانات البيئية المكانية، والتقييم الصريح لقوة الأدلة المتعلقة بالأنشطة الحيوية والفعالية السريرية.

الكلمات المفتاحية: *Artemisia herba-alba*؛ الجبل الأخضر؛ التنوع الوراثي؛ التباين البيئي؛ الزيوت العطرية؛ النمط الكيميائي.

Introduction:

Artemisia is a large and chemically diverse genus within the family Asteraceae, and recent reviews describe the genus as comprising more than 500 species, with marked diversity in volatile compounds, phenolics, and other secondary metabolites Abad et al., 2012; Bora & Sharma, 2011; Pandey & Singh, 2017).

The study of this genus is especially important in Mediterranean and semi-arid environments because genetic diversity, environmental adaptation, and variation in chemical products may interact. The literature shows that essential-oil composition can vary with geographic origin, phenological stage, environmental conditions, and analytical methodology; therefore, comparisons among sites are difficult to interpret without standardized sampling and analytical designs (Salido et al., 2004; Younsi et al., 2016, 2017).

Al-Jabal Al-Akhdar is one of the major centers of plant diversity in Libya. It is a limestone mountain range in Cyrenaica extending along the Mediterranean coast and characterized by marked gradients in elevation, rainfall, and habitat over relatively short distances. Previous studies have documented vegetation patterns and species distributions along elevation gradients, while other studies have examined the effects of edaphic factors and rangeland management on vegetation composition (Hegazy et al., 2011; Mohamed et al., 2021).

With respect to wormwood, the available Libyan literature is concentrated on *Artemisia herba-alba*, with complementary studies of *A. judaica*, *A. arborescens*, and other species in different contexts. However, the taxonomy of *A. herba-alba* requires careful modern wording: Plants of the World Online currently treats *Artemisia herba-alba* as the accepted name and lists *Seriphidium herba-alba* (Asso) Soják as a nomenclatural synonym in the current treatment (Alavi, 1983; Janacković et al., 2015; Saad & Belteben, 2023; Alkhajkhaj et al., 2025).

This review aims to: (1) harmonize the taxonomic interpretation of Libyan sources; (2) assess the strength of genetic, ecological, and chemical evidence; (3) distinguish direct findings from interpretive inferences; (4) correct citations or numerical claims that exceed what the sources actually demonstrate; and (5) propose an integrated, testable research design.

Review Methodology:

The paper was based on a structured search of PubMed, Scopus, Google Scholar, Crossref, and open indexing resources using combinations of *Artemisia*, *A. herba-alba*, Libya, Al-Jabal Al-Akhdar, essential oil, genetic diversity, chemotype, grazing, and *Seriphidium*. In the revised version, key references were rechecked against publisher pages, DOI records, and botanical nomenclatural databases wherever possible.

Priority was given to primary studies involving plant material from Libya, followed by regional studies providing direct comparisons or methodological context for *A. herba-alba*. Statements that could not be traced to a specific source, as well as numerical values that could not be linked to the text or tables of the original study, were excluded.

This review is structured and critical rather than a PRISMA systematic review, because the source materials did not contain a registered protocol or a numerical screening flow that could be reconstructed

accurately. In addition, differences in plant collection, drying, distillation, and GC-MS column procedures make pooled quantitative synthesis inappropriate at the present stage.

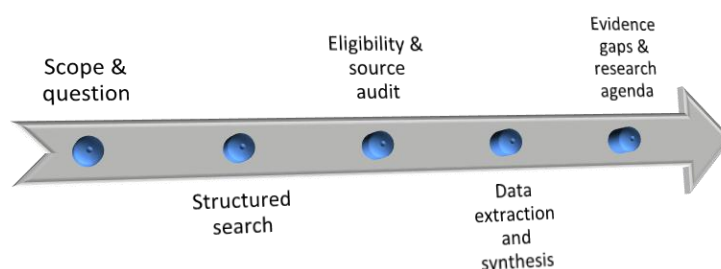


Figure (1): Search, verification, and critical-synthesis workflow used in the review.

