

Article

Aromatic and Medicinal Plant (AMP) Valorization via a Farmer-Centric Approach for the Sustainable Development of Climate-Challenged Areas Affected by Rural Exodus (Southeastern Tunisia)

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Abstract

The valorization of local plant cover, particularly through the integration of indigenous knowledge, is central to Tunisia's economic development strategies. These approaches focus on diversifying agriculture by enhancing local natural and cultural heritage to strengthen community resilience amid environmental and socio-economic changes and to address rural exodus. This study examines the feasibility of AMP-based micro-projects in Matmata (southeastern Tunisia) by applying the Water–Energy–Food–Ecosystem (WEFE) nexus and participatory methods involving local stakeholders. Field surveys, literature reviews, and statistical analyses reveal growing youth interest in AMP ventures, driven by rising pharmaceutical and cosmetic demand. Economic viability is confirmed by internal rate of return (IRR) values of 32%, 28%, and 43%, all well above the 10% profitability threshold. Profitability index (PI) values indicate efficient investments, yielding returns of 2.64, 2.13, and 5.31 dinars per dinar invested. The initiatives also deliver socio-cultural and environmental benefits through WEFE-based resource management. Beyond profitability, the study identifies gaps and opportunities to enhance AMP biodiversity, resource management, and sustainable diversification in southern Tunisia. Further efforts are required to increase market value and ensure equitable benefit distribution. Government policies should focus on raising WEFE awareness, building capacity, and investing in climate-smart agriculture, especially in vulnerable, migration-prone regions, supported by reforms in financing, taxation, and spatial planning.

Keywords: AMP valorization; indigenous knowledge; WEFE nexus; migration; southeastern Tunisia



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1. Introduction

The agricultural sector in Tunisia, reflecting broader trends across the southern Mediterranean basin and the MENA region, faces increasing challenges due to water scarcity and

prolonged droughts [1]. These environmental stresses, coupled with resource allocation issues, economic constraints, socio-political instability, and environmental fragility, exacerbate the vulnerability of agrosystems, especially in southern provinces [2–4]. A significant driver of rural exodus and social instability in these areas is the lack of sustainable livelihood options that balance socio-economic needs [4–7]. Rural communities urgently require defined employment opportunities and financial support for local small-scale projects, as emerging health and climate crises further strain already limited resources [7,8].

In response, Tunisia has implemented various development and resource management initiatives aimed at promoting rural development, social inclusion, and sustainable natural resource use [8,9]. These programs emphasize local actor participation, valuing indigenous knowledge and community expertise as pivotal to ecosystem resilience and adaptation to climate variability [9–11]. Capacity-building and awareness campaigns facilitate multi-stakeholder collaboration, skill development, and knowledge sharing. Additionally, governmental and non-governmental support has subsidized projects promoting water conservation, smart irrigation, and renewable energy adoption, such as cisterns and solar energy installations, covering over 55% of total costs [12–18].

Among recent strategies, valorizing local plant cover stands out as a promising approach for landscape management and agricultural diversification. This involves innovating cropping and irrigation systems and improving marketing practices to maximize the sector's economic value, thereby generating income sources for the local community. Introducing region-specific crop species has strengthened value chains in monoculture-dominated systems and improved resource efficiency [18–22]. Scientific studies confirm that such initiatives contribute positively to economic returns, environmental sustainability, community involvement, and societal resilience amid ongoing climatic and socio-economic changes [18].

Valorization of aromatic and medicinal plants (AMPs) offers a particularly promising avenue for sustainable agrosystem development [23,24], owing to the rich diversity of spontaneous AMP species in Tunisia's mountainous regions, which also shape the area's landscape identity. Nevertheless, environmental pressures—such as overgrazing, recurrent drought, soil erosion, and extreme rainfall—pose threats to biodiversity conservation. To address these challenges, management programs have been established to support the AMP value chain, responding to national and international demands in pharmaceutical, cosmetic, and aromatic industries [25]. Countries like India and Morocco have successfully expanded their AMP sectors through promotion of high-value species, essential oil extraction, and sustainable cultivation techniques. Their local initiatives support farmers throughout project lifecycles—cultivation, harvesting, processing, packaging, and commercialization—while strategic investments in technology, certification, and green economy alignment bolster sector competitiveness [26–29].

In contrast, Tunisia's AMP sector remains largely limited to spontaneous species in mountain ecosystems of the southeast. Despite growing awareness of the social, and economic value of AMPs, significant financial, technical, and logistical obstacles hinder large-scale cultivation [30–32]. Rural exodus, driven primarily by push factors detailed in neoclassical migration theory, is intensified by climate uncertainty and limited agricultural potential. However, targeted rural development efforts can mitigate these trends [33–35]. In this context, AMP valorization emerges as a promising employment generator and a vehicle for bolstering local economies and social welfare. This approach aligns with Tunisia's national ecological transition strategy, aiming to reinforce regional adaptive capacity by promoting efficient natural resource management and AMP processing and commercialization.

For smallholder farmers in arid regions, AMPs offer viable solutions to land fragmentation and small-scale farming challenges. This study assesses AMP valorization initiatives within the Tunisian Nexus Ecosystem Laboratory (NEL), focusing on the Matmata region, to

identify feasible alternatives for enhancing household resilience and promoting sustainable agricultural development. Although multiple studies exist, the current level of AMP development remains below expectations. Without an integrated approach encompassing local community involvement, traditional knowledge, AMP species potential, water availability, and unique ecosystem characteristics, the effectiveness of these efforts is limited. These components are essential to climate-smart agriculture, ecosystem resilience, and assigning real economic value to the AMP sector.

