Available online at www.sciencedirect.com
SCIENCE DIRECT®
Food Chemistry 99 (2006) 267–288
Food Chemistry
www.elsevier.com/locate/foodchem

Nutritional and antinutritional significance of four unconventional legumes of the genus *Canavalia* – A comparative study

K.R. Sridhar *, S. Seena

Microbiology and Biotechnology, Department of Biosciences, Mangalore University, Mangalagangotri, Mangalore 574 199, Karnataka, India

Received 11 April 2005; received in revised form 8 July 2005; accepted 8 July 2005

Abstract

Developing countries are under the clutch of malnutrition due to a lack of protein rich food. Protein supply can be broadened by exploration and exploitation of alternative legume sources. Even though many wild legume landraces have been identified, their utilization is limited due to insufficient attention. *Canavalia gladiata*, *Canavalia ensiformis*, *Canavalia maritima* and *Canavalia cathartica* are the common under-exploited legume species having the potential to be a rich protein source. This review envisages a comparative account of nutritional, antinutritional and functional properties and emphasizes the various methods employed in seed processing of *Canavalia* spp. The current study helps in understanding the nutritional and antinutritional versatility/potential of four *Canavalia* spp., thereby developing future strategies for optimum utilization.

Keywords: *Canavalia*; Wild legumes; Proteins; Energy; Essential amino acids; Concanavalin A; Detoxification

1. Introduction

Tropical developing countries are facing an increasing demand for protein-rich food due to teeming population, cereal-based diet and scarcity of fertile land (Sadik, 1991; Weaver, 1994). Legumes are an inexpensive source of proteins with desirable characteristic such as abundance of carbohydrates, ability to lower the serum cholesterol, high fiber, low fat (except oilseeds), high concentration of polyunsaturated fatty acids and a long shelf life. In addition to B complex vitamins, minerals and fiber, legumes are also major sources of proteins and calories (Rockland & Nishi, 1979). They are known to contain certain bioactive compounds whose beneficial effects need to be explored for exploitation.

The global production of food legumes in 1998 was 246 million tons (FAO, 1998). According to DOES (2000), India produced 39.91 million tons of food legumes in 1998–1999. Research has to be geared to exploiting the unconventional legume resources to meet the protein requirements of developing countries. Under-explored legumes are important in terms of food security, nutrition, agricultural development, enhancement of economy and also as rotation crops. Thus, little known legumes can play an important role in agriculture as they are potent plants, which contribute to the world food production due to their adaptation to adverse environmental conditions and high resistance to diseases and pests.

The current review deals with nutritional and antinutritional properties of whole seeds and cotyledons of *Canavalia* spp. (*Canavalia gladiata*, *Canavalia maritima*, *Canavalia ensiformis* and *Canavalia cathartica*). The physicochemical features, minerals, amino acids, fatty acids and functional properties of these landraces are furnished in this review. Antinutritional factors (concanavalin A, canavanine, canaline, canatoxin, urease, saponins, other toxins) and their effects and detoxification

* Corresponding author. Tel.: +91 824 2287 261; fax: +91 824 2287 367.
E-mail address: sirikr@yahoo.com (K.R. Sridhar).

0308-8146/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.foodchem.2005.07.049

studies have been discussed. The role of *Canavalia* in medicine and pest control has also been projected. Suggestions have also been made on possible future lines of action to exploit *Canavalia* spp.

2. Canavalia

The genus *Canavalia* consists of four subgenera with 51 species (Smartt, 1990) encompassing *C. ensiformis* (L.) DC. (Synonym: *Dolichos ensiformis* L.), *Canavalia gladiata* (Jacq.) DC. (Synonym: *Dolichos gladiatus* Jacq.), *C. maritima* Thouars [Synonym: *Canavalia lineata* (Thunb.) DC.; *Canavalia obtusifolia* (Lam.) DC.; *Canavalia rosea* (Sw.) DC.; *Dolichos maritimus* Aublet; Dolichos obtusifolius Lam.; *Dolichos roseus* Sw.] and *C. cathartica* Thouars [Synonym: *Canavalia microcarpa* (DC.) Piper; *Canavalia turgida* Graham ex A. Gray; *Canavalia virosa* (Roxb.) Wight et Arn.; *Dolichos virosus* Roxb.; *Lablab microcarpus* DC.].

C. gladiata (sword bean) has an Asian origin spreading throughout the tropics as they are resistant to drought (Herklots, 1972; Kay, 1979). They are cultivated in Asia, West Indies, Africa and South America. Average yield ranges from 720 to 1500 kg ha^{-1} in Central America (Bressani, Brenes, Gracia, & Elias, 1987). In India, three germplasm of *C. gladiata* are recognized (red flowers with red seeds, white flowers with white seeds and white flowers with red seeds) (Purseglove, 1968). Accessions of *C. gladiata* from different agroclimatic regions show variations in seed germination, plant height, number of branches and leaves, leaf area, flowering, fertility index and seed weight (Vadivel, Janardhanan, & Vijayakumari, 1998). Seeds of *C. gladiata* are similar to *C. ensiformis* except for hilum, which is as long as seed (Purseglove, 1968; Smartt, 1976). The white seeded variety is commonly preferred for consumption and contains less antinutritional factors (Purseglove, 1968). Mature seeds of *C. gladiata* were consumed by ancient Indians and currently by urban populations too (Rajaram & Janardhanan, 1992). Palliyar tribes of Srivilliputhur, Western Ghats consume *C. gladiata* seeds for food and also to supplement their diet (Arinathan, Mohan, Britto, & Chelladurai, 2003). In Indonesia seeds of *C. gladiata* are consumed after boiling, washing, decoating, soaking and fermenting (Kay, 1979). In other parts of Asia, *C. gladiata* seeds are soaked, boiled with sodium bicarbonate, rinsed, pounded and used in curries or as a substitute for potatoes (Kay, 1979). Pods of *C. gladiata* should be harvested during the 3–5 months before hardening to be used as vegetable (Hoshikawa, 1981a, 1981b). In Sri Lanka the immature pods of *C. gladiata* are used either directly or after boiling (Ekanayake, Jansz, & Nair, 2000a). The roasted and ground beans are used as a substitute for coffee in Central America (Bressani et al., 1987). Smartt (1976) and Ekanayake et al. (2000a) reported susceptibility of *C. gladiata* to root rot and scab diseases by *Colletotrichum lindemuthianum* and *Elsinoe canavaliae*. Immature seeds of *C. gladiata* are a source of novel gibberellins, GA22 and GA21 (Murofushi et al., 1969).

C. ensiformis (jack bean) originated in South America and is grown in the tropics and subtropics (Smartt, 1985). In the rest, they were cultivated in drought-prone areas of Arizona and Mexico and utilized as high protein food and forage crops (in Southwestern United States, Mexico, Central American countries, Brazil, Peru, Ecuador and West Indies) (Sauer & Kaplan, 1969). In Nigeria it is grown on walls and trees as an ornamental plant (Udedibie, 1990). Colonization of *C. ensiformis* by mycorrhiza and rhizobia results in good growth and regeneration under harsh soil and climatic conditions (Rodrigues & Torne, 1991a; Udedibie & Carlini, 1998a). Total yield of forage and dry seeds of *C. ensiformis* ranges from 1 to 10 t^{-1} ha^{-1} yr^{-1} (Addison, 1957; Kessler, 1990). Variation in seed yield was associated with differences in pod numbers and seed weight. Vadivel and Janardhanan (2001) reported the seed coat color of *C. ensiformis* ranging from maroon-red in south India. Green immature pods of *C. ensiformis* are usually consumed as vegetables (Purseglove, 1974). Occasionally the pods are subjected to decay by *Fusarium solani* in the monsoon season (Rodrigues & Torne, 1991b).

Bressani et al. (1987) advocated seeds of *C. gladiata* and *C. ensiformis* as a good source of proteins like most edible legumes. Processed young pods of *C. gladiata* and *C. ensiformis* are used in the preparation of pickles (Hoshikawa, 1981a, 1981b). *Fusarium moniliforme*, *F. solani* (endophytes), *Aspergillus flavus* and *A. japonicus* (epiphytes) are the main fungal components of seeds of *C. gladiata* and *C. ensiformis* (Rodrigues & Torne, 1990a).

C. maritima (beach bean) is a pantropical pioneer plant species (Gross, 1993), widely distributed on coastal sand dunes by drift dissemination of seeds (Nakanishi, 1988). In the United States, it occurs in central and southern Florida coasts as well as in Texas. Nitrogen fixing bacteria (*Sinorhizobium*) isolated from root nodules of *C. maritima* of Southern Taiwan are halotolerants (3–3.5% w/v NaCl) (Chen, Lee, Lanm, & Cheng, 2000). Thus, the unusual plant growth in dunes may be attributed by colonization of rhizobia as well as mycorrhiza (Arun & Sridhar, 2005; Beena, Arun, Raviraja, & Sridhar, 2001). *C. maritima* is commonly used as a biomass cover crop in third world countries and arid lands in Australia and Africa. It is a potent cover crop and prevents soil erosion in dry and sandy areas. Germination of *C. maritima* seeds decreased, with the increase in burial depth (Arun, Raviraja, & Sridhar, 2001) and permanent seawater flooding was found to be fatal (Martinez, Vazquez, White, Thivet, & Brengues, 2002). *C. maritima* was an important food for British explorer

captain James Cook and his crew during the world voyage from 1768 to 1771 (http://www.floridata.com/ref). The young pods and seeds (boiled or roasted) are edible in northern Australia.