Table (1): Core Libyan studies underpinning the review

Study	Material / site	Method	Role in the review
Elmeer & Elkhgkheg 2019	A. herba-alba; Al-Jabal Al-Akhdar; 18 individuals	SRAP + RAPD	Primary local molecular evidence
Janacković et al. 2015	A. judaica, A. herba-alba, A. arborescens; Libya	GC-MS + bioactivity assays	Reference for chemical composition and antimicrobial activity
Alkhajkhaj et al. 2025	A. herba-alba; 3 populations in Al-Jabal Al-Akhdar	Morphology + phytochemistry	Links elevation and grazing to phenotypic/chemical variation
Mohamed et al. 2021	Vegetation; Al-Jabal Al-Akhdar	Edaphic and environmental factors	Supports the role of soil
Mahmoud et al. 2021	Southern-slope rangelands; 28 sites	2006/2014 monitoring + grazing protection	Supports the rangeland-restoration axis
Giweli et al. 2025	A. herba-alba; Zintan	GC-MS + antibacterial and antiproliferative assays	Documents a recent, distinct Libyan chemical profile

Al-Jabal Al-Akhdar: Geographic and Environmental Context:

Al-Jabal Al-Akhdar is a limestone mountain range in Northeast Libya, and the literature documents clear gradients in elevation, rainfall, and vegetation over relatively short distances. Hegazy et al. (2011) documented altitudinal variation in species distribution and vegetation cover, while Mohamed et al. (2021) demonstrated the importance of edaphic factors in shaping plant communities.

These gradients provide an appropriate background for understanding variation within *Artemisia*, because differences among populations may reflect the combined effects of location, soil, grazing, and phenological stage. A rangeland study on the southern slope also used 28 monitoring sites to compare conditions in 2006 and 2014 and to test the effect of grazing protection on recovery trajectories (Mahmoud et al., 2021).

Severe storms and the 2023 Derna flood substantially affected river systems and floodplains in Northeast Libya; consequently, disturbance from extreme rainfall events should be incorporated into long-term habitat monitoring programs rather than treated only as a theoretical risk (Normand & Heggy, 2024; Nemnem et al., 2025).

taxonomy and Floristic Scope:

Libyan sources mention several *Artemisia* taxa in different geographic and use contexts, including *A. herba-alba*, *A. judaica*, *A. monosperma*, *A. campestris*, and *A. arborescens*. However, confirming the occurrence of each name at each site in Al-Jabal Al-Akhdar requires reference voucher specimens and consistent taxonomic identification. A definitive local species list should therefore not be based on secondary names reproduced in earlier reviews (Alavi, 1983; Dib & El Alaoui-Faris, 2019; Saad & Belteben, 2023).

This harmonization is important because mixing the two names in chemical or genetic tables can make differences among studies appear to represent differences between separate species, when part of the discrepancy may instead arise from taxonomic treatment. The methodological solution is to

deposit a voucher specimen and record the scientific name and synonyms used for every sample (Janacković et al., 2015).

Genetic Diversity:

The study by Elmeer and Elkhgkheg (2019) is the main anchor for the Libyan molecular evidence that could be verified. It sampled 18 individuals across elevation classes and used SRAP and RAPD markers; 17 SRAP bands were recorded with 94.12% polymorphism, and 61 RAPD bands with 100% polymorphism, with similarity coefficients ranging from 41% to 84%.

These results demonstrate molecular variation within the sampled material and support a possible elevation-associated structure, but they are insufficient on their own to estimate national-scale population structure or infer gene-flow rates or conservation units. The small sample size and the dominant nature of the markers prevent such strong inferences (Elmeer & Elkhgkheg, 2019).

In Tunisia, Haouari and Ferchichi (2008) analyzed 216 samples using four ISSR primers and 60 polymorphic loci, providing broader evidence of variation among populations. In Egypt, Badr et al. (2012) reported morphological, chromosomal, and molecular variation in *A. monosperma* and *A. judaica*, while an Algerian study of 22 populations documented diploid and tetraploid forms in *A. herba-alba*. More broadly, a study spanning Iberia and North Africa demonstrated complex phylogeographic and cytogeographic structure in the species.

