Coastal sand dune vegetation: a potential source of food, fodder and pharmaceuticals

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Abstract

Coastal sand dune (CSD) flora has a wide range of applications in nutrition, medicine, industry and agriculture. The native people are intimately associated with dune vegetation for a variety of traditional benefits particularly food, fodder, health, soil fertility and recreation. Temperate CSDs comprise of mainly the members of Poaceae, while tropics with Asteraceae, Cyperaceae and Fabaceae and Poaceae. Many CSD legumes meet the protein and energy requirement of rural population and livestock. *Canavalia maritima* is a major strand legume with pantropical distribution. Tender pods and seeds are edible after boiling or roasting in Northern Australia, while seeds are important source of dietary protein in West Africa and Nigeria. *Canavalia cathartica* is another wild legume with wide distribution throughout CSDs of tropical Asia and Africa. Seeds of CSD *Canavalia* serve as potential source of proteins, carbohydrates, amino acids, fatty acids and energy. The CSD legumes of west coast of India are useful as green manure, mulch, cover crop, pasture, fodder, oil and medicinal value. The strand plants possess several bioactive compounds of human, veterinary and industrial importance.

The CSD vegetation is under severe threat mainly due to global warming and human interference and thus needs stringent restoration measures for sustainable use for coastal rural development.

Keywords: bioactive compounds, Canavalia, coastal sand dunes, disturbance, fodder, food, nutrition, restoration, traditional knowledge, vegetation, wild legumes

Introduction

Animal husbandry plays an important role in rural development and economy of developing countries. Nutrition is one of the most critical constraints to increase animal productivity in developing countries (ILRI 1995). Perpetual gap exists between the demand and supply of digestible crude protein and total digestible nutrients to livestock in Asian continent (Singh et al 1997). One of the challenges to uplift the livestock production is to increase the quality of legume-based pasture diets (Poppi and Mclennan 1995). The use of forage legumes as ruminant feed has increased in tropics to meet the protein deficiency. However, supplementation of animal protein for monogastric animals is expensive and not affordable by farmers (Umoren et al 2005). Feed supplementation with wild native legumes is economically viable and provides additional proteins, minerals and energy during dry season. Over the past few decades, research has been directed to evaluate nutritional qualities of underexplored legumes adapted to different habitats (Siddhuraju et al 1995, 2000, Vijayakumari et al 1997, Makkar et al 1998).

Coastal sand dunes (CSD) constitute a variety of habitats and vital ecological and economic importance (Maun and Baye 1989, Martinez et al 1997). Growth, survival and heterogeneity of CSD vegetation spatially and temporally influenced by environmental factors such as temperature, desiccation, low moisture retention, sand erosion, sand accretion, salinity and salt spray (Watkinson and Davy 1985, Maun 1994). Among the dune disturbances, burial is the most important factor followed by salt spray, which influences the distribution of dune plant species (Maun and Perumal 1999). Studies on CSD vegetation, restoration and stabilization confined mainly to temperate regions (Sylvia and Will 1988, Sylvia 1989, Koske and Gemma 1997). Several microflora adapted to strand environment live independently or mutually with vegetation (e.g. rhizobia, *Frankia*, mycorrhizas). The CSD flora has a wide range of economic value (e.g. nutritional, medicinal, industrial, agricultural) particularly for rural coastal population. The native people intimately associated with dune habitats are dependent on vegetation for a variety of benefits (e.g. food, fodder, health, soil fertility, recreation). The purpose of this review is to project the nature of vegetation on CSDs; nutritional value and bioactive potential of selected dune plants; traditional knowledge of native coastal dwellers on the use of dune plants in human health, veterinary and agriculture; threats to dune vegetation due to human interference and restoration measures with emphasis on Southwest coast of India.

Dune flora

Ammophila(American beach grass) is a major dune building grass adapted to temperate US Atlantic coast has highly influenced the coastal geomorphology and plant community structure (Maun and Baye 1989). *Ammophila breviligulata* adapted to CSDs becomes senescent on dune stabilization and replaced by other species. *Ammophila arenaria* (European beach grass or marram grass) is native to European CSDs and deliberately cultivated to stabilize the dunes (Seabloom and Wiedemann 1994). *Desmoschoenus spiralis* and *Scirpoides nodosa* are native plants species on the CSDs of New Zealand. The foredune complexes of New Zealand comprise of *Calystegia soldanella*, is a cosmopolitan prostrate species consists of long rhizomes capable of forming sand mounds. This plant species grow in association with *Elymus farctus* and *Leymus arenarius* and tolerate inundation of seawater. *Uniola paniculata* (sea oats) is a semitropical C4 perennial grass dominates the foredunes of southeastern US Atlantic and Gulf coasts (Hester and Mendelssohn 1987). It is also widely distributed in Bahama Islands and some parts of Cuba. *Chamaecrista chamaecristoides* is a shrubby legume endemic to Mexico and partly to the Pacific coast (Martinez and Moreno-Casasola 1998). It grows on mobile dunes, increases the biomass significantly on sand covering, fixes nitrogen and facilitates the succession of associated flora.

