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Physical and mechanical properties of seeds and kernels of *Canavalia* of coastal sand dunes

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Abstract

The wild legumes *Canavalia cathartica* and *Canavalia maritima* are common inhabitants of the coastal sand dunes of pantropical regions possess agriculturally, nutraceutically and industrially valuable traits. This study projects the physical and mechanical properties of seeds and kernels of *Canavalia* of coastal sand dunes of Southwest India in view of designing the equipments necessary for harvesting, handling, sorting and processing. Average value of three characteristic dimensions (length, breadth and thickness) was higher for seeds than corresponding kernels. The thickness to breadth ratio was highest in seeds of *C. maritima* (0.88) followed by seeds of *C. cathartica* (0.84), kernels of *C. maritima* (0.69) and kernels *C. cathartica* (0.66). The bulk density, true density and porosity ranged from 478.9 to 533.9 kg/m^3, 834 to 954.9 kg/m^3 and 40 to 45% for seeds and 417.4 to 481.1 kg/m^3, 1007.6 to 1315.3 kg/m^3 and 57 to 58% for kernels, respectively. The seeds showed higher values of sphericity than kernels. The angle of repose was higher for *Canavalia* kernels (24.8-26.2°) than seeds (21.4-22.9°). Both seeds and kernels showed minimum static coefficient of friction against stainless steel (0.25-0.48) and maximum on glass (0.33-0.85). Rupture force and energy for rupture was significantly higher for seeds than kernels. All the basic and complex geometric parameters except angle of repose were significantly higher in seeds of *C. cathartica* than *C. maritima*. In view of importance of *Canavalia* seeds, impact of moisture, cooking, roasting and germination on the physical and mechanical properties needs further insight.

Introduction

Underutilized and less known wild legumes constitute potential source of food and bioactive compounds especially in tropical and sub-tropical regions of the world (Sridhar and Bhagya, 2007; Bhat and Karim, 2009; Vadivel and Biesalski, 2010; Sridhar and Niveditha, 2011). *Canavalia cathartica* and *C. maritima* are widely distributed on the coastal sand dunes in pantropical region are valuable source of nutrition and bioactive compounds (Bressani *et al.*, 1987; Martinez and Psuty, 2004). They exhibit xeric adaptation with fast growth, high seed yield, tolerance to salinity and resistance to diseases (Seena and Sridhar 2006). Coastal *Canavalia* spp. in Southwest India serve as cover crops, green manure and mulch in plantations and fix nitrogen with native rhizobia (Arun and Sridhar, 2004; Bhagya and Sridhar, 2009). The coastal dwellers of Southwest India utilize *Canavalia* seeds as food source after processing (e.g. soaking, boiling and removal of seed coat and testa). Studies have demonstrated that the seeds of coastal sand dune *Canavalia* possess adequate amount of proteins, carbohydrates, amino acids, fatty acids, fibre, bioactive compounds and energy (Seena and Sridhar, 2006; Sridhar and Bhagya, 2007; Niveditha and Sridhar, 2012; Niveditha *et al.*, 2012). Roasted seed powder of *C. maritima* serve as substitute for coffee and seed paste is used to cure skin diseases as well as burns (Chock, 1968; Bhagya and Sridhar, 2009). The kernels of *Canavalia* possess several functional properties in favor of preparation of value-added products (Seena and Sridhar 2005). Blending seeds of *Canavalia* at 5% with natural rubber elevated the tensile strength as well as softness and thus serve as alternative fillers in natural rubber compounding (Olutola, 2011). Being widely distributed in pantropical coastal region, *Canavalia* serve as maritime indicator of ^{210}Po bioaccumulation (Bhat *et al.*, 2005). Although *Canavalia* seeds possess antinutritional component like concanavalin (lectins: ConC and ConM) interfering with absorption in small intestine, it is of pharmaceutical significance (Niveditha and Sridhar, 2012). It is necessary

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to apply appropriate processing methods like soaking, extrusion cooking and fermentation before consumption. There is ample scope to improve the nutraceutical, functional and industrial potential of wild *Canavalia* landraces of coastal sand dunes.

Physical, mechanical and chemical properties of agriculturally, nutritionally and industrially valued seed materials are important in designing the equipment for harvest, transport, storage, processing, cleaning, hulling and milling (Akaaimo and Raji, 2006; Coskuner and Karababa, 2007; Sirisomboon *et al*., 2007). The bulk and true densities represent the measures of weight of seeds or kernels per unit volume, while the angle of repose play a chief role in designing the equipment for solid flow and storage. Knowledge on the frictional properties is valuable in designing the machines effective in dehulling and packaging. Physical and mechanical properties of seeds of a variety of legumes like chickpea (Nikoobin *et al*., 2009), cowpea (Ige, 1977), faba beans (Haciseferogullari *et al*., 2003; Altuntas and Yildiz, 2007), green gram (Nimkar and Chattopadhyay 2001), groundnut (Olajide and Igbeka, 2003), locust beans (Sobukola and Onwuka, 2011), moth gram (Nimkar *et al*., 2005), red kidney beans (Isik and Unal, 2007) and soybeans (Deshpande *et al*., 1993) have been studied. However, a few studies are available on the physical properties of *Canavalia* seeds (Seena and Sridhar, 2005; Eke *et al*., 2007). As future natural resource, *Canavalia* seeds and kernels need systematic account of physical and mechanical properties for large scale processing. Therefore, the present study aims at determination of physical and mechanical properties of seeds and kernels of *C. cathartica* and *C. maritima* collected from the coastal sand dunes of Southwest coast of India.