Accordingly, this study adopts the Water–Energy–Food–Ecosystems (WEFE) nexus framework (Figure 1), a holistic, cross-sectoral model designed to address social equity, economic viability, and governance issues by analyzing synergies and trade-offs among water, energy, food, and ecosystems [36]. The research combines community-based assessments with cost–benefit evaluation to explore the feasibility of AMP-related micro-projects in the Matmata region.

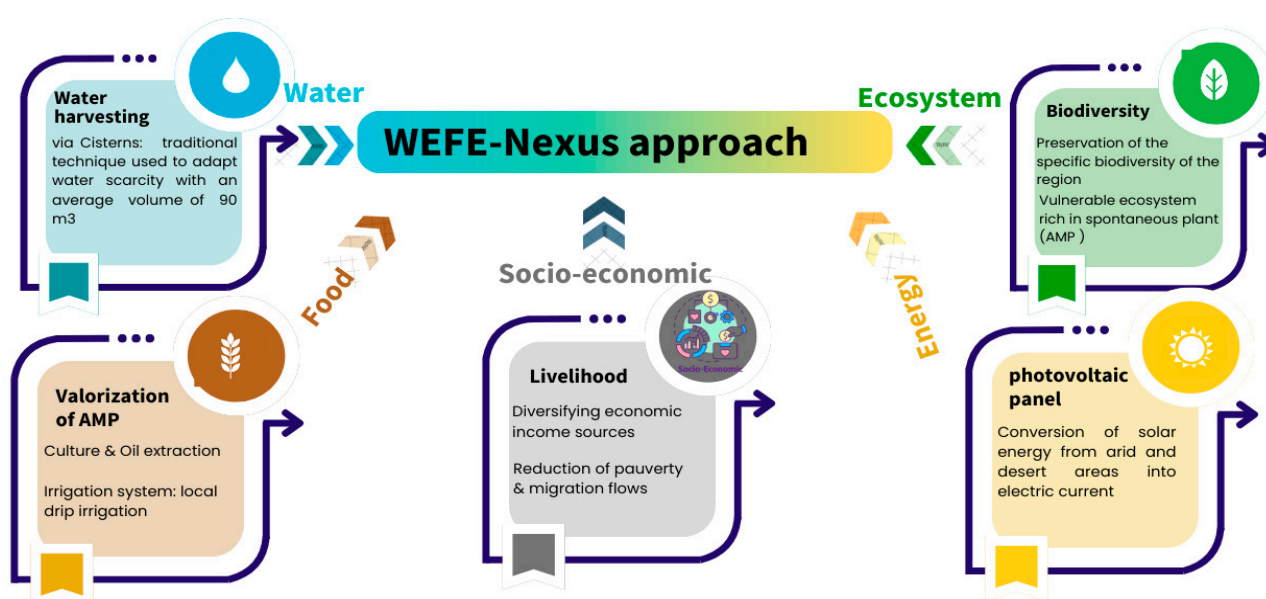


Figure 1. WEFE nexus approach components for the proposed AMP valorization project.

2. Methodological Approach

2.1. Site Description

The study area belongs to the Matmata mountains in southeastern Tunisia, characterized by an unstable context related to socio-economic, and climate challenges. It lies in the Mediterranean iso-climatic zone, known for rainy winters and dry summers. The annual rainfall amount varies from 100 to 200 mm with high irregularity and sporadicity, with a variation coefficient exceeding 50%, and the arid climatic conditions define a water deficit [18]. The region is characterized by variable geomorphologic and ecological features, from the hilly zones and underground troglodyte houses to the Djeffara plain irrigated lands (Figure 2).

The Mamata region is devoted principally to olive tree cultivation for a local variety, “Zarrazi,” with verified ISO standard quality and specific properties highly required for national and international markets and high economic added value. However, in spite of the socio-cultural value of agriculture in southern Tunisia, a progressive abandonment of farming lands is observed, especially for youth. In fact, along with the continuous expansion of family private farming dominated by the elderly community, an increasing immigration and migration flow of highly educated and diplomaed youth entrepreneurs is amplified by the dynamic of rural exodus, according to official national statistics. This social instability

is related principally to the growing poverty ratio (exceeding the national thresholds (Table 1), the increasing water stress, the challenging monoculture farming practices, the hard farm work, and the non-stable agricultural production of the compartmentalized small parcels. The agricultural activities have not been efficient for ensuring financial autonomy, diversification of income, and employment opportunities. The difficult natural conditions of the region, amplified by the unisectoral economic development, define the studied site, the “nexus ecosystem laboratory NEL,” as a typical example of arid and semi-arid regions requiring appropriate infield intervention to secure sustainable management at short and long terms.

