Technical Handbook on the Domestication of *Crithmum maritimum L.* (Case of Tunisia): A Review and Experimental Insights



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Foreword

This guide results from a scientific effort led by the National Research Institute of Rural Engineering, Water, and Forests (INRGREF, Tunisia), compiled from peer-reviewed literature and experimental trials conducted within the framework of the PRIMA project SEAFENNEL4MED and doctoral research on the domestication of *Crithmum maritimum* L.

Sea fennel (*Crithmum maritimum* L.) is a coastal halophyte of significant ecological, nutritional, and socio-economic value. Its domestication in Tunisia is both a scientific effort and a response to the urgent need for climate-resilient crops that can thrive in saline soils and under water scarcity.

This work aims to provide a practical guide for plantation and domestication methods, combining existing knowledge with insights from experimental trials conducted in Tunisian conditions. By merging field results with international scientific progress, this guide seeks to serve as a useful reference for those interested in this species' sustainable cultivation and valorization.

This guide is mainly for farmers, foresters, researchers, students, development practitioners, and stakeholders in the agri-food, cosmetic, and nutraceutical sectors. It aims to support the creation of pilot plantations, nursery systems, and value chains that promote biodiversity conservation, climate-smart agriculture, and local economic growth.

This document thus aims to support Tunisia's agroecological transition by increasing reference plots, encouraging the development of local nurseries, and fostering new value chains around a key patrimonial and strategic species for the country's agricultural and environmental future.

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Botanical, Ecological, and Socio-Economic Insights on *Crithmum maritimum* L. as a Precursor to Domestication

1. Origin of Crithmum maritimum L.

The cultivation and use of sea fennel (*Crithmum maritimum* L.), locally called “krafess” or “sea fennel” in Tunisia, dates back to ancient times. It was well known to the Greeks and Romans and was already described by Dioscorides and Pliny the Elder for its culinary and medicinal uses [1]. Traditionally, it was harvested from rocky seashores and valued as a condiment and a medicinal plant.

During the Middle Ages, sea fennel was preserved in vinegar or salt and used as a vegetable garnish. It was especially popular among Mediterranean sailors, who relied on its high vitamin C content to prevent scurvy. Its reputation as a health-boosting plant has persisted through the centuries and remains an essential part of Mediterranean culinary and medicinal traditions [2].

C. *maritimum* is the only species in the genus Crithmum and belongs to the Apiaceae family, which includes other economically significant aromatic and medicinal plants such as fennel, carrot, coriander, and celery. This uniqueness gives the species a high taxonomic and patrimonial value.

Historically, the plant has always been associated with its coastal environment. It grows on cliffs, stabilized sandy dunes, and areas exposed to sea spray, earning it the nickname “sailors’ plant.” In Tunisia, its presence along the entire coastline—from the northern regions (Tabarka, Bizerte) through Cap Bon (Haouaria, Kélibia) to the Sahel coast (Monastir)—demonstrates its long-standing relationship with coastal communities, which used it as a food, medicinal, and ecological resource [3].

In the 21st century, sea fennel has been rediscovered as a promising crop with significant economic potential. It is currently studied for its domestication and integration into Mediterranean farming systems, focusing on crop diversification, utilization of halophytic resources, and adaptation to climate change [4,5].

2. Morphological Description

Crithmum maritimum L. is a perennial aromatic halophyte that creates dense, bushy growth suited for harsh coastal environments. Its morphological features show adaptations to salinity, drought, and wind exposure.

- Growth habit and stems: The plant forms dense tufts, usually 30–70 cm tall, but can exceed 1 m in ideal conditions. Stems are upright, smooth, branched, and partially woody at the base [6,7].
- Leaves: Alternating, succulent, and bluish-green (glaucous) color. They are divided into narrow linear to lanceolate segments, giving the foliage a feathery appearance. This particular

morphology reduces transpiration and allows water storage, making the leaves a key adaptation to arid and saline environments [8].

- Inflorescences: Flowers are arranged in compound umbels with 6–20 rays. The small flowers (2–3 mm across) are yellowish-white to greenish and produce a lot of nectar, attracting pollinators, including bees, flies, and beetles [9].
- Fruits (schizocarps/diakens): At maturity, each fruit is ovoid, ribbed, and brownish, splitting into two mericarps. The fruits are rich in essential oils such as dillapiole, apiol, and carvacrol, which are believed to play roles in plant defense and ecological interactions [10].
- Root system: The species develops a strong taproot with lateral branches that penetrate deeply into sandy or rocky substrates. This system provides anchorage on cliffs and dunes while increasing tolerance to drought and salinity [8,11].

Overall, C. *maritimum*'s morphology shows a mix of succulence, structural compactness, and specialized secondary metabolites, making it a model plant for halophyte domestication.