Materials and Methods

Seed samples and processing

Healthy undamaged seeds of wild legumes *Canavalia cathartica* Thouars and *Canavalia maritima* Thouars were sampled from the coastal sand dunes of Kanwatheertha, Southwest India (12º44′N, 74º52′E) during summer (February-April). Physical and mechanical properties of intact seeds and kernels (dehusking of seeds on cutting by a nut cracker and separated the intact kernels by hand) were evaluated (Figure 1).

Mass and dimensions

Mass of randomly selected single (M_1, unit mass) and 1000 (M_{1000}) seeds and kernels were determined using an electronic precision balance (Shimadzu: AY120, ± 0.0001 g). Seed coat mass, S_m of randomly selected 100 seeds were determined gravimetrically.

Figure 1. Seeds of *Canavalia cathartica* (a) and *C. maritima* (b), and kernels of *C. cathartica* (c) and *C. maritima* (d)

Length (*l*), breadth (*b*) and thickness (*t*) of randomly selected 100 seeds and kernels were recorded using a calipers (Mitutoyo Vernier Calipers: 530-312, 0.01 mm) (Figure 2). The hilum length (H_l) and length-breadth (*l/b*) ratio of seeds or kernels were calculated:

$$l/b = \frac{l}{b} \qquad (1)$$

The arithmetic mean diameter, D_a (mm) and geometric mean diameter, D_g (mm) of 100 seeds and kernels were calculated using principal dimensions (Bahnasawy, 2007):

$$Da(mm) = \frac{l+b+t}{3} \qquad (2)$$

$$Dg(mm) = (l.b.t)^{1/3} \qquad (3)$$

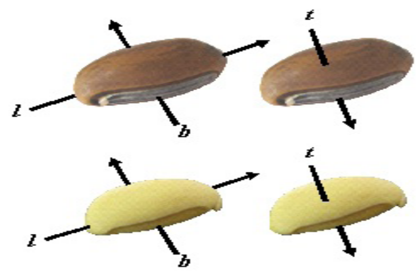

Figure 2. Three dimensions of *Canavalia* seeds and kernels measured, where horizontal (*l, length), transversal (b,* breadth) and vertical (*t,* thickness)

Volume

Unit volume, V_u (cm³) was calculated by assuming that seeds and kernels are similar to triaxial ellipsoid (i.e., *l* > *b* > *t*) (Mohsenin, 1986):

$$V_{u\,(cm^3)} = \frac{\left[\frac{4}{3}\pi.(l.b.t)\right]}{1000} \qquad (4)$$

Sphericity

Sphericity (Sφ) was calculated based on the isoperimetric properties of the sphere (Mohsenin, 1986):

$$S\varphi = \frac{Dg}{l} \qquad (5)$$

Density

Bulk density, ρ_b (kg/m^3), of seeds and kernels were determined according to Singh and Goswami (1996):

$$\rho b = (kg/m^3) = \frac{Ms}{V} \qquad (6)$$

Where M_s is mass of the sample; V is the volume.

True density or solid density, ρ_s (kg/m^3) was determined by toluene displacement method (Singh and Goswami, 1996). The ratio between the mass of seed and the true volume of the seed was determined using the toluene displacement by immersing a weighted quantity of seed or kernel in specific gravity bottles.

$$\rho s = (kg/m^3) = \frac{Ms}{V} \qquad (7)$$

Porosity

Porosity, ε (%) was calculated using the values of bulk and solid density (Mohsenin, 1986):

$$\varepsilon\ (\%) = \left[1 - \frac{\rho b}{\rho s}\right] 100 \qquad (8)$$

Angle of repose

The angle of repose of seeds and kernels was measured by emptying method in bottomless cylinder (diameter, 5 cm; height, 10 cm) (Taser *et al*., 2005; Garnayak *et al*., 2008):

$$\theta = \tan^{-1} \frac{2H_p}{D_p} \qquad (9)$$

Where θ, angle of repose (°); H_p, height of the pile (cm); D_p, diameter of the pile (cm).

Surface area

Surface area, S_a (mm^2) of seeds and kernels was calculated using the formula proposed by McCabe *et al*. (1986):

$$Sa\ (mm^2) = \pi.(Dg)^2 \qquad (10)$$

Specific surface area, S_s (cm^2/cm^3) was calculated (Sirisomboon *et al*., 2007):

$$Ss\ (\mathrm{cm}^2/\mathrm{cm}^3) = \frac{Sa.\rho_b}{M1} \qquad (11)$$

Where ρ_b, bulk density; M_1, unit mass of seed or kernel.

Coefficient of static friction

Coefficient of static friction (μ) was determined on five different surfaces (wood, plywood, stainless steel, galvanized iron and glass), which are commonly used for the processing and handling of pulses and grains (Balasubramanian, 2001):

$$\mu = \frac{F}{N_f} \qquad (12)$$

Where F, frictional force (weight added to the loading pan); N_f, normal force (weight of the sample).

Hydration

To determine hydration capacity (H_c) and hydration index (H_i) were determined according to the method proposed by (Adebowale *et al*., 2005):

$$H_c\ (g/seed\ or\ kernel) = \frac{(M_a - M_b)}{N} \qquad (13)$$

Where M_b, weight of seeds or kernels before soaking; M_a, weight of seeds or kernels after soaking; N, number of seeds or kernels.