C. cathartica (Maunaloa), a wild ancestral form of *C. gladiata*, is distributed throughout tropical Asia, Africa (Purseglove, 1974), and the southwest coast of India particularly in mangroves and coastal sand dunes (Arun, Beena, Raviraja, & Sridhar, 1999; Arun, Sridhar, Raviraja, Schmidt, & Jung, 2003). Sastrapradja, Lubis, Lubis, and Sastrapradja (1981) reported a natural hybrid of *C. cathartica* and *C. gladiata*, while artificial hybridization of *C. cathartica* and *C. ensiformis* decreased pollen fertility in F1 and F2 progenies. Gamma irradiation (4 and 6 krad) improved germination of *C. cathartica* seeds (Rodrigues, 1993). Kathiravan and Ignacimuthu (1999) successfully transplanted tissue cultured plants of *C. cathartica* to the field after hardening.

The study of epidermal features of leaves, pods and anthers of *C. gladiata, C. ensiformis* and *C. cathartica* revealed two distinct types of stomata (paracytic and anisocytic), crystalliferous cells and non-glandular trichome, and a broad based cell with pointed tip (Rodrigues & Torne, 1990a, 1990b).

3. Physicochemical properties

Canavalia are large seeded and structurally similar, but differ to each other in size, shape, color and thickness of the seed coat (Table 1). *C. gladiata* seed weight (2.23–4.87 g) was found to be the highest followed by *C. ensiformis, C. cathartica* and *C. maritima*. The percentage of cotyledon was more in *C. ensiformis* (84.67–89.13%) owing to its thin seed coat (10.87–15.33%). Arun et al. (2003) reported higher seed, cotyledon and seed coat weights of *C. cathartica* than *C. maritima* in coastal sand dunes of India, while seed weights of non-coastal *C. cathartica* (Siddhuraju & Becker, 2001) correspond to *C. maritima* of Central America (Bressani et al., 1987).

Chemical composition of the four species of *Canavalia* reviewed reveals inadequate information pertaining to *C. maritima* and *C. cathartica* (Table 2). Legumes consist of storage (70–80%) as well as structural proteins (20–30%), which are located in cells as discrete bodies. According to Salunkhe, Kadam, and Chavan (1985) the protein of major edible legumes ranged between 22.3% and 39.2%, of which the soybean is an outlier. The proteins of *Canavalia* seeds are higher than wheat (8.55%), parboiled rice (7.7%) and egg (12.6%) (Livsmedelsverk, 1988). The edaphic features of geographic locations influence the quantity and quality of *Canavalia* seed proteins. The minimum seed proteins of *Canavalia* ranges from 22.4% to 24.9% (Table 2), but Arinathan et al. (2003) reported only 12.9% in C. *gladiata*. Among the seed varieties of *C. gladiata*, the brown variety was found to have the highest protein (35%) (Siddhuraju & Becker, 2001). According to Rodrigues and Torne (1991c), seeds of *C. gladiata* and *C. ensiformis* have higher protein than *C. cathartica*. The highest percentage of protein attained at 16 weeks of cultivation (28.18%) facilitates *C. ensiformis* to be employed as a forage legume (Diaz, Gonzalez, Mora, & Curbelo, 1998). Mature and immature beans of *C. maritima* have 26.3% and 13.3% protein and proteins of leaves, pods of mature beans and dry beans of *C. maritima* were 19.3%, 8.6% and 7.8%, respectively (Graham & DeBravo, 1985).

Proteins are classified into three basic groups (globulins, 70%; albumins, 15%; glutelins, 15%) and possess essential amino acids. As with other common pulses, albumins and globulins are the major seed proteins of *Canavalia* spp. (Table 2). Albumins of *C. gladiata* are elevated after attaining 1.8 g seed weight, followed by the active synthesis of globulins (Yamauchi & Minamikawa, 1986), which accumulate until maturation. Protein digestibility of *Canavalia* seeds is poor due to their large proportion of globulins, antinutritional factors and secondary metabolites (Bressani et al., 1987; Bressani & Sosa, 1990; Ekanayake, Jansz, & Nair, 2000b). The in vitro protein digestibility of *C. gladiata* and *C. ensiformis* seeds are lower than *C. cathartica* and comparable

Table 1
Physical characteristics of seeds of *Canavalia* spp.

Seed features	*Canavalia ensiformis*[a]	*Canavalia gladiata*[b]	*Canavalia maritima*[c]	*Canavalia cathartica*[d]
Seed weight (g seed^{-1})	1.37–1.84	2.23–4.87	0.50–0.71	0.64–0.82
Cotyledon weight (g seed^{-1})	1.16–1.64	1.73–3.88	0.35–0.50	0.44–0.58
Seed coat weight (g seed^{-1})	0.2–0.21	0.48–0.99	0.15–0.21	0.20–0.24
Seed length (cm seed^{-1})	1.86–1.88	2.53–2.56	–	1.16
Seed width (cm seed^{-1})	1.28–1.32	1.58–1.64	–	0.98
Seed thickness (cm seed^{-1})	1.09	–	–	–
Hilum length (cm seed^{-1})	1.12	–	–	–

–, Not determined.
[a] Akpapunam and Sefa-Dedeh (1997), Bressani et al. (1987), and Siddhuraju and Becker (2001).
[b] Bressani et al. (1987), Ekanayake et al. (1999), and Siddhuraju and Becker (2001).
[c] Arun et al. (2003) and Bressani et al. (1987).
[d] Arun et al. (2003) and Siddhuraju and Becker (2001).

Table 2
Chemical compositions of raw seed flours of *Canavalia* spp.

Component	*Canavalia ensiformis*[a]	*Canavalia gladiata*[b]	*Canavalia maritima*[c]	*Canavalia cathartica*[d]
Moisture (%)	3.80–13.5	7.58–12.2	9.30–10.6	9.20
Crude protein (g 100 g^{-1})	22.8–35.3	26.8–35	22.4–34.1	24.9–35.5
True protein (g 100 g^{-1})	24.2–28.2	20.8–21.3	29.3	28.8
Albumins (g 100 g^{-1})	7.80–8.60	5.10–5.60	7.60	7.40
Globulins (g 100 g^{-1})	13.0–14.6	12.5–13.0	18.8	18.5
Prolamins (g 100 g^{-1})	0.63–0.91	0.91–0.98	0.30	0.30
Glutelins (g 100 g^{-1})	1.84–1.96	1.81–2.06	2.80	2.70
Crude lipid (g 100 g^{-1})	1.60–12.1	1.40–9.90	1.60–1.70	1.30–4.9
Crude fiber (g 100 g^{-1})	4.70–11.4	2.05–12.8	10.2–17.3	7.00–10.4
Ash (g 100 g^{-1})	2.30–5.80	3.19–4.18	3.20–3.50	3.03–3.80
Total starch (g 100 g^{-1})	24.7–36.9	31.8–39.6	–	32.0
Digestible starch (g 100 g^{-1})	26.1	18.7–20.0	–	23.0
Resistant starch (g 100 g^{-1})	10.8	11.8–14.0	–	9.00
Crude carbohydrates (g 100 g^{-1})	45.8–65.4	45.1–68.5	44.9–50.5	48.2–59.6
Energy value (kJ 100 g^{-1})	1470–1910	1690–1830	1590	1510–1790

[a] Agbede and Aletor (2005), Akpapunam and Sefa-Dedeh (1997), Arora (1995), Bressani et al. (1983), Bressani et al. (1987), D'Mello et al. (1985), D'Mello et al. (1988), D'Mello and Walker (1991), Ellis and Belmar (1985), Herrera (1983), Kessler et al. (1990), Laviada (1983), Mohan and Janardhanan (1994), Molina et al. (1974), Molina et al., 1977, Novus (1994), Ologhobo et al. (1993), Rajaram and Janardhanan (1992), Revilleza et al. (1990), Rodrigues and Torne (1991c), Siddhuraju and Becker (2001), Spoladore and Teixeria (1987), Udedibie et al. (1994), and Vadivel and Janardhanan (2001).
[b] Bressani et al. (1987), Ekanayake et al. (1999), Mohan and Janardhanan (1994), Rajaram and Janardhanan (1992), and Siddhuraju and Becker (2001).
[c] Abbey and Ibeh (1987), Arun et al. (2003), and Bressani et al. (1987).
[d] Arun et al. (2003), Siddhuraju and Becker (2001), and Thangadurai et al. (2001).

to different cultivars of *Phaseolus vulgaris* (Siddhuraju & Becker, 2001). The in vitro protein digestibility of *C. gladiata* of raw whole seeds and cotyledons were 71.73% and 70.08%, while in vivo digestibility were 41.8% and 51.4%, respectively (Ekanayake et al., 2000b). It is likely the in vitro protein digestibility might have been over estimated due to usage of enzymes of different origin.