3. Ecology and Distribution

Sea fennel (*Crithmum maritimum* L.) is a coastal halophyte—typically found in salt-rich environments like rocky coasts and sandy shores—where few other higher plants can thrive. Its ecology is influenced by its exceptional tolerance to various abiotic stresses, including high salinity, wind exposure, and prolonged drought.

3.1. Worldwide Overview

Geographical distribution

C. *maritimum* is found along the Atlantic and Mediterranean coasts, from the British Isles and western France south to Macaronesia (Azores, Madeira, Canary Islands) and North Africa, and east to the Mediterranean and Black Sea [15,16]. Global biodiversity databases show dense populations in the Mediterranean basin and Atlantic archipelagos, with additional naturalized populations in North America and Australia [17].

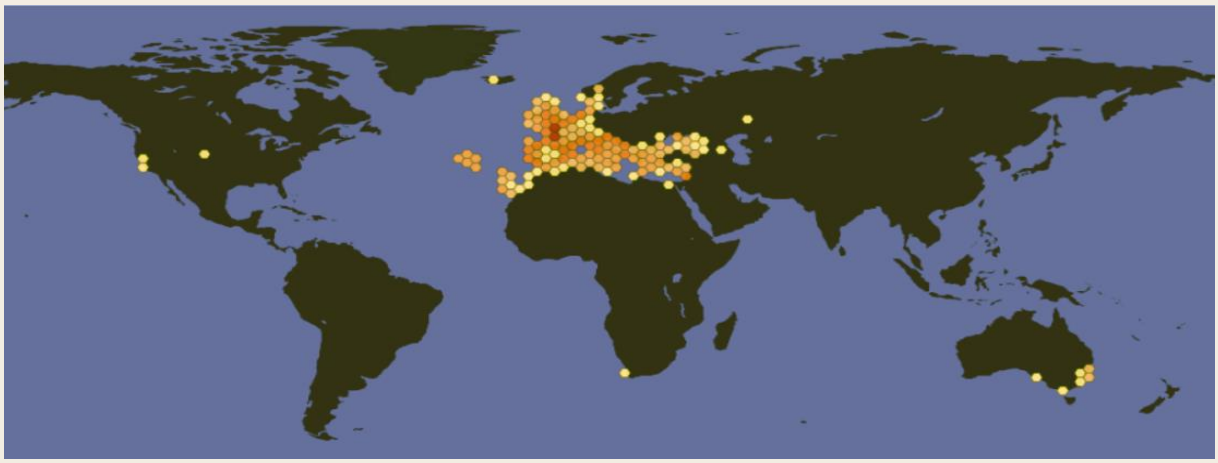


Figure 1. Worldwide Distribution of Sea Fennel

Habitat

Sea fennel usually inhabits seaside cliffs, rocks, breakwaters, and dune edges, mainly within the sea-spray zone just a few meters above sea level [18]. It is recognized as a pioneer coastal plant species, adapted to resist wind exposure, salt aerosols, and shallow soils, and helps stabilize fragile coastal habitats [19].

Climatic requirements

The species thrives in Mediterranean-type climates, characterized by mild, wet winters and hot, dry summers, consistent across its native range [20]. Mediterranean climate classifications emphasize the winter-wet, summer-dry cycle, which influences the dynamics of coastal vegetation communities [21]. Phenological and ecophysiological studies demonstrate that C. *maritimum* maintains vigorous biomass growth and flowering during warm-season droughts and maritime exposure, showing strong adaptation to this climate zone [22].

Rainfall

Natural populations of C. *maritimum* are typically found in semi-arid to sub-humid coastal areas, where annual rainfall varies from 250 to 700 mm [23]. Bioclimatic research on Mediterranean ecosystems indicates that the broader rainfall range for this climate is 250–900 mm annually, depending on latitude and topography [24]. Cultivation trials in southern Italy demonstrate successful growth and reproduction with approximately 400–500 mm annual rainfall [25]. Experimental data from central Italy show that the plant can form leaf rosettes with only 64.6 mm of spring rainfall (April–June), nearly 70% below the long-term average, emphasizing its drought tolerance [26]. In controlled experiments, establishment was achieved with as little as 4.6 mm over 88 days, highlighting its extreme ability to withstand low water availability [27].

Soil

Sea fennel is closely associated with shallow, sandy, or calcareous soils, often found in rock crevices and cliff ledges where substrates are nutrient-poor and exposed to constant marine aerosol deposits [28]. Field surveys along Iberian coasts show increased growth and seed production on coarse sandy soils with low microelement levels, indicating their adaptation to nutrient-poor environments. Physiological studies confirm that the species can tolerate salinity levels up to 200 mM NaCl, with adaptive changes in biomass distribution occurring at 200–300 mM, and osmotic adjustments in roots and leaves that help sustain growth under saline conditions [29].