Hydration index, H_i is the ratio of hydration capacity per seed or kernel to that of weight of a seed or kernel:

$$H_i = \frac{H_c}{M_b} \qquad (14)$$

Swelling

To determine swelling capacity (S_c) and Swelling index (S_i) were determined (Adebowale *et al*., 2005):

$$S_c(ml/seed\ or\ kernel) = \frac{(V_a - V_b)}{N} \qquad (15)$$

Where V_b, volume of seeds or kernels before soaking; V_a, volume of seeds or kernels after soaking; N, number of seeds or kernels.

Swelling index, S_i is the ratio of swelling capacity of seed or kernel to that of volume:

$$S_i = \frac{S_c}{V_b} \qquad (16)$$

Mechanical properties

To determine the rupture force (R_f) the seed was placed on a stationary platform along horizontal and vertical directions and pressed with a moving platform. The R_f was determined only in vertical direction for kernels. The energy required to rupture the sample (E_r) was determined from the area under the force distance curve between initial point and rupture point (Fig. 3). Rupture force (R_f) and energy for rupture (E_r) of *Canavalia* seeds and kernels was determined using texture analyzer (TA.XT plus, England).

Data analysis

The difference between physical parameters among seeds and kernels of *C. cathartica* and *C. maritima* were assessed by t-test (StatSoft, 2008).

Results and Discussion

Basic geometric characteristics

The unit mass of seed and kernel of *C. cathartica*

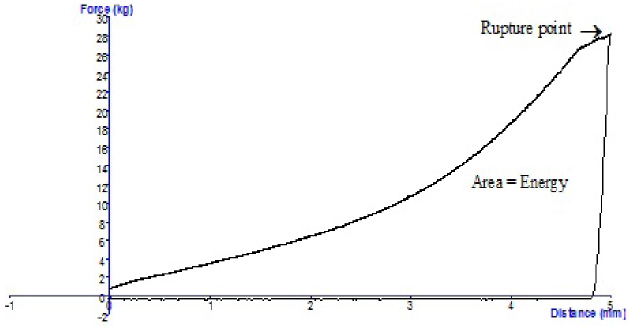

Figure 3. Typical force-distance curve of *Canavalia maritima* seed

Table 1. Basic geometric characteristics of *Canavalia* seeds and kernels (n = 5, mean ± SD with 100 seeds or kernels for each parameter except for row 2: n = 5, mean ± SD with 1000 seeds or kernels for mass; range in parenthesis)

	Seeds		Kernels	
	C. cathartica	*C. maritima*	*C. cathartica*	*C. maritima*
Unit mass of seed or kernel, M_1 (g)	0.71±0.13^{a}	0.47±0.08^{b**}	0.47±0.09^{a}	0.32±0.05^{b**}
	(0.46−1.01)	(0.29−0.68)	(0.31−0.67)	(0.20−0.47)
Mass of 1000 seeds or kernels, M_{1000} (g)	710.48±5.90^{a}	471.64±16.32^{b*}	470.32±8.23^{a}	323.95±11.21^{b***}
	(704.57−716.38)	(455.32−487.96)	(461.21−477.20)	(312.74−335.17)
Seed coat mass, S_m (g)	0.23±0.04^{a}	0.15±0.02^{b***}	–	–
	(0.15−0.33)	(0.09−0.20)		
Length, l (mm)	16.62±1.53^{a}	14.60±0.97^{b**}	16.54±2.27^{a}	13.74±1.80^{b***}
	(12.2−21.2)	(12.4−16.8)	(12.00−24.10)	(11.10−19.20)
Breadth, b (mm)	10.66±1.44^{a}	9.25±0.77^{b**}	9.99±2.07^{a}	7.78±1.30^{b***}
	(7.10−12.00)	(6.30−9.70)	(5.20−14.10)	(4.10−12.30)
Thickness, t (mm)	8.94±0.76^{a}	8.15±0.77^{a}	6.59±1.56^{a}	5.39±1.31^{b***}
	(11.39−18.90)	(14.44−18.02)	(4.20−18.00)	(3.00−8.10)
Hilum length, H_l (mm)	10.78±1.92^{a}	5.14±0.76^{b***}	–	–
	(8.60−19.80)	(3.10−8.00)		
l/b	1.57±0.12^{a}	1.58±0.09^{a}	1.72±0.39^{a}	1.81±0.38^{b*}
	(1.37−2.30)	(1.65−2.06)	(1.21−4.00)	(1.33−2.00)
Arithmetic diameter, D_a (mm)	12.07±1.09^{a}	10.67±0.79^{b***}	11.04±1.46^{a}	8.97±1.09^{b***}
	(11.31−15.84)	(11.27−14.30)	(7.67−15.33)	(5.33−12.33)
Geometric diameter, D_g (mm)	11.64±1.03^{a}	10.32±0.80^{b***}	10.20±1.43^{a}	8.25±1.24^{b***}
	(11.17−15.39)	(10.57−13.82)	(6.95−14.99)	(3.53−11.10)
Volume, V_u (cm^3)	0.68±0.20^{a}	0.47±0.11^{b***}	0.47±0.20^{a}	0.25±0.10^{b***}
	(0.58−1.52)	(0.75−0.25)	(0.14−1.41)	(0.02−0.57)