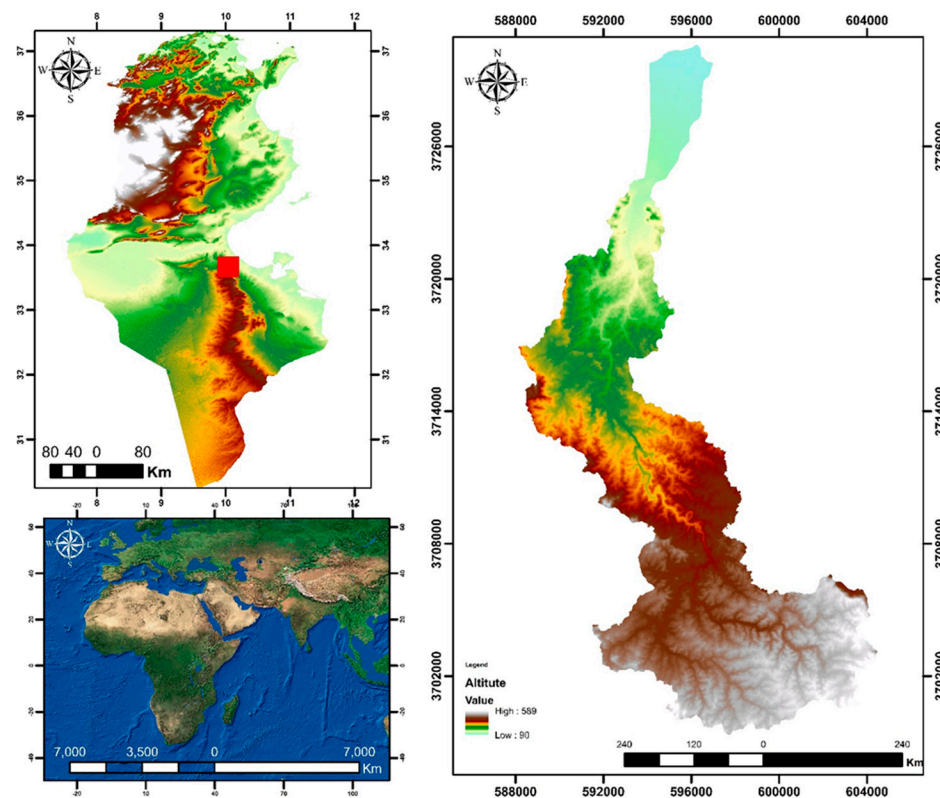


Figure 2. Study area.

Table 1. Demographic characteristics & net migration by delegation in the study area [37].

	Number of Households	Poverty (%)	Unemployment (%)	Number of In-Migrants			Number of Out-Migrants			Total Number of Migrants		
				Outgoing	Incoming	Net	Outgoing	Incoming	Net	Outgoing	Incoming	Net
Matmata	433	26.4	15.8	1754	123	−1631	36	1	−35	1790	124	−1666
New Matmata	1798	23.6	21.2	438	682	224	185	34	−151	623	716	93
Total	2231			2192	805	−1407	221	35	−186	2413	840	−1573

The local context specific to the NEL, as an area affected by rural exodus and characterized by a challenging natural environment linked to climate uncertainty, highlights the relevance of a transition toward a WEFE-Nexus approach. The different integrated stakeholders adopted the Nexus transition, which relies on a bottom-up scheme proposed, analyzed, and validated by the local community. This paper aims, consequently, to evaluate the feasibility of the AMP-valorization project based on the motivation of the local consumers and their perception of the feasible valorization of the important biodiversity of the local plant cover in order to reduce the socio-economic pressure on the natural resources and slow down the national (rural-urban) and international migration flows.

2.2. Methodology

The study adopts a Water–Energy–Food–Ecosystems (WEFE) Nexus approach, emphasizing the interconnections among the four pillars, water, energy, food, and ecosystems, and their links to the social dimension, policy reforms, and the regulatory framework (Figure 3). This framework follows a bottom-up methodology: it first evaluates the feasibility of AMP projects based on social perceptions and then performs a detailed cost–benefit assessment. The farmer-centered analysis draws on field surveys, multi-stakeholder dialogues, face-to-face interviews, and consumer questionnaires. These tools were employed to collect investment data for AMP-related projects, identify key opportunities for value-chain development, and highlight major constraints to implementation. In addition, a comprehensive cost–benefit analysis was conducted to assess the profitability of proposed AMP cultivation projects in the Matmata region, located within Tunisia’s Northeastern Lowlands (NEL).

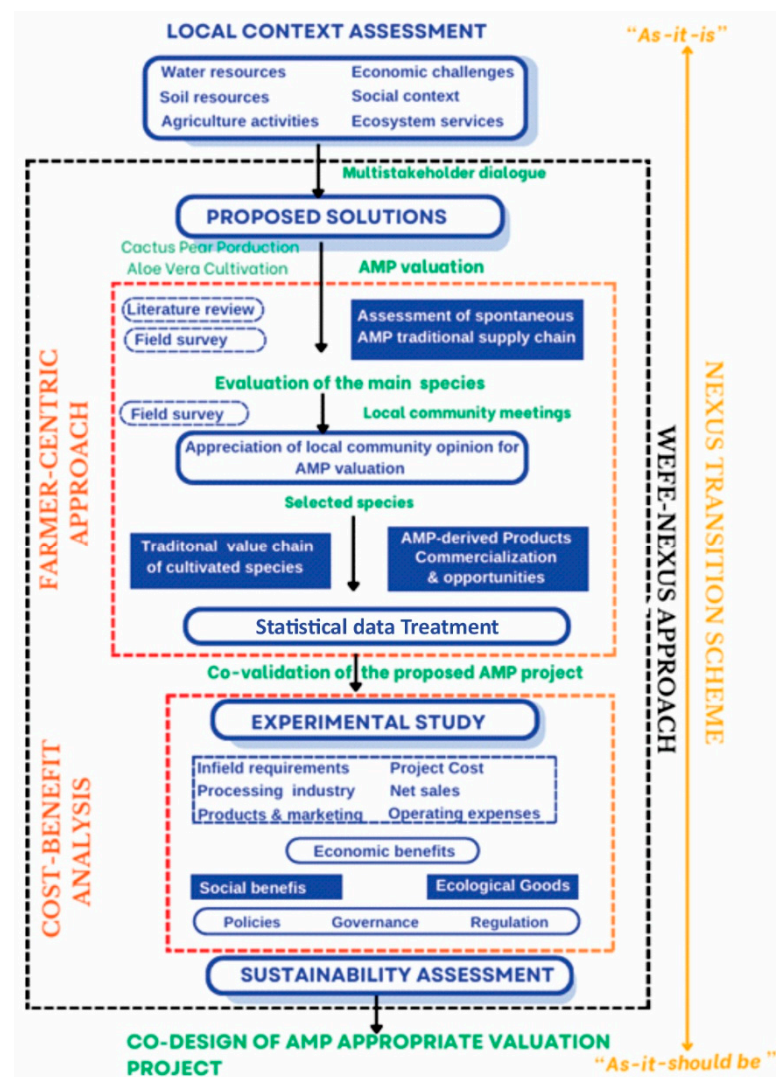


Figure 3. The used methodology.

