Trop J Nat Prod Res, January 2026 10(1): 6811 – 6820

ISSN 2616-0684 (Print)
ISSN 2616-0692 (Electronic)

Tropical Journal of Natural Product Research

Available online at https://www.tjnpr.org

Original Research Article

Ethnobotanical Survey of *Atractylis gummifera* L. Traditional Uses among Moroccan Herbalists: Bridging Cultural Practices with Safety Concerns

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ARTICLE INFO

Article history:
Received 14 November 2025
Revised 26 December 2025
Accepted 27 December 2025
Published online 01 February 2026

ABSTRACT

Atractylis gummifera L. (Asteraceae) presents a critical paradox in Moroccan traditional medicine: despite containing highly toxic metabolites (atractyloside and carboxyatractyloside) responsible for potentially fatal poisoning, this Mediterranean species remains extensively utilized across diverse therapeutic applications. This ethnobotanical survey investigated traditional uses, preparation methods, and sociodemographic factors influencing usage patterns to bridge the gap between cultural practices and safety concerns. A comprehensive survey was conducted among herbalists across multiple Moroccan regions using structured interviews and statistical analysis. Results revealed that *Atractylis gummifera* L. serves multiple roles within traditional medicine systems: therapeutic applications target diabetes, rheumatism, eczema, gastrointestinal and respiratory disorders, while cosmetic uses focus on skin lightening and hair loss management. Cultural applications extend to spiritual protection practices, demonstrating the plant's holistic integration into Moroccan society. The rhizome constitutes the primary plant part utilized (94.9%), with cosmetic applications predominating (68.1%). Statistical analysis demonstrated significant associations ($p<0.05$) between herbalists' educational level and their utilization approaches, including preparation methods and plant part selection. Knowledge transmission occurs predominantly through family inheritance (55.8%), yet 64.5% of practitioner's exhibit toxicity awareness, suggesting sophisticated risk assessment within traditional systems. These findings document *Atractylis gummifera* L. as Morocco's most paradoxical medicinal plant, simultaneously representing the country's leading cause of plant-related fatalities while maintaining essential cultural and therapeutic significance. The study provides crucial baseline data for developing culturally sensitive safety guidelines and establishes a foundation for evidence-based integration of traditional knowledge with modern healthcare approaches.

Keywords: *Atractylis gummifera* L., Ethnobotanical survey, Traditional uses.

Introduction

Glue thistle or *Atractylis gummifera* L. is a perennial herb belonging to the Asteraceae family that has been widely used in traditional medicine for its medicinal properties across many parts of the world.[1–3] This Mediterranean species is particularly abundant in southern Europe (Italy, Greece, Spain and Portugal) and northern Africa (Morocco, Algeria and Tunisia), where it has established extensive populations across diverse ecological niches.[4,5] *Atractylis gummifera* L. is renowned for its anti-inflammatory, antifungal, antioxidant and antidiabetic properties, which have provided scientific credibility to certain traditional applications.[6–9] However, despite its reputation as an effective natural remedy, the plant harbors a complex array of toxic compounds that can cause serious and potentially fatal poisoning in humans.[8] This paradoxical nature creates a critical tension between therapeutic value and safety risks that characterizes its use in traditional medicine systems. In Morocco, this plant represents a significant public health concern as the leading cause of plant-related poisoning cases reported to the Moroccan Poison Control and Pharmacovigilance Center (CAPM).[10] The species grows throughout the country, except in desert, arid and Anti-Atlas regions.[11] Poisoning incidents are frequently accidental and can prove fatal, with *Atractylis gummifera* L. accounting for 25% of plant-related deaths between 2009 and 2020 according to toxicovigilance reports.[10,12,13] Despite this alarming mortality rate, the plant continues to be widely used in Moroccan traditional medicine for various therapeutic treatments.[14] The persistent use of *Atractylis gummifera* L. despite known risks reflects the complex interplay between cultural beliefs, traditional knowledge systems, and perceived therapeutic efficacy. However, comprehensive ethnobotanical documentation of its traditional uses, preparation methods, and associated risk factors remains limited. While isolated studies have documented certain applications, systematic investigation of usage patterns across Morocco, factors influencing traditional practices, and the relationship between knowledge and safety awareness among practitioners is lacking.[12–14] This study represents the first comprehensive ethnobotanical investigation to systematically quantify *A.gummifera* L. usage patterns across multiple Moroccan regions while correlating traditional practices with sociodemographic factors. Unlike previous isolated reports, this research provides quantitative data on

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Citation: Sillahi B*, Hassani AC, Mzali A, Hassouni Z, Mdarhri IA, Metni KEB, Mechita NB, Doukkali A, Benzeid H. Ethnobotanical Survey of *Atractylis gummifera* L. Traditional Uses Among Moroccan Herbalists: Bridging Cultural Practices with Safety Concerns. Trop J Nat Prod Res. 2026; 10(1): 6811 – 6820 https://doi.org/10.26538/tjnpr/v10i1.52

Official Journal of Natural Product Research Group, Faculty of Pharmacy, University of Benin, Benin City, Nigeria

ISSN 2616-0684 (Print)
ISSN 2616-0692 (Electronic)

plant part preferences, preparation methods, and toxicity awareness levels among practitioners, establishing a crucial evidence base for culturally informed safety interventions.

Therefore, this ethnobotanical survey aims to explore the main traditional uses of *Atractylis gummifera* L., document plant parts utilized, investigate preparation and administration methods, and identify sociodemographic factors associated with usage patterns among Moroccan herbalists. An ethnobotanical approach was selected as the most appropriate methodology to capture both quantitative usage data and qualitative cultural context, enabling comprehensive documentation of traditional knowledge while identifying risk factors.