3.2. Tunisia Overview

Geographical distribution

Recent Tunisian surveys along rocky headlands, cliffs, and dune fringes confirm existing populations in Tabarka, Bizerte, Cap Negro, Haouaria, Kélibia, and Monastir. Meanwhile, historical records from Sousse, Gabès, Djerba, and Zarzis have not been reconfirmed—likely indicating local extirpations related to coastal urbanization and habitat degradation (Figure 1). Syntheses and primary Tunisian studies support a long-standing presence on the northern and Cap Bon coasts and document physiological tolerance that promotes survival in these areas [30–33].

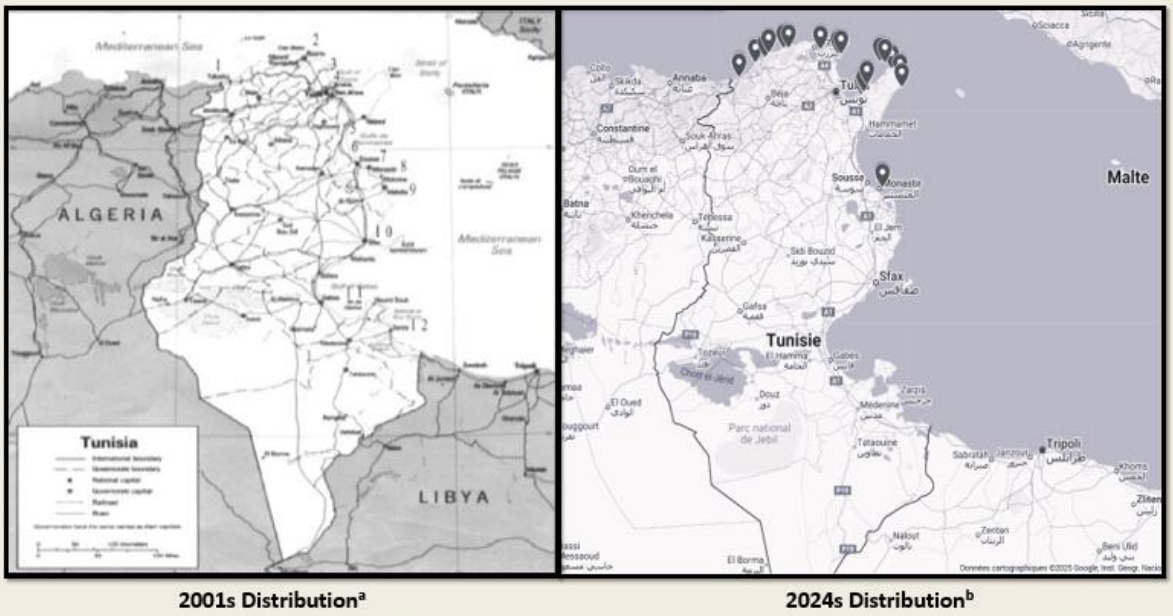


Figure 2. Comparative distribution of C. *maritimum* along the Tunisian coast.

Habitat

In Tunisia, C. *maritimum* inhabits salt spray zones just meters above sea level, including maritime rocks, cliff ledges, breakwaters, and saline dune edges. Experimental work in Tunisia identifies the species as

a pioneer halophyte capable of establishing and enduring salt-affected, nutrient-poor, calcareous soils—conditions typical of many Tunisian littorals [32–34].

Climatic requirements

The Tunisian coast experiences hot, dry summers and mild winters, with apparent north–south climate variations. C. *maritimum* populations thrive in semi-arid to sub-humid environments, tolerating summer temperatures often exceeding 40 °C [30,35]. Tunisian ecophysiological research shows resilience under high salinity, drought, and heat stress, indicating adaptation to the country's Mediterranean–semi-arid transition zones [31,32,36].

Rainfall

Along the northern coasts (Tabarka, Bizerte), annual rainfall exceeds 500 mm, while in Cap Bon (Haouaria, Kélibia) and the central Sahel (Monastir), it often falls below 400 mm [36]. This gradient shows the species' ecological flexibility: it thrives in humid Mediterranean areas and semi-arid coastal zones. Recent declines in southern Tunisia (Sousse, Gabès, Djerba, Zarzis) align with decreased rainfall levels (<300 mm/year) combined with increased human pressures [37].

Soil

Tunisian populations are linked to shallow, sandy to limestone soils that are often saline and low in organic matter. Germination studies show that seeds have a high tolerance for seawater immersion and NaCl concentrations, enabling them to establish in saline environments typical of the Tunisian coast [38]. These traits support the potential use of C. *maritimum* in biosaline agriculture and ecological restoration of degraded coastal soils [23].

