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Nutritional and bioactive potential of coastal sand dune wild legume *Canavalia maritima* (Aubl.) Thou.– An overview

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The wild legume *Canavalia maritima* (Aubl.) Thou. (Fabaceae) is a mat-forming creeper widely distributed in coastal sand dunes of pantropical region and prevents coastal erosion. Their seeds are rich in proteins (29-34%), carbohydrates (53-63%), dietary fibre (1-7.3%), energy (1490-1680 kJ/100 g), minerals and essential amino acids required in human diet. Seeds without seed coat, sprouted seeds (without seed coat) ripened beans (with intact seed coat and testa) and tender pods are nutraceutically valuable. Drastic reduction of globulin especially in cooked sprouted seeds (4.9-18.7 vs. 0-0.5%) indicate decreased antinutritional component and the *in vitro* protein digestibility raised significantly in cooked sprouted seeds (46 vs. 73%). The antinutritional principles of *C. maritima* especially lectin (ConM) and non-protein amino acid canavanine possess anticancer and antiviral properties. The ConM is useful as autophagic, antihepatomic (immunomodulation), stimulation of mitosis, inhibition of lymphocyte cap and patch formation (due to anti-immunoglobulin properties). Proteins of *C. maritima* seeds possess desired functional properties like oil-absorption, water-absorption, gelation, emulsion and foam formation, which is helpful in formulating fabricated foods. There is ample scope to use various landraces, germplasm and varieties of *C. maritima* for nutritional and health benefits of humans as well as livestock. In view of indigenous alternative potential natural resource of future, the current review provides an overview on the nutritional, antinutritional and bioactive potential of *C. maritima*.

Keywords: *Canavalia maritima*, Wild legume, Coastal sand dunes, Nutritional qualities, Bioactive compounds, Nutraceuticals.

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Introduction

Population explosion, insufficient animal-derived proteins, increasing cost of staple food and limited fertile land resulted in protein-energy malnutrition especially in developing countries[1-7]. Dependence on monocarbohydrate diet (eg. maize and rice), which lacks adequate supply of protein, fat, vitamin A, iodine and minerals (eg. zinc and iron) aggravated the malnutrition and in turn the health risks[8]. One of the promising solutions to overcome the protein-energy malnutrition of teeming population in developing countries is utilization of lesser known and underutilized legumes[9]. Economically viable natural nutritional source next to animal proteins is the angiosperm family Fabaceae[10-15]. Nutritional value and methods of analysis of a variety of conventional and unconventional foods are reviewed by Friedman[16]. Nutritional versatility of proteins is generally governed by the source, essential amino acids, protein digestibility and the food processing methods. Edible legumes (eg. peas, lentils and beans) and regionally cultivated wild legumes (eg. winged bean, cluster bean and velvet bean) are the important sources of protein-energy[8,17]. Besides proteins, legumes are the major source of many nutritional (carbohydrates, energy, fibre, minerals, polyunsaturated fatty acids and vitamins) and bioactive compounds (eg. phenolics, lectins, saponins, phytates, protease inhibitors, L-canavanine and L-DOPA)[18-20]. Legume rich diets decrease the incidence of colon cancer by lowering the intake of saturated fatty acids and increased level of resistant starch[21]. Frequent legume consumption resulted in decrease of coronary heart and cardiovascular diseases by 22% and 11%, respectively[22]. Utilization of bioactive compounds of legumes and fine tuning of their concentration to the level to serve as nutraceuticals is one of the major challenges of research in food technology.

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Coastal sand dunes (CSD) and mangroves of the Southwest coast of India encompass a variety of economically viable wild legumes[23-28]. *C. maritima* (Aubl.) Thou. is one of the most dominant and important legumes in the CSD throughout the pantropical region[29]. This legume possesses agronomically valuable traits such as fast growth, production of large quantity of seeds, tolerance to salinity and resistance to pests[30]. In view of easy availability and future prospects, the present review focuses mainly on the nutritional and bioactive potential of *Canavalia maritima* of CSD.