Materials and Methods

Type and Population

This observational descriptive cross-sectional study was conducted across multiple Moroccan cities to investigate traditional knowledge and usage patterns of *Atractylis gummifera* L. The study population comprised herbalists practicing in diverse geographical locations throughout Morocco, with particular emphasis on those operating in traditional commercial settings. Participants were strategically recruited from weekly souks (traditional markets) and historic medinas, which represent key centers of traditional medicine practice and cultural knowledge transmission. These locations were selected as they provide optimal access to experienced practitioners who maintain direct contact with local communities and possess extensive knowledge of traditional plant uses, preparation methods, and associated cultural practices.

Period and Location

This comprehensive ethnobotanical survey was conducted across two distinct phases to ensure seasonal variation capture and maximize data reliability. The first phase was implemented between September and November 2023, while the second phase extended from February to May 2024, providing temporal coverage across different periods of plant availability and usage patterns. The study encompassed a strategically selected network of 17 Moroccan cities representing diverse geographical regions and socioeconomic contexts (Figure 1). Major metropolitan areas included Rabat (capital city), Casablanca (economic hub), Fez (cultural center), Meknes, Marrakech, and Agadir, ensuring representation of Morocco's principal urban centers. Additionally, smaller cities and towns such as Mohammedia, Bir Jdid, Berrechid, El Jadida, Moulay Yacoub, Temara, Sefrou, Salé, Khenifra, and Had El Brachoua were incorporated to capture regional variations in traditional knowledge and practice patterns across Morocco's diverse cultural landscape.

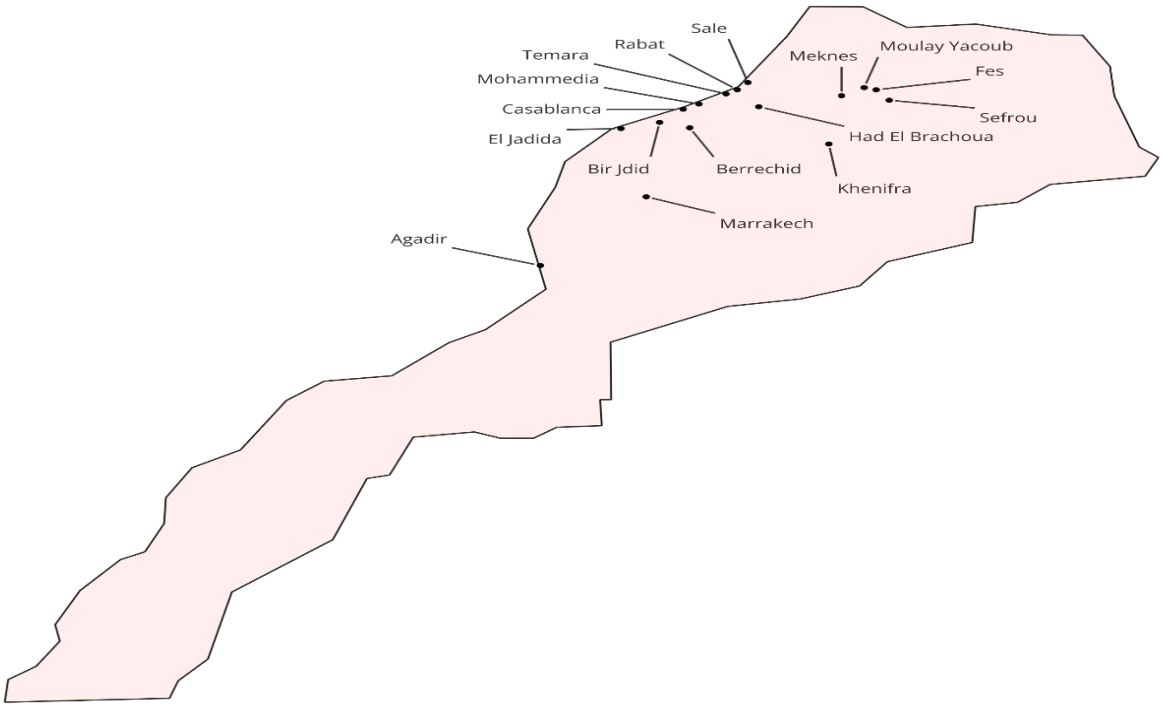

Figure 1: Map of the ethnobotanical survey locations in Morocco (generated using QGIS).

Data Collection

Data on *Atractylis gummifera* L. were collected through structured questionnaires administered during face-to-face interviews with participating herbalists. The questionnaire instrument was specifically developed for this study, incorporating validated elements from established ethnobotanical research methodologies while being adapted to address the specific objectives of investigating traditional usage patterns and associated risk factors. The questionnaire design followed internationally recognized ethnobotanical survey standards and underwent pre-testing with a pilot group of 15 herbalists to ensure clarity and cultural appropriateness.[15,16] Each herbalist was interviewed once, with no repeated measurements, as the study aimed to capture individual traditional knowledge and practice patterns rather than experimental replicability. The questionnaire comprised two comprehensive sections designed to capture both demographic characteristics and detailed ethnobotanical information. The first section focused on respondent demographics and professional background, including gender, place of residence, age, educational level, origin of traditional knowledge, and length of professional experience in herbal medicine practice. The second section addressed plant-specific information, encompassing vernacular nomenclature, geographical origin and sourcing, plant parts utilized, types of applications (therapeutic, cosmetic, cultural), specific therapeutic indications, documented cases of intoxication, and observed

ISSN 2616-0684 (Print)
ISSN 2616-0692 (Electronic)

undesirable effects. All interviews were conducted in local languages (Arabic or Berber) to ensure optimal communication and data accuracy.