Mahgoub et al. (2025) illustrates the value of a multi-marker approach: ITS2 provided better discrimination among the species examined than *psbA-trnH*, and ISSR alone did not completely separate *A. herba-alba* from *A. judaica*, whereas RAPD and SCAR improved molecular documentation.

The methodological conclusion is that Libya does not simply need more PCR primers; it needs spatially representative sampling across environmental gradients, cytotype assessment, and linkage of taxonomic, environmental, and chemical identity within the same sample or population.

Table (2): Brief comparison of regional genetic evidence

Source	Region / sample size	Method	Usable finding
Libya (Elmeer & Elkhgkheg, 2019)	18 individuals; elevation gradients	SRAP + RAPD	94.12% and 100% polymorphism; relative separation of the higher- elevation population
Tunisia (Haouari & Ferchichi, 2008)	216 samples; 4 primers	ISSR	60 polymorphic loci; broad variation among populations
Egypt (Badr et al., 2012)	10 populations	Karyology + RAPD	Differences in ploidy and molecular variation between <i>A. monosperma</i> and <i>A. judaica</i>
Algeria (Bougoutaia et al., 2016)	22 populations	Flow cytometry + FISH/rDNA	Diploid and tetraploid forms, including a mixed population
Iberia and North Africa (Bougoutaia et al., 2021)	Broad multi-site study	cpDNA + flow cytometry + habitat modeling	Complex phylogeographic and cytogeographic structure and independent polyploidy patterns

Ecological and Habitat Diversity:

Hegazy et al. (2011) showed that Al-Jabal Al-Akhdar has clear altitudinal and environmental gradients in vegetation distribution. Mohamed et al. (2021) likewise showed that soil properties are important for explaining plant-community composition. These findings justify treating elevation and soil as essential covariates when sampling *Artemisia*.

Alkhajkhaj et al. (2025) found clear differences among three *A. herba-alba* populations in Al-Jabal Al-Akhdar, with the Ras Al-Hilal population showing the highest values for canopy circumference and biomass. The differences were associated with elevation, grazing intensity, and local conditions, providing direct morphometric evidence that environmental context may be an important component of observed phenotypic variation.

Mahmoud et al. (2021) the southern-slope rangelands used 28 monitoring sites and assessed changes in vegetation cover, landscape function, and soil-surface condition, while also testing the effectiveness of grazing protection. This study supports including grazing intensity and protection history as covariates in any new study of *Artemisia* populations.

There is currently insufficient evidence from Al-Jabal Al-Akhdar to estimate precise climatic limits for each *Artemisia* species or to predict reliably how suitable ranges may contract under climate-change scenarios. Environmental-suitability modeling should therefore be treated as a subsequent research project rather than as an established result of this review.

Chemical Diversity:

The chemical composition of wormwood is highly sensitive to geographic origin, phenological stage, drying method, extraction procedure, and analytical approach. General reviews confirm that *Artemisia* essential oils contain variable mixtures of monoterpenes and sesquiterpenes, while phenolic and flavonoid compounds contribute to another component of chemical diversity and bioactivity (Abad et al., 2012; Bora & Sharma, 2011; Pandey & Singh, 2017).

Janacković et al. (2015) analyzed oils from *A. judaica*, *A. herba-alba*, and *A. arborescens* collected in Libya, the *A. herba-alba* oil showed a profile rich in chrysanthenone and chrysanthenyl acetate, whereas *A. judaica* was characterized by piperitone and *A. arborescens* by other constituents including camphor and chamazulene.

Giweli et al. (2025) analyzed on *A. herba-alba* from Zintan, camphor and thujone were dominant components, and antibacterial and antiproliferative activities were assessed. This recent result is important because it shows that another Libyan sample of the same species does not match the chemical profile reported in the 2015 study.

Accordingly, any wording claiming the existence of “seven fixed Libyan chemotypes” should be removed unless supported by standardized multi-site and seasonal sampling. The available evidence supports discussion of “multiple chemical profiles or patterns documented in Libyan samples,” rather than a complete national chemotype map.