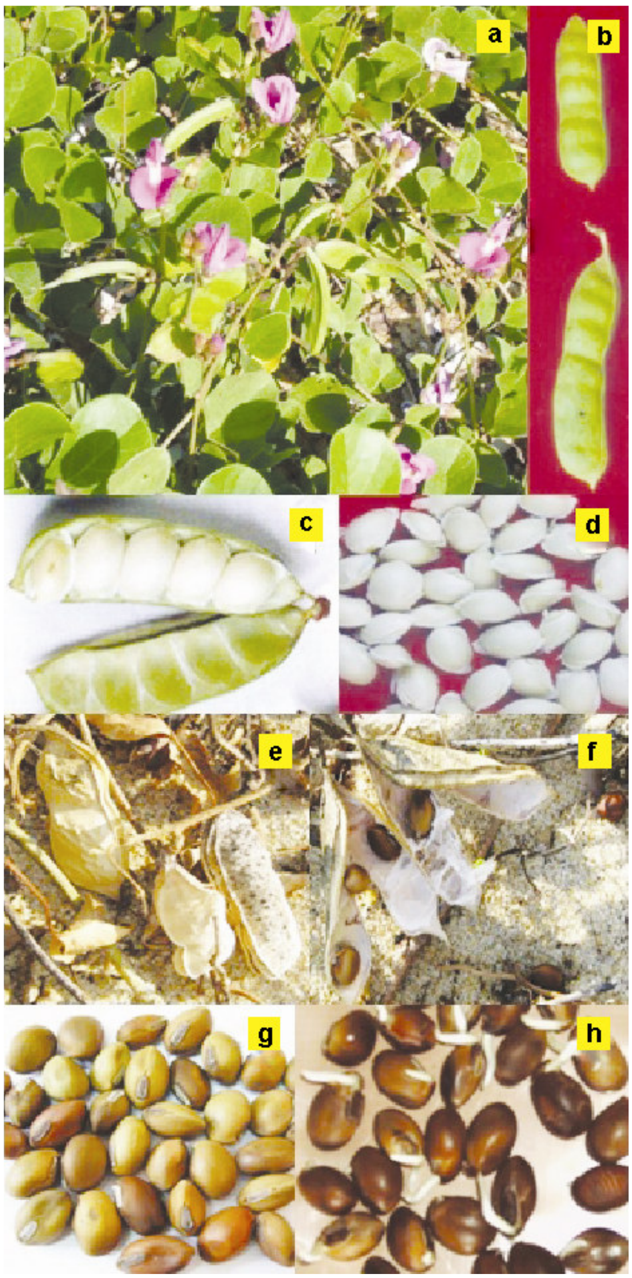

Plate 1—*Canavalia maritima* (Aubl.) Thou. on coastal sand dune with inflorescence and tender pods (a), ripened pods (b), opened ripened pod with beans (c), ripened beans with intact testa (d), undehisced dry pods (e) dehisced dry pods (f), dry seeds (g) and germinated seeds (h).

Canavalia maritima (Aubl.)Thou. [syn. *Canavalia lineata* (Thunb.) DC.; *C. obtusifolia* (Lam.) DC.; *C. rosea* (Sw.) DC.; *Dolichos maritimus* Aubl.; *D. obtusifolius* Lam.; *D. roseus* Sw.] commonly called beach bean is a pantropical pioneer strand legume on the CSD dispersed through drift dissemination of seeds[29-33]. It is known that seeds of *C. maritima* served as a major food source for the British voyager Captain James Cook and his crew in 1768 to 1771 (http://www.floridata.com/ref/C/cana_ros.cfm; accessed on February 20, 2013). Under optimal environmental conditions, the average seed yield of *C. maritima* is around 720-1,500 kg/ha[34]. Seeds of *C. maritima* used as potential source of dietary protein in West Africa and Nigeria[35]. It is common on the coasts of Hawaii, South Pacific, Africa and Southeast Asia[29, 33]. It serves as cover crop in arid regions of Australia and Africa[36].

The diploid chromosome number of *C. maritima* is 22[(Ref. 37)]. Studies on flowering, fruiting phenology, breeding system and floral visitors of *C. maritima* population in Indonesia revealed low fruit-set due to lack of pollinators or low levels of pollen deposit[33]. However, low fruit-to-flower ratios does not affect colonization success of *C. maritima* on the CSD as it flowers throughout the year. Another study on the pollination in *C. maritima* was carried out in Grumari sandbank of Rio de Janeiro revealed that the pollination was confined to *Xylocopa frontalis* (carpenter bee) for fruit and seed production[38]. Surprisingly, other flower visitors like *Apis mellifera* (honey bee), *Tetragonisca angustula* (soldier bee) and *Trigona spinipes* (stingless bee) collect pollen without pollinating the flowers. Excised cotyledons produced friable callus on the cut ends within four weeks on MS medium and also showed shoot bud induction[39]. On treating stem cuttings with IBA elevated the percentage of rooting response. Due to widespread distribution in pantropical region, *C. maritima* serves as an important indicator plant species on the natural or human interference of coastal habitats (e.g. soil, marine and air pollution)[40].

As one of the potential strand vegetation, *C. maritima* serve as mat-forming sand-binding creeper on the CSD of Southwest India[24, 27](Plate 1a). In addition to taproot and nodal roots, inter-nodal roots are common in *C. maritima* on the CSD[41]. Number of seeds per pods usually lower in

C. maritima (~4–8) than in *Canavalia cathartica* Thou. (~10–12), however, former produces more pods than the latter. Moreover, distribution of *C. maritima* is wider compared to *C. cathartica* on the CSD of Southwest India[24]. Tender pods, ripened beans and seeds are large and easy to process (Plate 1a, d, g). About 69–70% weight of seeds consists of cotyledons against 53% cotyledons in ripened beans (Table 1). Weight and dimensions of seeds, ripened beans and tender pods are lower than *C. cathartica* of CSD[42-44]. Ripened pods show prominently filled seeds and become light green to light yellow on maturity (Plate 1b). The ripened beans are white or light brown and covered with testa (Plate 1c, d). Usually, fisherman community cook ripened beans by removing the testa and seed coat for consumption. This traditional practice of safety concern is in conformity with a recent study that free radicals generated by irradiation, microwave roasting, pan-frying and pounding of *Canavalia* seeds[45]. As free radicals are present in high proportion in seed coat after conventional and radiation processing, removal of seed coat before consumption is advantageous. Moreover, removal of seed coat and testa of ripened beans is in practice for consumption in native dwellers.

Unlike *C. cathartica*, the dry pods dehisce and deposit seeds on the sand dunes (Plate 1e, f). Seeds are in different shades like light to dark brown, occasionally light red and rarely striated (Plate 1g). As the seeds are dormant, they need at least one year of exposure to dune conditions for cessation of dormancy. However, seeds imbibe water and germinate within 2-3 days on abrasion of hilum portion (Plate 1h). The bulk density, hydration and swelling characteristics of dry seeds are lower compared to *C. cathartica*[46]. Recently, detailed studies have been carried out on the physical and mechanical properties of seeds of *C. cathartica* and *C. maritima*[47].

Nutritional potential

The nutritional properties of conventional legumes beneficial in human nutrition have been investigated extensively. They are rich in proteins, carbohydrates, dietary fibre and minerals required in human diet[14,48]. In the interest of dual advantage (nutrition and health), a variety of non-conventional legumes deserves extensive evaluation. Nutritional quality of easily accessible seeds (without seed coat), sprouted seeds (without seed coat) ripened beans (with intact seed coat) and tender pods of CSD wild legume *C. maritima* have been compared in the following sections.