Statistical Analysis

Data entry and management were performed using Sphinx Plus² software (Le Sphinx Développement, version 5.0, 2018) to ensure systematic data organization and quality control. Statistical processing and analysis were conducted using jamovi software (The jamovi project, version 2.4.2, 2023), an open-source statistical platform providing robust analytical capabilities for ethnobotanical research.

The analytical approach involved multiple stages, beginning with comprehensive descriptive statistics to characterize the study population and usage patterns. Continuous variables were presented as means with standard deviations for normally distributed data or medians with interquartile ranges for non-parametric distributions, following appropriate normality testing. Categorical variables were expressed as frequencies and percentages with corresponding confidence intervals. Inferential statistics focused on identifying associations between demographic variables and usage patterns through chi-square (χ^2) tests for categorical variables.[17] The chi-square test was specifically employed to examine relationships between educational level, geographic location, age groups, and various aspects of plant utilization including preparation methods, application routes, and safety awareness. Statistical significance was established at $p < 0.05$, with effect sizes calculated where appropriate to assess practical significance of observed associations.

Ethical Approval

This study was conducted in accordance with the ethical guidelines established by the International Society of Ethnobiology (ISE) and international standards for ethnobotanical research. Prior informed consent was obtained from all participating herbalists following detailed explanation of study objectives and procedures in their preferred languages (Arabic or Berber).

Participant anonymity and data confidentiality were rigorously maintained throughout the research using coded identification systems and secure data storage with restricted access. The research protocol emphasized reciprocal benefit, providing participants with safety information regarding *Atractylis gummifera* L. toxicity based on current scientific evidence. All activities were conducted with cultural sensitivity, recognizing traditional knowledge as valuable intellectual heritage deserving protection and appropriate recognition while ensuring safeguards against misappropriation.

Results and Discussion

Characteristics of the study population

This study surveyed 276 herbalists across 17 Moroccan cities, constituting the most extensive systematic ethnobotanical investigation of *Atractylis gummifera* L. usage patterns among traditional medicine practitioners reported in the scientific literature (Table 1). The demographic composition reflected balanced age distribution: 33.3% under 30 years, 37.3% between 30-50 years, and 29.3% over 50 years. Male practitioners predominated (76.8%), consistent with gender patterns documented in Moroccan herbalist surveys conducted in Casablanca, Fez-Meknes, and Rabat-Salé-Kenitra regions. [18–20]

Educational backgrounds varied considerably: secondary education (35.9%), primary education (30.1%), university level (16.3%), and no formal education (17.8%). This heterogeneity provides unique opportunity to examine how educational attainment modulates traditional medicine practices, a relationship increasingly prioritized in contemporary ethnobotanical research design.[21,22] Knowledge transmission occurred predominantly through family inheritance (55.8%), followed by experiential learning from peer herbalists (32.2%) and media sources (12%). These patterns mirror observations from Algeria where family transmission reached 68%, and from Tarfaya Province where ancestral experience constituted 70.6% of knowledge sources.[23,24] A recent Rif region investigation similarly documented stronger plant familiarity among practitioners with family-lineage knowledge transmission.[25] This oral intergenerational heritage underscores both the cultural resilience and inherent vulnerability of traditional pharmacopeial knowledge. The predominance of male herbalists observed in our study reflects deeply rooted socioeconomic and cultural dynamics governing access to commercial traditional medicine practice in Morocco.

Table 1: Description of the study population

	N (%)
Gender	
Female	64 (23.2)
Male	212 (76.8)
Age	
< 30	92 (33.3)
30-50	103 (37.3)
> 50	81 (29.3)
Educational level	
No formal	49 (17.8)
Primay	83 (30.1)
Secondary	99 (35.9)
university	45 (16.3)
Source of information	
Experience of others	89 (32.2)
Family heritage	154 (55.8)
Media	33 (12)
Part used	
Rhizome	262 (94.9)
Others	14 (5.1)
Types of usage	
Therapeutic	88 (31.9)
Cosmetic	188 (68.1)
Application methods	
Oral route	14 (5.1)
Dermal route	188 (68.1)
Fumigation	74(26.8)
Intoxication	
Yes	178 (64.5)
No	98 (35.5)
Side effect	
Yes	195 (70.7)
No	81 (29.3)

This gender asymmetry has been consistently documented across Mediterranean and North African ethnobotanical surveys, where commercial herbal trade remains predominantly male-dominated while domestic plant knowledge and home-based remedies often reside with women.[26,27] Recent meta-analytical evidence suggests that gender differentially influences not only participation in herbal commerce but also the nature of botanical knowledge itself, with men typically possessing broader species awareness linked to market exposure while women demonstrate deeper understanding of practical preparation methods.[28] Understanding these gendered knowledge dynamics is essential for designing inclusive safety interventions that reach both professional practitioners and household-level users who may employ *A. gummifera* outside formal herbalist consultation. The educational diversity within our sample offers particularly valuable analytical leverage for understanding how formal schooling intersects with traditional knowledge systems. Contemporary ethnobotanical theory increasingly recognizes that education exerts complex, sometimes paradoxical effects on traditional plant knowledge: while higher education may enhance awareness of pharmacological mechanisms and safety considerations, it may simultaneously erode transmission of culturally-embedded botanical expertise accumulated over generations.[21,29] Our findings suggest that for *A. gummifera* specifically, core usage practices remain remarkably stable across educational strata, indicating that traditional knowledge regarding this culturally significant species has achieved sufficient entrenchment to resist erosion by formal education. This stability, however, carries dual implications: it ensures preservation of valuable ethnobotanical heritage while simultaneously perpetuating potentially hazardous practices that formal education might otherwise modify. The challenge for public health intervention lies in leveraging educational channels to enhance safety awareness without disrupting beneficial aspects of traditional knowledge architecture.