Selected species for cultivation: Based on the findings of the questionnaire of the local community, the main species chosen for cultivation are *Thymus hirtus* (capitate thyme), *Rosmarinus officinalis* (rosemary), *Artemisia herba Alba* (white wormwood), and *Origanum majorana* for the proposed project in the mountain zone, *Thymus hirtus* (capitate thyme), *Rosmarinus officinalis* (rosemary), *Artemisia herba Alba* (white wormwood) and *Capparis Spinosa* for the irrigated perimeter. This choice is primarily explained by a dichotomy between the region’s rich abundance of these types as spontaneous species and

the significant demand for their use mentioned by local actors within the framework of the project's living lab. (Table 1). The method of AMP valorization from traditional marketing circuit and (or) transformation industry was discussed according to the feedback of the local population based on a field survey. In fact, the used non-directive approach (WEFE nexus management approach) allows interviewees to express themselves freely across both parts of the interview. A significant amount of information was gathered and grouped into nine representative categories to reduce redundancy and facilitate clear interpretation (Table 2). Respondents either provided one or several answers or gave no response.

Table 2. Description of the quantitative data for statistical analysis.

Selected Variables	Code
People who only harvest the parts of the plant they find useful (leaf, fruit, stems, or whole plant)	SP
People who prefer to consume cultivated MAPs (home garden, intensive farming, organic, rainfed, or irrigated)	CULT
People who prefer to consume essential oils (traditional or industrial extraction)	EXTR_HE
People who prefer to consume MAPs without packaging (consumption after harvesting from the wild or after storage)	CONS_F
People who prefer to consume MAPs after processing (cleaned, dried, and packaged)	CONS_APTR
People who prefer to consume MAPs as medicinal products to treat certain diseases	USAGE_M
People who prefer to consume MAPs as aromatic spices in food	USAGE_A
People who prefer to consume certified MAP and essential oil products (traceability, labeling, etc.)	EMBAL
People who prefer to consume branded MAP and essential oil products (quality label and distinctive identity)	MARQUE

AMP Cultivation: For the proposed project in the mountain zone, the analysis was carried out for a 1 ha (100×100 m) area, which corresponds to 50 rows for each species and 200 plants per irrigation row. The distance maintained between two irrigation lines and between two planted trees is roughly 0.5 m. The land cost is not considered in the cost analysis since the local farmers are the owners of the irrigated agricultural lands. For the second proposed project, which involves intercropping AMP within the olive trees, the analysis was carried out for a total surface area of 1 ha (192×52.1 m). The total number of olive trees already cultivated in the parcels is 129 trees/ha, arranged in 18 vertical and 7 lateral lines with spacing of 8 and 10 m, respectively. The distance between two cultivated AMPs is 0.5 m, with 6 total lines of production.

Resource management: Both projects, as part of the nexus management approach, rely on water and energy conservation techniques along with appropriate farming practices to preserve agricultural land properties and fertility. Thus, as illustrated in Figure 1, the proposed activities additionally involve the adoption of smart irrigation, water harvesting techniques (namely cisterns), and photovoltaic panel use.

Smart Irrigation System: To enhance water use efficiency in such arid regions, the use of a smart irrigation system (semi-automatic: remotely monitored platform and manually controlled valves) is essential. This system reduces water consumption by 30% while increasing productivity by 12% and reducing chemical input use by 8%. The source of irrigation water differs: cisterns are used in the mountainous zone, while the deep well El

Aardh 5 irrigates the perimeter. The main difference in potential implementation between these two types of projects relates primarily to intercropping with olive trees in the plain.

Civil Engineering and Equipment: The project will also involve several construction techniques and the acquisition of agricultural equipment. Key components include the construction of a multipurpose building for cleaning, drying, processing, and packaging AMP products. In addition, an extraction unit with a 100-L capacity, along with a bottling machine, grinder, labeling machine, and other equipment for product processing, will be necessary. Agricultural machinery, such as mini-tractors and spreaders, will be employed for the development and cultivation of the selected species.

Sampling methodology: In this study, the sampling was conducted using the finite population correction method, as expressed by the following formula (Equation (1)):

$$n = \frac{Z^2 \times p \times (1 - p) \times N}{e^2 \times (N - 1) + Z^2 \times p \times (1 - p)} \quad (1)$$

where n = sample size; N = population size (number of households); Z = confidence level (1.96); p = estimated proportion (0.5); e = desired margin of error (5%)

Applying the formula with the collected data (Equation (2)):

$$n = \frac{1.96^2 \times 0.5 \times (1 - 0.5) \times 2231}{(0.05)^2 \times (2231 - 1) + (1.96)^2 \times 0.5 \times (1 - 0.5)} \quad (2)$$

The sampling rate for each delegation was calculated as (Equation (3)):

$$\text{Sampling rate} = \frac{\text{Population of the delegation}}{\text{Total population}} \quad (3)$$

The sample size for each delegation was then determined using the formula (Equation (4)):

$$\text{Sampling size} = n \times \text{sampling rate} \quad (4)$$

Households were randomly selected in the field (Table 3). A semi-structured interview guide, composed of two main sections, served as the primary data collection tool. The first section focused on aromatic and medicinal plants (AMPs) and their environment, while the guide overall explored local community perceptions regarding strategies for the production, consumption, and marketing of AMPs.

Table 3. Structure of the Study Sample.

