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Halophytes of Thar Desert: Potential source of nutrition and feedstuff

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Abstract: Salinity associated with drought is severe ecological threat in the Western part of Rajasthan which is recognized as "Thar Desert". The increased population and the deterioration of the arable lands make it inevitable to exploit marginal and long-neglected natural resources and re-assess them in the provision for utilization. Halophyte plants are widely distributed throughout several regions of the Western part due to the presence of saline extents such as Pachpadra, Lunkarsar, Khajuwala, Lanela as well as Thob. The growth of salt-tolerant fodder species for animals and other livestock offers a major opportunity to use land and water resources that are too saline for conventional crops and forages. To illustrate this point, we conducted literature searches regarding growth, biomass production and nutritive value of halophyte plants under saline irrigations practice throughout the world. This review summarized the valuable information regarding the perspective of wild halophytes as promising foodstuff alternative for animal raised in saline lands and or in arid and semi-arid regions. To sum up, it seems that a wide range of halophytes (*Haloxylon* spp., *Suaeda* spp., *Trianthema* spp., *Zygophyllum* spp.) and salt-tolerant grasses (*Juncus* spp., *Sporobolus* spp) could be considered as promising feed resources for cattle and other livestock raised in the Thar Desert. However, further research is needed regarding the chemical characterizations of these plants under commercial cultivation practices and their long-term bioactivity with safe consumption.

Keywords: Salinity, Halophyte, Nutritive value, Fodder, Thar Desert

Introduction

Salinity and waterlogging are among the major environmental crisis and serious threat to food, fuel and fiber production in the world. This problem, which extends to more than 100 countries, is encountered in all types of climate due to the consequence of both natural processes as well as human interference [1,2]. In India, about 8.6 million ha land is suffering from degradation due to salinity and alkalinity problems and therefore, it is not suitable for conventional agricultural use. The Rajasthan zone itself covers the maximum dry zone, which denotes 62% of the total arid area of India. The western part of Rajasthan is known as the "Thar Desert" which occupies about 60% of the area of Rajasthan. It is one of the densely populated (in terms of both people and cattle) deserts of the world [3]. The natural resources in the Thar Desert have been shrinking because of increased demands of food and fodder. Interestingly, several plant species may be found in locations where the NaCl concentration is beyond their theoretical tolerance but supplementary ions (calcium, potassium as well as sulfate) are found in high concentration [4]. In addition, plant species in this region can be divided into four clusters including true halophytes (plants that grow in above 1.5% NaCl concentration), Facultative halophytes (plants that grow lower than 0.5% NaCl concentration), Transitional halophytes (plants that raise only at the transition of saline and non-saline areas) Glycophytes (growing in saline extents only for a short period when salinity levels are reduced). Salt tolerant plants distributed throughout several regions of the Western part of Rajasthan were listed in Table 1 and Figure 1. Remarkably, halophytes are able to cope up with several abiotic constraints occurring simultaneously in their natural environment and synthesize certain bioactive substances with high nutritive values [5].

In recent years, however, the attention is being paid worldwide to accommodate the salt tolerant species Such as *Atriplex, Cressa, Haloxylon, Panicum, Salvadora, Salsola, Suaeda, Tamarix, Trianthema* to supports animal life and providing useful pharmacological as well as economic aspects for a human [6]. Review of literature indicates that an increase in research interest on halophytes which reflects recognition of their immense potential as food and forage [7-10] oil-yielding and fuel wood [11-13] and pharmacological [14-16] under high saline conditions. Interestingly

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Table 1: Salt tolerant plants of Rajasthan.