Total lipids of major legumes range from 1.0% to 46.7%, of which winged bean (15.9%), soybean (21.3%) and groundnut (46.7%) are the outliers (Salunkhe et al., 1985). Generally, *Canavalia* seeds are low in lipids, however, lipids of *C. gladiata* and *C. ensiformis* were higher than in commonly consumed pulses in India (*Vigna radiata*, *Phaseolus mungo*, *Cicer arietinum* and *Cajanus cajan*) (Mohan & Janardhanan, 1994). Crude lipids of different accessions of *C. gladiata* seeds significantly differed (Vadivel et al., 1998). The lipids of *C. ensiformis* and *C. gladiata* seeds are found to be higher than *C. maritima* and *C. cathartica*.

The fiber of *Canavalia* spp. falls within the range of 4.7–17.3% (Table 2). *C. maritima* possesses the highest amount of fiber (10.2–17.3%) compared to other *Canavalia* species and this may be attributed to seed coat features. The recommended daily intake of fiber is between 25 and 50 g. The physiological benefits of high fiber intake are increased fecal bulk and moisture, reduced plasma cholesterol, positive influence on blood glucose and insulin concentration. Cellulose and hemicellulose are the major constituents of crude fiber and are known to have hypocholesterolemic effects. Dietary fiber is known to absorb bile salt aided by saponins and also prevents various diverticular degenerative diseases. Low fiber intake is linked with incidence of cancer of the colon and rectum, diverticular diseases, coronary heart diseases, diabetes and gallstones (Burkett & Trowell, 1975). Neutral fiber of *C. ensiformis* was high (23.38%) and is attributed to the seed coat fraction and other cellulosic seed constituents. Germination of seeds of *C. ensiformis* elevates neutral fiber (40.08%) due to vegetative parts (Akpapunam & Sefa-Dedeh, 1997). Pectic substances (Arabinose, galactose and uronic acid) are the main non-soluble fibers of *Canavalia* spp. (Table 3). Glucose (neutral sugar) and arabinose and xylose (hemicellulose residue) are the major insoluble dietary fibers. Ash composition of *Canavalia* spp. ranged between 2.3% and 5.8% (Table 2). Siddhuraju and Becker (2001) indicated that ash percentage of *C. ensiformis*, *C. gladiata* and *C. cathartica* seeds fall within the range of several cultivated pulses.

Crude carbohydrates and energy of *Canavalia* spp. (44.9–68.5) are similar to common pulses (Table 2). The carbohydrates include monosaccharides, oligosaccharides, starch and other polysaccharides. The non-structural carbohydrates of legumes are not utilized by monogastric animals due to the difference in amylose–amylopectin ratio of starch (Rao & Rao, 1978) or presence of heteropolysaccharides and oligosaccharides (Bell, Lackey, & Polhill, 1978). Low molecular weight carbohydrates such as sucrose and sucrosyl oligosaccharides are present in legumes. The total non-reducing sugars (1.79–2.71%) found in *C. ensiformis* seeds are sucrose

Table 3
Soluble and insoluble dietary fiber constituents of *Canavalia* spp. (g kg^{-1} DM)[a]

Fiber	*Canavalia ensiformis*	*Canavalia gladiata*	*Canavalia cathartica*
Soluble fibers			
Rhamnose	0.23	0.31–0.39	0.27
Fucose	Trace[b]	Trace–0.05	0.06
Ribose	0.28	0.38–0.52	0.32
Arabinose	1.30	0.98–0.74	1.01
Xylose	0.30	0.30–0.49	0.24
Mannose	0.20	0.26–0.46	0.22
Galactose	0.45	0.59–0.82	0.46
Glucose	0.39	0.39–0.52	0.36
Uronic acids	5.05	5.36–6.25	6.75
Insoluble fibers			
Rhamnose	1.28	2.98–3.2	2.70
Fucose	0	0.28–0.48	0.31
Ribose	0.68	0	0
Arabinose	8.63	10.42–15.96	18.45
Xylose	7.16	9.30–10.27	9.76
Mannose	1.09	1.63–1.75	1.87
Galactose	5.18	4.32–4.4	4.26
Glucose	19.74	24.73–29.29	26.75
Uronic acids	18.43	25.26–31.04	21.15
Klason lignin	105.4	114.3–123.72	141.08
Total soluble fiber	8.20	0.16–8.65	9.69
Total insoluble fiber	167.59	210.61–202.72	226.33
Total dietary fiber	175.79	211.37–220.77	236.02

[a] Siddhuraju and Becker (2001).
[b] <0.05 g kg^{-1}.

(1.49–2.47%), raffinose (0.34–0.86%) stachyose (1.44–1.74%) and verbacose (0.01–0.11%) (Revilleza, Mendoza, & Raymundo, 1990). Flatulence potential of *C. gladiata* seeds are higher than *C. ensiformis* (Revilleza et al., 1990). The oligosaccharides (raffinose, stachyose and verbacose) of legumes are responsible for flatulence and hinder its acceptance as food. The most important legume carbohydrate, starch has a characteristic appearance for each plant species. The length and breadth of starch grains and gelatinization temperature of starch of *C. ensiformis*, *C. gladiata* and *C. cathartica* seeds differed (Rodrigues & Torne, 1991d). Seeds of *C. ensiformis* are known for their energy due to rich starch and amylose (287–350 g kg^{-1}) (Molina & Bressani, 1975). The percentage of digestible starch of *C. gladiata* is more than *C. ensiformis* and *C. cathartica* (Siddhuraju & Becker, 2001) and resistant starch is comparable to cultivated legumes (21–44%). Such low digestibility of starch is due to antinutritional factors such as phytic acid and polyphenols (Siddhuraju & Becker, 2001).

Digestible energy coefficients for most of the legumes fall between 85% and 90% of gross energy of legume seeds, while metabolizable energy is within the range of 75% and 85% (Ali, 2000). *Canavalia* spp. has higher energy (1470–1910 kJ 100 g^{-1}) than commonly cultivated pulse crops (1358–1426 kJ 100 g^{-1}) (Kuzayali, Cowan, & Sabry, 1966).

4. Minerals

Seed minerals of *Canavalia* spp. showed a narrow difference (Rodrigues & Torne, 1991c) and were less than in edible legumes (Bressani et al., 1987). However, Mohan and Janardhanan (1994) reported *C. ensiformis* and *C. gladiata* seeds are rich in minerals (sodium, potassium and calcium) comparable to common pulses (*Vigna unguiculata* and *C. arietinum*), while magnesium and phosphorus were higher than *C. cajan*. Among the macrominerals, potassium was found to be the highest in *Canavalia* spp. and *C. cathartica* and *C. maritima* are found to be a good source of zinc (Table 4). Except for sodium, the rest of the minerals were higher in *C. maritima* than *C. cathartica* (Arun et al., 2003). Decrease in minerals is evident after processing of seeds (e.g., cooking, roasting, soaking, dehulling) (Agbede & Aletor, 2005). Rajaram and Janardhanan (1992) indicated that the seeds of *C. gladiata* and *C. ensiformis* are the potential sources of minerals fulfilling two thirds of recommended dietary allowances by NRC/NAS (1989). Heavy metals (lead, <0.8 μg g^{-1}; cadmium, 0.05 μg g^{-1}; mercury, 325 μg g^{-1}) (Ekanayake, Jansz, & Nair, 1999) of *C. gladiata* are fall within the tolerable intake (0.04 mg day^{-1}) (FNB/NRC, 1989).

5. Amino acids and fatty acids

Glutamic acid and aspartic acid were the major amino acids of *Canavalia* spp. as in soybean, rice and egg protein (Table 5). Legumes are rich in lysine and deficient in tryptophan and methionine (chickpea, 0.8%, 1.2%; pigeon pea, 0.8%, 1.1%; black gram, 0.5%, 1.1%; green gram, 0.4%, 1.5%; lentil, 1.0%, 1.9%) (Gupta, 1982) corroborating the results of earlier studies in *Canavalia* spp. (Bressani et al., 1987; Ekanayake et al., 1999; Mohan & Janardhanan, 1994). Surprisingly, sulphur amino acids in *C. cathartica* and *C. maritima* were more than in soybeans (Table 5). Therefore, *C. cathartica* demands further exploration as a genetic base for hybridization in view of maximizing protein quality of other gene pools of *Canavalia*. Essential amino acids (EAA) (isoleucine, leucine, tyrosine, phenylalanine and lysine) of *C. gladiata* seeds were adequate (FAO/WHO, 1991), while EAA of *C. ensiformis* (isoleucine, leucine and tyrosine) were higher than common legumes (*Vigna mungo* and *V. radiata*, *C. arietinum* and *C. cajan*) (Mohan & Janardhanan, 1994). Seeds of red and brown varieties of *C. gladiata*, *C. ensiformis* and *C. cathartica* are rich in aspartic acid, glutamic acid and histidine (Siddhuraju & Becker, 2001). Thermal processing decreases the concentration