Figures across the columns with different alphabets between seeds and kernels are significantly different (*t*-test: *, p < 0.05; **, p < 0.01; ***, p < 0.001)

(0.71 and 0.47 g) was significantly higher than *C. maritima* (0.47 and 0.32 g), which was also reflected in mass of 1000 seeds and kernels (Table 1). The mass of 1000 seeds as well as kernels was uniformly distributed in *C. cathartica* (705-716 g) compared to *C. maritima* (455-488 g), which helps in selection of appropriate storage containers (Akaaimo and Raji, 2006). None of the parameters were correlated with seed mass of *C. cathartica*, while in *C. maritima* the seed mass was negatively correlated with dimensions, arithmetic and geometric mean diameters, surface area and unit volume (p < 0.05). The mass of kernels of both seeds was correlated negatively only with specific surface area (p < 0.001). The mass of seed coat was considerably higher in *C. cathartica* than in *C. maritima* (0.23 vs. 0.15 g). The seed weight and shape determines the free flowing or bridging tendencies in separators during seed processing (Eke *et al*., 2007).

The size determines occupation of space, which is based on the seed or kernel morphometric dimensions (e.g. length, breadth and thickness). Except for seed thickness, rest of the dimensions were significantly higher in *C. cathartica* than *C. maritima*. The *l/b* ratio of kernels differed significantly than the seeds. Length, breadth and thickness of seeds as well as kernels of both legumes were positively correlated with the volume (p < 0.001). The seed dimensions of *C. cathartica* and *C. maritima* are lower than that of *Canavalia ensiformis* (jackbean) (10-19 vs. 8-17 mm) (Eke *et al*., 2007). The arithmetic diameter, geometric diameters and volume of seeds and kernels of *C. cathartica* were significantly higher compared to *C. maritima*. Overall, the seeds of *C. cathartica* are larger heavier than seeds of *C. maritima*. The kernels of both seeds although differ in dimension and mass, they behave similarly during processing due to uniformity in shape. However, the volume of kernels of *C. cathartica* was almost twice that of kernels of *C. maritima* (0.47 vs. 0.25 cm^3). The size, surface area and volume have to be considered in bulk handling and processing operations especially in heat and mass transfer (Eke *et al*., 2007).

Variations in seed weight between or within plant species shows evolutionary responses of plant fitness by production of large number of seeds and increased chances of survival of seedlings through high allocation of resources to individual seeds (Westoby *et al*., 1992). However, the seed or kernel weight in *Canavalia* was not linearly increased against the length in our study. Although these *Canavalia* are exposed to same environmental conditions of coastal sand dunes, their seed dimensions varied significantly indicating differences in their genetic traits as well as reproductive strategy. Similarly, the germination pattern of these seeds varied under different regimes of temperature, salinity and burial (Arun *et al*., 2001). Those plant species adapted to dry habitats usually produce larger seeds than those occupied moisture-rich habitats (Mazer, 1989). Under optimum environmental conditions, the average seed yield of *C. maritima* was about 720-1,500 kg/ha (Bressani *et al*., 1987), which is higher than *C. cathartica* based on the assessment in the coastal sand dunes of Southwest India. This shows the tendency of more successful and wide distribution in coastal sand dunes of pantropical region by *C. maritima* than *C. cathartica* (Vatanparast, 2010).

Complex geometric characteristics

Seeds of *Canavalia* spp. showed higher sphericity compared to kernels, thus seeds are closer to the shape of a sphere than kernels (Table 2) and such results are reported by Garnayak *et al.* (2008). However,

Table 2. Complex geometric characteristics of *Canavalia* seeds and kernels (n =5, mean ± SD with 100 seeds or kernels for each parameter; range in parenthesis)

	Seeds		Kernels	
	C.cathartica	*C.maritima*	*C.cathartica*	*C.maritima*
Sphericity, S_φ	0.70±0.03^a	0.71±0.02^a	0.62±0.06^a	0.60±0.09^a
	(0.66–0.94)	(0.81–0.90)	(0.35–0.88)	(0.32–0.76)
Bulk density, ρ_b (kg/m^3)	514.97±31.27^a	503.50±5.22^a	465.83±14.17^a	432.81±14.80^{b*}
	(478.87–533.94)	(497.48–506.71)	(453.16–481.13)	(417.35–446.84)
True density, ρ_s (k g/m^3)	930.34±25.24^a	843.30±16.07^{b*}	1122.03±167.57^a	1020.5±12.95^a
	(904.46–954.88)	(833.96–861.86)	(1016.5–1315.25)	(1007.55–1033.45)
Porosity, ε (%)	44.57±4.64^a	40.28±1.01^a	57.82±6.71^a	57.58±1.80^a
	(41.17–49.85)	(39.24–41.25)	(53.49–65.55)	(56.21–59.61)
Angle of repose, q (°)	21.38±1.63^a	22.87±1.29^a	26.17±0.59^a	24.78±3.44^a
	(19.11–22.61)	(20.69–24.04)	(25.43–26.74)	(19.65–27.97)
Surface area, S_a (mm^2)	428.82±80.85^a	336.30±51.75^{b***}	333.13±92.68^a	218.57±60.13^{b***}
	(391.91–743.57)	(350.89–599.53)	(151.76–705.24)	(39.13–386.95)
Specific surface area, S_s (cm^2/cm^3)	3.19±0.90^a	3.69±0.96^{b***}	3.43±1.15^a	2.96±0.87^{b**}
	(1.69–8.43)	(2.01–6.93)	(1.29–8.03)	(0.50–5.41)
Hydration capacity, H_c	0.09±0.01^a	0.04±0.01^{b*}	0.54±0.04^a	0.43±0.01^{b*}
(g/seed or kernel)	(0.08–0.10)	(0.03–0.05)	(0.50–0.57)	(0.42–0.44)
Hydration index, H_i	0.15±0.04^a	0.09±0.03^{b**}	2.22±0.12^a	1.73±0.10^{b**}
	(0.11–0.18)	(0.06–0.12)	(2.08–2.29)	(1.62–1.82)
Swelling capacity, S_c	0.04±0.04^a	0.03±0.01^{b*}	0.35±0.01^a	0.36±0.03^a
(ml/seed or kernel)	(0.03–0.04)	(0.03–0.04)	(0.34–0.36)	(0.33–0.40)
Swelling index, S_i	0.05±0.002^a	0.04±0.003^{b**}	1.12±0.03^a	1.86±0.25^{b*}
	(0.04–0.06)	(0.03–0.04)	(1.08–1.14)	(1.61–2.11)