Proximal Qualities and Minerals

Raw (fresh), cooked, sprouted seeds, ripened beans and tender pods of *C. maritima* of the CSD have been evaluated for nutritional quality (Table 2). The moisture content was substantially less in cooked than in fresh seeds, ripened beans and tender pods (5.7-6.3 vs. 8.55-10.6%) indicating its importance in extended shelf life. The crude protein was higher in fresh seeds and ripened beans (30.6-34.4%) than in tender pods (18.7%) and decreased on cooking (16.8-28.4%), but comparable or higher than some of the edible pulses[49]. However, true protein was higher in fresh seeds followed by ripened beans compared to sprouted seeds and tender pods). Albumin was high in sprouted seeds, while globulins were high in fresh seeds and ripened beans. Drastic reduction of globulin especially in cooked sprouted seeds indicate decreased antinutritional component. The crude lipid was low and ranged between 1.6% (fresh seeds) and 2.9% (cooked sprouted seeds) comparable to common pulses in India[50]. The crude fibre was highest

Table 1—Dry weight, dimensions and physical properties of seeds, ripened beans and tender pods of *Canavalia maritima*

Physical properties	Seed(Ref. 34,46,61,108)	Ripened bean(Ref.109)	Tender pod(Ref.110)
Total weight (g)	0.42-0.71	0.19	1.51
Cotyledon weight (g)	0.29-0.50 (69.1-70.4%)	0.10 (52.6%)	-
Coat weight (g)	0.13-0.30 (31-42.3%)	0.09 (47.4%)	-
Length (L) (cm)	1.30	1.51	6.68
Breadth (B) (cm)	0.86	0.67	1.74
Thickness (T) (cm)	0.76	0.67	1.24
Hilum length (cm)	0.55	0.41	-
L/B ratio	1.51	ND	3.84
Bulk density (g/mL)	0.51	ND	-
Hydration capacity (g/seed)	0.02	ND	-
Hydration index	0.06	ND	-
Swelling capacity (mL/seed)	0.05	ND	-
Swelling index	0.10	ND	-

ND, Not determined

in tender pods followed by ripened beans, however, high fibre content in fresh seeds might be due to assessing the seeds with coat. Decreased ash content in cooked seeds and pods of *C. maritima* reveals the loss of minerals on cooking. Carbohydrates were elevated in cooked samples, so also the calorific value except for sprouted seeds. The vitamin C content was higher in fresh tender pods than ripened beans and its content decreased significantly on cooking. Besides, vitamin C serves as an antioxidant in dry seeds (raw, cooked and fermented)[51], ripened beans, tender pods and it enhances the iron absorption through inhibition of phytates[52,53].

Potassium constitutes the most abundant mineral especially in dry seeds, ripened beans and tender pods (800-1307 mg/100 g), but it meets requirements for infants (500-700 mg/100 g) than adults and pregnant lactating women (2000 mg/100 g) (Table 3). Sodium content is low in seeds, beans and pods than NRC-NAS[54] recommended levels (48-54.4 vs. 120-500 mg/100 g), but meets the Na/K ratio (<1) (0.02-0.1) to control high blood pressure[55]. Calcium and phosphorus contents are also lower than NRC-NAS[54] recommendations. Low calcium in seeds, beans and tender pods than NRC-NAS[54] pattern, does not affect the bioavailability of iron[56]. Magnesium, iron and manganese contents of sprouted seeds fulfils NRC-NAS[54] pattern, while copper meets requirements of infants. Zinc content in fresh and cooked seeds, fresh ripened beans and tender pods meets NRC-NAS[54] pattern for infants. Unlike seeds, beans and tender pods, zinc content in fresh and cooked sprouted seeds partially meets NRC-NAS[54] dietary allowance of infants as germination reduce binding of zinc with phytic acid[57]. The quantity of selenium was substantially higher in sprouted seeds, ripened beans and tender pods compared to the levels

Table 2—Proximal features of flours of seeds, ripened beans and tender pods of *Canavalia maritima*

Proximal features	Seed[Ref 34,35,46,61,71,108]		Sprouted seed [Ref.72]		Ripened bean [Ref.109]		Tender pod [Ref.110]	
	Fresh	Cooked	Fresh	Cooked	Fresh	Cooked	Fresh	Cooked
Moisture (%)	9.28-10.60	5.65	9.26	5.65	8.55	6.34	9.18	6.14
Crude protein (%)	22.4–34.43	28.39	29.04	27.89	30.62	27.47	18.72	16.80
True protein (%)	29.30	ND	19.79	5.39	27.01	20.93	18.27	10.66
Albumins (%)	7.46	ND	12.78	3.96	7.41	5.04	6.65	2.34
Globulins (%)	18.70	ND	4.87	0.50	16.61	13.25	7.16	5.53
Prolamins (%)	0.28	ND	1.36	0.57	0.74	0.55	1.12	0.68
Glutelins (%)	2.86	ND	0.77	0.06	2.25	2.08	3.33	2.12
Crude lipid (%)	1.57-1.70	1.70	2.84	2.87	2.26	1.92	2.50	2.10
Crude fiber (%)	2.23-7.30	1.70	1.38	1.07	10.65	6.98	16.72	10.53
Ash (%)	3.20-3.50	3.18	3.97	2.08	3.18	2.40	4.06	3.00
Carbohydrates (%)	44.90-58.37	65.80	62.77	66.08	53.29	61.23	57.99	67.58
Calorific value (kJ/100 g)	1590	1630	1678	1609	1490	1558	1379	1492
Vitamin C (mg/100 g)	ND	ND	ND	ND	0.23	0.07	0.43	0.30

ND, Not determined

Table 3—Mineral composition of flours of seeds, ripened beans and tender pods of *C. maritima* (mg/100 g)