Delegation	Household Size	Sampling Rate (%)	Sampling Size
Matmata	433	19.40	64
New Matmata	1798	80.60	264
Total	2231	100	328

Statistical data treatment: The qualitative data collected during the field survey were statistically analyzed using Principal Component Analysis (PCA), a multivariate method used to reduce data dimensionality. This approach projects the survey data into a new space with two or more dimensions, facilitating visualization. The selected dimensions are those with the highest variances (inertias). All statistical analyses were performed using SPSS (Statistical Package for the Social Sciences), version 24.

3. Results & Discussion

3.1. Farmer Perception

Data collected through field surveys and multi-stakeholder dialogues highlight the significant socio-cultural importance of the AMP sector, particularly for spontaneous species. The local community holds extensive indigenous knowledge regarding the harvesting and use of these plants for specific purposes. Despite this expertise, the sector remains largely traditional and receives limited investment. Survey findings indicate strong interest among youth to participate in AMP valorization projects. They recognize the national and international potential of AMP products and identify opportunities for investment through the development of new marketing strategies. This aligns with Porter's theory [38], which predicts that emerging value chains attract additional investments. However, respondents identified marketing and commercialization challenges as major obstacles and expressed dissatisfaction with the traditional AMP value chain, calling for modern management and marketing strategies (Table 4).

Table 4. Assessment of the consumption of the AMP according to the age of the participants.

Age Groups	Number of Respondents	Consumers Various Plants (%)
15_19	44	81.25
20_24	36	85.71
25_29	30	90
30_34	34	83.33
35_39	28	75
40_44	26	71.43
45_49	22	77.78
50_54	36	100
55_59	32	100
60_64	40	100
Total	328	86.45

The respondents' growing interest in Medicinal and Aromatic Plants (MAPs) reflects a strong attachment to their natural heritage. Survey results show that 86.45% of consumers use various plants for both aromatic and medicinal purposes. Despite production seasonality and dependence on rainfall, consumers remain loyal to MAPs as a means of preserving ancestral knowledge—a tradition increasingly embraced by younger generations.

Principal Component Analysis (PCA) reduced the survey data to two dimensions (two principal components) while retaining 91.99% of the information (Supplementary Materials). These components (Supplementary Materials), F1 (61.69% inertia) and F2 (30.30% inertia), were projected onto the x-axis and y-axis (variable A). The second step plotted the coordinates of F1 and F2 against age groups (variable B). The distribution and orientation of variables (A) and (B) toward the two axes (Figure 4) indicate that younger consumers (under 39 years old) favor a structured market for personal consumption products, including cultivation, essential oil extraction, processing, packaging, and brand valorization (variables circled in blue). In contrast, older consumers tend to prefer the traditional gathering of wild plants and direct consumption without processing (variables circled in green).

This generational shift indicates evolving practices: younger individuals envision a modernized AMP and essential oils sector with clear strategies for development, industrialization, and commercialization, whereas older generations maintain traditional

consumption habits. Overall, younger consumers display a more progressive, market-oriented vision compared to older ones.

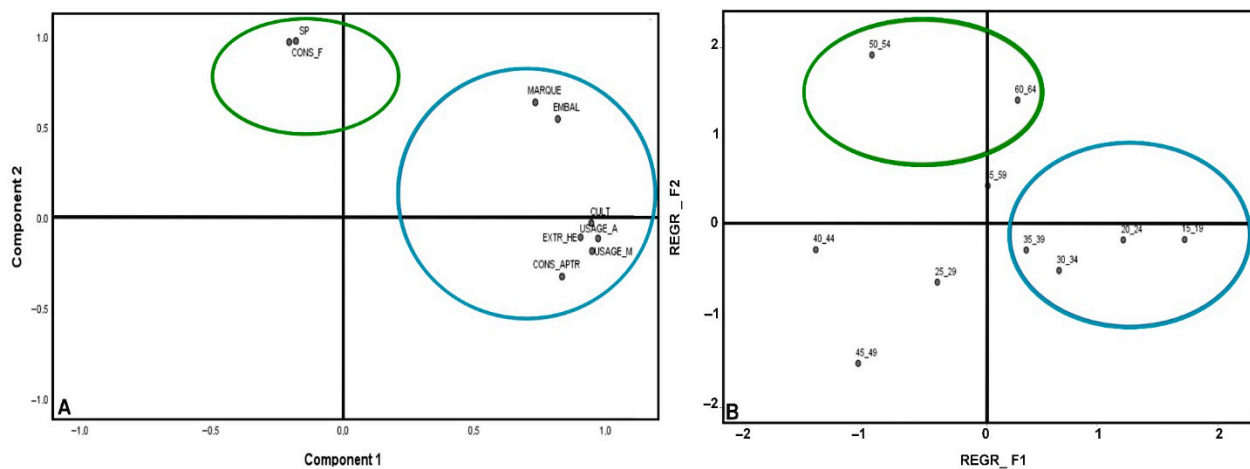


Figure 4. Distribution of variables (A) and individuals (B) on the two-dimensional factor plan.

3.2. Current Situation Assessment: AMP Traditional Value Chain

The region's rich native aromatic and medicinal plants (AMPs) possess strong cultural value, contributing to environmental resilience and diverse applications in medicine, cosmetics, and food. Indigenous knowledge ensures the high-quality use of these plants, supporting community resilience and biodiversity conservation. AMP micro-projects are already diversifying incomes, notably empowering rural women. However, growth is constrained by the limited number of cultivated species for continuous supply and poor access to local and national markets. Modern marketing strategies and increased investment in cultivation and processing are needed to boost commercialization [26,27,39]. Environmental challenges such as biodiversity loss, water scarcity, and rising energy costs further limit development [40–44]. Innovations like smart irrigation and renewable energy can promote bio-industrial growth [2,5,8]. Despite growing demand from pharmaceutical and cosmetic sectors, communities face financing, technical, and regulatory barriers [11]. Traditional farming investments no longer suffice to attract interest in new crops, making modernization, improved harvesting techniques, and climate resilience essential to maintain market access [18,20]. Water-saving practices are also critical to addressing ongoing climate pressures.