Table 4
Minerals compositions of seeds flours of *Canavalia* spp. (mg 100 g^{-1})

Mineral	*Canavalia ensiformis*[a]	*Canavalia gladiata*[b]	*Canavalia Maritima*[c]	*Canavalia Cathartica*[d]	Adult dietary allowance[e]
Sodium	5.80–1670	0.26–83.9	48.0	17.6–49.1	500
Potassium	450–2860	790–2280	800–974	889–977	2000
Calcium	100–600	150–310	86.2–290	83.8–225	800
Phosphorus	51–600	262–625	158–330	137–325	800
Magnesium	50.0–230	65.2–172	23.1–160	5.14–158	280–350
Iron	Trace–9.33	Trace–45.2	Trace–4.53	2.88–5.08	10
Copper	0.33–10.0	0.36–1.67	0.28–1.16	0.20–1.89	1.5–3
Zinc	1.10–98.1	1.37–8.42	3.85–13.1	11.4–12.58	15
Manganese	0.22–7.05	0.23–1.08	0.87–2.02	1.41–1.44	2–5

[a] Agbede and Aletor (2005), Arora (1995), Bressani et al. (1987), D'Mello et al. (1988), Kessler et al. (1990), Mohan and Janardhanan (1994), Novus (1994), Rajaram and Janardhanan (1992), Rodrigues and Torne (1991c), Siddhuraju and Becker (2001), Udedibie et al. (1994), and Vadivel and Janardhanan (2001).
[b] Arinathan et al. (2003), Bressani et al. (1987), Ekanayake et al. (1999), Mohan and Janardhanan (1994), Rajaram and Janardhanan (1992), and Siddhuraju and Becker (2001).
[c] Arun et al. (2003) and Bressani et al. (1987).
[d] Arun et al. (2003) and Siddhuraju and Becker (2001).
[e] NRC/NAS (1989).

of amino acids, particularly lysine and methionine. Methionine supplementation has been advocated to meet the deficiency of sulphur amino acids of *Canavalia* seeds (Bressani et al., 1987). However, according to Salunkhe (1982), fortification is difficult in legumes, as they will be cooked prior to consumption.

The fatty acid profile of *Canavalia* spp. is projected in Table 6. The polyunsaturated fatty acids (PUFA) are the principal fatty acids of legumes. The PUFAs: eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) have been studied for health benefits (Nair, Leitch, Falconer, & Garg, 1997; Simopoulos, 1999). Al-

Table 5
Amino acid compositions of *Canavalia* spp. (mg 100 mg^{-1} protein)

Amino acid	*Canavalia ensiformis*[a]	*Canavalia gladiata*[b]	*Canavalia maritima*[c]	*Canavalia cathartica*[d]	Soybean[e]	Rice[f]	Egg protein[g]	FAO/WHO Pattern[h]
Glutamic acid	2.4–16	6.3–17	18	11–17	17	15.2	13	
Aspartic acid	2.3–14	6.0–16	23	9.7–22	11	8.8	9.6	
Serine	1.1–5.0	2.2–5.4	5.0	5.2–5.4	5.7	5.4	7.6	
Threonine	1.0–4.3	2.4–4.2	5.2	4.0–4.7	3.8	3.2	5.1	3.4
Proline	0.8–4.3	2.5–4.4	4.5	2.5–4.7	4.9	4.3	4.2	
Alanine	0.1–4.7	2.5–4.6	5.2	3.5–5.4	4.2	5.8	5.9	
Glycine	0.9–4.3	2.2–4.6	4.4	3.5–4.6	4.0	4.5	3.3	
Valine	1.1–5.3	3.1–5	6.8	3.62–6.0	4.6	6.6	6.9	3.5
Cystine	Trace–0.9	Trace–0.9	6.1	1.1–6.4	1.7	1.2	5.9	
Methionine	Trace–1.2	Trace–3.8	0	0–1.5	1.2	2.6	3.4	2.5[i]
Isoleucine			5.3	3.4–5.1	4.6	4.3	6.3	2.8
Leucine	2.5–16[j]	8.6–13.8[j]	10	5.9–12	7.7	8.2	8.8	6.6
Tyrosine	0.8–3.3	2.2–4	4.0	2.6–4.1	3.4	3.7	4.2	
Phenylalanine	1.1–5.2	2.2–5.0	7.5	3.4–7.3	4.8	5.1	5.7	6.3[k]
Tryptophan	0.3–1.2	0.4–1.3	0	0–0.9	1.2	1.3	1.7	1.1
Lysine	1.3–6.8	4.3–6.1	13	4.9–15	6.1	3.7	7.0	5.8
Histidine	0.6–3.2	2.6–4.2	0	0–3.6	2.5	2.4	2.4	1.9
Arginine	1.1–5.6	3.4–5.1	2.8	3.4–4.1	7.1	7.7	6.1	

[a] Arora (1995), Bressani et al. (1987), D'Mello et al. (1985), D'Mello et al. (1988), D'Mello and Walker (1991), Kessler et al. (1990), Mohan and Janardhanan (1994), Novus (1994), Rajaram and Janardhanan (1992), and Siddhuraju and Becker (2001).
[b] Bressani et al. (1987), Ekanayake et al. (1999), Mohan and Janardhanan (1994), Rajaram and Janardhanan (1992), and Siddhuraju and Becker (2001).
[c] Arun et al. (2003).
[d] Arun et al. (2003) and Siddhuraju and Becker (2001).
[e] Bau et al. (1994).
[f] Livsmedelsverk (1988).
[g] Whole egg protein (FAO (1970)).
[h] FAO/WHO (1991) pattern
[i] Cystine + methionine.
[j] Isoleucine + leucine.
[k] Tyrosine + phenylalanine.

pha linolenic acid is converted into EPA and in turn DHA and is inhibited by linoleic acid (Emken, Adlof, & Gulley, 1994). The DHA is particularly important in infant nutrition (Oski, 1997). Seeds of *C. gladiata* and *C. ensiformis* are rich in essential fatty acids (linoleic and linolenic acid), which surpass *C. cajan* and *Glycine max* (Gupta, Rauf, Ahmad, Ahmad, & Osman, 1983; Mohan & Janardhanan, 1994; Siddhuraju & Becker, 2001). The PUFA of *Canavalia* spp. (71.1–77.6%) (*C.gladiata, C. ensiformis* and *C. cathartica*) also surpassed cowpea (68.1%), chickpea (67.1%) and broad bean (63.8%) (Siddhuraju & Becker, 2001). Low amounts of trans-fatty acids (elaidic and linoelaidic acids) are present in *Canavalia* spp. (Siddhuraju & Becker, 2001), which are responsible for an increase in low-density lipids and decrease in high-density lipids. Palmitic acid, oleic acid and linoleic acid of *C. gladiata* and *C. ensiformis*, and oleic acid are predominant fatty acids in *C. cathartica* and *C. maritima*, (Arun et al., 2003; Mohan & Janardhanan, 1994). Gupta et al. (1983) opined that *C. gladiata* should be considered as a potential minor oilseed.

6. Functional properties

Very little information is available on the functional properties of seeds of *Canavalia* spp. Functional properties of legume seed flours are essential for an advantageous utilization through various processing techniques. Raw seeds of *C. maritima* possess good water and oil absorption capacities, protein solubility (pH 12), foaming capacity (at increased concentration, addition of NaCl) and emulsion capacity (dependent on pH and salt concentrations) (Abbey & Ibeh, 1987). Raw *C. ensiformis* seed flours have better foaming capacity (20%) than germinated beans (6%) due to hydrolysis of germinated seed proteins by enzymes (Akpapunam & Sefa-Dedeh, 1997). Heat processing of seeds reduced foaming activity and stability of flours *C. ensiformis* (Akpapunam &

Table 6
Fatty acid compositions of seeds flours of *Canavalia* spp. (g 100 g^{-1})