Minerals	Seeds[Ref. 34, 61, 71, 108]		Sprouted seeds[Ref. 72]		Ripened beans[109]		Tender pods[Ref. 110]		Dietary allowance[54]		
	Fresh	Cooked	Fresh	Cooked	Fresh	Cooked	Fresh	Cooked	Adult	Infant	Pregnant and lactating women
Sodium	48.00	25.53	8.85	4.93	53.77	34.60	54.43	39.92	500	120-200	500
Potassium	800–974	251.49	280	300	1028	627.67	1306.86	659.25	2000	500-700	2000
Calcium	86.2–290	59.91	620	380	139.20	91.43	146.34	90.46	800	600	1200
Phosphorus	158–330	111.62	410	330	228.29	159.52	143.33	131.53	800	500	1200
Magnesium	23.1–160	17.51	440	360	84.73	78.20	191.05	91.72	280-350	60	355
Iron	Trace–4.54	1.99	16.0	13.23	1.39	0.70	2.01	0.86	10	10	13
Copper	0.28–1.16	0.11	1.24	1.07	0.48	0.27	0.37	0.23	1.5-3	0.6-0.7	1.5-3
Zinc	3.85–13.1	9.16	4.12	4.69	11.57	3.48	12.44	4.87	15	5	19
Manganese	0.87–2.04	1.13	4.76	5.04	1.58	0.31	2.38	0.50	2-5	0.3-1.0	2.5
Selenium	ND	ND	5.60	6.10	39.45	31.32	11.08	9.70	0.050.2[58]	-	-
Na/K ratio	0.05-0.06	0.10	0.03	0.02	0.05	0.06	0.04	0.06	0.25	0.24-0.29	0.25
Ca/P ratio	0.55-0.88	0.54	1.51	1.15	0.61	0.57	1.02	0.69	1.00	1.20	1.00

ND, Not determined

recommended by Pennington and Young (5.6-39.5 vs. 0.05-0.2 mg/100 g)[58]. Fresh and cooked sprouted seeds (1.15-1.5) and fresh tender pods (1.02) showed Ca/P ratio >1, such ratio is desirable to prevent calcium loss in urine[59,60]. Compared to cooked seeds, most of the minerals were retained in roasted seeds, which serve as an alternative method against cooking[61]. Overall, the mineral composition in fresh and cooked sprouted seeds is better than seeds, beans and tender pods.

Fatty acids and amino acids

Oleic acid was highest (63-63.9 g/100 g lipid) followed by stearic acid (21-21.6 g/100 g lipid) and linoleic acid (11-11.9 g/100 g lipid) in fresh seeds of *C. maritima* (Table 4). Cooking altered the fatty acid

Table 4—Fatty acid compositions of seeds flours, ripened beans and tender pods of *C. maritima* (g/100 g lipid) compared with soybean and wheat

Fatty acids	Seeds (Ref.61,71,108)		Sprouted seeds (Ref.72)		Ripened beans (Ref. 109)		Tender pods (Ref. 110)		Soybean (Ref. 62,63)	Wheat (Ref 64)
	Fresh	Cooked	Fresh	Cooked	Fresh	Cooked	Fresh	Cooked		
Saturated fatty acids										
Nonanoic acid ($C_{9:0}$)	-	-	-	8.03	-	-	-	-	-	-
Capric acid ($C_{10:0}$)	-	-	5.38		-	-	-	-	-	-
Undecanoic acid ($C_{11:0}$)	-	-	-	2.74	-	-	-	-	-	-
Lauric acid ($C_{12:0}$)	-	-	0.34	0.01	0.04	1.25	-	-	Trace-4.5	-
Tridecanoic acid ($C_{13:0}$)	-	0.103	-	0.05	-	-	-	-	-	-
Myristic acid ($C_{14:0}$)	-	-	0.14	-	0.01	0.03	0.001	0.004	Trace-4.5	-
Pentadecanoic acid ($C_{15:0}$)	-	0.066	0.04	-	0.02	0.03	0.13	0.028	-	-
Palmitic acid ($C_{16:0}$)	2.18-2.30	0.041	2.47	0.46	0.27	0.12	-	0.30	11.0-11.6	11-32
Heptadeconoic acid ($C_{17:0}$)	-	-	-	-	-	0.21	-	-	-	-
Stearic acid ($C_{18:0}$)	20.9-21.60	0.045	-	0.25	0.01	0.05	-	-	2.5-4.1	0-4.6
Nonadeconoic acid ($C_{19:0}$)	-	-	-	-	-	-	0.20	0.068	-	-
Henicosanoic acid ($C_{21:0}$)	-	-	-	0.07	-	-	-	0.22	-	-
Behenic acid ($C_{22:0}$)	-	-	-	0.01	-	-	-	0.06	-	-
Tricosanoic acid ($C_{23:0}$)	-	-	-	-	-	0.002	-	-	-	-
Lignoceric acid ($C_{24:0}$)	-	-	-	-	-	-	-	0.001	-	-
Pentacosanoic acid ($C_{25:0}$)	-	-	-	-	0.002	-	-	0.88	-	-
Polyunsaturated fatty acids										
Myristoleic acid ($C_{14:1}$)	-	0.156	-	0.92	0.03	0.002	0.05	-	-	-
Palmitoleic acid ($C_{16:1}$)	-	7.000	-	4.11	0.05	0.18	1.93	-	Trace	-
Elaidic acid ($C_{18:1}$)	-	-	3.38	-	-	-	-	-	-	-
Oleic acid ($C_{18:1}$)	63.00-63.90	0.075	-	0.38	0.61	-	-	-	21.1-22	11-29
Linoleic acid ($C_{18:2}$)	11.05-11.90	7.836	3.78	7.36	0.45	-	-	0.27	52.4-54	44-74
Linolenic acid ($C_{18:3}$)	-	-	-	4.47	-	0.73	0.13		7.1-7.5	0.7-4.4
Eicosenoic acid ($C_{20:1}$)	-	-	-	-	0.50		-	-	-	-
Eicosadienoic acid ($C_{20:2}$)	-	3.218	-	0.16	-	0.21	0.13	-	-	-
Eicosapentaenoic acid ($C_{20:5}$)	-	0.049	-	-	-	-	-	-	-	-
Nervonic acid ($C_{24:1}$)	-	0.0001	-	-	-	-	-	-	-	-
Arachidonic acid ($C_{20:4}$)	-	-	0.03	0.04	0.0001	-	-	-	-	-
Eicosapentaenoic acid ($C_{20:5}$)	-	-	-	-	0.0002	0.01	-	-	-	-
Nervonic acid ($C_{24:1}$)	-	-	-	-	0.0002	-	-	-	-	-
Total saturated fatty acids (S)	23.08-23.90	0.255	8.37	11.62	0.35	1.69	0.33	1.56	13.5-24.7	11.0-36.6
Total unsaturated fatty acids (P)	74.05-75.8	18.33	7.19	17.44	1.64	1.13	2.24	0.27	80.6-83.5	55.7-107.0
P/S ratio	3.17-3.21	71.88	0.86	1.50	4.69	0.67	6.79	1.00	3.38-5.97	2.92-5.06