Toxicological context Contextualizing

A. gummifera's toxicological profile is essential before examining usage patterns. The plant elaborates atractyloside (ATR) and carboxyatractyloside (CATR), diterpene glycosides that inhibit mitochondrial ADP/ATP carrier proteins, precipitating cellular energy failure.[30] CATR demonstrates 10-50 fold greater potency than ATR, with respective concentrations of 5.4 mg/g and 3.7 mg/g quantified in Moroccan specimens .[31] Toxin distribution follows predictable anatomical gradients, with maximum concentrations in underground organs diminishing progressively toward aerial structures.[32] In Morocco, *A. gummifera* ranks as the leading cause of plant-related poisoning, responsible for 25% of botanical fatalities between 2009-2020.[10] Historical surveillance documented 467 cases (1980-2009) with 39.2% case-fatality rate, pediatric victims under 15 years representing 81.1% of deaths.[33] Accidental exposures predominate (75.5-90.3%), primarily through pediatric ingestion of roots confused with edible *Scolymus hispanicus* or latex used recreationally. Therapeutic misadventures account for 18.1% and abortion attempts for 7.4% of documented poisonings. No specific antidote exists; management remains supportive. The International Society of Pharmacovigilance has recently underscored the imperative for robust safety monitoring frameworks for species with established toxicity profiles.[33]

Usage patterns and applications

Our findings reveal an unambiguous usage hierarchy (Table 1): cosmetic applications predominate (68.1%), followed by therapeutic uses (31.9%). The rhizome constitutes the overwhelmingly preferred plant part (94.9%), consistent with Mediterranean-wide traditional practices.[11] This preference reflects practical seasonality: leaves emerge only in winter, flowers in summer, latex rapidly solidifies. Yet this preference paradoxically concentrates usage on the organ harboring maximum toxin levels. Administration methods demonstrated systematic stratification: dermal application (68.1%), fumigation (26.8%), and oral administration (5.1%). This distribution suggests evolved risk-mitigation within traditional knowledge architecture, with external routes predominating despite elevated rhizome toxicity. Contemporary pharmacological research confirms that topical delivery circumvents gastrointestinal metabolism and hepatic first-pass effects, potentially attenuating systemic exposure compared to oral routes.[34]

Cosmetic applications

Cosmetic uses encompass skincare and haircare domains (Table 2). Skincare preparations target depigmentation, texture enhancement, and acne management through topical formulations combining powdered rhizome with henna, applied weekly for brief contact periods. Haircare applications address alopecia and pediculosis through rhizome decoctions or powder-henna mixtures requiring 1-2 hour contact. These practices align with documented North African traditions utilizing *A. gummifera* "as a natural scrub, to lighten the skin and eliminate dark spots".[35] Recent toxicological investigation, however, demonstrates that cosmetic rhizome extracts, while possessing measurable depigmenting activity, simultaneously induce dose-dependent chromosomal aberrations and mitotic abnormalities through mitochondrial permeability transition pore activation.[35] Furthermore, cutaneous application can precipitate systemic hepatorenal injury via percutaneous absorption.[36] These findings underscore that even ostensibly "safer" external routes carry toxicological burden, particularly with prolonged exposure or application to compromised integument. The predominance of cosmetic over therapeutic applications (68.1% versus 31.9%) represents a notable finding with implications for understanding contemporary *A. gummifera* usage evolution. This cosmetic emphasis may reflect broader sociocultural trends toward aesthetic self-care practices, particularly among younger populations seeking traditional alternatives to commercial cosmetic products perceived as chemically-laden or culturally foreign.[37] Additionally, the cosmetic predominance may indicate a gradual, perhaps unconscious, collective shift toward safer usage patterns, as dermal cosmetic applications inherently limit systemic exposure compared to oral therapeutic administration. This interpretation gains support from comparative analysis with historical ethnobotanical literature, where therapeutic applications including oral purgatives and abortifacients featured more prominently.[11] Whether this represents deliberate safety-conscious evolution or incidental cultural drift remains unclear, but the pattern suggests that traditional knowledge systems may possess inherent adaptive capacity favoring practices with lower observed adverse outcome frequencies over generational timescales. Such adaptive dynamics merit longitudinal investigation to inform culturally-aligned safety intervention strategies.

