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Learning to Live with Salt: From Traditional Coastal Agriculture to Halophyte-Based Futures

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Abstract

Salinity is increasingly recognized as a major challenge for agriculture and coastal livelihoods, yet saline environments have historically supported distinctive forms of agriculture, resource use and community adaptation. This Opinion argues that the future of saline landscapes should not be based solely on eliminating salt, but on learning to live productively with salinity. Traditional coastal systems such as Pokkali and Kaipad rice–fish cultivation, salt-tolerant landraces and historical approaches to water management demonstrate the value of locally adapted knowledge and biological diversity. Building on this legacy, halophytes offer new opportunities for the productive use of saline soil and water through food, fodder, salt recovery, cellulose and fibre production, water reclamation and other value-added products. *Juncus, Salicornia, Tamarix* and *Thespesia* illustrate the potential of saline-adapted plants to generate multiple resources while reducing pressure on fertile land and freshwater. Their interactions with beneficial microorganisms provide an additional opportunity to improve plant performance and resource recovery under saline conditions. We further emphasize that coastal communities should be active partners in selecting, cultivating, harvesting and utilizing halophytes rather than passive beneficiaries of technological interventions. Integrating traditional knowledge with modern plant, microbial and environmental sciences could transform saline landscapes from perceived wastelands into productive systems supporting food security, biomass recovery, environmental management and coastal livelihoods. The central message is that salinity should increasingly be viewed not only as a constraint, but as an opportunity for developing locally adapted and resource-efficient coastal futures.

Keywords: Halophytes; Saline soil; Saline water; Coastal agriculture; Pokkali; Kaipad; Coastal communities

Introduction

Salinity is increasingly becoming a critical challenge at the interface of agriculture, water and coastal ecosystems. Seawater intrusion, saline groundwater, inappropriate irrigation, inadequate drainage and increasing water scarcity are progressively affecting the productivity of agricultural land, particularly in arid and coastal regions. At the same time, saline water generated through agriculture, aquaculture and desalination is often regarded primarily as a waste or disposal problem. Conventional approaches generally focus on reducing soil and water salinity to create conditions suitable for conventional crops. However, in many coastal regions, complete removal of salt is neither economically feasible nor environmentally realistic. Salinity is also not a new challenge for human societies. Coastal communities have historically developed ways of managing landscapes where freshwater availability, flooding, tidal influence and seasonal salinity changed over time. These experiences raise an important question for contemporary saline agriculture: must productive agriculture always depend on eliminating salinity, or can agricultural systems be designed to function with it? The answer may require a shift from viewing saline environments only through the lens of degradation towards understanding their biological and resource potential. This perspective is particularly important as the demand for freshwater, food and land continues to increase. Large areas affected by salinity remain underutilized, while freshwater resources are increasingly diverted towards conventional agriculture. At the same time, coastal communities require livelihood options that are compatible with their local environmental conditions. There is therefore a need to reconsider saline landscapes not simply as areas requiring reclamation, but as environments in which appropriate biological resources, locally adapted practices and resource-recovery approaches may create new opportunities. This Opinion explores the proposition that learning to live with salt may be more realistic and sustainable than attempting to eliminate it everywhere. It considers what can be learned from earlier coastal agricultural practices, how biological adaptation can inform contemporary saline-land management, and whether saline environments can be transformed from constraints into productive resources. The discussion also raises a broader question: can the future of coastal agriculture be built by combining what communities have already learned from living with salinity with what modern science is now able to understand and develop?

Coastal Civilizations and Traditional Agriculture

The interaction between human societies and challenging coastal and water-limited environments has a long history. The Indus or Harappan Civilization extended into present-day Gujarat, with Lothal reflecting maritime connections and Dholavira demonstrating sophisticated water harvesting, reservoirs and drainage systems under the arid conditions of Kachchh [1]. Together, these examples highlight the importance of adapting land and water management to local environmental conditions rather than attempting to eliminate natural variability. Farmers in saline and coastal regions have selected and maintained crop varieties capable of tolerating combinations of salinity, waterlogging, submergence and fluctuating water availability. Traditional rice varieties associated with coastal production systems, including Kuthiru, Orkazhama, Kuttusan, Orthadiyan and Chovverian in the Kaipad region, represent locally adapted genetic resources maintained under saline conditions [2,3]. Similarly, Kharchia 65, a traditional wheat landrace from the saline areas of Rajasthan, has long been recognized as an important source of salt tolerance and has contributed genetic material to the development of salt-tolerant wheat varieties [4,5]. The continued conservation of such varieties is therefore important not only for agricultural heritage but also for maintaining genetic resources that may become increasingly valuable as salinity intensifies. Perhaps the strongest examples of traditional adaptation to coastal salinity are the Pokkali and Kaipad rice–fish systems of Kerala, where rice cultivation is synchronized with seasonal changes in salinity and subsequent fish production. In these systems, traditional rice landraces are cultivated during the less-saline monsoon period, while saline conditions later support fish and shrimp production, demonstrating an integrated response to seasonal hydrological variability [2]. Salinity tolerance is not restricted to true halophytes; conventional crops also show substantial differences in salt tolerance. Barley, cotton and sugar beet are among the more salt-tolerant major crops, whereas wheat, maize and other crops vary considerably in their response to salinity [6,7]. Quinoa (*Chenopodium quinoa* Willd.) provides a particularly interesting international example because it is a facultative halophyte with highly salt-tolerant varieties capable of maintaining growth under salinities approaching that of seawater [8,9]. These examples demonstrate that salinity resilience extends across both halophytic and conventional crops and highlight the importance of conserving traditional varieties, landraces and genetic diversity as resources for future saline agriculture.