-, Not detectable; P/S ratio, Polyunsaturated/saturated fatty acids ratio profile and the linoleic acid was highest in cooked seeds followed by palmitoleic acid and eicosadienoic acid. Sprouted seeds possess different composition of fatty acids with highest quantity of capric acid followed by linoleic acid, elaidic acid and palmitic acid. Cooked sprouted seeds showed more of nonanoic acid followed by linoleic acid, linolenic acid and undecanoic acid. Fatty acids were lower in ripened beans and tender pods compared to seeds and sprouted seeds. Among the essential fatty acids, linoleic acid was common except for cooked ripened beans and fresh tender pods. Linolenic acid was confined to cooked sprouted seeds, cooked ripened beans and fresh tender pods. Eicosadienoic acid was confined to cooked seeds, sprouted seeds, ripened beans and fresh tender pods. Arachidonic acid was seen only in fresh and cooked sprouted seeds and fresh ripened beans. Eicosapentaenoic acid was found only in cooked seeds. The P/S ratio was highest in cooked seeds. The ratio was elevated on cooking the seeds and sprouted seeds, while decreased in ripened beans and tender pods. Except for dry seeds, fatty acids of rest of the samples (sprouted seeds, ripened beans and tender pods) of *C. maritima* were not comparable with fatty acid composition and P/S ratio of soybean and wheat[62-64]. The fatty acid profile of split beans of *C. maritima* differed between hot extraction (Soxhlet method) and cold extraction (chloroform-methanol-water) methods[65,66].

The EAA of seeds, ripened beans and tender pods decreased on cooking, while it was vice versa in sprouted beans (Table 5). Except for tryptophan and histidine, fresh seeds meets FAO-WHO[67] stipulated standard. Among the samples studied (except for tryptophan), fresh seeds (except for histidine), fresh and cooked sprouted seeds were promising source of EAA and comparable or higher than soybean[68], rice[69], FAO-WHO[67] and FAO-WHO-UNU[70] patterns. Cooked ripened beans and tender pods were poor in EAA composition. But, the roasted seeds of *C. cathartica* retained most of the EAA compared to cooked seeds and helps as a method of choice to retain EAA[71].

Protein and functional attributes

In addition to biochemical analysis *in vivo* or *in vitro* protein digestibility studies reveal the quality and bioavailability of protein in a specific food item. The growth and nitrogen balance studies on seeds, ripened beans and tender pods of *C. maritima* have been compared in Table 6. Although cooked seeds, beans and tender pods have better biological indices than the fresh samples, the protein is of poor quality possibly due to incomplete loss of antinutritional components. However, positive nitrogen balance of cooked seeds, beans and tender pods than fresh samples indicates some improvement of protein quality due to partial loss of antinutritional components. No *in vivo* studies have been carried out for fresh and cooked sprouted seeds of *C. maritima*, but it is predicted that *in vivo* protein digestibility is better in fresh as well as cooked sprouted seeds due to better EAA composition in fresh as well as cooked sprouted seeds[72]. Moreover, drastic reduction of globulin especially in cooked sprouted (4.9 vs. 0.5%)

Table 5—Essential amino acid composition of flours of seeds, ripened beans and tender pods of *C. maritima* (g/100 g protein)

Essential amino acid	Seeds(Ref. 61,71,108)		Sprouted seeds(Ref.72)		Ripened beans(Ref.109)		Tender pods(Ref.110)		Soybean(Ref.68)	Rice(Ref.69)	FAO-WHO Pattern(Ref.67)	FAO-WHO-UNU Pattern(Ref.70)
	Fresh	Cooked	Fresh	Cooked	Fresh	Cooked	Fresh	Cooked				
Threonine	5.2	1.34	3.80	4.53	2.28	1.57	2.30	1.56	3.8	3.2	3.4	0.9
Valine	6.8	2.18	4.00	4.86	4.22	2.08	4.75	1.98	4.6	6.6	3.5	1.3
Cystine	6.1	2.03	0.73	0.91	ND	ND	ND	ND	1.7	1.2	2.5[a]	1.7[a]
Methionine	0-1.9	1.29	0.77	0.64	0.90	0.84	1.0	0.97	1.2	2.6		
Isoleucine	5.3-5.4	2.00	3.48	4.21	4.24	1.52	4.28	1.53	4.6	4.3	2.8	1.3
Leucine	10-10.3	4.20	6.79	8.69	4.52	0.26	4.34	0.24	7.7	8.2	6.6	1.9
Tyrosine	4.0	0.19	3.06	3.82	10.31	0.20	2.71	0.17	1.2-3.4	3.7	6.3[b]	1.9[b]
Phenylalanine	7.5-8.0	6.43	3.70	4.47	4.08	3.09	3.90	3.73	1.29-4.8	5.1		
Tryptophan	ND	ND	ND	ND	ND	ND	ND	ND	0-1.2	1.3	1.1	0.5
Lysine	13.0	3.72	4.89	6.12	4.26	4.22	4.26	3.67	6.1	3.7	5.8	1.6
Histidine	ND	ND	2.34	2.64	ND	ND	ND	ND	2.5	2.4	1.9	1.6

[a], Cystine + Methionine; [b], Tyrosine + Phenylalanine; ND, Not detectable

Table 6—*In vivo* bioavailability of proteins of seeds and tender pods of *Canavalia maritima*