Therapeutic applications

Therapeutic applications (31.9%, n=88) span diverse medical domains employing roots, leaves, and flowers through decoctions, infusions, poultices, and fumigation, reflecting complex traditional pharmacopeia with Mediterranean-wide parallels (Table 2). Musculoskeletal and dermatological disorders: Rhizome-based treatments for rheumatism and pedal ulcers through topical applications and foot baths constitute prominent categories. Spanish ethnopharmacological surveys in Badajoz Province documented analogous usage for wound healing, contusions, sprains, and arthritis.[38] Validated anti-inflammatory, antifungal, and antioxidant properties provide pharmacological rationale.[7,9,39–41] Regional consistency extends to North-eastern Algeria (burn treatment), Tunisia (psoriasis, syphilitic ulcers), and Settat Province (freckles, acne, abscesses).[37,42–44]

Gastrointestinal and hepatic disorders: Oral administration of rhizome infusions for abdominal pain and leaf preparations for gastric and hepatic complaints (5.1%, n=14) represents the highest-risk therapeutic category. The historical use for gastrointestinal disorders reflects purgative and emetic properties, yet these mechanisms simultaneously produce severe hepatotoxicity.[45,46] The paradox of employing a hepatotoxic plant for liver pain relief illuminates the complex risk-benefit calculus inherent in traditional medicine systems.

Respiratory and neurological conditions: Treatments for colds, migraines, and allergies employ fumigation predominantly (84.1% of therapeutic applications). This route may represent evolved toxicity mitigation, as inhalation theoretically provides systemic effects while minimizing gastrointestinal glycoside absorption.

ISSN 2616-0684 (Print)
ISSN 2616-0692 (Electronic)

Table 2: The various traditional uses of the gum thistle reported by herbalists in Morocco

Type of use	Part used	Method of use	Uses recommended by herbalists in the study	Indications from the literature References
Therapeutics	Root	- Use a decoction of the plant root as a foot bath	- Treating rheumatism and foot ulcers	Anti-inflammatory, antifungal,[8] antioxidant and antidiabetic activities demonstrated through multiple phytochemical studies.[7,40] Antimicrobial and insecticidal properties confirmed, validating certain traditional uses for infection control and pest management.[39] Wound healing, treatment of bruises, sprains, arthritis, and rheumatism.[41] Management of abscesses, colds, and dizziness; facilitation of childbirth; use as mouthwash and for abortifacient and purgative purposes.[43] Topical treatment of burns.[44] Treatment of skin infections, hemorrhoids, and calcaneal spurs.[38] Management of psoriasis and epilepsy.[42] Treatment of circulatory disorders, hepatitis, and biliary lithiasis with recognized diuretic effects.[30,46]
		- Decoction of the plant root and oral administration	- For abdominal pain.	
		- Infusion of the root alone	- For colds and cold. - For migraines. - For eye allergies.	
		- Poultice	- Abortion.	
		-Fumigation	- Stop bleeding.	
		- Used orally	- Diabetes.	
		-Fumigation	- Epilepsy and sinusitis	
		-Infusion	- eczema	
		-Fumigation		
		-poultice		
	Leaves	-Oral administration of an infusion of milk thistle leaves.	- Treating stomach problems	
		-Infusion	- For liver pain	
	Flowers	Infusion	- Detoxify the body.	
Cosmetics -Skin	Root	- Mix the powdered root of the Milk Thistle with henna and use as a poultice.	- Brightens and softens the skin. - Treat brown spots, blemishes and pimples.	General skin care and treatment of freckles and acne.[23,43]
		- Mix a decoction of glue thistle root with henna.	- Treat facial imperfections.	
		-Mix the powdered root with soap..	- Lighten the skin	
Hair	Root	-- Mix either the decoction of the root or the powder of the root of the plant with henna.	- Treating hair loss.	Treatment of hair loss.[23]
		-- Use the root decoction on the hair	- An effect against lice	
Other uses	Root	Fumigation	- In superstition against the evil eye - Insecticide	

ISSN 2616-0684 (Print)
ISSN 2616-0692 (Electronic)

However, fumigation safety remains understudied; reproductive toxicity including oxidative stress and gonadal damage has been documented from *Carlina gummifera* incense inhalation in animal models.[8]

Gynecological, metabolic, and oral hygiene applications: Abortifacient properties and parturition facilitation represent highest-risk applications. Antidiabetic uses align with validated pharmacological properties; recent Atractylis aristata research confirmed α-amylase inhibition and glycemic reduction.[6,9] Rhizome decoctions serve as mouthwash for dental whitening, representing localized application theoretically minimizing systemic absorption.

Cultural applications

Beyond medicinal and cosmetic applications, *A. gummifera* serves diverse cultural and practical functions. The root is traditionally used as a fumigant in superstitious practices designed to protect against the evil eye, while the plant is also recognized for its insecticidal properties.[8] These diverse applications demonstrate the plant's holistic integration into Moroccan society, extending beyond purely pharmacological considerations toward complex cultural-ecological relationships.[47,48] Such multifunctional uses reflect patterns increasingly recognized in ethnobotanical literature, where medicinal plants serve as bridges between practical utility and cultural significance.

Statistical analysis of associated factors

Chi-square (χ^2) analysis constituted our primary inferential approach for examining associations between demographic variables and usage practices. This methodology aligns with contemporary ethnobotanical research frameworks emphasizing quantitative analysis to identify determinants of traditional knowledge.[21,22] Recent surveys across Africa and the Mediterranean have demonstrated chi-square testing's utility for revealing sociodemographic influences on plant usage, including studies in Ethiopia , Kenya, and India.[49–51] Our analysis revealed multiple statistically significant associations providing quantitative evidence for systematic patterns in traditional knowledge organization (Table 3).

Educational level and plant part selection

A robust association ($p<0.001$) emerged between educational attainment and plant part preference. Rhizome utilization remained overwhelming across all educational strata: no formal education (17.4%), primary (30.1%), secondary (34.8%), and university (12.7%).