4. Usages, Benefits, and Socio-Economic Importance

Sea fennel (*Crithmum maritimum* L.) has gained increasing attention in the Mediterranean and beyond because of its unique phytochemical profile, organoleptic qualities, and ability to thrive in marginal environments. Its versatile benefits extend across culinary, medicinal, nutraceutical, cosmetic, and ecological fields, making it a promising multipurpose crop for local communities and emerging agri-food industries.

4.1. Nutritional and Culinary Benefits

Traditionally enjoyed along the Mediterranean coasts, sea fennel is valued as a leafy vegetable, condiment, and pickle ingredient. Its aromatic tissues are rich in essential oils (dillapiole, apiol, limonene), giving it a distinctive flavor similar to fennel or carrot [1]. Nutritional analyses highlight high levels of vitamin C, phenolics, flavonoids, carotenoids, and polyunsaturated fatty acids, contributing to strong antioxidant capacity [30,31]. Recent studies further emphasize its richness in ω-3 and ω-6 fatty acids, polyphenols, and minerals, with additional prebiotic potential in intestinal cell models [40]. Comparative evaluations also revealed variability in protein, lipid, and phenolic content

across habitats, with protein concentrations reaching up to 10 g/100 g DW [41]. Young shoots are pickled, blanched, or added to salads and sauces in Europe and North Africa. At the same time, modern research stresses their potential as functional food ingredients (powders, edible films, nutraceutical supplements) [32].

4.2. Medicinal and Nutraceutical Value

Sea fennel, traditionally used as a diuretic, digestive aid, and antiscorbutic, has gained renewed interest in nutraceutical research. Extracts demonstrate antioxidant, antimicrobial, antifungal, anti-inflammatory, and anti-biofilm activities, mainly attributed to phenolic compounds and volatile terpenes [33,34]. Essential oils inhibit foodborne pathogens and dermatophytes, supporting their application in natural food preservation and phytotherapy [35]. Recent studies confirm anticancer and hepatoprotective properties, consolidating its role as a health-promoting crop [36]. Additionally, newly characterized essential oil fractions revealed significant antibacterial and antifungal activity, highlighting sea fennel as a potential source of bioactive metabolites for pharmaceutical applications [42].

4.3. Cosmetic and Industrial Applications

Sea fennel extracts are increasingly incorporated into the cosmetic industry, particularly for anti-aging, skin hydration, and dermoprotective formulations. Rich in chlorogenic acid, rutin, and polyacetylenes, the plant is widely used in creams, emulsions, and serums, while essential oils contribute to aromatic and perfumery products [37,38]. Moreover, valorization of processing by-products (stems, flowers, residual biomass) has revealed high levels of polyphenols, tocopherols, and carotenoids, along with marked antioxidant and antimicrobial activity, thus extending its applications to the cosmeceutical and food industries [43].

4.4. Agro-Ecological and Environmental Benefits

Ecologically, *C. maritimum* plays a crucial role in coastal ecosystem stability. Its root systems contribute to dune and cliff stabilization, while its natural tolerance to salinity, drought, and wind exposure makes it a pioneer species for coastal rehabilitation [12]. Tunisian studies highlight its potential for biosaline agriculture, enabling productive use of marginal and saline soils while promoting sustainable land management [20]. Cultivating sea fennel could also reduce harvesting pressure on wild populations, contributing to biodiversity conservation.

4.5. Socio-Economic Importance

The combined culinary, medicinal, cosmetic, and ecological benefits make C. *maritimum* a valuable, versatile crop for Mediterranean communities. In Tunisia, it provides opportunities to:

- Develop premium niche food products (pickles, condiments, functional food powders, herbal teas).
- Provide bioactive-rich extracts to the cosmetic and pharmaceutical industries.
- Promote traditional recipes to boost eco-tourism and local cuisine.
- Support rural economies by diversifying income sources in coastal communities.
- Promote climate-smart agriculture using marginal coastal soils unsuitable for traditional crops [35].

Overall, the domestication and commercialization of C. *maritimum* can integrate cultural heritage with modern market demand, while supporting sustainable coastal development.

Given its nutritional, medicinal, cosmetic, and ecological value, *Crithmum maritimum* L. is a versatile and strategic crop in the Mediterranean. However, its wild populations in Tunisia are declining significantly, with local extirpations reported in the central and southern coastal areas. This decrease underscores the urgent need for domestication and cultivation initiatives to preserve this natural heritage before its genetic and cultural worth is lost [30].

The urgency is further emphasized by Tunisia's agro-environmental situation, where soils face increasing threats from salinization caused by seawater intrusion, overextraction of aquifers, and improper irrigation methods. National assessments estimate that more than 50% of Tunisian soils are affected by salinity, especially in the Sahel and southern regions [28]. At the same time, climate change is worsening aridity, with projections showing more frequent droughts, heat waves, and less rainfall across North Africa [44].