Bioavailability of proteins	Casein(Ref.41)	Seeds (Ref. 61,71)		Ripened beans(Ref. 109)		Tender pods(Ref. 110)	
		Fresh	Cooked	Fresh	Cooked	Fresh	Cooked
Growth assay							
Food intake (g in 28 days)	141.14	93.1	115.13	90.06	117.74	73.95	80.44
Protein intake (g in 28 days)	14.11	9.31	11.51	9.06	11.77	7.39	8.04
Gain in body weight (g in 28 days)	33.27	0.97	7.97	1.47	6.10	0.10	1.74
Food efficiency ratio (FER)	0.24	0.01	0.07	0.02	0.03	0.001	0.02
Protein efficiency ratio (PER)	2.35	0.10	0.48	0.17	0.54	0.014	0.22
Corrected PER[a]	2.5	0.11	0.73	0.17	0.56	0.014	0.23
Gain in weight (g in 10 days)	9.7	0.33	2.00	0.56	2.19	0.02	0.73
Weight loss (g in 10 days)	3.27	3.10	3.10	2.64	2.64	2.92	2.92
Protein consumed (g in 10 days)	4.87	3.46	3.79	2.97	3.93	2.67	2.96
Net protein retention (NPR)	2.62	0.99	1.34	1.08	1.24	1.10	1.24
Protein retention efficiency (PRE)	41.97	15.54	21.09	17.21	19.80	17.62	19.75
Nitrogen balance assay							
True digestibility (TD, %)	90.46	42.26	53.71	41.76	53.33	38.41	44.36
Biological value (BV, %)	87.96	37.55	47.83	30.40	40.20	28.94	35.57
Net protein utilization (NPU, %)	79.57	16.88	25.72	12.71	21.42	11.16	15.79

[a], Based on values of 2.5 as standard for casein

seeds indicate decreased antinutritional component (Table 7). Besides, the *in vitro* protein digestibility raised significantly in cooked sprouted seeds (46.4 vs. 73.4%). In two thermal treatments, the nitrogen balance was better in cooked seeds than in roasted seeds of *C. maritima*[71].

Functional properties of proteins, carbohydrates and fats of food stuffs are important for its effective use. As proteins of *C. maritima* seeds are strongly influenced by pH, it helps in protein extraction for commercial purposes[46]. Seeds of *C. maritima* also possess good water- and oil-absorption capacities, protein solubility (pH 12), foam capacity (FC) (at increased flour concentration and addition of salt) and emulsion capacity (EC) (dependent on pH, salt and flour concentrations)[35,46]. Heat processing of seeds reduced the FC and EC due to the heat denaturation of the proteins[35]. Addition of carbohydrates (starch, lactose, maltose and sucrose) reduced the gelling capacity[46]. Emulsion activity (EA) and emulsion stability (ES) were decreased with increasing flour concentration. Minimum EA and ES were attained at pH 4 and attained maximum at pH 10. Maximum EA was seen at 0.4 M NaCl, while FC and foam stability (FS) reached highest at 6% flour concentration. The FC and FS of the seed flours improved with elevation of pH (2-10) and at 0.4 M NaCl the highest FC was achieved. Comparatively flour *C. maritima* was better in functional properties than the flour of *C. cathartica.*

Table 7—Antinutritional/bioactive components of flours of seeds, ripened beans and tender pods of *C. maritima*

Antinutritional/bioactive components	Seeds (Ref. 61,71,108)		Sprouted seed (Ref. 77)		Ripened bean (Ref. 109)		Tender pod (Ref. 110)	
	Fresh	Cooked	Fresh	Cooked	Fresh	Cooked	Fresh	Cooked
Total phenolics (mg/100 g)	1370-1400	1100	3700	2500	5480	2720	3400	2400
Othodihydric phenols (mg/100 g)	ND	ND	ND	ND	NP	NP	ND	ND
Tannins (mg/100 g)	NP	NP	NP	NP	51	19	NP	NP
Canavanine (mg/100 g)	2390	1810	2300	1880	2900	2270	1670	1370
Trypsin inhibition activity (mg/g)	NP	NP	NP	NP	NP	NP	NP	NP
Phytohemagglutinin activity								
Human RBC (A+) (titre)	ND	ND	6	3	ND	ND	ND	ND
Human RBC (B+) (titre)	ND	ND	4	0	ND	ND	ND	ND
Human RBC (O+) (titre)	ND	ND	4	2	ND	ND	ND	ND
Rabbit RBC (clumping/titre)	+++	++	ND	ND	23	13	14	8

[a], Clumping: ++, moderate ; +++, strong; ND, Not determined; NP, Not present

Bioactive principles

In spite of possessing antinutritional factors, legumes are gaining increased attention for developing nutraceutical products as many components have potential health benefits (eg. fibre, polyphenolic compounds, lectins, unsaturated fatty acids, trypsin inhibitors and phytic acid)[73,74]. Such phytochemicals are responsible for antioxidant, antimutagenic, anticarcinogenic and enhanced bifidogenic activities. Wide distribution of *C. maritima* in the maritime habitats throughout pantropical region[29] offers a variety of region-specific and habitat-specific germplasm for breeding purpose in favour of developing cultivars endowed with balanced nutraceutical features.

Phenolics and tannins

The total phenolics in fresh ripened beans was highest followed by fresh sprouted seeds, tender pods and fresh seeds (Table 7). However, cooking considerably decreased the total phenolics. Ripened beans were devoid of orthodihydric phenols, but other samples were not evaluated for this component. Tannins were restricted to ripened beans. As phenolics are water soluble, considerable loss was seen in cooked seeds, sprouted seeds, ripened beans and the tender pods indicating that it will not interfere with bioavailability of iron[56]. Phenolics and tannins are well known antioxidants, activate antioxidant enzymes and reduce cardio-cerebrovascular and cardiovascular diseases[20,75,76]. Total phenolics and tannins in *C. maritima* in fresh and cooked sprouted seeds and ripened beans are in sufficient quantities and likely serve as potential nutraceuticals. Their concentration was elevated on solid-state fermentation with *Rhizopus oligosporus* leading to enhanced antioxidant activities[51].