Table 3: Factors associated with the part used, type of usage and mode of preparation

	Part used		P value
	Rhizome	**Others**	
Educational level			**0.000**
No formal	48(17.4%)	1(0.7%)	
Primay	83(30.1%)	0(0%)	
Secondary	96(34.8%)	3(1.1%)	
university	35(12.7%)	10(3.6%)	
Types of usage			**0.041**
Therapeutic	80(28.98%)	8(2.9%)	
Cosmetic	182(65.94%)	6(2.2%)	
Application methods			**0.000**
Oral route	6(2.8%)	8(2.9%)	
Dermal route	182(65.9%)	6(2.2%)	
Fumigation	74(26.8%)	0(0%)	

	Application method			P value
	Oral route	**Dermal route**	**Fumigation**	
Educational level				**0.000**
No formal	4(1.4%)	28(10.1%)	17(6.2%)	
Primay	0(0%)	55(19.9%)	28(10.1%)	
Secondary	2(0.7%)	73(26.4%)	24(8.7%)	
university	8(2.9%)	32(11.6%)	5(1.8%)	
Part used				**0.000**
Rhizome	6(2.2%)	182(65.9%)	74(26.8%)	
Others	8(2.9%)	6(2.2%)	0(0%)	
Types of usage				**0.000**
Therapeutic	14(5.1%)	0(0%)	74(26.8%)	
Cosmetic	0(0%)	188(68.1%)	0(0%)	

	Types of usage		P value
	Therapeutic	**Cosmetic**	
Educational level			**0.215**
No formal	21(7.6%)	28(10.1%)	
Primay	28(10.1%)	55(19.9%)	
Secondary	26(9.4%)	73(26.4%)	
university	13(4.7%)	32(11.6%)	
Part used			**0.041**
Rhizome	80(29%)	182(65%)	
Others	8(2.9%)	6(2.2%)	
Application methods			**0.000**
Oral route	14(5.1%)	0(0%)	
Dermal route	0(0%)	188(68.1%)	
Fumigation	74(26.8%)	0(0%)	

Alternative plant parts showed minimal but educationally-graded usage: no formal education (0.7%), primary (0%), secondary (1.1%), and university (3.6%). This finding demonstrates that formal education does not fundamentally alter rhizome preference (94.9% overall) but rather modulates awareness of alternative plant parts. The marginally elevated use of aerial parts among university-educated practitioners may reflect exposure to comparative toxicological information indicating lower glycoside concentrations in leaves and flowers. This pattern contrasts with Kenyan findings where.[50] documented that higher education correlated with broader species knowledge ($p<0.001$). For *A. gummifera* specifically, traditional practices remain remarkably consistent across educational strata, potentially reflecting deep cultural entrenchment of rhizome-based preparations accumulated over centuries of use. The exceptional rhizome preference aligns with toxicological literature confirming maximum diterpene glycoside concentrations in underground organs. [32] quantified atractyloside levels ranging 1.8-4.2 mg/g across Algerian collection regions, with consistent concentration gradients from roots to aerial structures. Comparative ethnobotanical data from Tata Province documented regional variation with 72% rhizome usage for therapeutic purposes and 22% for skincare.[52] Spanish surveys similarly reported rhizome preference for wound healing and calcaneal spurs, indicating Mediterranean-wide recognition of rhizome as the primary medicinal organ despite, or perhaps because of, its elevated bioactive compound concentrations.[38]

Educational level and application method

The relationship between educational attainment and application method demonstrated remarkable statistical strength ($p<0.001$). Dermal application predominated across all categories: no formal education (10.1%), primary (19.9%), secondary (26.4%), and university (11.6%), totaling 68.1%. Fumigation showed an inverse educational gradient: no formal education (6.2%), primary (10.1%), secondary (8.7%), and university (1.8%), totaling 26.8%. Oral administration remained minimal overall but revealed a striking paradox: no formal education (1.4%), primary (0%), secondary (0.7%), and university (2.9%), totaling 5.1%. This association reveals counterintuitive safety implications demanding careful interpretation. University-educated herbalists demonstrated proportionally higher oral route utilization (2.9%, representing 8 of 45 university-educated practitioners) compared to other educational groups (0-1.4%). This paradoxical finding, where higher education correlates with increased use of the most dangerous administration route, carries profound public health significance. Several hypotheses may explain this paradox. First, university-educated practitioners may possess greater awareness of documented pharmacological properties (antipyretic, purgative, antidiabetic effects) requiring systemic absorption achievable only through oral or inhalation routes. Second, higher education may correlate with perceived dosage control competence, potentially fostering overconfidence regarding therapeutic windows. Third, university-educated herbalists may serve clientele seeking treatment for systemic conditions that cosmetic applications cannot address. Similar educational paradoxes have been documented elsewhere:.[27] reported in Saudi Arabia that "education and urbanization exert greater impact on preference for biomedical or traditional medicinal usage," with educated populations sometimes demonstrating unexpected preference patterns. Importantly, Chan documented in Hong Kong that targeted publicity measures successfully reduced aconite poisoning incidence among herbalists, demonstrating that practitioner behavior is modifiable through appropriate interventions. [53] The dominance of dermal application (68.1%) in our survey contrasts markedly with toxicological case series where oral administration represents the primary exposure route. This discrepancy admits two interpretations: herbalists may underreport oral recommendations due to toxicity awareness, or accidental poisonings predominantly occur outside professional contexts, primarily through pediatric ingestion of roots confused with edible species.

