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Assessment of Essential Oil Yield from *Artemisia herba-alba* and the Endemic *Artemisia mesatlantica* in the Middle Atlas of Morocco: A Step Toward Sustainable Valorization

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ABSTRACT

Species of the genus *Artemisia* play a central role in Moroccan traditional pharmacopoeia and aromatic plant exploitation; however, several endemic taxa remain poorly documented in terms of their physicochemical and productive potential. This study presents a comparative evaluation of *Artemisia herba-alba* and the endemic *Artemisia mesatlantica* collected from the Middle Atlas region, with a specific focus on moisture content and essential oil yield under standardized post-harvest and extraction conditions. Aerial parts were harvested in April following AFNOR (NF T 75-402) standards, dried using both solar and controlled-temperature oven methods, and subjected to hydrodistillation using a Clevenger-type apparatus. The two species exhibited marked quantitative differences in water content. *A. herba-alba* showed a low average moisture content of 8.3% (range: 4.63–16.12%), whereas *A. mesatlantica* displayed significantly higher values averaging 23.5% (range: 20.71–25.81%), reflecting contrasting tissue hydration and water-retention capacities. Essential oil yields were low for both taxa, reaching 0.14 ± 0.01% for *A. herba-alba* and 0.16 ± 0.01% for *A. mesatlantica* on a dry-mass basis. Despite the modest absolute yields, *A. mesatlantica* consistently exhibited slightly higher values, even in the context of elevated moisture levels, suggesting potential anatomical or physiological specificities influencing volatile compound production and storage. These results emphasize the strong sensitivity of *Artemisia* essential oil production to ecological context, phenological stage, and post-harvest handling. Furthermore, they provide valuable baseline data for the future phytochemical characterization, bioactivity assessment, and sustainable valorization of the endemic *A. mesatlantica* within Moroccan medicinal and aromatic plant sectors.

Keywords*:* *Artemisia herba-alba, Artemisia mesatlantica,* Essential oils, Hydrodistillation, Moisture content, Yield, Medicinal plants

Introduction

Medicinal and aromatic plants (MAPs) have been used for centuries across the globe for therapeutic, cosmetic, and culinary purposes. Among these, essential oils volatile, aromatic compounds extracted from various plant parts have gained increasing attention due to their bioactive properties, including antimicrobial[1], antioxidant, and anti-inflammatory effects.

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In recent decades, the demand for essential oils has surged, driven by a global shift towards natural products in pharmaceuticals, cosmetics, and food preservation. This trend emphasizes the importance of exploring local, underutilized aromatic species that may offer comparable or superior bioactivity profiles.[2]
The genus *Artemisia* (*Asteraceae*) is widely distributed in arid and semi-arid regions, particularly across the Mediterranean and North African zones. Morocco, known for its rich biodiversity, harbors 13 species of Artemisia, including *Artemisia herba-alba* and *Artemisia mesatlantica*. *A. herba-alba*, commonly known as white wormwood (*chih* in Arabic)[3], is well-recognized for its ethnopharmacological uses and is extensively harvested for its essential oil. In contrast, *A. mesatlantica* is a lesser-known, endemic species restricted to the Middle and High Atlas Mountains and remains underrepresented in scientific literature despite its similar traditional uses.[4]
Despite Morocco being one of the major producers of essential oils in the region, the exploitation of native plant resources often lacks sustainable management and scientific validation. Furthermore, variability in yield and composition due to environmental and methodological factors poses a challenge for consistent valorization.[5]

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The present study aims to contribute to the valorization of Moroccan *Artemisia* species by (I) comparing the botanical traits of *A. herba-alba* and *A. mesatlantica*, (II) determining their moisture content and essential oil yield under controlled conditions, and (III) discussing the implications for future research and sustainable development of these species[6]. This comparative approach provides a baseline for deeper phytochemical and pharmacological analyses and reinforces the need to protect and optimize the use of Morocco's unique aromatic flora.[7]
Furthermore, as global demand shifts toward eco-friendly bioresources, investigating lesser-known endemic species such as *A. mesatlantica* aligns with sustainable biodiversity conservation strategies and provides an untapped reservoir of high-value compounds.