In the study area, as in much of the southern mountain zone, AMPs hold significant socio-cultural value [8,45]. These spontaneous species are widely used as eco-treatments for various ailments [20], and in preparing regional juices and meals. They are also consumed for their essential oils and dried for future use. Despite their importance, the traditional AMP market remains limited to a small user base [18,20], with the marketing chain generally yielding low income [3,32,45–47]. The traditional marketing process involves four main distribution channels (Supplementary Materials):

Channel 1: Direct sale of fresh or dried AMPs from collectors to consumers without intermediaries.

Channel 2: Collectors sell fresh or dried AMPs to permanent herbalists (H), wholesalers (CG), or itinerant sellers/retailers (VA), who then supply consumers.

Channel 3: Products move from VA to CG and herbalists. VA may also sell directly to consumers or retailers depending on seasonality, demand, and supply.

Channel 4: Intermediaries purchase large quantities directly from collectors, sometimes employing salaried harvesters, and distribute through herbalists, wholesalers, and retailers to consumers.

3.3. Economic Profitability

Integrated agricultural projects like these are largely subsidized, with subsidy availability depending on investment zone, crop type, and irrigation system. To attract new investors for local development, Tunisia offers significant incentives for agricultural innovation (Table 5). After subtracting subsidies from total project costs, the remaining investment is typically financed with about 25% equity and the remainder via bank loans. Loan interest is calculated on annual repayments following a one-year grace period, using an average monthly money market rate (MMMR) of 8% (Table 5).

Table 5. The smart irrigation component (DT).

Smart Irrigation	Name of the Measure	Design	Cost (Tunisian Dinars)
Smart Irrigation for the Mountain Zone	Water pump	Pumping water from buried cisterns	294
	Controller pump	regulator pumping water	300
	Irrigation Kit	Power supply board and cable/humidity sensors	5000
	Smart phone	One phone	1000
	Drip pipes	200 × 100 m drip pipes	8000
	Drippers	40,000 drippers (one/tree)	12,000
	Valves	2 Spherical valves (76) + low-pressure ball valves (PN 63)	200
	Filtration system	Water filtering	100
	Moisture sensors	Two sensors	52
	Cistern « Fesguia »	average storage volume is 90 m ³ (50% de grants)	4000
	Access for irrigation	Shepherd's elbow, Shepherd's tube, Shepherd's tee, etc.	2000
	PV panels components	3 kw	12,000
	Total		44,946
Smart irrigation for the irrigated perimeter	Water pump	Pumping water from wells	294
	Controller Pump	flow controller	300
	Irrigation kit	Power supply board and cable and humidity sensors	4714
	Tuyaux Goutte à goutte	13 × 192 m drip pipes	998.4
	Drippers	2808 drippers	842.4
	Valves	2 Spherical valves (76) + low-pressure ball valves (PN 63)	200
	Electromagnetic valve	Electromagnetic valve for each line of irrigation	169
	Filtration system	Water filtration	100
	Moisture sensors	13 sensors	338
	Accessories for irrigation	Shepherd's elbow, Shepherd's tube, Shepherd's tee, etc.	2000
	Smartphone	One phone	1000
	PV implementation	Solar pumping	12,000
	Total		22,955.8

3.3.1. Production and Amortization Forecasts for PAM and HE

The development of the AMP is characterized by two production cycles. The annual production of AMP varies significantly due to variable conditions, making it difficult to predict with accuracy the average yields. Experimental data from Tunisia indicate that a single plant produces an average of 0.5 to 0.8 kg. Over a one-hectare area, the annual PAM harvest is estimated at 49 tonnes for the two production cycles. The processing and packaging industry aligns with market demand, which increasingly favors essential oils as both a consumer product and a raw material for industrial applications. In this micro-project, 41 tonnes of dried plant material are allocated for essential oil extraction. The unit prices of the finished products for each species are determined based on market selling prices, as referenced in empirical studies by [18] (Tables 6 and 7).

Table 6. Estimated total costs of the projects.

Components	Project 1 (DT)	Project 2 (DT)	Project 3 (DT)
Smart Irrigation	44,946	22,955.8	22,955.8
Civil engineering, planting, and equipment	167,750.365	115,077.314	40,700
Approach and miscellaneous expenses	4000	4000	4000
Study fees	2500	2500	2500
Working capital	22,500	5000	5000
Total	245,696.365	149,533.114	75,155.8

Table 7. Financial Model.

	Project 1			Project 2			Project 3		
	Estimated Cost (DT)	Grant (%)	Grant (DT)	Estimated Cost (DT)	Grant (%)	Grant (DT)	Estimated Cost (DT)	Grant (%)	Grant (DT)
Supplementary grant for areas with extreme climates	245,696.365	8	19,655.7092	149,533.114	8	11,962.649	75,155.8	8	6012.464
Installation of water efficiency devices	48,946	50	24,473	22,955.8	50	11,477.9 *	22,955.8	50	11,477.9
Solar water pumping system installation	12,000	60	7200	12,000	60	7200 *	12,000	60	7200
Research allowance	2500	100	2500	2500	100	2500 *	2500	100	2500
Total Grant *		53,828.709			33,140.549			27,190.364	
Net investment to be funded (total costs-Grant)		191,867.656			137,570.464			47,965.436	
Financial model	%	Value (DT)		%	Value (DT)		%	Value (DT)	
Own funds	25	47,966.914		25	34,392.616		25	11,991.359	
Bank financing	75	143,900.742		75	103,177.847		75	35,974.077	
Total	100	191,867.656		100	137,570.464		100	47,965.436	

* Subsidies will be disbursed following the recovery period, defined as the year in which the initial investment costs are fully recouped.