Canavanine

Although many reports are available on canavanine in *Canavalia* spp. distributed in non-marine habitats, there seems to be dearth of reports on canavanine in *C. maritima*[77]. Fresh ripened beans possess highest canavanine content followed by fresh seeds and fresh sprouted seeds (Table 7). Canavanine content in seeds, sprouted seeds, ripened beans and tender pods of *C. maritima* decreased on cooking, thus it is possible to reduce its content to desired level[77]. Canavanine is known to possess antimicrobial, insecticidal and anti-neoplastic properties and its extraction from C. *maritima* will be useful. Canavanine administration at 1% level in the diet possessing protein higher than 15.7% on dry weight basis enhanced the longevity of BALB/c mice[78] and canavanine also elevated the survival of mice administered with lethal doses of lipopolysaccharides[79]. As seen in *C. maritima*, sprouting reduced canavanine content in seeds of *C. ensiformis*[80]. Besides, soaking, heating and draining methods were more effective to reduce canavanine[81]. Canavanine also serve as potent insecticide[82-85], antiviral and anticancer agent[79,86-88]. Besides, canavanine is known to inhibit the growth of colon tumors, hence canavanine in seeds, sprouted seeds and ripened beans serve as excellent source in combating colon cancer[77,89]. Different processing methods especially soaking and cooking decrease the canavanine content to desired levels to serve as nutraceutical.

Lectin

Plant lectins represent carbohydrate-binding proteins (glycoproteins) and serve as valuable tools for biochemical, analytical and therapeutic evaluations[90]. The legume lectins belonging to sub-tribe Diocleinae are highly similar to protein features, but present significant differences in the potency and efficacy of biological activities. The ConM derived from seeds of *C. maritima* has been studied in detail for its structural complexities[91-95]. It belongs to the orthorhombic space group of protein having 25.5 kDa with 237 amino acid residues per monomer with high similarity in its sequence with ConA (*C. ensiformis*) and ConC (*C. cathartica*) (90-91%)[91-94]. More intense studies on ConM on the amino acid sequence showed similarity with ConA up to 98%. Purified subunit of ConM revealed two fragments (4,600 kDA and 20,400 kDA), which were devoid of methionine in position 130, but ConA possess methionine in that position. The amino acid composition in each subunit of lectins showed two methionine residues in ConC (*C. cathartica*) and in *C. gladiata* lectin, but only one methionine residue was found in ConM[96]. The ConM has replacement of Pro202 by Ser202, which promotes the Tyr12 for carbohydrate-binding site. Further evaluation of ConM by Gadelha *et al*[93] revealed that it has 1.95Å resolution, the dimer in asymmetric unit with two metal binding sites per monomer, loops are involved in the molecular oligomerization and has up to 98 % similarity with ConA and ConBr (*C. brasiliensis*). The ConM subunits show high degree of tertiary folding and conserved ion binding site. Further elucidation of crystal structure of ConM by complexing with trehalose and maltose showed point mutations similar to ConA-like lectins. Although lectins are very similar in structure and folding properties, minor modifications in amino acid sequence leads to alter their efficiency in biological activities[94]. For instance, mutation of ConM at position 202 (substitution of Pro202 by Ser202) elevated its carbohydrate-binding capacity compared to ConA, which was responsible for conformational alterations at position 12 and predicted that safe structure-function variability developed evolutionarily. The N-terminal analysis of amino acids of ConC revealed the sequence of 17 amino acids (Ala-Asp-Thr-***Lys***-Val-Ala-Val-Glu-Leu-Asp-Thr-Tyr-Pro-Asn-Thr-Asp-***Ile***)[97], which partially differed from that of ConM (Ala-Asp-Thr-***Ile***-Val-Ala-Val-Glu-Leu-Asp-Thr-Tyr-Pro-Asn-Thr-Asp-***Val***) (difference in amino acids among ConC and ConM are given in bold face italics).

Studies performed by Bezerra *et al*[95] on ConM revealed several distinct biological activities. The ConM exerts a concentration-dependent relaxant action on isolated aortic rings and seems to occur via an interaction of a specific lectin-binding site on the endothelium results in release of nitric oxide, such specific biological activity helps in elucidation of structural correlations among different lectins[93]. Evaluation of vascular actions of ConM in the rat models of paw edema and isolated aorta was performed by Assreuy *et al*[98]. Unlike ConA and ConBr, the edematogenic activity was elicited by ConM without involvement of nitric oxide and prostacyclin. The edematogenic activity by plasma exudation and aorta relaxation was strictly dependent on lectin domains with participation of nitric oxide and/or prostanoids. The minimal concentration of ConM required to agglutinate the rat erythrocytes was 4 µg/mL and the saccharide-binding specificity is similar to that of ConA[99]. Trehalose and maltose strongly inhibited the hemagglutination of purified ConM. According to Bressani *et al*[34], ConM is heat-labile and it is possible to inactivate by suitable thermal treatment. Decrease in globulin fraction in sprouted seeds of *C. maritima* was associated with extremely low hemagglutinin activity of human erythrocytes (titre value: 4-6 vs. 0-3 HU/mg)[72]. Purified ConM was mitogenic against human peripheral blood mononuclear cells[100]. The ConM is also useful as autophagic, antihepatomic (immunomodulation), stimulation of mitosis, inhibition of lymphocyte cap and patch formation (due to anti-immunoglobulin properties) as seen in ConA and ConC. Lectins possess several applications like blood grouping, immunomodulation and tissue markers[101-103]. It is also known that lectins are effective vectors to deliver therapeutics to control inflammatory bowel disorder[104]. Meagre information is available on the hemagglutinin activity of *C. maritima*. The available studies reveal that cooking reduces the potency of lectins in seeds, sprouted seeds, ripened beans and tender pods (see Table 7). Hemagglutinin activity reveals the varied potency of lectins in different samples (eg. seeds, leaves, stem and roots), which helps for commercial exploitation.