Fatty acid	*Canavalia ensiformis*[a]	*Canavalia gladiata*[b]	*Canavalia maritima*[c]	*Canavalia cathartica*[d]
Saturated fatty acids				
Laurie acid ($C_{12:0}$)	0.12	0.17–0.21	–	0.20
Myristic acid ($C_{14:0}$)	0.51	0.55–0.72	–	0.90
Palmitic acid ($C_{16:0}$)	15.9–21.8	16.7–47.3	2.30	0–21.3
Stearic acid ($C_{18:0}$)	1.92–7.37	2.74–11	21.6	2.43–28.2
Arachidic acid ($C_{20:0}$)	0.83	0.76–0.78	–	0.75
Henicosanoic acid ($C_{21:0}$)	0.07	0.10–0.12	–	0.12
Behenic acid ($C_{22:0}$)	0.65	0.45–0.48	–	0.53
Tricosanoic acid ($C_{23:0}$)	0.16	0.14–0.15	–	0.22
Lignoceric acid ($C_{24:0}$)	1.68	1.19–1.53	–	1.66
Cerotic acid ($C_{26:0}$)	0.58	0.63–1.05	–	0.70
Polyunsaturated fatty acids				
Myristoleic acid ($C_{14:1}$)	0	0–0.16	–	0
Palmitoleic acid ($C_{16:1}$)	2.02–9.44	0–2.79	0	0–1.82
Heptadecenic acid ($C_{17:1}$)	0.11	0.25–0.31	–	0.27
Elaidic acid ($C_{18:1}$)	0	0	–	0.07
Oleic acid ($C_{18:1}$)	36.8–47.4	22.5–47.4	63.9	38.6–71.0
Linoleic acid ($C_{18:2}$)	11.6–18.0	10.7–16.4	11.9	0–24.8
Linolelaidic acid ($C_{18:2}$)	0.03	0–0.04	–	0.05
Linolenic acid ($C_{18:3}$)	6.62–13.3	6.56–8.49	0	0–3.54
Eicosenoic acid ($C_{20:1}$)	2.20	1.01–1.35	–	0.88
Eicosadienoic acid ($C_{20:2}$)	0.24	0.16–0.22	–	0.23
Eicosatrienoic acid ($C_{20:3}$)	0	0	–	0.04
Arachidonic acid ($C_{20:4}$)	0	0	–	0
Erucic acid ($C_{22:1}$)	0.18	0.17–0.18	–	0.09
Docosadienoic acid ($C_{22:2}$)	0.03j	0	–	0
Docosatetraenoic acid ($C_{12:0}$)	0.04	0.04–0.09	–	0
Docosapentaenoic acid ($C_{12:0}$)	0.45	0.63	–	0.68
Nervonic acid ($C_{12:0}$)	0.06	0.07–0.11	–	0.05
P/S ratio[e]	2.43–3.46	0.72–3.12	3.17	2.47–2.56

–, Not determined.
[a] Mohan and Janardhanan (1994) and Siddhuraju and Becker (2001).
[b] Mohan and Janardhanan (1994), Siddhuraju and Becker (2001), and Spoladore and Teixeria (1987).
[c] Arun et al. (2003).
[d] Arun et al. (2003) and Siddhuraju and Becker (2001).
[e] Ratio of polyunsaturated/saturated fatty acids.

Sefa-Dedeh, 1997), and also foaming activity and emulsion capacity of *C. maritima* (Abbey & Ibeh, 1987) due to the heat denaturation of the proteins. The protein solubility profile of raw seed flours of *C. ensiformis* and *C. maritima* did not project wide variation (Adebowale & Lawal, 2004; Abbey & Ibeh, 1987). Raw seed flours of *C. ensiformis* showed improved functional properties on employing various physicochemical parameters (gelation capacity at low ionic strength and addition of carbohydrates; water absorption capacity at ionic range 0–0.2 M NaCl; emulsion activity and stability at pH 10 and 2% w/v flour concentration; foaming capacity at pH 10, low ionic strength and 4% w/v flour concentration; foaming stability at pH 4, low ionic strength, and high flour concentration) (Adebowale & Lawal, 2004).

Functional properties of legume proteins except for soybean are scanty. Protein isolates of *C. ensiformis* have good nitrogen solubility (acidic and alkaline pH), water and oil holding capacities, while emulsion stability and viscosity were pH dependent (Chel, Perez, Betancur, & Davila, 2002). Fibrous residues of *C. ensiformis* seeds have high emulsifying activity, low emulsifying stability and high water holding capacity (Betancur, Peraza, Moguel, & Fuertes, 2004). Succinylated *C. ensiformis* seed starch has improved paste and gel clarity, solubility, swelling capacity and viscosity (Betancur, Garcia, Cañizares, & Chel, 2002). Starch of *C. ensiformis* seeds has poor cooked paste properties due to ratio of amylose/amylopectin fractions, types and quantities of lipids, proteins and salts (Akpapunam & Sefa-Dedeh, 1997).

7. Antinutritional features

Raw seeds of *Canavalia* spp. consist of antinutritional factors (ANF) such as phenolics, tannins, saponins, cyanogenic glycosides, concanavalin A, canavanine and hydrogen cyanide (Table 7). Most of the legume ANFs are heat-labile. The major ANFs in legumes include: protease inhibitors, lectins, goitrogens, antivitamins, phytates, saponins, estrogens, flatulence factors, allergens and lysinoalanine (Liener, 1981). Heat-stable ANFs (e.g., phytate and polyphenols) are not eliminated by simple soaking and heating, but through germination or fermentation. Nowadays, some of the ANFs (e.g., tannins) are of much interest due to antioxidant activity as a potential health benefit.

7.1. Concanavalin A

Concanavalin A (Con A) is the most studied plant lectin, it was first isolated and crystallized by Sumner and Howell (1936). *C. ensiformis* seeds are the natural source of Con A (Merck, 1989). Con A represents 20% of the total proteins of the seeds (Dalkin & Bowles, 1983) and is the most widely explored lectin as a biochemical reagent due to its ease of isolation, purification and availability of a great variety of molecules with which it can interact. Con A exists in two conformations (locked and unlocked) that differ in their metal ion and saccharide binding properties (Brown, Koenig, & Brewer, 1982). In the presence of excess metal ions (e.g., Mn^{2+} and Ca^{2+}), Con A (100%) are bound tightly to the metals and associated with saccharide (locked) and the reverse condition of Con A is the unlocked conformation. Con A is specific for the monosaccharides such as D-mannose and D-glucose (Liener, 1974). Immunological and peptide mapping studies of Con A and Con A-like lectin (α-D-glucoside and α-D-mannoside) of *C. ensiformis* showed a close structural relationship and is inversely related in relative abundance at different stages of seed development (Raychaudhuri & Singh, 1986).

Synthesis of Con A and canavalin (a major storage protein and modified form of the enzyme α-D-mannosidase) initiates after 30 days of flowering (Yamauchi & Minamikawa, 1986, 1987). Accumulation of canavalin was active at 30–50 days after flowering and Con A increases until seed maturation (80 days of flowering). Con A is synthesized as pro-Con A (glycosylated precursor), it will be processed by the excision of a small glycosylated from the center of pro-Con A and the ligation of two polypeptides (Faye & Chrispeels, 1987). The processing is complex with intermediate-sized polypeptides appearing at different phases of development of cotyledons. In *C. ensiformis*, the key step of conversion of Con A into an active lectin is by the removal of N-glycan from it which is catalyzed by N-glycanase (Sheldon, Keen, & Bowles, 1998). The largest amounts of functional mRNA for Con A and α-D-mannosidase are found in the early stages of seed development, i.e., before the period of highest protein deposition, indicating slow post-translational modification of these proteins which is distinct from other legumes (Raychaudhuri, Nayogim, & Singh, 1987).

Con A is present in cultured tissues of isolated embryos and cotyledons of *C. ensiformis* (90 days), but it was absent in root cultures, hence, tissue culture can be an important research tool to study biosynthesis of Con A (Sato et al., 1993). Tissue cultures obtained from embryos or cotyledons of *C. cathartica* were investigated for lectin biosynthesis (Jayavardhanan, Padikkala, & Panikkar, 1996). In *C. cathartica*, lectin was present in all the callus cultures except in the roots and the callus derived from the cotyledon of immature seeds exhibited the largest concentration. In mature seeds of *C. ensiformis*, Con A was present in protein-storage vacuoles of parenchyma cells and during seed development it was localized in the endoplasmic reticulum and Golgi apparatus (Herman & Shannon, 1984). Con A-like lectin was

Table 7
Antinutritional components of seed flour of *Canavalia* spp.

Component	*Canavalia ensiformis*[a]	*Canavalia gladiata*[b]	*Canavalia maritima*[c]	*Canavalia cathartica*[d]
Total phenolics (mg 100 g^{-1})	730–1818	640–710	1400	1500–1552
Tannins (mg 100 g^{-1})	0–900	0–230	0	0–5800
Condensed tannins (mg 100 g^{-1})	0	Trace	–	0
Saponins (mg 100 g^{-1})	571	813–1005	–	852
Cancanavalin A (mg 100 g^{-1})	1500–3500	–	–	–
Canavanine (mg 100 g^{-1})	2500–5100	2637–3060	–	2860–3270
L-DOPA (mg 100 g^{-1})	2460–2630	2130–3010	–	4300
Hydrogen cyanide (mg 100 g^{-1})	0–11.2	5–109.3	–	13
Phytic acid (mg 100 g^{-1})	0–2800	0–868	–	478–1100
Phytin (mg 100 g^{-1})	18.5	–	–	–
Phytin phosphorus (mg 100 g^{-1})	5.22	–	–	–
Trypsin inhibition activity (mg g^{-1})	0.022–6.3	8.85–10.22	0	0–5.26
Unit g^{-1}	12.4			
Chymotrypsin inhibition activity	1.26	2.2–3.48	–	0.5
Unit mg^{-1}				
Alpha-amylase inhibition activity	0	0	–	–
Unit g^{-1}				3.77
Phytohemagglutinin activity				
Cattle RBC (HU mg^{-1})	163	161–164	–	163
Human RBC (A)	+ (Alb)	0, + (Alb)	–	–
	+ (Glo)	+, ++ (Glo)		
Human RBC (B)	+ (Alb)	+ (Alb)	–	–
	+ (Glo)	+, ++ (Glo)	–	–
Human RBC (O)	+ (Alb)	+ (Alb)	–	–
	+ (Glo)	+, ++ (Glo)	–	–
HU mg^{-1}	40.6	80.5–81.9	–	40.8
Rabbit RBC	++	–	+++	+++
HU mg^{-1}	4.0			