For *Capparis spinosa*, the production is estimated to be 0.6 kg/plant for the first year. From the fourth year, production may reach 4 kg. For the present case, the second-year production is assumed to be 1.8 kg/ft, while for the third, it is about 3 kg/ft. The market price for a kilo of *Capparis Spinosa* is between 7 and 10 DT, depending on size (fine, medium, large). The average cost of 7 DT per kg is used for the assessment of the profitability of the project.

For one production cycle of olives, the production varies between 1.02 and 1.27 t/ha. The average of 1.14 t/ha was opted for the CBA assessment. The production is evaluated by “Galba olive” (14 to 15 kg) and “Weba” (2*galba = 28 to 30 kg). So 1.14 ha can produce from 38 weba to 40.71 weba of olives (one weba unit can produce 6–10 L of olives). For this case, the average production is assumed to be 8 L/weba of olive with an average selling price of 16 DT/L.

3.3.2. Financial Profitability Analysis

An accurate profitability assessment is essential to evaluate the viability of investment projects by identifying opportunities and constraints. In this study, both sales and operating costs are projected to increase by 5% annually. Production is expected to reach its peak at the beginning of the second year for the first two projects, while for the *Capparis spinosa* cultivation project, peak production occurs at the start of the fourth year.

AMP Cultivation in the Mountain Zone: Production costs include plowing, tractor and equipment rental, and organic and chemical inputs. Packaging expenses cover dried plants and essential oils. Labor costs consist of salaries for three skilled workers and one technician. Other expenses, such as infrastructure, utilities (water, telephone), labeling, and advertising, are included as miscellaneous costs. A 10% discount rate is applied to calculate the net present value (NPV). The project yields a discounted net cash flow of 315,344.78 DT against an initial investment of 191,867.66 DT. The Internal Rate of Return (IRR) is 32%, exceeding the minimum required 10%, confirming profitability. The Profitability Index (PI) is 2.64, meaning each dinar invested generates 2.64 dinars in discounted returns (Table 8).

Intercropping AMP within Olive Trees: Labor costs cover salaries for two seasonal workers. Other expenses include fixtures, water, and telephone. The 10% discount rate is applied, and the project is income tax exempt. It produces a discounted net cash flow of 155,693 DT with an initial investment of 137,570.46 DT. The IRR is 28%, surpassing the 10% threshold, and the PI is 2.13, indicating 2.13 dinars returned per dinar invested.

Intercropping *Capparis spinosa* with Olive Trees: Costs include land preparation and purchase of organic and chemical inputs. Labor covers a permanent agronomist and two seasonal workers. Other expenses include landscaping, water, telephone, plowing equipment, and transport. The 10% discount rate applies, and the project is income tax exempt. It generates a discounted net cash flow of 206,776.40 DT against an initial investment of 47,965.44 DT. The IRR is 43%, well above the 10% minimum, with a PI of 5.31, meaning every dinar invested returns 5.31 dinars in discounted earnings.

Table 8. Economic feasibility analysis.

		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Project 1	Revenue	74,435	148,870	156,313	164,128	172,344	180,961	190,009	199,509	209,484	219,958
	Depreciation & amortization expense (Supplementary Materials)	25,611.17	256,11.17	256,11.17	22,277.836	22,277.836	13,328.636	13,328.636	13,328.636	13,328.636	13,328.636
	Total operating costs	92,597.17	95,935.97	99,722.21	76,814.018	80,655.718	84,688.252	88,922.983	93,370.293	98,038.107	102,940.91
	Finance costs	11,512.06	11,512.06	10,590.18	9594.544	8519.26	7357.954	6103.743	4749.196	3286.284	1706.343
	Cash-flow	−4063.059	67,033.14	71,611.78	99,997.274	105,446.86	102,243.43	108,310.91	114,718.15	121,488.25	128,639.38
Project 2	Revenue	24,739.726	49,479.45	51,953.424	54,551.095	57,278.649	60,142.581	63,149.710	66,307.195	69,622.554	73,103.681
	Depreciation & amortization expense (Supplementary Materials)	16,542.22	16,542.22	16,542.22	13,208.921	13,208.921	9697.761	9697.761	9697.761	9697.761	9697.761
	Total operating costs	16,565.22	16,566.37	16,567.57	13,235.539	13,236.859	9727.085	9728.539	9730.071	9731.673	9733.357
	Finance costs	8254.227	8254.227	7593.231	6879.355	6108.369	5275.705	4376.427	3405.206	2356.289	1223.457
	Cash-flow	16,462.5	41,201.08	44,334.84	47,645.122	51,142.342	54,837.552	58,742.505	62,869.679	67,232.353	71,844.628
Project 3	Revenue	23,383.55	62,090.75	100,798	133,053.95	133,053.95	133,053.95	133,053.95	133,053.95	133,053.95	133,053.95
	Depreciation & amortization expense (Supplementary Materials)	9244.49	9244.49	9244.49	5911.16	5911.16	2120	2120	2120	2120	2120
	Total operating costs	58,448.99	60,909.22	63,762.45	63,140.869	66,003.354	65,216.553	68,371.03	71,684.131	75,161.637	78,814.618
	Finance costs	2877.926	2877.926	2647.462	2398.562	2129.749	1839.432	1525.889	1187.262	821.546	426.572
	Cash-flow	−28,698.9	7548.1	43,632.5	73,425.68	70,832.01	68,117.97	65,277.03	62,302.56	59,190.77	55,932.76