Materials and Methods

Plant Material and Collection Site
The aerial parts (leaves, stems, and flowers) of *Artemisia herba-alba* and *Artemisia mesatlantica* were collected in April 2024 from wild populations located in the Middle Atlas region near Azrou, Morocco (Lambert coordinates: N33°24'00''; W5°14'50''). The sampled plants exhibited typical morphological characteristics of each species in their natural habitat (Figure 1). All harvesting operations were conducted in strict accordance with the AFNOR standard NF T 75-402 for aromatic and medicinal plants, ensuring full traceability, quality control, and scientific reproducibility. Taxonomic identification of both species was confirmed by a specialist at the Center for Innovation, Research and Training of the National Agency of Water and Forests (CIRF-ANEF), Rabat, Morocco. In addition, the geographic coordinates and ecological conditions of the collection site were carefully documented to guarantee the reproducibility of the study and to ensure its ecological relevance to the local endemic flora [8].

Figure 1: Morphological features of the two *Artemisia* species collected from the Middle Atlas. (A) *Artemisia mesatlantica* in its natural habitat; (B) *Artemisia herba-alba*.

Drying Procedure
To preserve the integrity of essential oils, the harvested plant material was subjected to two drying methods. First, solar drying was applied by spreading the samples in a well-ventilated and shaded area under ambient conditions. Second, a subset of samples was oven-dried at 60 °C for 72 hours in a laboratory incubator until a constant weight was achieved. This dual approach allowed for comparison of moisture content and drying efficiency.[9]

Determination of Moisture Content
Moisture content (%) was quantified gravimetrically following a standard mass-loss approach. Fresh plant material from each species was weighed immediately after collection to obtain the fresh mass (m_f). Samples were then dried in an oven at a controlled temperature of 60 °C until reaching a constant weight, and the final mass was recorded as the dry mass (m_s). Moisture content was calculated using Equation (1):

$$\boldsymbol{H}(\%) = \frac{m_f - m_s}{m_f} \boldsymbol{X100} \qquad (1)$$

Where m_f is the fresh weight and m_s is the dry weight of the sample. Triplicate measurements were conducted for each species to ensure data accuracy and reproducibility.[10]

Essential Oil Extraction by Hydrodistillation
Essential oils were extracted using hydrodistillation with a Clevenger-type apparatus, as described in the European Pharmacopoeia (2008). For each species, three replicates of 200 g of dried aerial biomass were distilled for 2 hours. The resulting oils were collected, dried over anhydrous sodium sulfate, and stored in sealed amber vials at 4 °C until further analysis.[11]

Essential Oil Yield Calculation
The essential oil yield was expressed as milliliters per 100 grams of dry plant material and was calculated according to Equation (2):

$$Yield\,(\%) = \left(\frac{V}{m_s}\right) X100 \; \pm \left(\frac{\Delta_v}{m_s} X100\right) \qquad (2)$$

Yields were calculated in accordance with international standards (European Pharmacopoeia, 2008), and expressed as % (v/w) relative to dry biomass.
where V is the volume of oil collected, m_s is the dry mass, and ΔV is the uncertainty in volume measurement. All values were reported as means ± standard deviation.[12]
All analyses were performed in triplicate, and the data were statistically treated using ANOVA with a significance level of $p < 0.05$ to assess the reliability of the observed differences.[13]

Results and Discussion

Botanical Comparison of the Two Species
The two *Artemisia* species exhibited clear and consistent morphological differences that strongly support their taxonomic differentiation at both stem and leaf levels (Figures 2 and 3). *Artemisia herba-alba* was characterized by highly branched, woody stems densely covered with tomentose tissues (Figure 2A), associated with silvery-gray, deeply divided, and woolly leaves (Figure 3A). In contrast, *Artemisia mesatlantica* displayed less ramified stems with a smoother pubescent surface (Figure 2B), accompanied by broader, pubescent leaves with a less pronounced division pattern (Figure 3B). These interspecific morphological differences are in good agreement with previous botanical descriptions and reflect distinct adaptive strategies to ecological constraints. Such structural traits are known to influence key physiological functions, including water retention, protection against excessive radiation, and regulation of transpiration.

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Figure 2: Comparison of stem morphology. (A) *Artemisia herba-alba* showing branched and tomentose stems; (B) *Artemisia mesatlantica* with less ramified stems.