Figures across the columns with different alphabets between seeds and kernels are significantly different (*t*-test: *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$)

higher sphericity for kernels than seeds has also been reported by Sirisomboon *et al*. (2007). Seeds and kernels of both legumes showed positive correlation with surface area as well as volume ($p < 0.001$) except for seeds of *C. Cathartica*. The sphericity closer to 1.0 results in higher tendency to roll about any of the three axes, while the ratio of thickness to breadth closer to 1.0 indicates higher tendency to rotate about the major axis. The thickness to breadth ratio was highest in seeds of *C. maritima* (0.88) followed by seeds of *C. cathartica* (0.84), kernels of *C. maritima* (0.69) and *C. cathartica* (0.66). This shows that the seeds of *Canavalia* role, while the kernels slide in the hoppers and separators.

The bulk density of *Canavalia* seeds (503.50-514.97 kg/m^3) is lower than that of soya bean (840 kg/m^3) (Mohsenin, 1986), *C. ensiformis* (780 kg/m^3) (Eke *et al*., 2007) and African yam bean (740-760 kg/m^3) (Taser *et al*., 2005). The true density of *Canavalia* seeds was <1000 kg/m^3 indicates that the seeds are lighter than water and hence float. The bulk density of kernels of *Canavalia* was lower than the seeds (432.81-465.83 kg/m^3), but their true density was >1000 kg/m^3 (Table 2) and thus sink in water. The bulk and true densities between seeds and kernels did not differ significantly between seeds and kernels of *C. cathartica* but significant difference ($p < 0.01$) was found between seeds and kernels of *C. maritima*. This data is useful to design the cleaning and separation machines for seeds as well as kernels of *Canavalia*.

Porosity is an important data necessary to design the aeration systems during storage. Higher the porosity, better the aeration and water vapour diffusion during deep-bed drying (Vishwakarma *et al*., 2012). *Canavalia* seeds showed higher porosity (40.1-44.6%) than the seeds of *C. ensiformis* (32.6%) (Eke *et al*., 2007) and *Prosopis africana* (35.6%) (Akaaimo and Raji, 2006). The kernels of *Canavalia* seeds possess higher porosity compared to seeds (57.6-57.8 vs. 40.3-44.6%).

The angle of repose indicates the cohesion among the individual units of seeds and kernels. The angle of repose for locust bean (20.31^o; Ogunjimi *et al*., 2002) and *P. africana* (22.4^o; Akaaimo and Raji, 2006) were below the highest angle of repose (45.01^o) for most of the agricultural materials (Mohsenin, 1986). In *Canavalia* seeds, the angle of repose is comparable to seeds of locust bean and *P. africana* indicates similar seed morphology. The angle of repose was higher for *Canavalia* kernels (24.8-26.2^o) than seeds (21.4-22.9^o) and similar results were reported for *Jatropha curcas* seeds (Sirisomboon *et al*., 2007; Garnayak *et al*., 2008). This can be attributed that *Canavalia* kernels are viscous and thus cohesion forces are stronger between kernels and the surface compared to seeds. Seeds and kernels of lower unit mass exhibit higher cohesion leading to decreased angle of repose. For instance, although the unit mass of kernels of *C. cathartica* and seeds of *C. maritima* possess same unit mass (0.47/g), the angle of repose was higher in kernels of *C. maritima* (26.2 vs. 22.9^o). Among the seeds and kernels, seeds of *C. cathartica* showed the highest unit mass of (0.71 vs. 0.32-0.47/g) with least angle of repose (21.4 vs. 22.9-26.2°). Smooth coat and shape of *Canavalia* seeds are apparently responsible for relatively low values of angle of repose.