Halophytes and Recent Advances

Halophytes represent an important biological foundation for the management of saline environments because they have evolved physiological mechanisms that enable them to function under salt stress. Ion exclusion, ion compartmentalization, osmotic adjustment, succulence and selective ion transport allow many halophytes to maintain cellular water balance and metabolic activity under saline conditions [10]. Their potential, however, should be evaluated beyond simple survival greening the area. A halophyte that survives at high salinity but produces little biomass may have limited value for agricultural production or phyto management. There is a need to identify plus trees with higher biomass and phytochemical recovery by long term monitoring. Greater attention should therefore be given to biomass productivity, nutrient capture, salt accumulation, harvesting, product quality, ecological compatibility and economic value. The performance of halophytes under salinity also cannot be separated from their associated microbial communities. The rhizosphere contains bacteria and fungi involved in nutrient cycling, organic matter transformation and plant–microbe signalling [11]. Plant-associated microorganisms may contribute to plant productivity and salinity adaptation through phytohormone production, phosphate solubilization, siderophore production, nitrogen cycling, antioxidant stimulation and other mechanisms. Some microbial associations may also influence osmotic adjustment and ion regulation, potentially helping plants maintain physiological function under salt stress [12]. This microbial perspective also provides an opportunity to reconnect modern research with traditional biological resources [12,13]. Native halophytes and traditional salt-tolerant crops may harbour microbial communities that have persisted under particular combinations of salinity, temperature, soil chemistry and water conditions. Rather than focusing exclusively on commercial microbial inoculants developed under controlled conditions, and identifying salinity tolerant genes, future research should be more focused on selection of high quality plants across saline sites for their robust adoptability, and associated microbial communities associated with locally adapted plants contribute to their long-term field performance. Long-term field experiments are therefore needed to determine whether

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particular plant–microbe associations can contribute consistently to saline-land productivity and restoration. Consequently, recent research has increasingly moved beyond the question of how halophytes tolerate salt towards the more practical question of how saline environments and halophytic biomass can be converted into useful resources. Their applications are extended to food, fodder, table salt, animal licking salt, and lignocellulosic recovery, bioenergy, phytoremediation, aquaculture integration for coastal livelihoods [14-16]. The recent studies have shown that halophytes like *Juncus, Tamarix,* and *Thespesia* are the potential source of >21% lignocellulose 2019 [17-19]. There cultivation will reduce pressure on forest and fertile land for timber cultivation for cellulose production, along with revenue generation of coastal farmers. The harvested plant material can potentially be used as fodder, and fibre for handicrafts, paper and other bio-based products. Salicornia can be cultivated for edible salt [20]. *Salicornia* and *Juncus* require adequate atmospheric and soil-moisture for optimum growth and biomass productivity. Therefore, improved cultivation practices should be developed to enhance their productivity and resource-recovery potential under saline conditions. In particular, cultivation of Juncus in constructed wetlands offers an opportunity to combine water reclamation with biomass production, including potential recovery of nutrient-rich fodder and animal-licking salt [21]. Measures should be taken to prevent further soil salinization, particularly where salinity results from human-induced changes in water and land management. Australia provides an important example of a catchment-scale approach in which groundwater, vegetation and water movement are managed collectively, supported by salt-interception schemes and revegetation to reduce the movement of saline groundwater. Such experience highlights the importance of managing salinity beyond individual farms and involving local communities in landscape-level solutions.