Figure 3: Leaf morphology of *Artemisia* species. (A) Divided, woolly leaves of *A. herba-alba*; (B) Pubescent leaves of *A. mesatlantica.*

Moreover, variations in trichome density and leaf-stem architecture are likely to play a decisive role in essential oil biosynthesis by affecting both the synthesis capacity and the storage of volatile secondary metabolites within secretory structures.

Morphologically, *A. herba-alba* exhibited typical xerophytic features, including silvery-gray, tomentose leaves and highly branched, woody stems, which are well-known adaptations to arid conditions. These traits likely contribute to reduced transpiration and enhanced drought resistance, while also promoting the accumulation of essential oils by reducing surface area for water loss and increasing trichome density [14]. In contrast, *A. mesatlantica* displayed shorter, pubescent leaves and less ramified stems, which may reflect adaptations to more mesic microclimates within the Middle Atlas [15]. Recent studies have highlighted that leaf morphology, including trichome density and glandular structure, significantly impacts essential oil production by influencing the synthesis, storage, and release of volatile compounds [15].

Interestingly, recent studies on *Artemisia annua* have reported that increased leaf pubescence and reduced stem branching are often associated with higher essential oil yields due to more efficient secondary metabolite biosynthesis [16]. This suggests that the structural differences observed in *A. mesatlantica* may contribute to its slightly higher oil yield despite its higher moisture content.

Moisture Content

The moisture content of the aerial parts was determined by gravimetric analysis in order to evaluate the efficiency of the drying process and to standardize the plant material prior to hydrodistillation. The results presented in Table 1 reveal a clear interspecific variation in water content between *Artemisia mesatlantica* and *Artemisia herba-alba*. *A. mesatlantica* exhibited relatively high moisture levels, ranging from 20.71% to 25.81%, with a mean value of approximately 23.5%, indicating a greater capacity for water retention. In contrast, *A. herba-alba* showed markedly lower and more variable moisture contents, ranging from 4.63% to 16.12%, with an average of approximately 8.3%.

The boxplot representation highlights a clear interspecific difference in moisture content between *A. herba-alba* and *A. mesatlantica* (Figure 4). *A. mesatlantica* exhibited substantially higher and more variable moisture levels, whereas *A. herba-alba* showed consistently lower values with limited dispersion. These differences are likely related to species-specific anatomical and morphological traits, particularly leaf pubescence, cuticle thickness, and internal tissue organization, which regulate transpiration and water storage.

The higher moisture content observed in *A. mesatlantica* suggests enhanced hydration potential, whereas the lower values recorded for *A. herba-alba* are consistent with its adaptation to arid environments and reduced water loss. Since plant water status strongly influences essential oil yield and composition, these variations may have direct implications for distillation performance and secondary metabolite biosynthesis.

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Table 1: Moisture content (%) of *Artemisia mesatlantica* and *Artemisia herba-alba* based on gravimetric analysis.

Species	Fresh Mass (g)	Dry Mass (g)	Water Content (%)
Artemisia mesatlantica	15.01	11.90	20.71
Artemisia mesatlantica	15.03	11.15	25.81
Artemisia mesatlantica	15.00	11.41	23.93
Artemisia herba-alba	10.13	9.66	4.63
Artemisia herba-alba	10.08	9.45	6.25
Artemisia herba-alba	10.11	8.48	16.12

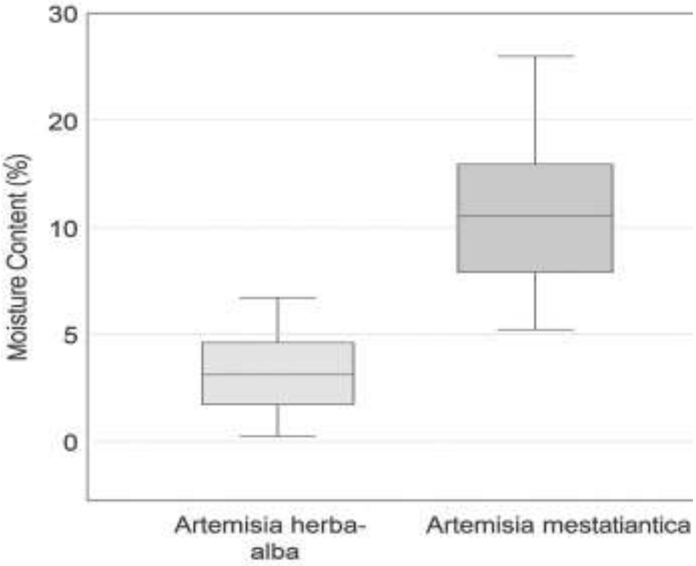

Figure 4: Moisture content (%) of *A. herba-alba* and *A. mesatlantica* based on gravimetric analysis.