Within this challenging environment, sea fennel is a resilient halophyte capable of thriving in high salinity and severe water stress, as demonstrated by Tunisian and international studies [3,23,26]. Its natural tolerance makes it a model crop for biosaline agriculture, ideally suited for marginal lands where conventional crops cannot grow.

Therefore, the domestication of C. maritimum serves as both a conservation strategy and a development opportunity. By integrating this species into structured value chains—from cultivation and agro-processing to cosmetics and nutraceuticals—Tunisia can create new economic prospects, decrease rural unemployment, and support climate-resilient agriculture. In this way, the domestication of sea fennel is not just a botanical project but also a socio-economic and ecological necessity, combining biodiversity conservation with sustainable development goals [5].

Plantation and Domestication: Guide of Crithmum maritimum L. in Tunisia

(through literature review and experimental insights)

1. Seed Biology and Propagation

The propagation of *Crithmum maritimum* L. mainly relies on seeds, whose germination physiology has been thoroughly studied under saline and abiotic stress conditions. Early Tunisian research showed that germination can happen even at high salinity levels, with seawater and NaCl delaying but not entirely stopping germination [23]. Hormonal regulation involving abscisic acid (ABA), gibberellic acid (GA_3), and nitrate also plays a role in controlling seed dormancy and germination during saline stress, confirming the complex eco-physiological adaptations of this halophyte [22]. Additional research emphasized the importance of antioxidant responses in seedlings exposed to salinity, highlighting the resilience of early developmental stages [3,24].



Seed priming has been evaluated as a pre-sowing technique to improve germination performance. Hydropriming and osmopriming notably increased germination rates and early seedling growth under saline conditions up to 150 mM NaCl, providing a practical method for cultivation on marginal lands [45].

Recent research has expanded the domestication perspective. Zenobi et al. (2021) reported that seeds transplanted under Mediterranean organic cropping systems exhibited satisfactory germination and establishment, with field density reaching nearly 98,000 plants per hectare under controlled irrigation and fertigation [4]. Similarly, doctoral research in Italy demonstrated the feasibility of scaling up propagation protocols, including seedling establishment in nurseries and successful transplantation to field plots [46]. These findings confirm that seed-based propagation remains the most efficient and cost-effective strategy for large-scale domestication while providing the genetic variability necessary for breeding programs.

In addition to published studies, experimental trials were conducted at the National Research Institute of Rural Engineering, Water and Forests (INRGREF, Tunisia) to assess the germination capacity of C. *maritimum* under local conditions. Seeds collected from wild populations along the northern Tunisian coast were sown directly without pre-treatment (no stratification, no priming, no hormonal induction). Results demonstrated that germination occurred successfully under controlled greenhouse conditions, with average germination rates exceeding 70% within 10–15 days [47]. This confirms that, unlike many halophytes requiring dormancy-breaking protocols, C. *maritimum* seeds are physiologically predisposed to germinate without special treatments.

These findings are consistent with the species' ecological adaptation to opportunistic recruitment in coastal environments, where seeds must germinate rapidly after rainfall events in saline and nutrient-poor soils. From a practical perspective, the ability of C. *maritimum* seeds to germinate without priming or pre-conditioning highlights its potential as a low-input crop suitable for marginal land cultivation in Tunisia.

Although seed propagation ensures genetic variability and remains the cornerstone of domestication, vegetative propagation offers a practical alternative for clonal multiplication and rapid field establishment.

2. Vegetative Propagation

Vegetative propagation provides an alternative approach for domesticating C. *maritimum*, especially for preserving elite genotypes with desirable agronomic and biochemical traits. While seed propagation maintains genetic diversity and is the most commonly used method, vegetative propagation through stem cuttings ensures clonal uniformity and can speed up crop establishment in cultivation systems [1,2].

Trials conducted in Mediterranean regions confirmed the feasibility of vegetative multiplication under controlled greenhouse conditions. Experiments using sand, peat, and mixed substrates reported moderate success rates, generally lower than those of seeds [4,17]. The rooting ability of C. *maritimum* cuttings is strongly influenced by substrate type, photoperiod, and humidity, with peat substrates usually promoting higher success rates [2]. Auxin-based growth regulators such as indole-3-butyric acid (IBA) and naphthaleneacetic acid (NAA) have been tested in related Apiaceae crops, where they significantly improved root induction. However, responses remain variable across genotypes and environments [48].

Beyond traditional methods, in vitro propagation techniques have also been investigated for large-scale multiplication and germplasm preservation. Micropropagation using nodal explants showed potential for callus induction and shoot regeneration, providing opportunities for pathogen-free plant production and ex situ conservation strategies [49]. Although these methods are technically challenging and more expensive, they offer a way to rapidly produce uniform planting material, which is especially important for domestication programs.