-, Not determined.
+, ++, +++, Extent of RBC clumping.
[a] Agbede and Aletor (2005), Akpapunam and Sefa-Dedeh (1997), Babar et al. (1988), Belmar et al. (1999), Mohan and Janardhanan (1994), Rajaram and Janardhanan (1992), Rodrigues and Torne (1992), and Siddhuraju and Becker (2001).
[b] Laurena et al. (1994), Mohan and Janardhanan (1994), Okolie and Ugochukwu (1989), Rajaram and Janardhanan (1992), Rodrigues and Torne (1992), Siddhuraju and Becker (2001), and Thangadurai et al. (2001).
[c] Arun et al. (2003).
[d] Arun et al. (2003), Rodrigues and Torne (1992), and Siddhuraju and Becker (2001).

detected in large amount in tissues of cotyledons and embryos of *C. gladiata*, while only in minor quantities in epicotyls and hypocotyls (early stage), and it declined in cotyledons with growth (Ghosh, Dasgupta, & Sircar, 1985). The seeds of *C. ensiformis* contain lectin-binders associated to respective lectins, of which Con A binder appears in the roots during germination and growth (Gansera, Schurz, & Ruediger, 1979). Marcus, Burgess, Maycox, and Bowles (1984) opined that several molecular forms of lectins occur during the development of the *C. ensiformis* seedling.

Siddhuraju and Becker (2001) observed that all the *Canavalia* spp. were found to have high hemagglutination activity against cattle and human erythrocytes. Compared to seeds of *C. gladiata*, 50% reduction of agglutination was noted in *C. ensiformis* and *C. cathartica* against human erythrocytes. The minimal concentration of *C. maritima* lectin which agglutinate rat blood cells was 4 μg ml^{-1} and the saccharide binding specificity of this lectin is similar to that of Con A in *C. ensiformis* (Su, Chen, & Tung, 1980). Mohan and Janardhanan (1994) showed that the globulin seed fraction of *C. gladiata* strongly agglutinated all types of human erythrocytes as in the case of *Entada scandens* and *Alysicarpus rugosus*, but albumin weakly agglutinated A and O blood groups. However, albumin and globulin of seeds of *C. ensiformis* exhibited only a weak agglutination with no blood group specificity as in *Dolichos lablab*, *Psophocarpus tetragonolobus*, *P. scandens* and *Vigna sesquipedalis* (Mohan & Janardhanan, 1994). Lectins of *Canavalia* spp. also exhibited a strong agglutination activity against rabbit RBC (Table 7). Agglutinin activity of *C. gladiata* seeds can be detected by a hemagglutinin assay using trypsinized erythrocytes and by a binding assay with horseradish peroxidase (Kojima, Ogawa, Seno, & Matsumoto, 1991). The latter method could become a method of choice as it determines agglutinins at 50–500 mg ml^{-1} concentrations. The agglutination studies indicated that lectins of *C. gladiata* has sugar-binding specificities similar to Con A. The amino acid sequences of major lectins of *C. maritima* derived from proteins after enzymatic digestion with trypsin,

chymotrypsin and protease from *Staphylococcus aureus* were found to be very similar (91%) to Con A of *C. ensiformis* (Perez, Perez, Sousa, Moreira, & Richardson, 1991), and also lectins of *C. maritima* and *C. cathartica* studied by Fujimura, Terada, Jayavardhanan, Panikkar, and Kimoto (1993).

Binding of Con A to mucosal glycolipids of the digestive tract (Jaffe, 1980) inhibits the activity of brush border enzymes of enterocytes (Rosenthal, 1972), interferes with the enterobacterial adherence to intestinal wall (Jayne-Williams, 1973), and exerts side effects on immune functions, protein metabolism, enzyme activity and hormonal regulation (Putsztai, 1989). Purified lectin of *C. maritima* is mitogenic for human peripheral blood mononuclear cells (Karnboj et al., 1992). On offering rats a Con A containing diet, food rejection was a common feature. The gastric incubation studies hypothesized food rejection could be due to binding of Con A to the glycosylated molecules of the gut membrane impairing food intake and absorption (Larue, Picard, & Louis, 1992). Con A also induces severe reduction in food intake by non-ruminants (Liener, 1953). The dose response curves of food intake by young chicks projected a linear decrease up to 0.85% con A (Léon, Caffin, Plassart, & Picard, 1991). This is associated with the hemagglutinating and carbohydrate binding capacity involving glycosylated proteins and lipids of the gut cells. Feeding of raw seed diet of *C. ensiformis* containing Con A (24 g kg^{-1}) to broiler chicks resulted in endocytosis due to binding of Con A to intestinal villi (Mendez, Vargas, & Michelangeli, 1998). Feed intake and body weight were reduced by the diet containing 10% raw *C. ensiformis* seeds indicating broiler chicks can tolerate daily intake of 100 mg Con A over 6 weeks without affecting growth. On administration of 20 mg *C. ensiformis* Con A, caused intensive scaling of the apical portion, ulceration and necrosis of villi of Wistar rats (DeOliveira, Vidal, & Sgarbieri, 1989).

Con A from *C. ensiformis* has a wide range of applications (e.g., antiviral, mitogenecity, isolation of immunoglobulins, blood group substances and glycoprotein hormones) (Surolia, Prakash, Bishayee, & Bachhawat, 1973). Con A is a potential molecule to be considered for tumor therapy by immunomodulation (Ruediger & Gabius, 2001). Lee and Damjanov (1984) provided a detailed map of *C. ensiformis* Con A-binding sites in the mouse testis and epididymis. Hence, lectins can be used as specific markers of spermatogenic cells and epididymal segments. Histological observations of normal and pathologically altered human peripheral nerves through fluorescein isothiocyanate labeled Con A provides baseline data of the reaction pattern of lectins with human peripheral nerves and thereby Con A can be a tool to study peripheral nerve pathology (Estruch & Damjanov, 1986). Con A histochemistry is a reliable tool to study structural and secretary glycoconjugates of jejunal mucosa and is useful in the study of diseases related to cell maturation cycle of small bowel (Vecchi et al., 1987). Con A may be used 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 a more uniform distributions of carbohydrates than normal mucosa which was found by employing Con A of *C. ensiformis* (Caldero et al., 1989). Con A shows distinct binding patterns in different nerve structures and can be used to reveal heterogeneity in sugar residues of glycoconjugates within neural and vascular components of nerves. Thus, it is useful in detecting changes in glycoconjugates during nerve degeneration and regeneration after trauma or pathological states (Gulati, Zalewski, Sharma, Ogrowsky, & Sohal, 1986). Rodrigues and Torne (1990c) suggested that seed lectins of *C. gladiata* can be used as an anti A, anti B, while lectins of *C. cathartica* as anti O and anti Oh (Bombay group) blood grouping reagents. Mannose-binding lectins (Con A) are useful in creating transgenic plants resistant to insect herbivory (Sauvion, Charles, Febvay, & Rahbe, 2004). Lectins provide protection against fungi (Ensgraber, 1958), mediation of sugar storage and transport (Ensgraber, 1958; Sumner & Howell, 1936), control of cell division during germination (Sharon & Lis, 1972) and influence the entry of rhizobia into the root cortex (Bohlool & Schmidt, 1974; Hamblin & Kent, 1973).

Seeds of *C. ensiformis* also possess another lectin known as concanavalin B (33.8 kD) constituting 0.9% of the total seed protein (Schlesier, Nong, Horstmann, & Hennig, 1996) and shows 40% sequence identity with plant chitinases belonging to glycosyl hydrolase family devoid of chitinase activity (Hennig, Jansonius, Terwisscha, Dijkstra, & Schlesier, 1995).

7.2. Canavanine and canaline

Non-protein toxic amino acid, L-canavanine (2-amino-4-guanidinooxy-butyric acid) (Cav) an analog of L-arginine (2-amino-5-guanidinovaleric acid) (Rosenthal, 1991) is stored in the seeds of many leguminous plants (Lavin, 1986). Cav is naturally abundant in seeds of *C. ensiformis*, *C. gladiata* and *C. cathartica* and can be commercially exploited for extraction (Rodrigues & Torne, 1992). Cav of *Canavalia* spp. ranges from 2500 to 5100 mg 100 g^{-1} (Table 7). The Cav was first isolated from *C. ensiformis* seeds by Kitagawa and Tomiyana (1929). It constitutes about 26.5–50 g kg^{-1} of dry weight of seeds of *C. ensiformis* (Natelson, 1985; Rosenthal, 1972) and is thermostable (melting point, 184 °C) (Merck, 1989). Cav and arginine in *C. maritima* accounts for 30% and 5% of total free amino acids, respectively, and are located in the vacuoles (Yu & Kwon, 1992). Cav is cleaved into canaline (Can) (a natural poisonous product) by arginase and detoxified by the for-

mation of a stable oxime between Can and glyoxylic acid in *C. ensiformis* (Rosenthal, Berge, & Bleiler, 1989). Analysis of arginase (L-arginine amidinohydrolase) from mitochondria of *C. ensiformis* revealed that arginine-dependent and Cav dependent activities (ADA and CDA) were localized within it (Downum, Rosenthal, & Cohen, 1983). It has been revealed that a single macromolecule appears to be responsible for both ADA and CDA of arginase of *C. ensiformis*. The Cav administered plants had a similar degradation patterns to those of Can administered plants indicating the importance of arginine-mediated hydrolysis of Cav to Can during Cav metabolism (Rosenthal et al., 1989).