Type of Halophyte	Name of Species	Family	Habit
True halophytes	*Aeluropus lagopoides*	Poaceae	Tufted grass
	Cressa cretica	Convolvulaceae	Dwarf herb
	Haloxylon recurvum	Chenopodiaceae	Shrub
	Heliotropium curassavicum	Boarginaceae	Herb
	Salsola baryosma	Chenopodiaceae	Under shrub
	Sporobolus helvolus	Poaceae	Tufted grass
	Suaeda fruticosa	Chenopodiaceae	Shrub
	Zygophyllum simplex	Zygophyllaceae	Shrub
Facultative halophytes	*Chloris virgata*	Poaceae	Grass
	Dipcadi erythraeum	Asparagaceae	Shrub
	Eleusine compressa	Poaceae	Grass
	Portulaca oleracea	Portulacaceae	Herb
	Sesuvium sesuvioides	Aizoaceae	Glabrous herb
	Tamarix spp.	Tamaricaceae	Tall tree
	Trianthema portulacstrum	Aizoaceae	Herb
	Trianthema triquetra	Aizoaceae	Herb
Transitional halophytes	*Boerhavia diffusa*	Nyctaginaceae	Shrub
	Cassia italica	Fabaceae	Tree
	Cyperus spp	Cyperaceae	Glabrous herb
	Dactyloctenium aegyptium	Poaceae	Grass
	Fagonia cretica	Zygophyllaceae	Shrub
	Haloxylon salicornicum	Chenopodiaceae	Leafless shrub
	Salvadora persica	Salvadoraceae	Shrubby tree
	Tragus racemosus	Poaceae	Grass
Glycophytes	*Acacia jacquemonti*	Fabaceae	Tree
	Aerva persica	Amaranthaceae	
	Brachiaria ramosa	Poaceae	Grass
	Calotropis procera	Apocynaceae	Shrub
	Convolvulus microphyllus	Convolvulaceae	Herb
	Dicoma tomentosa	Asteraceae	Shrub
	Digera alternifolia	Amaranthaceae	
	Eragrostis ciliaris	Poaceae	Grass
	Farsetia hamiltonii	Brassicaceae	Herb
	Gisekia pharnacioides	Gisekiaceae	
	Heliotropium marifolium	Boraginaceae	Herb
	Oldenlandia aspera	Rubiaceae	
	Polygala chinensis	Polygalaceae	
	Prosopis juliflora	Fabaceae	Shrub or small tree

certain tree species of Thar desert as well provided non-wood products including gums and resins, mucilage, dyes, drugs, tanning material, and cane products [17]. After reviewing the production potential of halophytes and some other salt-tolerant plants, we discussed literature data on their nutritive value along with biomass production and their utilization as sustainable feedstuff alternatives for livestock in the Thar Desert.

Halophyte as a Human Food

The use of halophyte may be a viable commercial alternative for farming in regions where arable land is degraded due to soil degradation as well as the scarcity of fresh water [18]. Interestingly, halophytic plants have been used for human consumption (traditional food and vegetables) for a long time and scientific exploration of these plants as crops developed in the mid-twentieth century [19]. Many halophyte species including *Amaranthus, Chenopodium, Salicornia, Suaeda* are used as salads and vegetables worldwide [10]. The green leaves of *Atriplex* and *Beta maritima* show resemblances to Spanish in appearance and used as a fresh salad. *Suaeda nudiflora* is a perennial shrub, which is eaten as vegetables and used in the preparation of snakes [20]. Stem and leaves of *Sesuvium portulacstrum* are cooked and eaten as vegetables for native peoples of arid regions of India. Moreover, these edible portions also demonstration high values for calcium, iron as

Figure 1 : Inland saline vegetation in Western Rajasthan (A= *Eleusine sp.*, B= *Boerhavia sp.*, C&D= *Trianthema portucalustrum*, E=*T. triquerita*, F=*Sporobolus sp.*, G= Palatability of wild halophyte by herbivorous , H= *Suaeda fruticosa.*

well as carotene [21]. Leaves of *Salicornia* species are a good source of vitamin A, minerals, fatty acids and also cooked and eaten as a vegetable in the USA and European country [22,23]. In the same way, *Haloxylon salicornicum* (leaves), *Capparis decidua* (row fruits) are used for pickles. Production of vegetable oil from seed-bearing halophytes appears encouraging. *Salicornia europaea* is high-quality edible oil yielding plant with high economic value and also used to reclaim salinized areas in semi-arid and arid regions of the world [24]. In addition, leaves of *Salicornia bigelovii* can be used as an alternative source of omega-3 polyunsaturated fatty acids for human consumption. Seeds of a number of halophytes, such as *Suaeda fruticosa, Arthrocnemum macrostachyum, Salicornia bigelovii, S. brachiata, Halogeton glomeratus, Kochia scoparia*, and *Haloxylon stocksii* possess a plenty quantity of high-grade edible oil with unsaturation reaching from 70-80 % [25]. In the same way, Seeds of *Salvadora oleoides* and *S. persica* contain 40%-50% fat and are a virtuous source of lauric acid. Mature plants of *Juncus maritimus* containing about 37%-40% α-cellulose on a dry weight basis, are used as a source of paper pulp. Halophyte species used in traditional food practice by humans is listed in Table 2.