INRGREF Experimental Trials (Tunisia)

Vegetative propagation experiments were also conducted at the National Research Institute of Rural Engineering, Water and Forests (INRGREF, Tunisia) to assess the rooting ability of C. *maritimum* cuttings under local greenhouse conditions [50]. Stem cuttings (15 cm long) were harvested from wild plants, carefully cleaned, and stripped of aerial parts (leaves and umbels). Each cutting was trimmed 2–3 cm below the node and subjected to three treatments.

- Control (T): no hormonal treatment.
- 5-minute immersion of the basal portion in indole-3-butyric acid (IBA, 4 g/L).
- 15-minute immersion of the basal portion in IBA (4 g/L).

The cuttings were cultivated in three substrates: sand, peat, and a 1:1 sand–peat mixture. Rooting success was evaluated, and the results are presented in Figure 3.

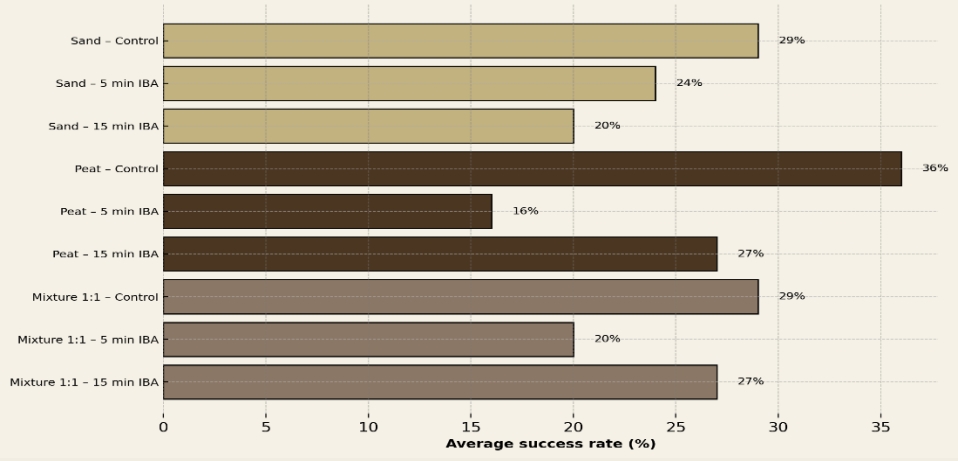


Figure 3. Rooting success (%) of *C.maritimum* cuttings under different substrates and IBA treatments (INRGREF, Tunisia)

Beyond propagation methods, successful domestication also depends on agronomic practices such as soil selection, irrigation management, and planting density, which strongly influence growth and productivity.

3. Agronomic Practices for Cultivation

Site and soil selection: C. *maritimum* performs best in well-drained, sandy to calcareous coastal soils with low organic matter and moderate-to-high salinity. Greenhouse and field trials in Mediterranean environments confirm successful establishment under such conditions, including in low-rainfall scenarios [4,17,18,25,29]. Where direct evidence for Crithmum is limited, guidance can be adapted from related Apiaceae grown in semi-arid systems (fennel, celery, carrot), which emphasize drainage, moderate salinity loads, and avoidance of waterlogging [51–54].

Field establishment: direct seeding versus transplanting. Transplanting nursery seedlings (4–6 true leaves) into pre-formed, well-drained beds improves early survival in Mediterranean trials for Crithmum and aligns with practices in fennel (*Foeniculum vulgare*) and celery (*Apium graveolens*), which reduce mortality under episodic salinity or heat [4,17,51,52]. The recommended initial spacing for domestication blocks is 40–60 cm between rows and 25–40 cm in-row, adjustable based on the target product (leafy shoots versus biomass), similar to fennel spacing experiments where 60 cm row width with approximately 30 cm in-row spacing optimized yield and essential oil traits [51].

Irrigation & salinity management: For establishment, keep substrates moist—but not saturated; once rooted, Crithmum tolerates saline irrigation better than most vegetables [4,18,29]. As a practical threshold for mixed halophyte systems, maintain irrigation water below approximately 100 mM NaCl for young plants; celery (Apiaceae) shows sharply reduced growth beyond this level in controlled trials, serving as a conservative benchmark during seedling stages [52]. Carrot (Apiaceae) demonstrates measurable photosynthetic decline only at higher salinity, with growth remaining relatively unaffected at low salinity but decreasing around ~80 mM when CO_2-saturated rates drop by about 30%—useful for defining tolerance ranges for Apiaceae physiology under salt irrigation [53]. General vegetable salt-tolerance summaries support converting crop-specific EC thresholds into irrigation setpoints and leaching fractions for effective field management [54].