The enzyme, carboxymethyltransferase (109 kD), an isoform of ornithine isolated from leaves of *C. maritima*, utilizes Can as a substrate (Lee & Kwon, 2000) and plays an important role in Can biosynthesis. Cav and Can metabolism revealed that they were synthesized by homoserine. The Cav metabolism is similar to the mammalian Krebs–Henseleit ornithine–urea cycle (Rosenthal, 1982). Studies conducted on the utilization of carbamoylphosphate by seedlings of *C. ensiformis* implied biosynthesis of Cav from Can via the *O*-ureido-L-homoserine pathway constitutes an important in vivo route of Cav production. Cav cleavage to Can is a degradative phase and there is no evidence for the reutilization of Can in ureidohomoserine formation.

The callus of *C. maritima* grown in light (green callus) showed Cav and Can, but only Can was detected in callus grown in darkness (white callus) (Hwang, Kim, & Kwon, 1996a). Supplementation of Can to suspended green callus cells resulted in *de novo* synthesis of Cav. Exogenous supply of Cav to white callus cell suspensions resulted in synthesis of Can and homoserine. Hwang, Lee, Kim, Lee, and Kwon (1996b) concluded that Cav synthesis is controlled by the coordination of ornithine cabamyltransferase, argininosuccinate synthetase and argininosuccinate lyase. Rosenthal, Berge, Ozinskas, and Hughes (1988) demonstrated that Cav functions as nitrogen storing metabolite in seeds of *C. ensiformis*. When L-(guanidiooxy) Cav was injected into a fresh green cotyledon of 9-day old *C. ensiformis* seedlings, it was transported from the cotyledons to the shoots (but not the roots) and was divided uniformly in 90 min (Rosenthal & Rhodes, 1984). Hence, Cav plays an important role in nitrogen storage within the developing cotyledons. Cav shows plant-inhibitory effect and was demonstrated by an immersion test and a microdrop test that employed rice seedlings (Nakajima, Hiradate, & Fujii, 2001).

The Cav in seeds of *C. ensiformis* was reported to disappear during germination (Bell, 1960; Nakatsu, Matsuda, Sakagami, Takahashi, & Yamatato, 1996; Rosenthal, 1970). During inhibition and germination of seeds, Cav is mobilized and released into the rhizosphere (Rosenthal, 1990). However, Esonu (1996) demonstrated that *C. ensiformis* seeds exhibit strong effects in chicks even after sprouting and prior to heating. During germination of *C. ensiformis* seeds in light and dark only minor changes in amino acids were determined, the Cav of seeds declined slightly during germination and reached the lowest value after 24 h of germination in the dark (D'Mello, Walker, & Acamovic, 1988). Obizoba and Obiano (1988) and D'Mello and Walker (1991) demonstrated that Cav solubilizes in water and converts to non-toxic cyclic deaminocanavanine on heating (Rosenthal, 1977).

The mechanism of inhibition of Cav is closely related to the inhibition of arginine metabolism. The Cav replaces arginine in proteins resulting in aberrant macromolecules of reduced activity (Crine & Lemieux, 1982) and causes deleterious biological effects in those organisms that are sensitive to Cav (Rosenthal, Berge, Bleier, & Rudd, 1987). Poultry can catabolize Cav because of the presence of arginase in the kidney and liver (D'Mello, 1989). The biological effects of Cav include reduction of protein and glycoprotein synthesis, inhibition of alkaline phosphatase activity and RNA synthesis (Rosenthal, 1977). The structural similarity of Can to ornithine allows it to react with pyridoxal phosphate moiety of B6-containing enzyme to form covalently bonded Schiff base, thus, Can inhibits pyridoxal phosphate-dependent enzymes (Rosenthal, 1981) by competing with ornithine in the arginine urea cycle or by complex formation with pyridoxal-phosphate cofactor (Acamovic, 1987). The Can reductase (~167 kD) isolated and purified from 10-day old leaves of *C. ensiformis* performs three important functions: detoxification of Can, increment of one-half of overall yield of ammoniacal nitrogen release from Cav and permitting carbon skeleton of Cav to support vital metabolic reactions (Rosenthal, 1992a).

The Cav incorporation in diets of growing chicks depressed feed intake and growth (~25%) than control diet (Michelangeli & Vargas, 1994). The Cav exerts growth depression exclusively by reduction in feed intake. Although Cav is not the principal antinutritional factor in *C. ensiformis* seeds, its presence in the diet precludes optimum growth performance of chicks. Seeds of *C. ensiformis* fed to sheep resulted in a decrease of ammonia and valerate concentrations in the rumen and an increase in the relative proportion of Gram-negative rumen bacteria (Dominguez & Stewart, 1990). However, studies with Can suggested that it was not responsible for the shift in the rumen microbial population. Cav is toxic against viruses (Robertson, Bates, & Stout, 1984), microorganisms and insects (Rosenthal, 1988, 1992b). On feeding larvae of *Spodoptera* with castor leaves sprayed with Cav (50–1000 mg kg^{-1}) extracted from *C. ensiformis*, growth was seen until pupation (30 days), thereafter (first instar larvae) growth was retarded (Koul, 1985). Feeding of Cav-treated food

(1000 mg kg^{-1}) to third instar larvae reduced growth rate significantly. The Cav of *C. ensiformis* causes antifertility in *Periplaneta americana* with no significant effects on body weight and food intake (Koul, 1983).

The Cav showed antitumor activity against Walker carcinoma, human melanoma, pancreatic cancer (Kruse & McCoy, 1958; Mattei, Damasi, Mileo, Delpino, & Ferrini, 1992; Swaffar, Ang, Desai, & Rosenthal, 1994), in vivo murine leukemia and rat colon tumors (Green, Brooks, Mendelsohn, & Howell, 1980; Thomas, Rosenthal, Gold, & Dickey, 1986). The Cav is suitable for pancreatic cancer studies due to lack of considerable amount of arginase in the pancreas (Swaffar & Ang, 1999).

7.3. Canatoxin

Carlini and Guimaraes (1981) isolated canatoxin, a neurotoxic protein from the seeds of *C. ensiformis*. It is also present in most of the leguminous seeds except for peanuts and castor (Carlini, Barcellos, Baeta, & Guimaraes, 1988). Canatoxin is a covalently linked dimer polypeptide (95 kD) possessing zinc and nickel (Follmer et al., 2001), whose internal peptides share homology with urease of *C. ensiformis*, but are unrelated to urease activity. Canatoxin (LD_{50}, 2 mg kg^{-1}) is immunologically related to soyatoxin (LD_{50}, 7–8 mg kg^{-1}) and is lethal to mice as well as insects (Vasconcelos, Trentim, Gulmaraes, & Carlini, 1994). Canatoxin in the crude extract of *C. ensiformis* seeds induced dyspnea, ataxia, hypothermia, coma, tonic convulsions and death in mice when administered intraperitoneally (100–200 mg toxin kg^{-1}) (Carlini & Guimaraes, 1981; Carlini, Oliveira, Azambuja, Xavier, & Wells, 1997). However, Carlini and Guimaraes (1991) hypothesized that canatoxin from *C. ensiformis* seeds is unstable at acidic pH of the stomach and is therefore not an antinutritional factor. The pharmacological and toxicological effects of canatoxin in mice and rats resulted in lethal tonic convulsion after 10–15 min of intravenous injection (pure toxin, 2–3 mg kg^{-1}) (Carlini et al., 1984). The CNS was found to be the site of action but mode remains unexplained. It also causes in vitro aggregation of platelets in rabbits, human and guinea pigs (Carlini, Guimaraes, & Ribeiro, 1985), biphasic alteration in blood glucose level when injected intravenously into rats and mice (Ribeiro, Carlini, Pires, & Guimaraes, 1986) and release of insulin from isolated rat pancreatic islets (Barja, Guimaraes, & Carlini, 1991; Enyikwola, Addy, & Adoga, 1991). Canatoxin inhibits DNA synthesis, produces a cytolytic effect (0.050–0.500 μM) to various cells in vitro (Campos, Carlini, Guimaraes, Marques, & Rumjanek, 1991), induces lipoxigenase-dependent hypoxia in rats (Ribeiro, Prado, Collaresm, & Siste, 1992), serotonin release from rabbit platelets and rat brain synaptosomes (Barja et al., 1991), induction of dose-dependent rat hind–paw oedema (Alves, Ferreira, Ferreira, & Carlini, 1992), inhibition of Ca^{2+} accumulation catalyzed by Ca^{2+} ATPase and neutrophile migration in rats (after 4 h) on intraperitoneal injection of canatoxin (Ghazaleh, Araujo, Barja, & Carlini, 1992). Canatoxin is also highly toxic to some species of insects dependent on cathapsin-based digestion (Ferreira, Gombarovits, Masuda, Oliveira, & Carlini, 2000), because of its characteristic digestive correlation (Carlini et al., 1997).