Surface area in irregular shaped seeds plays an important role in determining the projected area of the seeds moving in turbulent air stream and thus useful in designing the seed cleaners, separators and conveyors. Increased surface area to volume ratio elevates heat and mass transfer rate of seeds or kernels facilitating drying, cooling and heating operations (Vishwakarma *et al*., 2012). In our study, the ratio of surface area to volume was highest in kernels of *C. maritima* (874) followed by seeds of *C. maritima* (716), kernels of *C. cathartica* (709) and seeds of *C. cathartica* (630). This reveals the necessity to apply

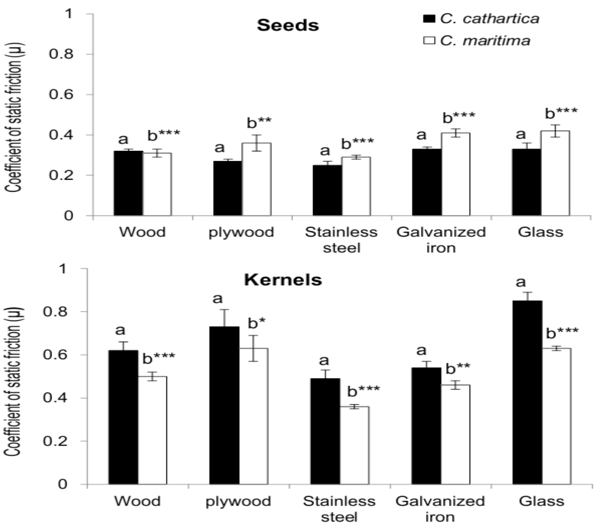

Figure 4. Coefficient of static friction (µ) of seeds and kernels of *Canavalia* (*, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$)

different strategies for drying, cooling and heating operations for seeds and kernels. The seed surface area of *C. cathartica* was higher than *C. maritima* (429 vs. 226 mm^2), which results in higher percentage of seed germination (Pollard *et al*., 2011).

In the present study, coefficient of static friction on all surfaces was higher for kernels than seeds of *Canavalia* corroborating the reports on *Jatropha* seeds and kernels (Sirisomboon *et al*., 2007; Karaj and Müller, 2010). Seeds and kernels showed highest static coefficient of friction against glass, while it was least on stainless steel (Figure 4). Stainless steel also offered minimum friction for Jatropha and moth gram (Nimkar *et al*., 2005; Karaj and Müller, 2010). This may be attributed to polished and smoother surface of stainless steel compared to other test surfaces used. The increased coefficient of static friction in kernels is due to higher moisture content compared to seeds (11.3413.64 vs. 6.077.87%). Lower moisture content and smooth surface of seeds resulted in the easy movement on test surfaces, while viscous nature of kernels leads to high resistance.

The hydration and swelling capacities of seeds *C. maritima* were significantly lower than *C. cathartica* indicating their hardness and impermeability. Hydration and swelling capacities of kernels of *C. cathartica* was 6 to 10-fold higher than seeds, while it was 9 to 12-fold higher in *C. maritima*. It is interesting to note that the swelling capacity of kernels of both seeds did not differ significantly (0.35-0.36/kernel), however the swelling index of kernels was significantly higher in *C. maritima* than *C. cathartica* (1.86 vs. 1.12). Length, thickness, volume and surface area of seeds of *C. maritima* were correlated negatively with hydration capacity ($p < 0.01$), so also the breadth of kernels of *C. maritima* ($p < 0.05$). Elevated hydration and swelling capacities of *C. cathartica* shows their softness and high permeability. These characteristics help to process the seeds (e.g. soaking, germination, dehusking and fermentation) for extraction of active principles or to eliminate antinutritional components.

Mechanical properties

Rupture force determination of seeds is similar to that of texture determination. The force required to rupture both the seeds in horizontal orientation was significantly higher than vertical orientation ($p < 0.001$) (Figure 5). This may be attributed to the force applied on the hilum portion of seeds in vertical position leading to easy rupture of the seeds. The seeds of *C. cathartica* are larger and heavier than *C. maritima* (see Table 1), hence the former seeds required higher rupture force in both the orientations ($p < 0.001$) supporting the reports by Subramanian *et al.* (1990) and Denis *et al.* (1994) on size, shell thickness and shell ratio of seeds. It is observed that the rupture force was significantly higher for seeds than kernels ($p < 0.001$), which is similar to the studies on *Jatropha* (Sirisomboon *et al.*, 2007; Karaj and Müller, 2010). Preliminary attempts failed to rupture the kernels at horizontal orientation, rupture force were determined only in the vertical position. The decrease in rupture force in kernels is due to the higher moisture content than seeds. The results on energy for rupture of seeds and kernels *Canavalia* followed similar to that of rupture force (Figure 5) corroborating the studies carried out on seeds and kernels of *Jatropha* (Sirisomboon *et al.*, 2007; Karaj and Müller, 2010).

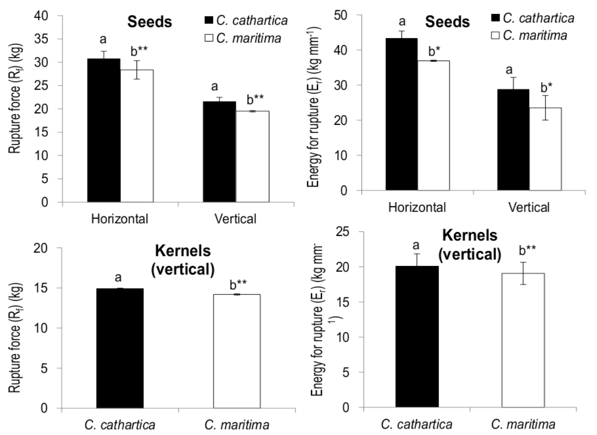

Figure 5. Rupture force (R_f) and energy for rupture (E_r) of seeds and kernels of *Canavalia* (*, $p < 0.05$; **, $p < 0.001$)