The dominant tropical coastal sand dune vegetation belongs to the Asteraceae, Cyperaceae, Fabaceae and Poaceae (Moreno-Casasola 1988; Arun et al 1999, Rao and Sherieff 2002). Most tropics and warm temperate shores consist of *Ipomoea pes-caprae* (Convolvulaceae) (St John 1970). It is a stoloniferous perennial creeping strand species confined to the Indian Ocean establishes along with 73 typical beach plant species in the Gulf of Mexico and tolerates sand erosion, accretion and inundation (Britton and Morton 1989, Devall 1992). *Ipomoea brasiliensis* is pantropical except for the Indian Ocean (Fosberg and Sachet 1977), while *Ipomoea imperati* confined to beaches and several islands (Leonard and Judd 1999). In addition to *Ipomoea* spp., CSDs of east coast of Africa consists of 156 plant species with Gramineae (17 species) and Papilionaceae (16 species) (Musila et al 2001). Stable sand dunes support higher richness and diversity of plant species than disturbed dunes. Dune plants of different microenvironments within the dunes are adapted to exploit nutrient pulses from rain and salt spray and exhibit different growth responses. They have more plasticity in allocation of biomass, wherein significantly high biomass will be allocated to roots than aerial tissues under most unfavourable conditions facilitates dune stabilization.

Indian subcontinent has a coastline of about 7516 km long with 2.1 million km^2 exclusive economic zone and 0.13 million km^2 continental shelf (Khoshoo 1996).The coastal zone is one among the 10 biogeographically important habitats of the Indian subcontinent (Rodgers and Panwar 1988). The CSD biogeographic regions of the Indian subcontinent have been divided into eight subdivisions (Pakistan, Kutchchh and Northwest Kathiawar, Southern Kathiawar-Gujarat, Konkan, Malabar, Coromandel-Circar, islands between India and Sri Lanka, Utkal and Bengal, Andaman and Nicobar Islands) (Rao and Meher-Homji 1985). A variety of psammophytic strand vegetation exists on the CSDs of the Indian Subcontinent (e.g. mat-forming creepers, prostrate/erect herbs and sedges, climbers, plants with perennating organs, scrubs, trees) (Rao and Meher-Homji 1985). Strand and associated flora of Indian CSDs consist of 154 species belonging to 108 genera and 41 families (Arun et al 1999, Rao and Sherieff 2002). Based on the number of species in each family, Fabaceae stands the highest (24 species) followed by Poaceae (22 species), Asteraceae (15 species) and Cyperaceae (13 species) (Table 1).

Table 1. Families and species of coastal sand dune flora of the Indian Subcontinent

Family	Number of species	Family	Number of species
Acanthaceae	4	Lythraceae	1
Aizoaceae	1	Malvaceae	3
Amaranthaceae	4	Molluginaceae	1
Anacardiaceae	1	Nyctaginaceae	1
Asclepiadaceae	2	Onagraceae	1
Asteraceae	15	Palmae	2
Boraginaceae	2	Pandanaceae	1
Cactaceae	1	Pedaliaceae	1
Capparaceae	1	Poaceae	22
Caryophyllaceae	1	Portulaceae	1
Casuarinaceae	1	Rhamnaceae	1
Clusiaceae	1	Rubiaceae	7
Commelinaceae	2	Salvadoraceae	1
Convolvulaceae	4	Sapindaceae	1
Cyperaceae	13	Scrophulariaceae	5
Euphorbiaceae	4	Solanaceae	4
Fabaceae	24	Sterculiaceae	1
Goodeniaceae	2	Tiliaceae	2
Lamiaceae	4	Verbenaceae	5
Lauraceae	1	Violaceae	1
Liliaceae	1		

Source: Arun et al 1999, Rao and Sherieff 2002

Among the species of Fabaceae, frequency of occurrence of *Canavalia maritima* was highest (44.4%) followed by *Canavalia cathartica* (22.2%), *Crotalaria verrucosa* (18.1%), *Derris triflorum* (16.7%), *Erythrina indica* (15.3%) and *Crotalaria retusa* (12.5%) (Table 2). Economic value of some nitrogen fixing CSD legumes of Southwest coast of India has been given in Table 2.

Table 2. Nitrogen fixing coastal sand dune legumes on the Indian Subcontinent, their habit, frequency of occurrence and economic value

Taxon	Habit	Frequency of occurrence, %	Economic value
Aeschynomene indica	Herb	ND	Cover crop, green manure and mulch
Alysicarpus bupleurifolius	Herb	ND	
Alysicarpus monilifer	Herb	ND	
Alysicarpus rugosus	Herb	2.8	Fodder and seeds are edible
Alysicarpus vaginalis	Herb	2.8	Fodder and seeds are edible

Canavalia cathartica	Perennial creeper	22.2	Cover crop, green manure, forage, source of con A and medicinal
Canavalia maritima	Perennial creeper	44.4	Cover crop, green manure, forage, source of con A, medicinal and source of hallucinogen (L-betonicine)
Cassia tora	Herb	ND	Medicinal
Crotalaria nana	Herb	ND	Cover crop and green manure
Crotalaria pallida	Herb	ND	Cover crop and green manure
Crotalaria retusa	Under shrub	12.5	Cover crop, green manure and pesticide
Crotalaria striata	Herb	9.7	Cover crop, green manure and medicinal
Crotalaria verrucosa	Herb	18.1	Medicinal
Derris triflorum	Woody creeper	16.7	Insecticidal and piscicide
Desmodium triflorum	Herb	ND	Medicinal
Erythrina indica	Small tree	15.3	Medicinal
Erythrina variegata	Small tree	ND	Medicinal
Geissaspis cristata	Herb	ND	
Mimosa pudica	Herb	5.6	Medicinal
Pongamia pinnata	Tree	5.6	Medicinal and source of biodiesel
Tamarindus indica	Tree	1.4	Pulp and seeds are edible, medicinal and leaves produce yellow dye
Tephrosia purpurea	Under shrub	ND	Cover crop, green manure, vegetable, antifeedant, pesticide, piscicide, cytotoxic and antitumor
Vigna spp.	Creeping herb	4.2	Seeds edible, cover crop, green manure and mulch
Zornia gibbosa	Herb	ND	