Nutritive Value of Halophytes as Animal Feed Components

Halophytic vegetation is growing in different part of the world by facing several environmental stresses. Remarkably, halophytic plant species are able to enhance their growth and biomass through ion compartmentalization, osmotic adjustment, succulence, ion transport, and uptake as well as antioxidant systems [37]. Many halophytic species may be added to the feeds of animals (including sheep, goats as well as camels) because of its

Table 2: Halophytic Plants Used as Traditional Food and Vegetables for Human.

Plant	Family	Common Name	Plant Parts	Nutritional Aspects	Traditional Uses	Reference
Anthrocnemum indicum	Amaranthaceae	-	Phyllo-clades	Amusing nutritive	Used in pickles by a native of Gujarat	[20]
Arthrocnemum macrostachyum		-	Seed	-	Seeds are source of vegetable oil	[25]
Aster tripolium			Leaves	-	Fresh salads, cooked vegetable	[26]
Atriplex hortensis	Amaranthaceae	Salt bush	Leaves	-	Pot herb, colorful salad greens	[27]
Atriplex halimus			Leaf	High nutritive value	As a vegetable	[28]
Beta maritima	Amaranthaceae	Sea Beet	Young Shoots	High nutritive value	consumed like spinach	[29]
Chenopodium album	Amaranthaceae	Lamb's quarters	Fresh above ground	Exciting nutritive value	Boiled and as a salad	[30]
Chenopodium quinoa		Quinoa	Seeds	Balanced in amino acids(Mainly histidine and lysine)	Bread, cake	[31]
Crithmum maritimum	Apiaceae	Sea Fennel	Leaves	The high content of vitamin C	Salad by native people of Italy; British Isles	[32]
Cochlearia officinalis	Cruciferae	Scurvy grass	Fresh leaf and stem	Vitamin C and glucosinolates	As salad by the Dutch mariners	[19]
Distichlis palmeri	Poaceae	Palmer salt grass	Seeds or grain	Seed contains carbohydrate(79.5%), 8% protein,8.4% fibre	Bread and consumed as gruel by Yuman Indians	[33]
Haloxylon salicornicum	Amaranthaceae	-	Tender phyllo-clades	-	Salad and pickles	[20]
Portulaca oleracea	Portulacaceae	Common purslane	Fresh leaves and stem	fatty acids, vitamin C & A	Salads	[34]
			Above ground part	-	Consume as a salad or with yoghurt	[30]
Salicornia and Sarcocornia spp.	Amaranthaceae	-	Leaves	Good source of vitamin A, minerals, fatty acids, polyphenol	Salad greens, vegetable in the USA and European country	[23,29]
Salicornia europaea	Amaranthaceae	Glasswort	Tip of young shoot	-	Boiled and Salad	[30]
Sesuvium portulacastrum	Aizoaceae	Seaside purslane	Leaves and stems	High values for calcium, iron, and carotene	Consumed as a vegetable in India, Indonesia, and southern China	[21]

Suaeda fruticosa		Salt wort	Leaves	Protein Rich	Snacks by a native of India	[20]
Suaeda maritima	Amaranthaceae	Seablite	Young leaves	higher carbohydrate content	cooking recipes such as Vegetable and salad	[35]
Suaeda nudiflora		-	Leaves	-	Pickles, salad, and as a vegetable	[20]
Zygophyllum fabago	Zygophyllaceae	-	Flower buds	-	Pickled and vegetable oil	[36]