Tunisian studies indicate that *A. herba-alba* may exhibit camphor- and thujone-dominant patterns, while a study from southern Jordan reported a thujone-rich profile containing 1,8-cineole and camphor; the 2025 Moroccan study identified four compositional groups across six sites and 60 samples. A study from southern Spain also demonstrated intraspecific variability (Younsi et al., 2016, 2017; Abu-Darwish et al., 2015; Al-Wahaibi et al., 2020; Baranová et al., 2025; Chaari et al., 2025).

Juteau et al. (2002) provide an additional example of phenological effects: oil composition changed among vegetative, flowering, and seed-bearing stages. Therefore, chemical differences among *A. herba-alba* populations should not be interpreted as genetic differences unless phenological stage and extraction protocol are controlled.

Table (3): Documented examples of chemical variation in *A. herba-alba*

Region / source	Major constituents	What the study supports
Northeast Libya (Janacković et al., 2015)	Chrysanthenone 20.8%; cis-chrysanthenyl acetate 17.6%; cis-thujone 13.6%	A documented Libyan chemical profile in a specific sample
Zintan, Libya (Giweli et al., 2025)	Camphor 30.53%; thujone 22.47%	A different Libyan profile documented in a recent study
Tunisia (Younsi et al., 2017)	Camphor 19.61%; α-thujone 19.40%; β-thujone 9.44%	Regional intraspecific variation
Southern Jordan (Abu-Darwish et al., 2015)	β-thujone 25.1%; α-thujone 22.9%; 1,8-cineole 20.1%	Importance of geographic origin for comparison
Morocco (Chaari et al., 2025)	4 compositional groups across 6 sites / 60 samples	Need for standardized, data-driven chemical classification

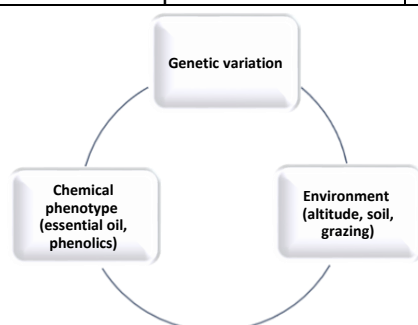


Figure (2): Simplified conceptual framework for the proposed interaction between genetic diversity, environment, and chemical profiles ($G \times E \rightarrow C$).

The figure is a proposed interpretive framework, not an experimentally established causal result.

Interactions Among Genetic, Ecological, and Chemical Diversity:

This review proposes that observed chemical variation in *Artemisia* may result from interactions among genetic background, environment, phenological stage, and analytical methodology. This is a testable interpretive framework rather than a final causal conclusion (Elmeer & Elkhgkheg, 2019; Janacković et al., 2015; Alkhajkhaj et al., 2025; Giweli et al., 2025).

- **Hypothesis H1:** Measurable associations exist between genetic groups and essential-oil profiles after controlling for site, soil, and season.
- **Hypothesis H2:** Grazing intensity is associated with systematic changes in phenolic compounds and biomass, but separating environmental effects from genetic effects remains necessary.
- **Hypothesis H3:** Altitudinal gradients contribute to population structure that can be detected with broader sampling and SNP- or GBS-based markers, with cytotype included in the design.

The following design is proposed: select 20–30 populations along environmental gradients, with 20–30 individuals per population as an initial target subject to subsequent power analysis; collect a voucher for each sample; estimate ploidy by flow cytometry; perform SNP/GBS-based genotyping; quantify essential oils by GC-MS and phenolic extracts by HPLC; record elevation, soil, grazing intensity, and phenological stage; and use mixed-effects models, redundancy analysis (RDA), and spatial linkage to test interactions. Seasonal measurements should preferably be repeated at a subset of sites to assess temporal replication.

Traditional Uses and Applied Value:

Libyan reviews indicate that *Artemisia* has a long-standing presence in folk and traditional medicinal use. However, documentation of traditional use is not equivalent to clinical proof, and therapeutic claims require a clear distinction among ethnographic evidence, bioassays, and clinical studies (Saad & Belteben, 2023; Al-Waili, 1988).