Source: Arun et al 1999, Rao and Sherieff 2002; ND not indicated

The CSD vegetation withstand xeric and saline conditions probably due to association with a variety of stress-tolerant bacteria (e.g. nitrogen fixing) (Will and Sylvia 1990, Chen et al 2000, Arun and Sridhar 2004), endophytic fungi (Beena et al 2000, Seena and Sridhar 2004), endo- (Sturmer and Bellei 1994, Koske and Gemma 1997, Kulkarni et al 1997, Beena et al 2000, 2001, Bhagya et al 2005, Arun and Sridhar 2006) and ectomycorrhizae (van der Heijden et al 1999, Ashkannejhad and Horton 2005). These stress-tolerant microbes will be of immense value to domesticate CSD plants having forage and veterinary potential.

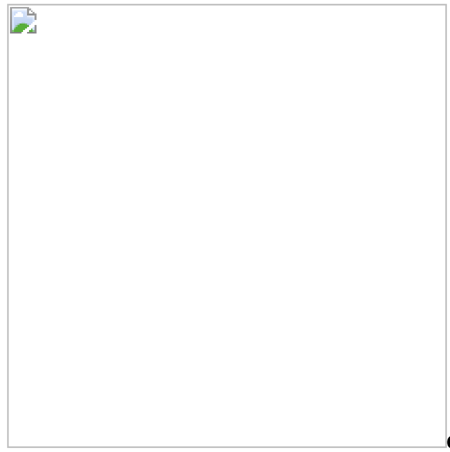
Food and fodder

Varieties of strand plants are useful as food or fodder. The whole plants of *Cakile edentula* serve as forage, its powdered roots with other flours used in bread preparation and the leaves are used in salads (Maun et al 1990). *Mucuna* and *Sesbania* of west coast of India are useful as fodder (Arun et al 1999, Arun 2002). Pods and seeds of *Mucuna pruriens* and *Sesbania bispinosa* are edible (Anonymous 1986, Arun et al 1999). Seed accessions of *Sesbania bispinosa* collected from Southern India possess adequate quantity of minerals, essential amino acids and essential fatty acids (Pugalenthi et al 2004). *Canavalia maritima* is one of the major mat-forming creepers of CSDs of southwest India (Arun et al 1999, Beena et al 2001, Seena and Sridhar 2006). The young pods and seeds consumed on boiling or roasting in Northern Australia, while seeds serve as source of dietary protein in West Africa and Nigeria (Abbey and Ibeh 1987). The whole plant is used as feed for rabbits in the southwest coast of India. Similarly, *Canavalia cathartica* is another wild ancestral form of *Canavalia gladiata* widely distributed in tropical Asia, Africa (Purseglove 1974) and southwest coast of India (Arun et al 1999, 2003). This legume is also known from Kenya, Seychelles, Tanzania, Japan, Taiwan, Bangladesh, Cambodia, Indonesia, Malaysia, Myanmar, Papua New Guinea, Philippines, Sri Lanka, Thailand, Vietnam, Australia and Hawaiian Islands (http://www.ars-grin.gov/cgi-bin/npgs/html/taxon.pl?310991). In view of economic value, agrobotanical, nutritional, antinutritional properties and bioavailability of proteins of *Canavalia maritima* and *Canavalia cathartica* of CSDs of southwest coast of India have been documented.

Canavalia cathartica and *Canavalia maritima* are perennial, stoloniferous herbaceous plant species withstand dry conditions of tropical CSDs (figure 1 a, b).

a **b**

c



d

Figure 1. *Canavalia* maritima (a) and *Canavalia cathartica* (b) grown on the coastal sand dunes of southwest coast of India showing tender and matured pods, dried seeds of *Canavalia maritima* (c) and *Canavalia cathartica* (d)

Canavalia cathartica yield larger and heavier pods than *Canavalia maritima.* The pods of *Canavalia* spp. are smooth, elongated, thick-walled and green turning yellow on ripening during October-November on the southwest coast of India. Dry seeds of *Canavalia maritima* are small, oval, bulged, bright orange to maroon with short hilum (figure 1 c), while *Canavalia cathartica* are large, oval, flattened, brownish black and occasionally striated with long hilum (figure 1 d) (Table 3).

Table 3. Physical properties of seeds of *Canavalia* of coastal sand dunes (mean, n=20)

Properties	***Canavalia maritima*[a,b,c]**	***Canavalia cathartica*[a,b]**
Total dry weight, g	0.42-0.5	0.64-0.74
Cotyledon weight, g	0.29-0.35	0.44-0.53
Coat weight, g	0.13-0.15	0.20-0.21
Length, cm	1.3	1.54
Width, cm	0.86	1.17
Thickness, cm	0.76	0.83
Hilum length, cm	0.55	0.97

[a]Arun et al 2003, [b]Seena and Sridhar 2006, [c]Seena et al 2005

Raw seeds of *Canavalia cathartica* possess highest crude protein (35.5%). Roasting and cooking decreased protein as well as crude fiber, while elevated crude lipids and total carbohydrates (Table 4).