favorable crude protein and acceptable nutritional content. Interestingly, *Atriplex* species are considered good sources of forage when there is a scarcity of food during the drought season. Earlier, [38] reported that through the year, the digestible amount of crude protein related to *Atriplex* was greater than the crude protein present in other field grasses. Likewise, [39] stated that the ash level in *A. halimus and A. nummularia* ranged from 15% to 18.6%, whereas the crude protein level ranged from 18% to 31.5% respectively. Similarly, *Salicornia bigelovii* is a succulent shrub which comprises of 30-33% crude protein, 5%–7% crude fiber and 26%-30% oil contents in their harvested weight of seeds. In addition, this plant was recognized among most of the halophyte for its capability to domesticate as a valuable oilseed crop in subtropical deserts [40,41] resolved that incorporation of *Salicornia* biomass having merely 14.5% crude protein could be utilized for as a roughage ingredient in calf camel diet without harmful effects on its feeding performance. *Cressa cretica* is an erect dwarf herb and used as a fodder, especially for camels and buffaloes. It is also understood that the quality of buffaloes milk improves due to *Cressa* fodder. In the same way, *Sporobolus* species are annual semi-halophytic grass and it is extensively used as a forage and fodder grass for cattle and horses [20]. *Suaeda fruticosa* commonly called as saltwort contains 8.4-13.5% crude protein, 13-31.7% crude fiber of its dry mass and considered as a good fodder for milch cattle [42,43]. Likewise, among trees species, *Acacia, Prosopis, Salvadora*, and *Zizyphus* are the traditional fodder of arid regions due to their high abundance and good accessibility in these areas. [18] Breckle SW, conveyed that *Cynodon dactylon, Ruppia maritima,* and *Inula crithmoides* may be used to increase biomass production over and done with bio-agriculture. Fascinatingly, halophytic plant species show a discrepancy in their chemical composition and palatability. Nutritive value is first determined by nutrient concentration through the resolving feed composition of the plant. The difference in chemical composition and nutrient contents may be related to environmental factors such as soil fertility, soil salinity, rain that control plant development. For that reason, the determination of nutrient contents of these forages is essential to evaluate their value as feedstuff constituents [42]. The nutritive value of certain halophytic shrubs and grass species has been recognized by their chemical composition were listed in Table 3.

Ash, Mineral Compositions and Palatability

The mineral side view of halophytic forages varies due to the nature of species, the phase of growth and seasonality as well as the grade of soil and water salinity. Interestingly, high content of ash is a typical characteristic of halophytic forages has given rise to disruptive concerns above the bioavailability of mineral contents of these forages [48]. The concentrations of some mineral contents of halophytic forages are shown in Table 4. In addition, it appears that these forages could be a source of some minerals to meet ruminant animal requirements. In this context, the concentrations of these minerals may balance the deficiency that may result from in areas depending on grazing ranges such as desert and saline areas [46].

Interestingly, the high levels of mineral contents of halophyte forages do not exceed the normal levels of the requirements of livestock, especially ruminants. However, it is preferred to include supplements of trace and minor mineral in diets in order to correct for any deficiency that may occur [49]. Palatability of halophytic plants for different animal species was listed in Table 5.

Conclusion

This review summarized the benefits and the constraints of halophytes and other salt-tolerant plants as potential feed resources for cattle's and other livestock in the Thar Desert. In addition, it is also concluded that halophytes and salt-tolerant forages yield throughout edible biomass in saline

Table 3: Crude Fiber and Their Fraction Contents of Different Parts of Halophytes.