Studies have shown that some *Artemisia* extracts or essential oils possess antimicrobial or antioxidant activity, and an experiment using *A. campestris* and *A. herba-alba* reported effects on the parasite *Leishmania infantum* in vitro. There are also older experimental reports concerning hypoglycemic activity and early reports involving *Enterobius vermicularis*. These findings do not justify presenting *Artemisia* as a proven treatment for cancer or chronic disease without appropriate clinical trials (Janacković et al., 2015; Younsi et al., 2016; Aloui et al., 2016; Twaij & Al-Badr, 1988).

In 2026 a letter to the editor drew attention to the unregulated use of *Artemisia* preparations among cancer patients in Libya. Because this source is a short correspondence rather than an epidemiological study, it should be used to support calls for awareness, research, and regulation rather than to estimate prevalence or efficacy (Alhudiri et al., 2026).

Table (4): Level of evidence for biological activities

Activity	Source	Evidence type	Editorial note
Antibacterial / antifungal (Janacković et al., 2015)	Libyan essential oils	In vitro	Presented as in vitro activity, not therapeutic efficacy
Antiproliferative (Giweli et al., 2025)	<i>A. herba-alba</i> oil from Zintan	Experimental / cellular	Preliminary evidence requiring extension before any clinical inference
Antileishmanial (Aloui et al., 2016)	<i>A. campestris</i> and <i>A. herba-alba</i>	In vitro; promastigotes	Does not equate to treatment of human infection
Antioxidant / anticholinesterase (Younsı et al., 2016, 2017)	Tunisian studies	In vitro	Geographic context differs from Libya
Hypoglycemic / <i>Enterobius</i> (Twaij & Al-Badr, 1988; Al-Waili, 1988)	Older reports and experiments	Experimental / early clinical	Insufficient for a current therapeutic recommendation

Threats and Conservation:

Available evidence indicates that grazing, land-use change, climatic disturbances, fires, and extreme rainfall events exert interacting pressures on rangeland habitats in Al-Jabal Al-Akhdar. Rangeland studies provide evidence for the value of grazing protection, while studies from 2023–2024 illustrate the magnitude of disturbance that severe floods can produce (Mahmoud et al., 2021; Normand & Heggy, 2024; Nemnem et al., 2025).

Plant conservation should combine in situ and ex situ approaches, with genetic and taxonomic documentation of samples and the establishment of seed banks or propagation material where the

biological characteristics of the species permit. Uniform numerical harvesting or grazing limits should also be avoided until local experiments quantify responses and recovery rates.

Any subsequent monitoring program should record grazing intensity, protection history, soil condition, vegetation cover, and changes in species density at the same sites over time. This will allow demographic changes to be distinguished from chemical or morphometric changes.

Critical Analysis and Evidence-Gap Matrix:

The evidence review reveals seven major gaps: (1) the small Libyan molecular dataset; (2) the lack of systematic integration of cytotype information with molecular data; (3) the absence of standardized chemical surveys covering sites and seasons; (4) weak recording of environmental variables and grazing history; (5) taxonomic confusion among overlapping names in the literature; (6) the scarcity of integrative studies measuring $G \times E \times C$ on the same samples; and (7) the need to separate laboratory bioactivity from clinical claims (Elmeer & Elkhgkheg, 2019; Bougoutaia et al., 2016, 2021; Mahgoub et al., 2025).

The most important editorial correction is to avoid converting a limited sample into a national characterization. Accordingly, broad genetic-diversity estimates such as H and GST that could not be clearly traced to verified Libyan studies were removed from the revised version, as were mortality or cover-loss estimates that could not be directly attributed to a specific primary source (Elmeer & Elkhgkheg, 2019).

Chemotype wording was also revised: instead of stating that seven fixed Libyan chemotypes exist, the text is limited to patterns documented by specific Libyan studies, while other patterns are treated as hypotheses requiring standardized surveys. The 2025 Moroccan study was also corrected from “16 chemotypes” to four compositional groups, as reported in the published study itself (Janacković et al., 2015; Giweli et al., 2025; Chaari et al., 2025).