Table 4. Proximate composition (%) and energy (kJ/100 g) of seed flours of *Canavalia* of coastal sand dunes

Composition	***Canavalia maritima* [a,b,c]**			***Canavalia cathartica* [a,b,d]**		
	Raw	**Roasted**	**Cooked**	**Raw**	**Roasted**	**Cooked**
Crude proteins	34.1	30.0	28.39	35.5	30.5	29.2
Crude lipids	1.65-1.7	1.78	1.7	1.3	1.38	1.36
Total carbohydrates	50.5	60.53	65.8	52.8	65.3	65.42
Starch	ND	ND	ND	32.0	ND	ND
Crude fiber	2.26-10.2	2.14	1.7	1.7-7	1.66	0.96
Total dietary fiber	ND	ND	ND	236.02	ND	ND
Ash	3.5	3.5	3.18	3.08-3.1	3.0	3.1
Energy	1590	1622	1625	1520	1618	1630

[a]Arun et al 2003, [b] Seena and Sridhar 2006, [c] Seena et al 2005, [d] Siddhuraju and Becker 2001, ND Not determined

The dietary guidelines published by USDA/HEW (1980) emphasize on increasing the amounts of dietary fiber in daily diet. As *Canavalia* seeds are excellent source of dietary fibers, it helps to prevent certain intestinal diseases (Hellendoorn 1979). Crude fiber promotes fast transmission of food through bowel (Van Soest 1975, Cummings 1978). The food containing high dietary fiber protects against atherosclerosis on binding to bile salts (Kritchevsky and Tepper 1968). The energy of raw and thermally processed *Canavalia* seeds (1520 and 1630 kJ/100 g) is higher than many cultivated legumes (1358.3-1426.2 kJ/100g (Kuzayali et al 1966).

There is a clear gap in our knowledge on vitamins, starch, sugars, dietary fiber, toxins and enzymes of *Canavalia* seeds. *Canavalia* seeds are known for several minerals, but it should be considered in conjunction with bioavailability (Table 5).

Table 5. Mineral composition (mg/100 g) of seed flours of *Canavalia* of coastal sand dunes compared with NRC/NAS recommended pattern

Mineral	***Canavalia maritima* [a,b,c]**	***Canavalia cathartica* [a,b]**	**NRC/NAS Pattern[d]**

	Raw	Roasted	Cooked	Raw	Roasted	Cooked	
Sodium	47.96-48	41.13	25.53	49.2-49.1	43.8	24.14	120-200
Potassium	974	931	251.49	889-895	821	190	500-700
Calcium	86.16-86.2	69	59.91	83.78-83.8	69.9	44.04	600
Phosphorus	158	124.14	111.62	137	112	99.4	500
Magnesium	23.11-23.13	22.8	17.51	5.14-5.3	4.55	3.58	60
Iron	4.53-4.54	2.57	1.99	2.88	2.45	2.18	10
Copper	0.28	0.18	0.11	0.2-0.35	0.13	0.1	0.6-0.7
Zinc	13.08-13.1	9.70	9.16	11.4	7.44	0.91	5
Manganese	2.02-2.04	2.3	1.13	1.36-1.44	1.22	0.79	0.3-1

[a]Arun et al 2003, [b] Seena and Sridhar 2006, [c] Seena et al 2005, [d] NRC/NAS 1989

Cooking lowered sodium, which is nutritionally advantageous in view of recommended low sodium intake in the diet. High quantity of potassium in *Canavalia* seeds is beneficial to those who take diuretics to control hypertension and suffer form excessive excretion of potassium through body fluids. Zinc and manganese meet the NRC/NAS (1989) requirements for infants, while phosphorus, magnesium, iron, copper and calcium are inadequate. Fatty acid composition of seeds reveals that palmitic and stearic acids are high in raw seeds of *Canavalia maritima*, while stearic acid in *Canavalia cathartica* (Table 6).

Table 6. Fatty acid composition (mg/g lipid) and P/S ratio of seed flours of *Canavalia* of coastal sand dunes

Mineral	*Canavalia maritima* [a,b,c]			*Canavalia cathartica* [a,b]		
	Raw	**Roasted**	**Cooked**	**Raw**	**Roasted**	**Cooked**
Saturated fatty acids						
Palmitic ($C_{16:0}$)	21.8-23	0.56	0.41	ND	ND	ND
Stearic ($C_{18:0}$)	209-216	0.37	0.45	281.6	0.02	0.02
Arachidic ($C_{20:0}$)	ND	ND	ND	ND	ND	ND
Behenic ($C_{22:0}$)	ND	ND	ND	ND	ND	ND
Polyunsaturated fatty acids						
Oleic ($C_{18:1}$)	630-639	1.48	0.75	714	3.34	0.14
Linoleic ($C_{18:2}$)	115-119	71	78.36	ND	81.35	76.35
Linolenic ($C_{18:3}$)	ND	ND	ND	ND	ND	3.36
Total saturated fatty acids	234.9	0.93	0.86	281.6	0.02	0.02
Total unsaturated fatty acids	751.5	72.48	79.11	714	84.69	110.13
P/S ratio[d]	3.12	78	92	2.5	4234.5	5506.5

[a]Arun et al 2003, [b]Seena and Sridhar 2006, [c]Seena et al 2005,
[d]Polyunsaturated / Saturated fatty acid ratio, ND Not detectable