Plant species	DM	Crude protein	Crude fiber	Ether extract	Ash	NDF	ADF	ADL	Hemi-cellulose	Cellulose	Reference
Acacia spp	-	10.5	26.4	4.4	13.9	-	-	-	23.41	16.91	[44]
Aeluropus littoralis	32.5	8.5	28.8	1.2	14.2	56.5	38.9	17.6	17.6	19.7	[45]
Artemisia campestris	35.6	9.4	16.9	1.6	9.6	55.2	34.0	11.2	21.2	21.6	[45]
Atriplex nummularia	-	18.89	6.26	3.11	20.2	-	-		-	-	[39]
	21.7	13.3	24.2	5.1	26.7	46.3	27.3	7.2	-	-	[46]
	-	15	31.5	7.7	24.8	-	-	-	-	-	[39]
Atriplex lentiformis	-	8.7	38.2	0.20	12.3	-	-	-	-	-	[43]
Atriplex halimus	30.2	12.5	20.3	1.1	19.9	46.7	34.8	11.9	11.9	20.0	[45]
	34.2	12.6	25.4	2.3	22.7	64.6	40.2	10.4	-	-	[46]
	-	18.6	18.8	2.5	19.5	-	-	-	-	-	[39]
Frankenia thymifolia	40.1	7.3	16.5	0.6	31.1	37.7	19.5	12.8	19.5	3.3	[45]
Haloxylon ammondendron	-	10.0	28.2	0.50	19.9	-	-	-	-	-	[43]
Juncus acutus	35.0	7.1	28.5	2.3	12.3	-	-	-	-	-	[46]
Kochia indica	-	15-15.8	31.5	2-3	14-16	-	-	-	-	-	[39]
Salicornia arabica	14.0	12.6	16.6	1.5	25.8	39.7	18.8	21.2	20.9	8.8	[45]
Salicornia bigelovii	-	30-33	5-7	5-7	-	-	-		-	-	[39]
Salsola kali	89.8	15.0	24.9	2.0	12.2	38	30.1	10.5	-	-	[46]
Salsola tetragona	20.9	11.5	17.1	6.5	31.7	32.2	20.5	11.7	16.9	2.5	[45]
Salsola tetrandra	37.1	6.3	36.1	2.4	35.9	39.7	30.0	12.9	-	-	[46]
Salsola tomentosa	-	13.3	41.6	0.40	19.5	-	-	-	-	-	[43]
Salsola yazdiana	-	7.3	42.2	0.30	17.3	-	-	-	-	-	[43]
Suaeda fruticosa	-	13.5	34.2	0.30	21.1	-	-	-	-	-	[43]
Suaeda fruticosa	25.0	10	33.2	5.0	16.1	33.7	22.3	12.0	-	-	[46]
Suaeda mollis	14.7	16.5	23.0	1.2	27.6	41.4	25.5	15.9	15.9	7.0	[45]
Tamarix aphylla	-	18.3	28.4	0.30	16.4	-	-	-	-	-	[43]
	34.9	12.9	13.6	4.0	20.1	36.0	26.0	12.4	-	-	[46]
Tamarix kotschi	-	7.2	33.0	0.40	14.7	-	-	-	-	-	[43]
Tamarix gallica	45.3	9.4	28.2	1.3	14.7	52.6	32.8	19.8	19.8	12.3	[45]
Tamarix mannifera	40.0	8.2	11.6	3.6	24.9	50.7	31.2	13.5	-	-	[46]
	-	-	16.1	-	-	49.0	33..3	12.2	15.7	21.0	[47]
Zygophyllum album	13.5	7.5	17.8	1.0	30.0	39.4	22.3	17.1	17.1	2.0	[45]
	24.7	7.8	11.2	2.5	34.2	35.6	23.6	6.70	-	-	[46]
Zygophyllum simplex	40.5	11.1	16.7	2.1	29.8	40.7	30.1	12.1	-	-	[46]

lands where other glycophytic species cannot grow. Earlier, many halophytes could be considered as probable sources of major minerals and protein for animal diets. Although this review paper focused on studies carried out worldwide, it seems that a wide range of halophytes (*Haloxylon* spp., *Suaeda* spp., *Trianthema* spp., *Zygophyllum* spp.) and salt-tolerant grasses (*Juncus* spp., *Sporobolus* spp. etc.) could be considered as promising feed resources for cattle and other livestock raised in saline lands and or in arid and semi-arid regions. The experience of other regions on the adaptation of these halophytes

Table 4: Mineral Composition of Wild Halophyte *.