3.4. Discussion

The assessment of consumer perceptions regarding Aromatic and Medicinal Plant (AMP) development in Tunisia's arid regions reveals two main consumer groups, differentiated by age and their engagement with the value chain. Indigenous knowledge and cultural heritage remain central, playing a critical role in coping with harsh environmental constraints such as water scarcity and limited natural resources [16,18]. This cultural embeddedness underscores the socio-economic importance of AMPs in local livelihoods. Younger consumers (under 39 years old) express strong support for a modernized AMP sector. Their vision includes a fully integrated value chain encompassing cultivation, harvesting, essential oil extraction, processing, packaging, and branding. They recognize the importance of adopting advanced extraction technologies, improving regulatory frameworks, and meeting evolving market standards to enhance the sector's competitiveness. For them, economic viability depends on scaling up operations while aligning with consumer expectations for quality and sustainability. This cohort's market-oriented outlook reflects a shift toward industrialization and commercialization, aiming to unlock new economic opportunities within the AMP sector. Conversely, older consumers emphasize traditional practices focused on the collection and use of spontaneous AMP species. They value the low capital requirements and the competitive advantage of small-volume, high-value production. This group prioritizes maintaining indigenous knowledge and cultural continuity, with practices deeply rooted in generational experience. Their preference for simplicity

and direct consumption underscores the socio-cultural foundation of the AMP sector in rural communities.

The coexistence of these two perspectives suggests a generational transition rather than a sharp divide. While younger generations pursue modernization and value chain development, they also build upon the traditional knowledge and practices of their elders. Importantly, these approaches do not disrupt the dominant olive-based agro-system, which remains central to regional agriculture. Intercropping AMPs with olive trees presents a viable diversification strategy that maintains social acceptance among farmers who may be reluctant to abandon monoculture systems due to land fragmentation and traditional leadership structures. Adopting the Water–Energy–Food–Ecosystems (WEFE) Nexus approach provides an effective framework for addressing the multidimensional challenges of AMP sector development. By promoting integrated resource management, this approach supports agricultural productivity, economic returns, energy transition, and sustainable ecosystem use—crucial factors in climate-vulnerable regions with fragile economies. The WEFE nexus facilitates socially inclusive, bottom-up development processes that strengthen local resilience and adaptive capacity. Economic analyses of AMP valorization micro-projects confirm the sector’s potential to contribute meaningfully to social stability, reduce rural exodus, and generate employment. The profitability and feasibility demonstrated by these projects support the scaling-up of AMP cultivation, processing, and marketing as pathways to diversified and resilient agro-systems. Strengthening processing industries and distribution networks will be key to maximizing these benefits. Nonetheless, commercialization and equitable market access emerge as primary challenges limiting sector growth. Addressing these requires coordinated efforts among stakeholders across the entire AMP value chain. Inclusive governance and strategic policies are essential to ensure fair benefit-sharing, enhance market competitiveness, and foster sustainable sector development.

Despite providing valuable insights, this study is limited by the geographic scope and sample size of its field surveys. Expanding the research to include more diverse regions and larger populations will improve the statistical robustness and generalizability of findings. Additionally, broadening the focus to incorporate a wider range of AMP species, including underutilized and endemic plants, could enhance the socio-economic and environmental impacts of valorization initiatives. Future research should develop dynamic models and scenario analyses to simulate long-term outcomes of various cultivation, processing, and marketing strategies under fluctuating environmental and socio-economic conditions. Incorporating validated quantitative indicators will increase model reliability. Moreover, fostering cooperative and participatory frameworks involving farmers, communities, policymakers, and industry actors is crucial. Such collaborative approaches will facilitate co-design of shared visions for the AMP sector, improve acceptance of interventions, and support evidence-based policymaking aimed at equitable market access, sustainable resource management, and fair benefit distribution. By addressing these limitations and pursuing these research avenues, future efforts can significantly enhance the robustness, relevance, and impact of AMP valorization programs in Tunisia and other similarly vulnerable arid regions.

4. Conclusions & Perspectives

Achieving social and economic development in Matmata’s vulnerable, arid environment—rich in natural and cultural heritage and shaped by a long history of migration—requires integrated, community-centered approaches. Rural exodus, often driven by climate and socio-economic challenges, can contribute positively through migrant remittances invested in local employment-generating projects. A field-based approach

that simultaneously enhances household incomes and local resilience is critical. In this context, the WEF nexus framework provides an effective tool for integrated resource management.

The study highlights the strong local knowledge and community engagement in Medicinal and Aromatic Plants (AMPs) collection and use, which support sustainable land use and contribute to economic revitalization. Younger consumers drive demand for a modernized, branded AMP sector emphasizing cultivation, extraction, processing, and commercialization, whereas older generations maintain traditional practices focused on wild collection and direct consumption. This generational divergence indicates a gradual shift toward market-oriented modernization while building on traditional knowledge. Cost–benefit analyses of AMP-based micro-projects confirm their economic viability and social benefits, demonstrating that traditional practices can evolve within a sustainable development model. The sector also embodies circular economy principles through low-impact cultivation, reuse of plant material, and reinvestment in local labor, generating inclusive and regenerative economic value.

Persistent challenges include institutional fragmentation, limited market access, and weak logistics, which require strengthened stakeholder coordination, support for territorial dynamics, and empowerment of emerging entrepreneurs. Engaging diaspora remittances and knowledge transfers offers further potential for innovation and investment. By integrating economic, social, and cultural dimensions, AMP valorization under the WEF and circular economy frameworks provides a replicable, climate-resilient development model for Matmata and other similarly vulnerable arid regions, promoting sustainable livelihoods, youth employment, and local economic diversification.

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