Raw seeds of *Canavalia cathartica* possess high quantity of oleic acid, while linoleic acid in *Canavalia maritima*. Roasting and cooking drastically decreased linoleic acid in *Canavalia maritima* (115-119 vs. 71-78.4 mg/g lipid). Although raw seeds of *Canavalia cathartica* were devoid of linoleic acid, roasted and cooked seeds possess linoleic acid (76.4-81.4 mg/g lipid). Similarly, linolenic acid was found only in cooked seeds of *Canavalia cathartica*. As animals and humans cannot synthesize essential fatty acids, they are required in diets for normal growth and function of all tissues, synthesis of prostaglandin (FAO/WHO 1977) and development and functions of brain (Lamptey and Walker 1976) and retina (Benolken et al 1973). In *Canavalia* spp. polyunsaturated to saturated fatty acid ratio (P/S ratio) progressively increased from raw, roasted and cooked seeds. High P/S ratio is known to lower the risk of cardiovascular diseases (Ezeagu et al 1998).

Albumins and globulins are the major storage proteins, which constitute about 90% of the total proteins in *Canavalia* seeds (Table 7).

Table 7. True protein and fractions (mg/100 mg protein) of seed flours of *Canavalia* of coastal sand dunes

Fraction	***Canavalia maritima***[a,b,c]	***Canavalia cathartica***[a,b]
True protein	29.3	28.6-28.8
Albumins	7.46-7.6	7.28-7.4
Globulins	18.74-18.8	18.3-18.5
Prolamins	0.28-0.3	0.3
Glutelins	2.86-2.8	2.7

[a]Arun et al 2003, [b]Seena and Sridhar 2006, [c]Seena et al 2005

Albumins are rich in sulfur-amino acids and other essential amino acids (EAA) (Baudoin and Maquet 1999). Although many legumes are deficient in sulfur-amino acids, they are rich in lysine (Evans and Bauer 1978, Pusztai et al 1979, Sathe et al 1981). Interestingly, all EAA except for tryptophan and histidine in raw *Canavalia* seeds surpassed the FAO/WHO (1991) and FAO/WHO/UNU (1985) recommended patterns (Table 8).

Table 8. Essential amino acid composition of seed flours of *Canavalia* of coastal sand dunes (mg/100 mg protein) compared with FAO/WHO/UNU recommended patterns

Amino acid	*Canavalia maritima* [a,b,c]			*Canavalia maritima*[a,b]			FAO/WHO	FAO/WHO/
	Raw	Roasted	Cooked	Raw	Roasted	Cooked	Pattern[d]	UNU pattern[e]
Threonine	5.2	2.4	1.34	3.8-4.7	2.0	1.82	3.4	0.9
Valine	6.8	2.7	2.18	4.8-5.95	2.9	2.23	3.5	1.3
Cystine + Methionine	6.08-8.0	6.6	3.32	6.39-6.8	5.6	4.11	2.5	1.7[f]
Isoleucine	5.4	2.3	2.0	4.1-5.14	2.6	1.9	2.8	1.9
Leucine	10.3	4.9	4.20	9.4-11.65	5.1	3.9	6.6	1.3
Tyrosine + Phenylalanine	11.5	7.5	6.62	9.2-11.4	6.1	5.89	6.3	1.9[g]
Tryptophan	ND	ND	ND	ND	ND	ND	1.1	0.5
Lysine	13	7.5	3.72	12-14.7	6.1	4.58	5.8	1.6
Histidine	ND	ND	ND	ND	ND	ND	1.9	1.6

[a]Arun et al 2003, [b] Seena and Sridhar 2006, [c] Seena et al 2005, [d] FAO/WHO 1991, [e]FAO/WHO/UNU 1985, [f]Cystine + Methionine, [g]Tyrosine + Phenylalanine, ND Not detectable

The EAA of seeds reduced on thermal processing (e.g. pressure-cooking), however most EAA meets the required standard. As in other legumes, seeds of *Canavalia* are also known to possess antinutritional factors (ANFs) such as phenolics and phytohemagglutinins. Elimination or reduction of ANFs is desirable to improve the nutritional quality and acceptability. Total phenolics in *Canavalia* seeds were low, while tannins and trypsin inhibition activity are absent (Table 9).

Table 9. Antinutritional components of seed flours of *Canavalia* of coastal sand dunes

	Canavalia maritima[a,b,c]			*Canavalia cathartica*[a,b]		
	Raw	Roasted	Cooked	Raw	Roasted	Cooked
Total phenolics, mg/100 mg	1.37	1.42	1.1	1.5	1.53	1.29
Tannins	NP	NP	NP	NP	NP	NP
Trypsin inhibition activity	NP	NP	NP	NP	NP	NP
Phytohemagglutinin activity						
Rabbit RBC	+++	++	++	+++	++	++

[a]Arun et al 2003, [b]Seena and Sridhar 2006, [c]Seena et al 2005,
NP Not present, ++ RBC showed clumpy patches, +++ Grainy

In vivo growth and nitrogen balance studies of *Canavalia* seeds with rat model revealed that roasting and pressure-cooking partially effective in detoxifying the undesirable components (Table 10).