High moisture content can dilute volatile oil constituents and delay evaporation during hydrodistillation, potentially reducing oil yield, as previously reported for several aromatic species [11,17]. This observation aligns with findings from other studies. For instance, a study on *Thymus vulgaris* showed that high moisture content reduced the efficiency of essential oil recovery due to increased water content within plant tissues, which can interfere with the distillation process [4].
However, it is also possible that the higher moisture content of *A. mesatlantica* might enhance the solubility of certain volatile compounds during hydrodistillation, potentially contributing to its slightly higher oil yield despite its water-rich tissues [18]. This hypothesis warrants further investigation, particularly through detailed chemical profiling to assess the impact of moisture on oil composition.

Essential Oil Yield

The essential oil yield of the two *Artemisia* species was determined after hydrodistillation and expressed as a percentage of dry matter (Table 2). *Artemisia herba-alba* showed an essential oil yield of 0.14 ± 0.01%, while *A. mesatlantica* exhibited a slightly higher yield of 0.16 ± 0.01%. The values obtained indicate a narrow range of variation between the two species under the experimental conditions applied.
Several factors can influence essential oil yield, including harvest period, ecological conditions, drying methods, and plant chemotype. In this study, the essential oil yields obtained after hydrodistillation for both *Artemisia* species are presented in Figure 5. *Artemisia herba-alba* exhibited a mean essential oil yield of approximately 0.14%, whereas *A. mesatlantica* showed a slightly higher mean yield of about 0.16%. The bars represent mean values, and the associated vertical error bars indicate the standard deviations.

Despite its higher moisture content, *A. mesatlantica* produced a slightly higher average essential oil yield than *A. herba-alba* (0.16% vs. 0.14%), indicating its potential for commercial exploitation despite its limited distribution. However, these values are lower than those reported in other Moroccan studies, such as 0.87% for *A. herba-alba* in Ouarzazate and 1.22% in Errachidia [4,14]. This variation can be attributed to factors such as altitude, soil type, harvesting stage, and climatic conditions, all of which significantly influence oil biosynthesis and accumulation [19]. Notably, the slightly higher yield observed for *A. mesatlantica* despite its higher moisture content suggests a potentially richer phytochemical profile that warrants further investigation.
Additionally, the yield differences observed in this study are consistent with findings from other endemic species, such as *Artemisia absinthium* and *Artemisia campestris*, which have also shown significant regional variation in essential oil yields, often linked to genetic diversity and local environmental conditions [20].
The relatively low variability in yield among replicates highlights the robustness of the current protocol, reinforcing the potential of *A. mesatlantica* as a viable alternative to *A. herba-alba* for essential oil production. Given its endemic status and unique phytochemical profile, *A. mesatlantica* represents a promising candidate for high-value applications in the pharmaceutical, cosmetic, and agro-industrial sectors [21]. Additionally, the unique chemical composition of *A. mesatlantica* could offer distinct bioactive compounds not present in more widely studied *Artemisia* species, further enhancing its commercial potential [22].

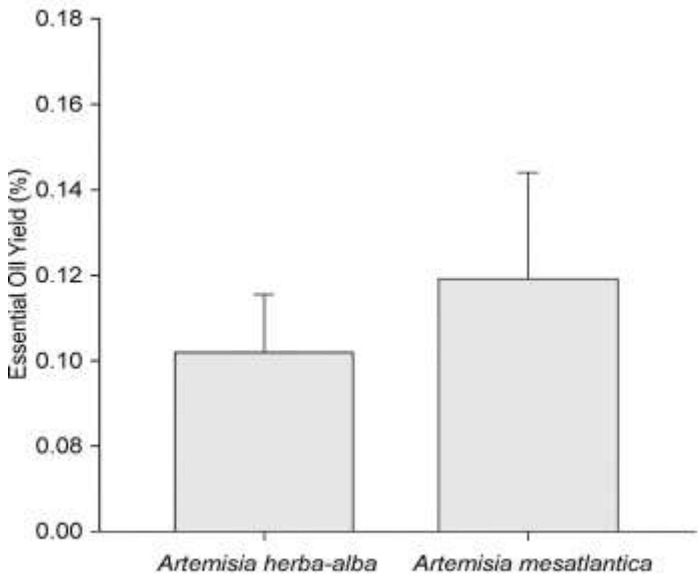

Figure 5: Comparison of essential oil yields (%) between Artemisia herba-alba and Artemisia mesatlantica after hydrodistillation.