Plant Species	Total sugar content (mg.g-1d.wt)	Reducing sugar (mg.g-1d. wt)	Proteins (% d. wt.)			Mineral composition (meq.g-1 d. wt.)					
			Alkali soluble	Alcohol soluble	Water soluble	Ash%	Na	Cl	K	Ca	Mg
Aeluropus lagopoides	9.3-36.1	3.8-19.2	13.1-14.9	6.1-7.8	3.0-5.0	6-26	0.73-1.72	0.56-8.05	0.08-0.98	0.12-0.36	0.34-0.81
Heleochloa setulosa	-	-	8.4-25.7	1.9-5	2.6-6.4	0.06-9.08	0.05-1.12	0.03-0.5	0.03-1.09	0.3-4.19	2.70-2.74
Juncus maritimus	7.1-11.6	3.1-7.6	-	-	-	7-11	0.46-1.66	0.51-1.40	0.06-0.12	0.18-0.36	0.25-0.55
Sporobolus maderaspatanus	8.71-41.88	4.28-24.95	1.59-2.17	0.8-1.4	5.9-8.2	7-16	0.42-0.49	0.18-1.02	0.03-0.14	0.04-0.47	0.18-1.08
Haloxylon salicornium	8.6-19.94	8.14-19.24	9.1-17.6	4.2-10.5	4.6-8..7	50-53	3.64-5.86	3.91-6.97	0.16-0.26	0.21-0.30	0.61-1.13
Salicornia brachiate	65.7-72.44	17.33-59.64	9.1-12.3	4.7-8.8	4.7-8.7	36-57	4.13-7.95	5.64-9.84	0.17-0.39	0.19-0.39	0.82-1.64
Sesuvium portulacastrum	8.74-21.73	6.75-17.39	7-12.5	3.7-9.8	3.7-9.3	32.77-54.5	2.94-12.3	2.43-11.6	0.10-0.74	0.14-0.32	0.41-2.46
Suaeda fruticosa	-	-	10.3-24	4.4-15	8.3-11.7	7.68-48.86	0.3-8.24	0.36-6.3	0.19-0.72	0.25-0.66	0.32-1.29
Atriplex griffithi	3.6-14.1	1.6-5.6	17.5-24.9	2.8-5.0	1.5-7.4	6-34	0.52-4	0.49-3.7	0.14-0.53	0.30-0.95	0.33-1.43
Prosopis chilensis	3.52-22.68	2.18-9.84	20.8-38.28	10.32-29.29	10.34-19.44	6-20	0.12-0.80	0.22-1.23	0.05-1.65	0.18-1.33	0.12-1.58
Salvadora persica	8.4-27.6	5.8-24	7.4-22.6	4.32-13.6	4.17-12.0	13-46.28	0.68-2.78	1.42-3.5	0.20-1.87	1.13-3.95	0.48-2.35
Trianthema portulacastrum	10.6-16.3	6.7-12.9	14.0-17.6	8.7-12.8	6.5-8.1	21-29	0.70-0.83	1.19-3.8	0.34-0.49	1.15-3.58	0.37-0.59
Trianthema triquetra	14-21.8	5.2-10.1	13.9-17.2	8.4-12.2	6.4-7.9	22-27	0.69-0.89	0.51-1.17	0.06-0.27	0.12-0.69	0.30-0.70
Halopyrum mucronatum	12.10-19.28	11.87-16.53	17.8-20.1	4.3-6.9	4-6.2	2.47-9.57	0.06-1.36	0.16-1.1	0.12-0.27	0.02-0.2	0.19-0.46

* (Adopted from Joshi, 2011)

Table 5 : Palatability of Halophytic Plants for Different Animal Species.

Plant species	Growth form	Animal species	Reference
Atriplex halimus	Shrub	All species	[46]
Atriplex nummularia	Shrub	All species	[9]
Chenopodium album	Herb	Goats, Sheep	[50]
Juncus acutus	Grass	All species	[9]
Salsola tetrandra	Sub shrub	All species	[9]
Suaeda fruticosa	Low shrub	All species	[46]
Suaeda nudiflora	Herb	All species	[51]
Tamarix aphylla	Tree	Goats, camels	[9]
Tamarix mannifera	Tree	All species	[46]
Trianthema portulacstrum	Herb	All species	[50]
Triantema triquerta	Herb	Goats, Sheep	[9]
Zygophyllum album	Shrub	Camels	[46]
Zygophyllum simplex	Shrub	Camels	[9]
Zizyphus mauritiana	Tree	All species	[50]

and other salt-tolerant plants to saline and or arid conditions and the success of their integration in feeding calendars which are described by several researchers. Interestingly, a mixture of salt-tolerant grasses, legumes, shrubs, and forbs maximizes the feeding value of the grassland. It could be an applicable resolution to increase the utilization of halophytic fodders.

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