Table 10. *In vivo* protein bioavailability of seed flours of *Canavalia* of coastal sand dunes

	Canavalia maritima[a,b]		
	Raw	Roasted	Cooked
Protein efficiency ratio (PER)	0.1	0.38	0.48
True digestibility (TD), %	42.26	51.29	53.71
Biological value (BV), %	37.55	43.34	47.83
Net protein utilization (NPU), %	16.88	22.23	25.72

[a] Seena and Sridhar 2006, [b] Seena et al 2005

The biological indices analysed for raw *Canavalia* seed proteins significantly different with casein-fed rats. However, the bioavailability studies proved that pressure-cooked seeds have better biological indices than roasted seeds. Low performance of rats fed with raw seed diet may be due to the presence of ANFs. Single method of processing cannot eliminate all the ANFs of *Canavalia* seeds and combination of methods warranted. Several methods of seed processing (e.g. soaking, cooking, germination, dehusking, fermentation, roasting or frying) are available to overcome the problems posed by ANFs.

Bioactive compounds and medicinal value

The strand plants possess many useful bioactive compounds of pharmaceutical and veterinary importance. Extracts of *Ipomoea pes-caprae* serve as ingredient in indigenous medicines (hot water extract used to treat strain, fatigue and physical weakness) (Halberstein and Saunders 1978). *Ipomoea pes-caprae* is useful as diuretic in French Guyana, in treatment of rheumatism in India and arthritis in Nigeria (Luu 1975, Iwu and Anyanwu 1982). *Cakile edentula* is diuretic, antiscorbutic and purgative agent (Maun et al 1990). Some legumes of CSDs of southwest coast of India yield oil and possess many medicinal uses (Arun et al 1999, Arun 2002). Monocrotaline of *Crotalaria retusa* is antileukemic, antitumor, cardio-depressant and hypotensive, while retusin is antineoplastic. Indigotin derived form *Indigofera tinctoria* has antiseptic and astringent properties, whereas indirubin of *I. tinctoria* is antileukemic. Various phytochemicals derived from

Mucuna pruriens are pharmacologically valuable. Bufotenine is a cholinesterase inhibitor, 3,4-dihydroxy phenylalanine (L-DOPA) is anti-Parkinsonian, mucunain is antihelminthic and serotonin is antiaggregant, antigastric, cholinesterase inhibitor, coagulant, myorelaxant and myostimulant. Lupeol derived from *Tephrosia purpurea* fights against tumors and rheumatic problems. *Derris triflorum* stem consists of rotenone, which serve as antitumor compound (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=15229812) as well as potential bioinsecticide. Trigonelline of *Canavalia maritima* fights against cervical and liver cancers and lowers blood sugar level.

Concanavalin A (con A) of *Canavalia ensiformis* is known for a wide range of uses (e.g. antiviral, mutagenic, isolation of immunoglobulin, tumor therapy by immunomodulation, blood group substances, glycoprotein hormones) (Surolia et al 1973, Ruediger and Gabius 2001). Con A can be used as spermatogenic and epididymal-specific cell markers. Histological observations of normal and pathologically altered human peripheral nerves through fluorescein isothiocyanate labeled con A provides baseline information on the reaction pattern of lectins with human peripheral nerves and thereby a tool to study peripheral nerve pathology (Estruch and Damjanov 1986). Histochemistry using con A is a reliable tool to understand the structural and secretary glycoconjugates of jejunal mucosa related diseases of cell maturation cycle of small bowel (Vecchi et al 1987). Con A also serves as a marker of structural changes in various stages of normal and abnormal epidermal cell differentiation (Reano et al 1982). Carcinomas from different colonic regions have uniform distribution of carbohydrates than normal mucosa was traced using con A of *C. ensiformis* (Caldero et al 1989). Rodrigues and Torne (1990) suggested that seed lectins of *C. gladiata* can be used as an anti A, anti B, while lectins of *Canavalia cathartica* as anti O and anti Oh (Bombay group) blood grouping reagents. As mannose-binding lectin, con A is useful in creating transgenic plants resistant to insect herbivory (Sauvion et al 2004). The L-amino-4-(guanidinooxy) butyric acid or L-canavanine (also known as cav) of *Canavalia* possesses antitumor activity against Walker carcinoma, human melanoma, pancreatic cancer (Kruse and McCoy 1958, Mattei et al 1992, Swaffar et al 1994), *in vivo* murine leukemia and rat colon tumor (Green et al 1980, Thomas et al 1986). The Cav is also suitable for pancreatic cancer study due to lack of considerable amount of arginase in pancreas (Swaffar and Ang 1999). Seeds of *C. ensiformis* are commercial source of urease and it catalyzes hydrolysis of urea to ammonia, carbon dioxide and water (Rosenthal 1974, Staples and Reithel 1976, Dixon et al 1980). Saponins are recently shown to have hypocholesterolemic as well as anticarcinogenic effects (Koratkar and Rao 1997), thus exploration of nutraceutical properties of CSD *Canavalia* is important.