Fertilization: Under saline conditions, prioritize split applications of nitrogen and moderate potassium supplementation to reduce competitive Na^+ uptake, ensuring the overall electrical conductivity (EC) of fertigation remains within the crop's tolerance. Agronomic studies on fennel indicate yield responses to nitrogen levels and planting spacing, supporting site-specific nitrogen calibration (e.g., approximately 80–120 kg N ha^{-1} in low-fertility soils) while preventing excessive salinity accumulation from fertilizers [51]. PubMed

Crop density, canopy management, and harvest: For leafy-shoot production, higher densities (e.g., 50–60 cm × 25–30 cm) can speed up canopy closure and decrease weed pressure; for biomass or seed production, increase spacing (e.g., 60 cm × 40 cm) to allow for branching and umbels, based on fennel field data [4,17,51]. Sequential harvests (cut-and-come) are feasible if at least one-third of the vegetative canopy is kept to support regrowth under saline and dry summer conditions [4,18].

Stress mitigation: In hot, dry spells typical of Tunisian summers, early-morning irrigation and surface mulches (inert or organic) help reduce evaporative salinity buildup in the root zone. Lessons from celery and carrot cultivation under saline irrigation suggest monitoring leaf chlorophyll and relative water content as quick stress indicators, and adjusting irrigation frequency rather than volume to control EC peaks [52,53,54].

Pest & weed management: As with other Apiaceae, young stands are vulnerable to weed competition; mechanical or mulch-based suppression is preferred in low-input systems. Apiaceae pests (aphids, leafminers) are generally less problematic in coastal windy sites but should be checked

regularly; saline stress can make crops more vulnerable, so maintain consistent irrigation and avoid fertilizer EC spikes [1,2].

INRGREF agronomic trials (Tunisia)



Nursery stage (plug trays) and pot experiment. Seeds collected from wild plants were grown in plug trays; once seedlings developed three true leaves, they were transplanted into 30-cm diameter pots filled with three different substrates: (i) peat, (ii) commercial potting soil ("terreau"), and (iii) Acacia compost made from *Acacia saligna* (Labill.) H.L.Wendl. (syn. *Acacia cyanophylla* Lindl.) [62]. Plants grew faster and more vigorously in the Acacia compost than in peat or potting soil, which aligns with the nitrogen enrichment expected from legume residues; note that fresh aqueous leachates of A. *saligna* can be phytotoxic, so only well-matured compost should be used [47]. (INRGREF data, 2024)



Field transplantation. Seedlings were transplanted with a 45 × 45 cm spacing on raised, well-drained beds at the INRGREF Oued Souhil station (Nabeul). The site's climate is semi-arid in the Mediterranean, with an average annual temperature of about 18.6 °C and approximately 400 mm of rainfall [55]. Local agronomic and soil studies around Oued Souhil describe sandy soils (about 79% sand, 7.5% silt, 13.5% clay), low organic matter, and a deep water table—conditions that match C. *maritimum*'s requirements for drainage and maritime exposure [56]. Before planting, the field was tilled with a tractor to a standard moldboard depth of approximately 25–30 cm [47].



Irrigation and Water Quality. Plots were irrigated with drip systems (one standard horticultural emitter ≈ 2 L h^{-1} per plant) [59]. Summer irrigation lasted 4–5 hours per day (≈ 8–10 L per plant per day with one 2 L h^{-1} emitter); in winter, about 2 hours per day (≈ 4 L per plant per day), with rainfall days skipped. These volumes fall within typical vegetable-crop drip scheduling guidelines when adjusted for coarse, low-AWC soils [16]. Regional monitoring around Oued-Souhil reports groundwater EC often exceeds 2.25 mS cm^{-1} (2250 µS cm^{-1}) in several wells, highlighting the importance of monitoring EC at the inlet and managing leaching fractions during heat waves [57].



Transplant size effect: Three transplant sizes (approximately 10 cm, 20 cm, and 30 cm or taller) were compared. Plants at 20 cm established the fastest and flowered or fruited earliest after field transfer; 10 cm plants lagged in canopy closure, while plants of ≥ 30 cm

showed higher initial transplant shock. (INRGREF data, 2024)

Direct seeding (January). Additional plots were direct-seeded in January using (a) bare seeds and (b) intact dry fruits (achenes). With drip irrigation once daily for 30 minutes at approximately 2 L h^{-1} emitters, emergence occurred about 7 days after sowing; bare seeds germinated slightly earlier than whole fruits under the same conditions. (INRGREF data, 2024)



Fertilization & crop protection. No fertilizers or pesticides were used. Weed pressure was high during the first month after transplanting in this sandy soil; for future cycles, implement pre-plant weed control methods such as false-seedbed or mulch, and consider pre-emergence options if compatible with Apiaceae production. Early manual weeding should also be performed, especially under saline irrigation, where open soil encourages weed colonization.



Summary of practical takeaways. For Oued Souhil-type coarse sands, (i) mature *Acacia saligna* compost is a promising substrate or amendment for nursery growth; (ii) a 20 cm transplant size optimizes establishment and early growth; (iii) drip irrigation with approximately 2 L h^{-1} emitters and the specified runtime bands maintain vigor, but EC should be monitored (target less than ~2.5 mS cm^{-1} during early stages); (iv) standard 25–30 cm tillage before bed formation is sufficient for rooting on sandy soils.