Other bioactive properties

Three pterocaprin derivatives [(–) medicarpin, (–)2-hydroxy4,9-dimethoxypterocarpan and 4-hydroxy3-methoxy8,9-methylenedioxypterocarpan] were isolated from seeds of *C. maritima* of China[105]. Cytotoxicity tests revealed that (–) medicarpin possess pro-apoptotic activities on cultured human tumor HeLa cells *in vitro* via suppression of NF-κB activation. This compound also induced nuclear condensation,

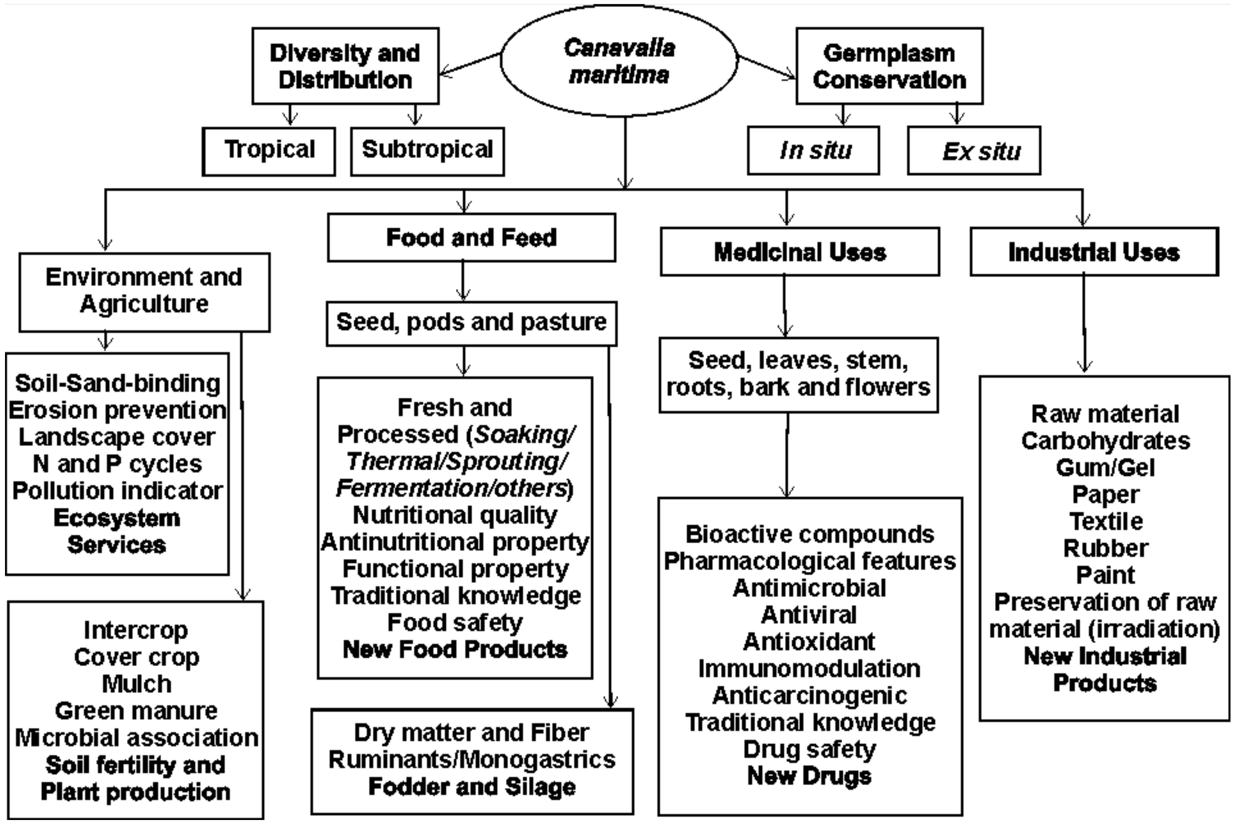

Figure 1—Future prospects of coastal sand dune *Canavalia maritima* (Aubl.) Thou.

increased the membrane permeability and mitochondrial transmembrane potential of HeLa cells, which was dose- and time-dependent predicting the potential of seeds of *C. maritima* in cancer therapy. Methanol extract of cooked and fermented *C. maritima* seeds have potential to inhibit cancer cell lines (MCF-7 and HT-29)[106]. Besides, extracts of cooked and fermented seeds are likely control colon cancer through diet management.

The lectin ConM derived from seeds of *C. maritima* of Ceará State, Northeast Brazil was effective against biofilm development by *Streptococcus mutans* via membrane damage opened up new possibilities to control dental caries[107]. It is predicted that the carbohydrate-binding site of the bacterial surface plays a key role in binding ConM leading to inhibitory activity paving way in prevention of dental caries.

Conclusion

Although several indigenous legumes are traditionally used in different parts of the world, their full potential is yet to be recognized. They serve not only staple food sources, but provide health security owing to their bioactive potential. Wide spread *C. maritima* on the CSD in pantropical region has well adapted to withstand saline habitats, high temperature, alkaline pH and disturbances (wind, sand abrasion, burial, desiccation and tidal fluctuations). With developing technologies, there is a wide scope for improvement of *C. maritima* landraces as potential indigenous alternative to the currently used legumes for nutritional and pharmaceutical benefits. As many accessions of *C. maritima* are available in the repositories and in natural habitats throughout the pantropical region, there is ample scope for breeding this germplasm in favour of nutraceutical advantages. Prevention of microbial deterioration of seeds using irradiation assumes importance to extend the shelf life for future applications[111]. *C. maritima* being a widespread landrace with rich proteins, carbohydrates, fibre and bioactive compounds qualifies its beneficial utilization in agriculture, food and pharmaceutical industries in future (Fig. 1).

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