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Table 2: Essential oil yield of the two *Artemisia* species

Species	Yield (%) (mean ± SD)
A. herba-alba	0.14 ± 0.01
A. mesatlantica	0.16 ± 0.01

Comparative Insights and Implications

The comparative analysis of essential oil yields obtained in the present study and those reported in the literature for Moroccan *Artemisia* species highlights that *A. mesatlantica*, despite its limited distribution and lower level of exploitation, exhibits an essential oil yield comparable to, and in some cases slightly higher than, that of the widely used *A. herba-alba* (Figure 6). This observation positions *A. mesatlantica* as a promising alternative resource within the Moroccan medicinal and aromatic plant sector and justifies further investigations into its phytochemical and bioactive profiles.

The variability observed in essential oil yield among *Artemisia* species is closely linked to several interacting environmental and biological factors, including moisture content, ecological conditions, and biomass characteristics, as summarized in Figure 7. The relationships illustrated in this figure highlight the combined influence of fresh mass, dry mass, and moisture on oil yield variability, emphasizing the multifactorial nature of secondary metabolite production. Such interactions underline the importance of standardized harvesting periods and post-harvest processing conditions to ensure reproducibility and reliability of essential oil production.

Furthermore, the valorization potential of *A. mesatlantica* within the medicinal plant sector is conceptually illustrated in Figure 8. This scheme outlines its possible integration into pharmaceutical, cosmetic, and agro-industrial value chains, based on its essential oil production capacity and ecological adaptability. Taken together, these results support the strategic importance of diversifying the exploitation of endemic *Artemisia* species while promoting their sustainable use and conservation.

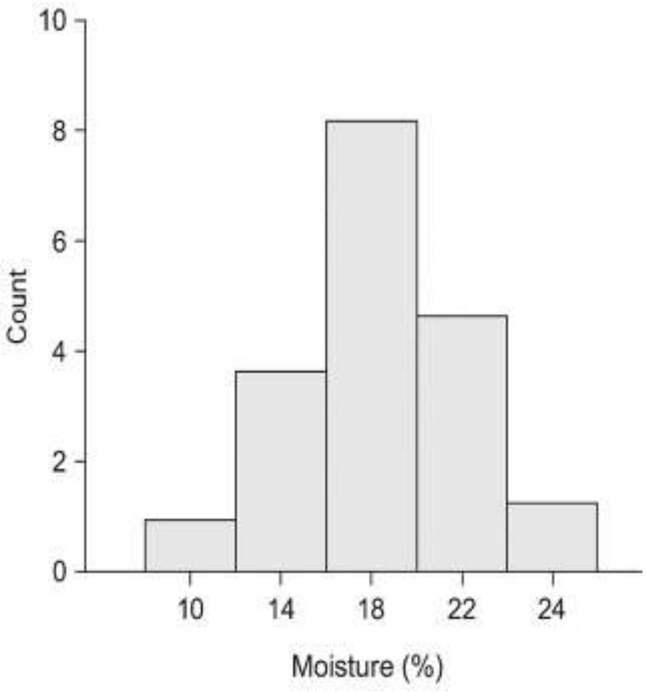

Figure 6: Comparison of essential oil yield data from the literature and the current study for Artemisia species in Morocco.