The cultivation efforts at the Arid Regions Institute (IRA) in Médenine, southeastern Tunisia, offer a valuable case study for C. *maritimum* under hot, arid, and saline conditions. Field trials showed that the species can be successfully established and maintained in soils with low organic matter, high salinity, and coarse texture, typical of southern Tunisian environments. Physiological assessments further confirmed a strong recovery ability after drought stress, emphasizing the crop's resilience to water scarcity and high temperatures [61].

These observations demonstrate the potential to expand C. *maritimum* domestication beyond the humid and sub-humid northern coasts into semi-arid and arid Mediterranean areas. The approach supports larger regional efforts, including those promoted through IRA Médenine official programs [62] and the SEA FENNEL4MED (PRIMA) project [63], which seek to incorporate halophytes into climate-resistant farming systems for marginal and saline soils.

4. Harvesting and Post-Harvest Handling

Switching from in-field cultivation to preparing products for market requires careful harvesting and handling practices tailored to *Crithmum maritimum's* physiology and perishability.

6.1. Optimal Harvest Timing and Method

Harvesting usually targets young shoots and umbels with the highest levels of aromatic compounds. Manual harvesting in the early morning preserves turgidity and minimizes post-harvest wilting, as seen in sea fennel and other Apiaceae vegetables like fennel (*Foeniculum vulgare)* [64].

6.2. Pre-harvest salinity management

Cultivating crops with saline fertigation (up to ~150 mM NaCl) can boost shoot biomass but may reduce shelf life by disrupting mineral balance and nitrate levels [65]. Proper pre-harvest salinity control is essential to balance yield and post-harvest stability.

6.3. Post-harvest handling and storage

- Cleaning: Fresh leaves should be rinsed in chilled (4 °C) sanitized water, such as 150 ppm NaOCl.
- Drying: For powder production, leaves can be dehydrated at low temperatures (<40 °C) to preserve phenolics and aromatic compounds [66].
- Cold storage: Modified atmosphere packaging and refrigeration (~5 °C) extend shelf life to approximately 10–12 days by slowing microbial growth and reducing oxidative losses [64].
- Biodegradable packaging: PLA-based films have been successfully tested on sea fennel and wild rocket, ensuring freshness while achieving eco-sustainability goals [64].

6.4. Industrial case study – RINCI (Italy)

The Italian company RINCI combines cultivation and processing of sea fennel in the Marche region. They grow and process their crops directly into gourmet preserves and functional products, reducing storage time and maintaining quality [67]. This model demonstrates the potential of vertically integrated value chains for halophyte crops, which is relevant for upcoming Tunisian efforts.

Taken together, these propagation and cultivation strategies demonstrate the potential of C. maritimum as a resilient halophyte crop, especially suitable for Mediterranean environments facing salinity and climate challenges.

5. Perspectives and Conclusions

The domestication of *Crithmum maritimum* L. in Tunisia, as examined through bibliographic evidence and local experimental trials, highlights its promising agricultural potential. Propagation from seeds proved effective in both controlled and field conditions, while vegetative propagation provided additional options despite lower success rates. Agronomic trials, including transplantation at INRGREF and experimental plantings in southern Tunisia (IRA Médenine), confirmed that the species can thrive in various environments, from sub-humid coastal zones to arid, saline soils. These findings demonstrate that sea fennel can be successfully incorporated into Tunisian farming systems with minimal external inputs.



From a broader perspective, C.*maritimum* represents the resilient crop urgently needed amidst climate change. Rising temperatures, extended droughts, and increasing soil and water salinization across Tunisia and the Mediterranean basin progressively make conventional crops less viable. In contrast, sea fennel naturally tolerates salinity levels up to 200 mM NaCl, endures water scarcity, and recovers after drought stress [61–63]. These traits position it as a climate-smart solution for biosaline agriculture and sustainable land management.

Looking ahead, the domestication of C. *maritimum* presents significant socio-economic opportunities. Its incorporation into structured value chains—from functional foods, nutraceuticals, and cosmetics to ecological restoration—could create new jobs, boost rural economies, and lessen reliance on overharvested traditional crops. Models like RINCI in Italy already show the potential of vertically integrated production and processing systems [67]. Similar strategies in Tunisia could promote innovation, entrepreneurship, and value addition while easing harvesting pressure on wild populations and supporting biodiversity conservation.

In conclusion, investing in the domestication of sea fennel is not only about conserving heritage but also a strategic way to address agro-environmental challenges. By combining tradition with innovation, Tunisia can turn C. *maritimum* into a flagship climate-resilient farming crop, promoting ecological sustainability and socio-economic growth.

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