Conclusions and outlook

This study provided basic information on physical and mechanical properties of seeds and kernels of *Canavalia* of coastal sand dunes. The present investigation was carried out at the available moisture content of seeds (6.077.87%) and kernels (11.3413.64%). The average length, breadth and thickness of seeds and kernels was found to be 14.6-16.6, 9.3-10.7, 8.2-8.9 and 13.7-16.5, 7.8-1.0, 5.4-6.6 mm, respectively. Surface area differed significantly among seeds, kernels and between seeds and kernels ($p < 0.05$). Seeds are closer to the shape of sphere than kernels (0.70-0.71 vs. 0.60-0.62). Hydration capacity, hydration index, swelling capacity, swelling index is higher for kernels than seeds indicating the better water absorption capacity of kernels. Kernels with higher moisture content resulted in higher static coefficient of friction and lower rupture force and energy for rupture compared to seeds. Further studies on the impact of moisture, cooking, roasting and germination on the physical and mechanical properties are useful. There is ample scope to improve the nutraceutical, functional and industrial potential of protein-carbohydrate rich *Canavalia* seeds and their germplasm and cultivars in future.

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References

Adebowale, Y.A., Adeyemi, A. and Oshodi, A.A. 2005. Variability in the physicochemical, nutritional and antinutritional attributes of six Mucuna species. Food Chemistry 89: 37–48.

Akaaimo, D.I. and Raji, A.O. 2006. Some physical and engineering properties of *Prosopis africana* seed. Biosystems Engineering 95: 197–205.

Altuntas, E. and Yildiz, M. 2007. Effect of moisture content on some physical and mechanical properties of faba bean (*Vicia faba* L.) grains. Journal of Food Engineering 78: 174–183.

Arun, A.B. and Sridhar, K.R. 2004. Symbiotic performance of fast-growing rhizobia isolated from the coastal sand dune legumes of west coast of India. Biology and Fertility of Soils 40: 435–439.

Arun, A.B., Raviraja, N.S. and Sridhar, K.R. 2001. Effect of temperature, salinity and burial on seed germination and seedling emergence of five coastal sand dune legumes. International Journal of Ecology and Environmental Sciences 27: 23–29.

Bahnasawy, A.H. 2007. Some physical and mechanical properties of garlic. International Journal of Food Engineering 3: 1–18.

Balasubramanian, D. 2001. Physical properties of raw cashew nut. Journal of Agricultural and Engineering Research 78: 291–297.

Bhagya, B. and Sridhar, K.R. 2009. Ethnobiology of coastal sand dune legumes of southwest India. Indian Journal of Traditional Knowledge 9: 611–620.

Bhat, R. and Karim, A.A. 2009. Exploring the nutritional potential of wild and underutilized legumes. Comprehensive Reviews in Food Science and Safety 8: 305−331.

Bhat, R., Sridhar, K.R., Rajashekara, K.M. and Narayana, Y. 2005. ^{210}Po bioaccumulation in coastal sand dune wild legumes - *Canavalia* spp. of southwest coast of India. Journal of Environmental Monitoring 7: 856−860.

Bressani, R., Brenes, R.S., Gracia, A. and Elias, L.G. 1987. Chemical composition, amino acid content and protein quality of *Canavalia* spp. seeds. Journal of Science of Food Agriculture 40: 17–23.

Chock, A.K. 1968. Hawaiian ethnobotanical studies 1: Native food and beverage plants. Economic Botany 22: 221–138.

Coşkuner, Y. and Karababa, E. 2007. Some physical properties of flaxseed (*Linum usitatissimum* L.). Journal of Food Engineering 78: 1067–1073.

Denis, L., Coelho, V. and Vear, F. 1994. Pericarp structure and hullability in sunflower inbred lines and hybrids. Agronomie 14: 453–461.

Deshpande, S.D., Bal, S. and Ojha, T.P. 1993. Physical properties of soybean. Journal of Agricultural Engineering Research 56: 89–98.

Eke, C.N.U., Asoegwu, S.N. and Nwandikom, G.I. 2007. Physical properties of jackbean (*Canavalia ensiformis*). Agricultural Engineering International 9: 1–11.

Garnayak, D.K., Pradhan, R.C., Naik, S.N. and Bhatnagar, N. 2008. Moisture-dependent physical properties of jatropha seed (*Jatropha curcas* L.). Industrial Crops and Products 27: 123–129.

Haciseferogullari, H., Gezer, I., Bahtiyarca, Y. and Menges, H.O. 2003. Determination of some chemical and physical properties of Sakiz faba bean (*Vicia faba* L. var. major). Journal of Food Engineering 60: 475–479.

Ige, M.T. 1977. Measurement of some parameters affecting the handling losses of some varieties of cowpea. Journal of Agricultural Engineering Research 22, 127–133.

Isik, E. and Unal, H. 2007. Moisture-dependent physical properties of white speckled red kidney bean grains. Journal of Food Engineering 82: 209–216.

Karaj, S. and Müller, J. 2010. Determination of physical, mechanical and chemical properties of seeds and kernels of *Jatropha curcua* L. Industrial Crops and Products 32: 129–138.

Martinez, M.L. and Psuty, N.P. 2004. Coastal Dunes: Ecology and Conservation. Springer-Verlag, Berlin and Heidelberg.