Intense studies should be focused on the bioactive compounds of CSD vegetation to meet the specific veterinary requirements of coastal rural dwellers. The rural traditional veterinary healers use several dune plant species for healing ailments of livestock. Following are some examples of use of CSD plant species of Southwest coast of India for veterinary purpose. The leaf juice of *Cassia alata* useful in preventing hair fall of cattle skin, while ground leaves of *Cassia tora* with salt is useful in prevention of cattle skin diseases. The ground *Crotalaria* seeds are also useful in treating cattle skin diseases. *Pongamia* seed oil and stem juice are useful to treat a vaeiety of cattle skin diseases. For cattle indigestion or constipation, bark of *Erythrina* ground into paste and administered orally, likewise the juice made out of ground *Tamarindus* bark is also given orally. The paste of ground leaves of *Indigofera* will be applied to prevent swelling of udder, while the roots of *Indigofera* are useful in treatment for diarrhea of calves. The whole plant of *Mimosa* administered orally after delivery of calf to control bleeding. Similarly, juice of the whole plant of *Mimosa* is useful in prevention of slipping of uterus after delivery. The specific knowledge on the veterinary uses of CSD plant species have been gained through inherent traditional means and practice by the coastal dwellers. More information has been given in the following section about the traditional knowledge of coastal dwellers. Assessment of plant parts in different seasons may provide more insight to use specific part of plants to meet the nutritional or pharmaceutical or veterinary requirement. Production of value-added metabolites by CSD vegetation under xeric and stressed habitats needs further exploration. In view of pharmaceutical as well as veterinary potential, specific dune plant species besides *in situ* conservation deserves *ex situ* conservation and domestication in coastal farms.

Traditional knowledge

Several direct and indirect uses of CSD plant species are unnoticed as they are traditional practices. Many legumes of CSDs of west coast of India are useful as green manure, mulch, cover crops, fodder, pasture legumes, oil and medicinal value (Arun et al 1999, Arun 2002). *Canavalia* seeds are important source of dietary protein in West Africa and Nigeria for humans and livestock (Abbey and Ibeh 1987). Boiled or roasted tender pods and seeds of *Canavalia* are edible in Northern Australia, while fishermen occasionally consume processed tender pods and ripened beans in southwest coast of India. *Pandanus* fruits are used as insect repellent and leaf fibers are useful to preserve paddy (packed paddy called 'Mudi') in coastal India. *Canavalia maritima* is a common cover crop in arid lands of Australia and Africa. It checks soil erosion in dry and sandy areas of southwest coast of India and grown by farmers in agricultural fields as cover crops after harvest of main crops (e.g. paddy, sugarcane) to improve the soil nitrogen budget. Australian aboriginals use *Canavalia maritima* for medicinal purposes. In South America, Africa and Gulf of Mexico its beans are ingested or smoked with dried leaves, which has an active principle L-betonicine and suspected to be similar to marijuana. Roots of *Canavalia maritima* are also useful in curing skin diseases in southwest coast of India. *Derris triflorum* leaves are crushed and used to stun or kill fish and shrimp for easy catch, while leaves and roots are also used as laxative (Bhandaranayake 1998). Stem of *Derris triflorum* is highly fibrous and serves as cordage for coastal dwellers. Documentation of traditional knowledge and uses of CSD vegetation for nutritional and health purposes is utmost important in view of intellectual property rights of specific geographical region. No systematic efforts have been focused on the traditional uses of CSD vegetation by the coastal dwellers (e.g. fisherman community), such efforts facilitates to develop strategies for effective use as well as appropriate conservation measures. Exploration and implementation of traditional knowledge of coastal dwellers in preservation and sustainable use of xeric CSD vegetation for the benefit of livestock and veterinary uses needs utmost importance.

Threats and restoration

Various natural forces influencing CSD vegetation include sea level changes, wind regime, movement of dunes, storms and climatic changes. Global warming and climatic changes (e.g. increase in sea level) has direct impact on CSD vegetation. Several human interferences (industrialization, pollution, waste disposal, harbours, roads, sand mining, sea-fencing, commercial or social forestry, construction of resorts and beach tourism) cause destabilization of CSDs and severely influence the dune ecosystem. According to Oosting and Billings (1942), disturbances such as fire, grazing and foot and vehicular traffic cause migrating dunes. Migration of sand dunes enhanced when the vegetation on stabilized dunes is seriously damaged or destroyed. As sea erosion is a major problem in temperate and tropical regions, extensive projects have been implemented to avoid beach erosion in US Atlantic coast (Sylvia and Will 1988, Sylvia 1989, Read 1989, Koske and Gemma 1997).

Grasses have been planted along the beaches to initiate dune-building processes to prevent erosion losses in the Atlantic coast. Intermediate scale of disturbance of CSDs facilitates the insulation of seedling roots from high temperature and desiccation, access to soil moisture, high nutrient resulting in increased plant species richness and diversity (Connell 1978, Maun 1994, Beena et al 2000). Burial of seeds, seedlings and plants in CSDs increase the abundance of tolerant plant species (Maun 1998). Burial of six tropical sand dune plant species resulted increased plant vigor and allocation of more biomass to aerial parts (Martinez and Moreno-Casasola 1996). Severe disturbance of CSDs reduces or destroys the obligate plant symbiotic fungi (arbuscular mycorrhizae), which results in the reduction or elimination of plant species (Reeves et al 1979). Such disturbances are fatal and require long-term for re-establishment of mycorrhizal vegetation, natural plant succession and dune stabilization. A variety of human interferences affect CSD biota (e.g. fishing activities, recreation activities, dredging, shell mining, sand mining, gravel harvesting, shoreline modification, oil spills, waste dumping, stone fencing and road construction). Stone fencing cannot replace vegetation of CSDs, but reduce the input of nutrients to dunes. These activities besides affecting dune microflora and vegetation, interferes the biogeochemical cycles (e.g. nitrogen, phosphorus). Deficiency of organic carbon reduce the N, S and P storage capacity of soil, thus decrease soil fertility (Hartenstein 1986). Turnover of organic matter by soil invertebrates helps biogeochemical cycling of elements (Krivolutzky and Pokarzhevsky 1977). For instance, calcium assimilation takes place in invertebrates through fungi as calcium oxalate. Microbial transformation of calcium oxalate and oxaloacetic acid into ionic calcium in the digestive system influences the calcium cycle in soil.