Table (5): Evidence gaps and priority matrix

Gap	Reason	Proposed approach	Priority
Small genetic dataset	Difficult to generalize a local result	20–30 populations $\times$ 20–30 individuals as an initial target after power analysis; SNP/GBS	Highest
Cytotype information not integrated	May explain part of evolutionary and chemical variation	Flow cytometry + chromosome counting on representative samples	Highest
Non-standardized chemical survey	Hinders chemotype definition	Standardized GC-MS and HPLC + seasonal replication	Highest
Limited $G \times E \times C$ integration	Difficult to separate environmental from genetic effects	Coupled design + mixed models + RDA	High
Weak long-term monitoring	Insufficient baseline for recovery / climate responses	Fixed sites + vegetation cover + soil + grazing records	High
Unregulated medicinal use	Gap between traditional use and clinical efficacy	Awareness + toxicity studies + controlled clinical studies before marketing	High

Recommendations and Research Agenda:

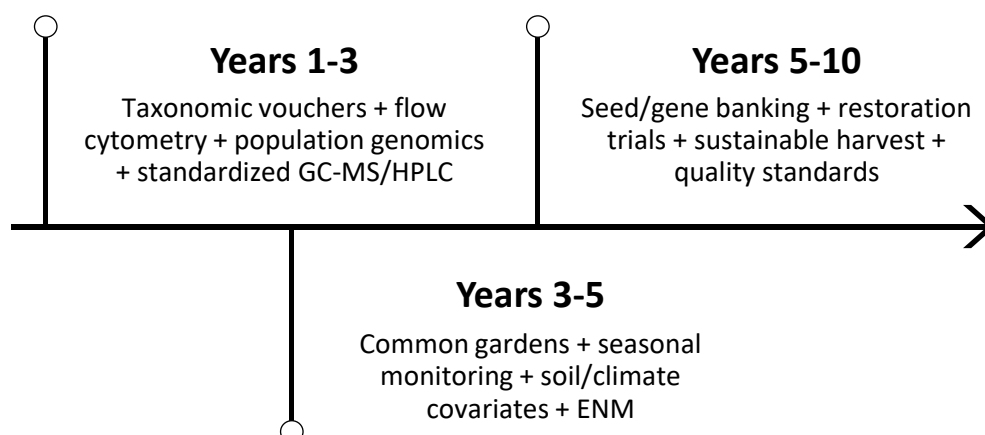
Short term (1–3 years): conduct an integrated survey of *Artemisia* populations, with reference voucher specimens; implement SNP/GBS-based genetic design; estimate ploidy by flow cytometry; and standardize GC-MS and HPLC protocols with partial seasonal replication.

Medium term (3–5 years): conduct common-garden experiments or controlled grazing experiments where feasible; link environmental, morphometric, and chemical data to genetic groups; and develop environmental-suitability models based on local data.

Long term (5–10 years): establish an ex-situ conservation program, develop sustainable collection protocols based on local experiments, link oil and extract quality to applicable standards, and archive raw data and specimens in institutional repositories.

Commercial or therapeutic recommendations should not precede the establishment of a robust identity and diversity baseline. The first step is to determine “which plant, which population, and under which environmental conditions?” and then test how these factors relate to chemical composition and biological activity.

Proposed research and management roadmap:



Priority: first establish identity and baseline variability; then test drivers; finally translate evidence into management.

Figure (3): Proposed roadmap from identity and diversity documentation to driver testing and translation into conservation and sustainable use.

Conclusion:

The available evidence indicates that *Artemisia* in Al-Jabal Al-Akhdar is a promising system for studying population-level variation, but the current evidence base is too small to support a complete national characterization of genetic or chemical diversity. Libyan studies demonstrate molecular, morphometric, and chemical variation, while regional studies show that *A. herba-alba* has a complex history of chromosomal and geographic variation.

The scientific value of the next phase lies in moving from demonstrating that “differences exist” to testing “why the differences exist”: are they associated with the genome, elevation, soil, grazing, season, or an interaction among these factors? Answering this question requires coordinated sampling and multi-level analyses on the same samples.

This review recommends documenting synonyms used in older sources, avoiding unsupported inflation of chemotype numbers or diversity indices, and linking any medicinal or commercial use to an appropriate level of evidence.

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