Mazer, S.J. 1989. Ecological, taxonomic and life history correlates of seed mass among Indiana dune angiosperms. Ecological Monograph 59:153–175.

McCabe, W.L. and Smith, J.C., Harriott, P. 1986. Unit Operations of Chemical Engineering. McGraw-Hill Press, New York.

Mohsenin, N.N. 1986. Physical Properties of Plant and Animal Materials.: Gordon and Breach Science Publishers, New York.

Nikoobin, M., Mirdavardoosti, F., Kashaninejad, M. and Soltani, A. 2009. Moisture-dependent physical properties of chickpea seeds. Journal of Food Process Engineering 32: 544–564.

Nimkar, P. M. amd Chattopadhyay, P.K. 2001. Some physical properties of green gram. Journal of Agricultural Engineering Research 80: 183–189.

Nimkar, P.M., Mandwe, D.S. and Dudhe, R.M. 2005. Physical properties of moth gram. Biosystems Engineering 91: 183–189.

Niveditha, V.R. and Sridhar, K.R. 2012. Concanavalin and canavanine in seeds of coastal sand dune legumes (*Canavalia*). Advanced Biotech 11: 30–34.

Niveditha, V.R. and Sridhar, K.R. 2012. Antioxidant activity of raw, cooked and *Rhizopus oligosporus* fermented beans of *Canavalia* of coastal sand dunes of Southwest India. Journal of Food Science and Technology: DOI: 10.1007/s13197-012-0830-9

Niveditha, V.R., Sridhar, K.R. and Chatra, S.K.R. 2012. Fatty acid composition of cooked and fermented beans of the wild legumes (*Canavalia*) of coastal sand dunes. International Food Research Journal 19: 1401-1407.

Ogunjimi, L.A.O., Aviara, N.A. and Aregbesola, O.A. 2002. Some engineering properties of locust bean seed. Journal of Food Engineering 55: 95–99.

Olajide, J.D. and Igbeka, J.C. 2003. Some physical properties of groundnut kernels. Journal of Food Engineering 58: 201–204.

Olutola, E.A. 2011. The use of jack beans (*Canavalia ensiformis*) and sandbox (*Hura crepitans*) seeds as fillers in natural rubber compounding. Dissertation, Federal University of Agriculture, Abeokuta, Nigeria (Abstract).

Pollard, M.A., Fischer, P. and Windhab, E.J. 2011. Characterization of galactomannans derived from legume endosperms of genus *Sesbania* (Faboideae). Carbohydrate Polymers 84: 550–559.

Seena, S. and Sridhar, K.R. 2005. Physicochemical, functional and cooking properties of under explored legumes, *Canavalia* of the southwest coast of India. Food Research International 38: 803–814.

Seena, S. and Sridhar, K.R. 2006. Nutritional and microbiological features of little known legumes, *Canavalia cathartica* Thouars and *C. maritima* Thouars of the southwest coast of India. Current Science 90: 1638–1650.

Singh, K.K. and Goswami, T.K. 1996. Physical properties of cumin seed. Journal of Agricultural Engineering Research 64: 93–98.

Sirisomboon, P., Kitchaiya, P., Pholpho, T. and Mahuttanyavanitch, W. 2007. Physical and mechanical properties of *Jatropha curca*s L. fruits, nuts and kernels. Biosystems Engineering 97: 201–207.

Sobukola, O.P., Onwuka, V.I. 2011. Effect of moisture content on some physical properties of locust bean seed (*Parkia fillicoidea* L.). Journal of Food Process Engineering 34, 1946–1964.

Sridhar, K.R. and Bhagya, B. 2007. Coastal sand dune vegetation: a potential source of food, fodder and pharmaceuticals. Livestock Research for Rural Development 19, Article # 84: *http://www.cipav.org.co/lrrd/lrrd19/6/srid19084.htm.*

Sridhar, K.R. and Niveditha, V.R. 2011. Wild legume *Canavaia cathartica* - An overview on nutritional and bioactive potential. In: Medina, D.A. and Laine, A.M. (Eds.), Food Quality: Control, Analysis and Consumer Concerns, p. 269-302. New York: Nova Science Publishers Inc.

StatSoft, 2008. Statistica, Version # 8. USA: StatSoft Inc.

Subramanian, R., Sastry, M.C.S. and Venkateshmurthy, K. 1990. Impact dehulling of sunflower seeds: effect of operating conditions and seed characteristics. Journal of Food Engineering 12: 83–94.

Taser, O.F., Altuntas, E. and Ozgoz, E. 2005. Physical properties of Hungarian and common vetch seeds. Journal of Applied Science 5: 323–326.

Vadivel, V. and Biesalski, H.K. 2010. HPLC analysis of bioactive compounds in ten different wild type under-utilized legume grains. Institute of Integrative Omics and Applied Biotechnology Journal 1: 17–24.

Vatanparast, M. 2010. Phylogeography of a Pantropical Plant with Sea-Drifted Seeds: *Canavalia rosea* (Sw.) DC. (Fabaceae). Ph.D. Thesis, Chiba University, Japan.

Vishwakarma, R.K., Shivhare, U.S. and Nanda, S.K. 2012. Physical properties of guar seeds. Food and Bioprocess Technology 5: 1364–1371.

Westoby, M., Jurado, E. and Leishman, M. 1992. Comparative evolutionary ecology of seed size. Trends in Ecology and Evolution 11: 368–372.