Plant part and application method correlation

The association between plant part and application method demonstrated exceptional statistical strength ($p<0.001$). For rhizome preparations, dermal application dominated (65.9%), followed by fumigation (26.8%), with minimal oral use (2.2%). For aerial plant parts, this pattern reversed: oral administration predominated (2.9%), dermal use was limited (2.2%), and fumigation was absent. This relationship reveals systematized traditional knowledge encoding sophisticated toxicological awareness. Rhizome, containing maximum ATR and CATR concentrations, associates preferentially with external applications (92.7% dermal or fumigation), while aerial parts with lower toxin concentrations associate primarily with oral administration. This pattern represents intergenerational risk-benefit assessment, demonstrating that contemporary Moroccan herbalists have evolved safer practices compared to historical patterns documented in classical Arabic medicine texts, where rhizome was routinely administered orally for antipyretic, diuretic, and abortifacient purposes.[11] Morocco's extensive poisoning documentation with pediatric mortality has likely created strong community memory of toxicological risks, facilitating transmission of safety-conscious practices across generations. This phenomenon aligns with observations that poisonous plants in traditional medicine systems often develop sophisticated usage protocols reflecting accumulated experiential learning about therapeutic windows and toxic thresholds.[48,54–56]

Types of usage and plant part selection

A moderate association ($p=0.041$) emerged between usage type and plant part preference. For therapeutic applications, rhizome accounted for 90.9% of usage; for cosmetic applications, rhizome preference reached 96.8%, a 2.28-fold stronger rhizome preference for cosmetic versus therapeutic domains. The intensified cosmetic-rhizome association reflects the plant's latex content. After fruiting, yellowish-white latex exudes from bracts and rhizome, historically valued in aesthetic treatments, hence the vernacular "glue thistle." However,.[35] confirmed that cosmetic extracts, while possessing depigmenting activity, simultaneously induce genotoxic effects with potential long-term carcinogenic implications even without acute systemic toxicity. The therapeutic domain demonstrates greater plant part diversity (90.9% rhizome versus 96.8% for cosmetics), potentially reflecting traditional recognition that different organs possess distinct pharmacological profiles suited to different therapeutic objectives. This aligns with observations in other ethnobotanical contexts where practitioners demonstrate sophisticated understanding of organ-specific bioactivity.[57,58]

Types of usage and application method correlation

The relationship between usage type and application method yielded the strongest statistical signal in our study ($p<0.001$), with Cramér's $V=1.00$ indicating perfect categorical association. Cosmetic applications were exclusively dermal (100%); therapeutic applications distributed across oral (16%) and fumigation (84%) with complete dermal route avoidance. This perfect segregation, absolute cosmetic-dermal versus therapeutic-oral/fumigation separation, constitutes the most striking finding of our analysis. Such categorical systematization demonstrates that Moroccan traditional knowledge encodes distinct usage pathways with zero overlap between cosmetic and therapeutic domains. This segregation reflects sophisticated understanding that cosmetic objectives require only local tissue effects achievable through topical application, while therapeutic objectives necessitate systemic bioavailability unattainable through intact integument. The fumigation predominance for therapeutic applications (84.1%) merits attention. Traditional burning of dry rhizome as incense serves both therapeutic and ritualistic purposes across North Africa. Fumigation may represent evolved compromise between systemic delivery and oral toxicity avoidance, as inhalation theoretically provides pulmonary absorption while bypassing gastrointestinal exposure to concentrated glycosides. However, fumigation safety remains inadequately characterized; documented reproductive toxicity indicates this "safer" route may carry underappreciated risks. [8] The 14 herbalists (5.1%) recommending oral therapeutic use represent a critical intervention target. Extrapolating nationally using herbalist population estimates of 3,000-5,000 practitioners, this oral-route minority represents 150-255 practitioners requiring urgent safety education. This targeted approach aligns with Hong Kong evidence demonstrating that focused campaigns successfully modified herbalist behavior.[53]

Educational level and types of usage

The analysis between educational level and usage type yielded no statistically significant association (p=0.215). Cosmetic applications predominated across all educational levels (cosmetic/total ratios: 57.1% no formal education, 66.3% primary, 73.7% secondary, 71.1% university). This non-significant relationship indicates that educational background does not determine therapeutic versus cosmetic emphasis. However, the trend toward higher cosmetic preference among educated practitioner's approaches significance and warrants interpretation. Educated herbalists may demonstrate greater toxicological risk awareness, incentivizing preference for lower-risk cosmetic applications. Ethiopian research documented analogous patterns where educated informants showed greater safety awareness. [49] The sustained therapeutic usage across all educational levels (28.9-42.9%) despite documented toxicity suggests persistent demand for *A. gummifera*'s pharmacological properties. Historical literature documents genuine therapeutic efficacy: antipyretic, diuretic, purgative, and emetic effects. Balkrishna et al.[59] recently emphasized that bridging traditional wisdom with modern science requires acknowledging therapeutic effects sustaining traditional usage while developing evidence-based safety frameworks. The absence of specific antidotes presents compelling argument for therapeutic substitution programs offering safer alternatives with comparable profiles from other Atractylis species.[6,9,60]