Garcia-Mora et al (2000) monitored plant diversity of 30 coastal dunes of Portugal and Spain and concluded that the dune vulnerability is mainly due to human disturbance. Large dune areas have been reclaimed for forest and farmland in New Zealand to implement traditional principles and knowledge to restore dunes for future needs (Gadgil and Ede 1998). Among the methods employed to stabilize the CSDs, revegetation is the best alternative because as it is least expensive, long lasting and self-sustaining (Woodhouse 1978). In the absence of such vegetation, the wind action on the exposed sand leads to migrating dunes that move back and forth with the wind (Chapman 1976). In an effort to stabilize the dunes, extensive plantations of exotic tree species (e.g. *Casuarina,* Acacia) has been planted at about 50 m away from the low tide line (Nordstorm and Lotstein 1989, Kutiel et al 2000). However, unless the site is well vegetated, the dune will not last long against wind erosion and storm tides. Several measures have been implemented to prevent erosion in Atlantic Coast of the US (Read 1989, Sylvia 1989, Koske and Gemma 1997). Planting grasses along the beaches to initiate dune building is one of the important measures. Native plant species withstand environmental perturbations of dunes and support stabilization. In Pacific Coast, establishing grass stands with perennial legume purple beachpea (*Lathyrus maitimus*) was effective in nourishment of dunes (Brown 1948). Fertilizing the American beachgrass with N, P, K and limestone showed success in Atlantic Coast (Seliskar 1995). A few pioneer perennial dune grasses are effective to stabilize CSDs of the US: American beachgrass (*Ammophila breviligulata*) (North Pacific, North Atlantic and Great Lakes), European beachgrass (*Ammophila arenaria*) (North and South Pacific), bitter panicum (*Panicum amarum*) (South Atlantic and Gulf Coasts), sea oats (*Uniola peniculata*) (South Atlantic and Gulf Coasts) and salt-meadow cordgrass (*Apartina patens*) (South Atlantic Gulf Coasts) (Woodhouse 1978). Inoculation of arbuscular mycorrhizal fungi (e.g. *Gigaspora gigantea*) enhanced the success of transplant of *Ammophila* (Maun and Baye 1989, Gemma and Koske 1997). In Southern US, *A. berviligulata*, *I. pes-caprae* and *Uniola paniculata* have been used for dune stabilization (Woodhouse et al 1968).

Tree species adapted to coastal habitats immensely useful in dune stabilization and habitat restoration. Tree fencing is an effective means in trapping sand and reduces the wind velocity in their immediate vicinity (Woodhouse 1978). Barron and Dalton (1996) attempted direct seeding of *Acacia sophorae* and *Eucalyptus diversifolia* on CSDs of southern Australia. Success of seedling survival and growth of shrub plant species (*Myrica cerifera*) in Virginia Barrier Island was dependent on nitrogen fixing symbiont (*Frankia*) (Wijnholds and Young 2000). Multistoried cropping using mat-forming creepers, grasses, sedges, xerophytes, scrubs, herbs and tree species may effectively withstand wind and wave action, build the dunes and restore landscapes of CSDs. There is ample scope to restore the tropical CSDs as they consist of diverse stress-tolerant plant species. The ecological services derived from CSDs are of immense value than currently considered as benefits (e.g. shell mining, sand mining, gravel harvesting, waste dumping). Strategies have to be implemented for protection and sustainable use of CSD vegetation in coastal areas for the benefit of farmers particularly for food, fodder and health promotion.

Conclusions

- Coastal sand dunes are the important sites for a variety of flora, fauna and microbes. Members of Poaceae have a major share of vegetation in temperate dunes, while Asteraceae, Cyperaceae, Fabaceae and Poaceae in tropical dunes.
- Coastal sand dune plant species have value-added nutritional, medicinal and agricultural uses. They are useful as food, fodder, green manure, byproducts, bioactive compounds (pharmaceutical and veterinary) and traditional applications particularly useful in rural development.
- *Canavalia maritima* and *Canavalia cathartica* constitute major strand legumes with tropical and pantropical distribution have potential to meet the requirement of dietary proteins, carbohydrates, amino acids, fatty acids and energy of rural population and

livestock.

- Symbiotic mycorrhizas and rhizobia are the major biocatalytic links for the flow of nitrogen and phosphorus to dune habitats. Accumulation of organic matter on the dunes appears to be extremely important for the supply of nitrogen as well as phosphorus. Human interference severely affects the incorporation of organic matter on the dunes and in turn dune nitrogen and phosphorus cycles.

- Anthropogenic interference (e.g., agriculture, waste disposal, road traffic, stone fencing) accelerates the loss of dunes and their habitats. Dune destruction or alteration leads to loss of natural landscape, dune-dependent flora, fauna, microbes and social/cultural or traditional heritage of coastal dwellers.

- Systematic measures and stringent policies need to be enforced to prevent destruction, support nourishment, restoration and stabilization of coastal dune habitats through *in situ* and *ex situ* conservation for sustainable rural coastal development.

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Go to top