Coastal Communities as Active Partners

The success of any saline-land intervention ultimately depends on the people who use and manage the landscape. Coastal communities should therefore not be considered passive beneficiaries of halophyte-based restoration or microbial technologies. They should be treated as co-designers, managers and beneficiaries. Farmers can contribute knowledge regarding seasonal salinity and crop performance, fisherman and aquaculture workers can provide information about water movement and changes in aquatic conditions, and local communities can contribute knowledge about vegetation, resource availability and historical changes in coastal landscapes. Such knowledge can complement scientific measurements rather than replace them. Community participation can extend from the initial assessment of saline areas through species selection, cultivation, monitoring, harvesting and value addition. In areas where halophytes are appropriate, community-managed nurseries and cultivation systems could provide employment while also supporting soil stabilization or ecological restoration. Biomass may potentially be used for fodder, fibre, bioenergy, compost, biochar, biomaterials or other products depending on species and site conditions. However, the use of halophytes for food or feed requires particular caution because plants growing in contaminated saline water or soils may accumulate undesirable elements. Chemical, microbiological and toxicological assessments must therefore precede commercialization for nutritional applications. The integration of traditional knowledge with modern science is especially important here. Traditional systems such as Pokkali and Kaipad demonstrate that coastal communities have historically adapted production to seasonal salinity rather than attempting to eliminate all saline influence. Modern research can build on this principle by investigating the physiological, soil and microbial mechanisms that allow such systems to function and can answer How to do it? The goal should not be to idealize traditional practices or assume that all historical systems were inherently sustainable. Instead, traditional knowledge should be viewed as a repository of locally adapted genetic resources, environmental observations and potentially useful management hypotheses that can be scientifically evaluated and, where appropriate, integrated into contemporary systems.

Towards an Integrated Halophyte–Microbe–Community Framework

The saline coastal landscapes should be managed through a framework that connects saline ecosystem. The process should begin with site-specific assessment of salinity, water quality, soil properties, contaminants, tidal influence and existing vegetation. Suitable halophytes or traditional salt-tolerant crops can then be selected according to environmental conditions and intended use, while associated microbial communities should be considered as part of the biological system rather than as an afterthought. Community knowledge can assist with identifying suitable locations, seasonal management practices and locally valuable species, while scientific measurements provide quantitative assessment of soil, water, plant and microbial processes. The resulting systems could potentially connect agriculture, aquaculture and coastal ecosystems. In appropriate locations, halophytes may be integrated into saline agricultural margins, aquaculture-associated treatment areas or degraded saline landscapes. Nutrient-rich saline water generated by aquaculture could potentially be treated through constructed wetland system systems in which plants and microorganisms contribute to nutrient capture, and water reclamation and contamination risks must be evaluated carefully. Similarly, saline agricultural drainage could potentially pass through appropriate biological treatment zones before reaching sensitive coastal waters. Such approaches create opportunities to connect agricultural production, nutrient recycling, halophyte biomass and aquatic ecosystems rather than treating each component separately. The most important feature of the proposed framework is its place-specific nature.

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There is unlikely to be one halophyte, one microbial inoculant or one community-management model that will work across all saline coastal environments. Salinity varies in concentration, ionic composition, duration and spatial distribution, while coastal communities differ in their livelihoods, land tenure, markets and institutional structures. The objective should therefore be to develop locally appropriate systems based on the interaction between environmental conditions, biological resources and community priorities. Future research should consequently move beyond short-term greenhouse experiments and evaluate complete field systems over multiple seasons. Measurements should include soil salt balance, water quality, nutrient recovery, plant productivity, microbial diversity and function, biodiversity, carbon accumulation, freshwater savings and livelihood outcomes. Traditional salt-tolerant varieties should be investigated not only for their agronomic performance but also for their associated microbial communities. Particularly interesting research questions include whether traditional varieties maintain distinctive rhizosphere microbiomes under saline conditions and whether these plant–microbe associations contribute to their resilience. Such research could connect traditional crop conservation with modern microbial ecology and potentially reveal biological interactions that have been overlooked.

Conclusion

Coastal environment is complete ecosystem and should be operated accordingly. However, salinity is commonly framed as a condition that must be eliminated before productive agriculture. In the past human communities have repeatedly developed ways of adapting their livelihoods to dynamic relationships between freshwater, saline water, land and aquatic resources. Traditional crop varieties and integrated systems such as Pokkali and Kaipad demonstrate that environmental stress can sometimes be accommodated through biological selection, seasonal management and integration of agricultural and fisheries activities. The decline of such systems may therefore represent more than cultural change. It may also mean the loss of locally adapted genetic resources and ecological knowledge that could become increasingly valuable under expanding salinity and freshwater scarcity. The disappearance of traditional saline-land practices is consequently an important concern and need to be taken care. Modern science provides an opportunity to document, test and extend this knowledge for next generation. Moving one step ahead for revenue generation using saline ecosystem, the recovery of value added products using halophytes. The objective should not be to reclaim every saline landscape. Rather, coastal landscapes should be differentiated: reclaim where reclamation is practical, conserve where ecological protection is required, and productively manage where salinity itself can be incorporated into sustainable biological and livelihood systems. The future of saline coastal landscapes may therefore depend less on our ability to eliminate salinity and more on our ability to understand, manage and live productively with it.

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Conflict of interest

The authors declare no conflict of interest.

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