Synthesis and epidemiological implications

The constellation of associations identified, four highly significant (p<0.001), one moderate (p=0.041), one non-significant (p=0.215), provides unprecedented quantitative evidence for systematic traditional knowledge organization surrounding *A. gummifera*. The pattern reveals coherent internal logic: highest-risk routes are minimized overall but paradoxically associated with higher education; plant parts with maximum toxin concentrations are predominantly relegated to external applications; and usage domains demonstrate complete segregation by application route. The disconnect between herbalist-reported practices (5.1% oral) and poisoning epidemiology (>90% oral exposure) represents a critical finding. This discrepancy suggests that professional herbalist practices have evolved toward safer patterns, while accidental poisonings, primarily pediatric, occur in community contexts outside professional influence. Effective interventions must therefore operate at multiple levels: continuing professional development targeting university-educated oral-route practitioners; community education emphasizing botanical identification; and pediatric safety awareness addressing latex ingestion and species confusion. This multi-level approach aligns with regulatory frameworks being developed across Africa.[61]

Toxicity awareness among practitioners

Most participating herbalists (64.5%) acknowledged the toxicity of the plant and its side effects, such as digestive disorders, respiratory problems, vomiting, diarrhea, abdominal pain, headaches and dizziness. This awareness is crucial given that in Morocco, this plant is the leading cause of plant-related poisoning cases reported to the Moroccan Poison Control and Pharmacovigilance Center (CAPM).[10,62] According to the general toxicovigilance report for 2022, *Atractylis gummifera* L. is the leading cause of death in Morocco, accounting for 25% of deaths between 2009 and 2020.[10] However, they also stated that inappropriate use of plants can have harmful effects on health. It is important to note that some authors recommend that *Atractylis gummifera* L. should mainly be used on the skin, due to its high toxicity.[63] Galen historically recommended that the use of this plant should be limited to external applications only.[64] The toxicity of *Atractylis gummifera* L. is mainly due to the presence of atractyloside and carboxyatractyloside.[35,65,66] A study conducted between Italy and Algeria found that intoxicated patients manifested characteristic symptoms, such as nausea, vomiting, epigastric and abdominal pain, diarrhea, anxiety, headaches and convulsions, often followed by coma.[30] To date, no specific pharmacological treatment for *Atractylis gummifera* L. intoxication is available, and current therapeutic options are limited to symptomatic treatments. Consumption of *Atractylis gummifera* L. is particularly dangerous in spring when the toxins are concentrated in the roots or when the plant is confused with wild artichoke.[67] In Greece, a study focusing on popular plants known to be associated with severe and sometimes fatal hepatotoxicity identified *Atractylis gummifera* L. at the top of the list.[68] While our study provides valuable insights into traditional uses, it is important to note that accidental poisoning by the root of glue thistle is common in Morocco and can be fatal.[12,13] Our study also raised awareness among herbalists of the risks associated with using *Atractylis gummifera* L., while highlighting the traditional knowledge related to this plant.

Comparative epidemiological positioning and public health implications

Our study's sample size (n=276 herbalists) represents the largest systematic ethnobotanical investigation of *A. gummifera* L. usage patterns among traditional medicine practitioners documented to date. The multiple highly significant associations (p=0.000 for four key relationships, p=0.041 for one relationship) provide unprecedented quantitative evidence for systematic traditional knowledge organization surrounding this toxic-yet-utilized Mediterranean plant. Comparative regional context reveals *A. gummifera's* widespread public health impact across the Mediterranean basin: beyond Morocco's documented poisoning burden, Algeria reported cases at Centre Antipoison d'Alger with varying atractyloside concentrations (1.8-4.2 mg/g) across six collection regions, Tunisia documented intensive care admissions for plant poisonings including *A. gummifera* between 1983-1998, Spain recorded fatal poisonings in Badajoz Province requiring ethnopharmacological risk assessments, Greece reported severe pediatric hepatotoxicity cases with fatal outcomes; and Italy documented livestock poisoning in Sicily.[32,45,66,69] The associations identified enable targeted, evidence-based interventions. World Health Organization guidelines emphasize approaches respecting cultural practices while prioritizing safety.[70,71] For *A. gummifera*, this translates to: elimination of oral therapeutic recommendations; standardized dermal preparation protocols minimizing percutaneous absorption; fumigation safety guidelines addressing inhalation toxicity; therapeutic substitution programs; and community botanical identification education. The Moroccan phytovigilance curriculum represents a model for integrating safety education within traditional medicine practice.[10,23,72,73]

Conclusion

This ethnobotanical survey of 276 Moroccan herbalists documents the paradoxical nature of *Atractylis gummifera* L. as both a culturally valued therapeutic resource and the country's leading cause of plant-related fatalities. Our findings reveal predominantly cosmetic applications (68.1%), with rhizome as the primary plant part used (94.9%). Therapeutic uses encompass diverse medical conditions, while cultural applications include spiritual protection and pest control. Statistical analysis demonstrated significant associations between educational level and utilization practices, with traditional knowledge transmitted primarily through family inheritance (55.8%). Importantly, 64.5% of herbalists exhibited toxicity awareness, suggesting sophisticated risk assessment within traditional systems. Cross-Mediterranean comparative analysis validates documented applications while highlighting the plant's widespread recognition as therapeutically valuable yet potentially lethal. The absence of standardized protocols poses safety challenges, particularly given that *Atractylis gummifera* L. accounts for 25% of Morocco's plant-related deaths. This study contributes to ethnobotanical heritage preservation while addressing critical safety imperatives. Results provide a foundation for developing evidence-based guidelines that honor traditional practices while ensuring user safety. Future research should prioritize protocol standardization, practitioner education, and bioactive compound investigation to enable safe therapeutic exploitation of this culturally significant species.

Conflict of interest

The authors declare no conflicts of interest.

Authors' 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.

Acknowledgements

The authors thank all herbalists who participated in this study for sharing their traditional knowledge and the local communities for facilitating access to study participants.

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