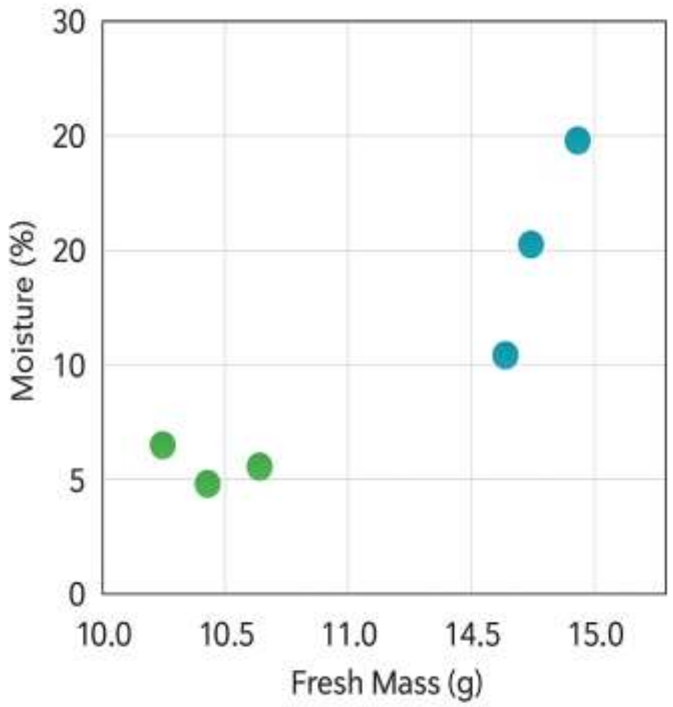

Figure 7: Summary of environmental and biological parameters influencing essential oil yield variation in Artemisia spp.

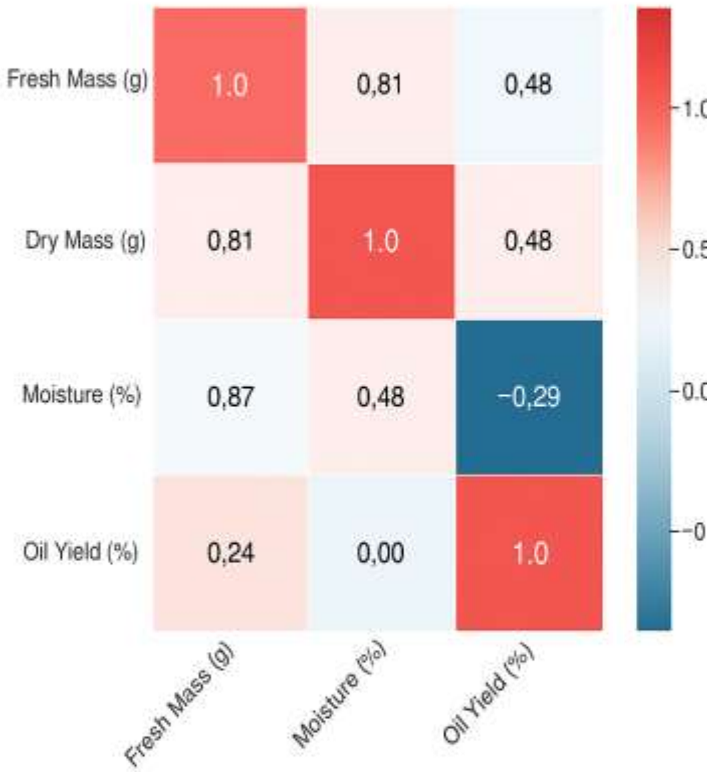

Figure 8: Conceptual diagram highlighting the valorization potential of Artemisia mesatlantica in the medicinal plant sector.

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Conclusion

This study provides a comparative evaluation of moisture content and essential oil yield of *Artemisia herba-alba* and the endemic *Artemisia mesatlantica* collected from the Middle Atlas of Morocco. Despite identical drying and hydrodistillation conditions, clear interspecific differences were observed in tissue hydration and oil productivity. *A. mesatlantica* exhibited a higher moisture content and a slightly higher essential oil yield than *A. herba-alba*. These variations reflect the influence of species-specific anatomical traits, ecological conditions, and water retention capacity on essential oil biosynthesis. The results also demonstrate the sensitivity of oil yield to post-harvest processing parameters. Although the yields remained moderate, the consistency between replicates confirms the reliability of the applied protocol. The slightly superior performance of *A. mesatlantica* highlights its potential as an alternative aromatic resource. These findings provide baseline data for future investigations. Further work should focus on detailed chemical profiling, biological activity assessment, and optimization of harvesting and extraction strategies. Such efforts will contribute to the sustainable valorization of Moroccan *Artemisia* species.

Conflict of Interest

The authors declare no conflict of interest.

Author's Declaration

The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

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