7.4. Polyphenols and polyamines

Polyphenols are known to complex with iron, which renders iron unavailable for absorption (Brune, Rossander, & Hallberg, 1989; Hurrel, Reddy, & Cook, 1999). About 1.3% of polyphenols have been reported in *Canavalia* spp. Germination of *C. ensiformis* seeds (40 h) results in a decrease of 35% polyphenols (Babar, Chavan, & Kadam, 1988). Total phenolics of *Canavalia* spp. ranges from 640 to 1818 mg 100 g^{-1} (Table 7). As in most legumes, *C. gladiata* seeds have lower levels of condensed tannins (0–2.48 catechin g^{-1}) and protein precipitable polyphenols (0.16–0.77 mg tannic acid g^{-1}) (Laurena, Rivilleza, & Mendoza, 1994). Among the various *Canavalia* species assessed by Siddhuraju and Becker (2001), the total phenols of the red seed variety of *C. gladiata* (1.82%) is higher than brown-seeded *C. gladiata* (1.53%) and *C. cathartica* (1.55%) and comparable to faba bean and higher than cultivated legumes. Tannins were absent in brown-seeded *C. gladiata* and *C. ensiformis* unlike red-seeded *C. gladiata* and *C. cathartica*. Tannins were also absent in *C. maritima* and *C. cathartica* of the coastal sand dunes (Arun et al., 2003). Rajaram and Janardhanan (1992) reported very low amounts of total free phenols and tannins in seeds of *C. ensiformis* and *C. gladiata*. The total free phenols of *C. ensiformis* and *C. gladiata* seeds are lower than other wild legumes (*V. sesquipedalis*, *V. sinensis*, *V. umbellata* var. RBL 40, var. K1 and *Phaseolus lunatus*) (Mohan & Janardhanan, 1994).

The polyamines viz., sym-homospermidine (*C. gladiata* root nodules) and canavalamine (senescent nodules) were found in *Canavalia* spp., but absent in other leguminous crops (Fujihara, Nakashima, Kurogochi, & Yamaguchi, 1986). Canavalamine appeared in the immature seed and its concentration increased as seed formation progressed (Matsuzaki, Hamana, Okada, Niitsu, & Samejima, 1990). Aminopropyl and aminobutyl (novel pentaamines) derivatives of canavalamine were detected in *C. gladiata*.

7.5. Protease inhibitors

Trypsin and chymotrypsin inhibitors reduce protein digestibility and induce pancreatic hypertrophy (Liener,

1976). They form stable complexes with trypsin and chymotrypsin (1:1 M ratio) obstructing their binding sites and disrupting enzymatic action. Orru and Demel (1941) reported trypsin inhibitors in *C. ensiformis* seeds for the first time. The trypsin and chymotrpisin activities of *Canavalia* spp. ranged from 0.022 to 10.22 mg g^{-1} and 0.5 to 3.48 unit mg^{-1}, respectively (Table 7). Rajaram and Janardhanan (1992) reported low levels of trypsin inhibitors in *C. ensiformis* and *C. gladiata*. Three novel chymotrypsin inhibitors were isolated and sequenced by Terada, Fujimura, Kino, and Kimoto (1994) from *C. maritima* seeds. Heat-stable and pH stable (pH 2 and 11) protease inhibitor of *C. ensiformis* seeds is active against bovine and porcine trypsins (Kumari & Pattabiraman, 1990) and was effective in blocking proteolytic, tryptic and chymotryptic activities of rabbit pancreas. Among the *Canavalia* spp. studied (Siddhuraju & Becker, 2001), trypsin inhibitor activity of red-seeded *C. gladiata* was higher than brown-seeded *C. gladiata*, *C. ensiformis*, and *C. cathartica* and was comparable to lima bean, lablab bean and lower than soybean. Chymotrypsin inhibitor activity in *C. ensiformis*, *C. gladiata* and *C. cathartica* seeds was lower than important food legumes, field beans and comparable to *C. arietinum* (Siddhuraju & Becker, 2001). Seed germination in *C. ensiformis* is known to decrease trypsin inhibitors (Akpapunam & Sefa-Dedeh, 1997). The α-amylase inhibitor activity was absent in all *Canavalia* spp. except for *C. cathartica* (Siddhuraju & Becker, 2001) and was lower than *Vicia faba* and *Phaseolus vulgaris*. Lorenzo, Tovar, Pinelli, and Seidl (1989) reported variety- and species-specific subtilisin inhibitors from *C. ensiformis*.

7.6. Phytates and cyanides

Legume seeds constitute 1–3% of phytate (or inositol hexaphosphate) and are dependent on species, cultivars, climatic conditions, soils, locations, seasons and seed germination. It is necessary to select those landraces possessing low amounts of phytate for consumption. Phytates reduce the uptake of essential dietary minerals such as iron, zinc and calcium in the human intestine (Brune, Rossander-Hulthén, Hallberg, Gleerup, & Sandberg, 1992; Hallberg, Brune, & Rossander, 1989; Onuegbu, Zibokere, Chinah, & Ukata, 1993). Vitamin C counteracts the inhibitory effect of phytate as it is an iron absorption enhancer (Siegenberg et al., 1991). Green pods of *C. gladiata* are rich source of vitamin C (Daloz, 1988) and phytates of seeds of *Canavalia* spp. (0.48–1.092%) were within or lower than many legumes (Siddhuraju & Becker, 2001).

Cyanide is an antinutritional component in leguminous seeds that can be eliminated by soaking and removal of testa prior to boiling. Seeds of *C. gladiata* have 50 μg g^{-1} as in most legumes (Laurena et al., 1994). However, Okolie and Ugochukwu (1989) reported cyanide up to 1093, 285, 953 mg kg^{-1} in dry seeds, testa and cotyledons of *C. gladiata*. Hydrogen cyanide of raw seeds of *C. ensiformis* and *C. cathartica* is 0–11.2 and 13 mg 100 g^{-1} (Table 7). Soaking (24 h) and boiling (3 h) reduces cyanide tremendously in cotyledons (Okolie & Ugochukwu, 1989). Similarly, germination was effective in considerable reduction of hydrogen cyanide (49.1%) (Akpapunam & Sefa-Dedeh, 1997).

7.7. Saponins, urease and L-DOPA

Saponins consist of a steroidal or triterpene aglycone attached by ester- or ether-linked bonds to one or three variably sized saccharide chains. It causes erythrocyte hemolysis, reduction of blood and liver cholesterol, growth depression, bloat, inhibition of smooth muscle activity and reduction in nutrient uptake (Cheeke, 1971). Saponins like lectins, bind to the cells of the small intestine affecting nutrient absorption across the intestinal wall (Johnson, Gee, Price, Curl, & Fenwick, 1986). Oakenfull, Topping, Illuman, and Fenwick (1984) reported cholesterol-lowering effects in animals and humans by the formation of micelles and bile acids into micellar bile acid molecules by saponins. The concentration of saponins varies among the *Canavalia* spp. (571–1005 mg 100 g^{-1}) (Table 7), possibly due to different cultivars belonging to different geographical locations. Price, Curl, and Fenwick (1986) reported that seeds of *C. ensiformis* are devoid of saponins, while Acamovic (1987) and Belmar and Morris (1994) reported their presence. However, saponins in *Canavalia* spp. are less than in chickpea and soybean (Siddhuraju & Becker, 2001). Saponins are recently shown to have hypocholesterolemic as well as anticarcinogenic effects (Koratkar & Rao, 1997), hence exploration of neutraceutical properties of *Canavalia* spp. are warranted.

Seeds of *C. ensiformis* are a commercial source of urease (EC 3.5.1.5; 489,000 kD), which catalyzes hydrolysis of urea to ammonia, carbon dioxide and water (Dixon, Riddles, Gazzola, Blakeley, & Zerner, 1980; Rosenthal, 1974; Staples & Reithel, 1976). Urease is present in the cytosol of the storage parenchyma cells of *C. ensiformis* cotyledons (Faye, Greenwood, & Chrispeels, 1986). As it is heat-labile, it can be easily removed from *Canavalia* seeds by thermic treatments.

Concentration of non-protein amino acid, L-DOPA (3,4-dihydroxy phenylalanine) of seeds of *Canavalia* spp. were relatively low to moderate (2130–4300 mg 100 g^{-1}) (Table 7) compared to *Mucuna* spp. L-DOPA is a neurotoxic agent used in the treatment of Parkinson's disease (Bell & Janzen, 1971). However, it can result in hallucinations, dyskinesias and gastrointestinal disturbances (Prada, Keller, Pieri, Kettler, & Haefely, 1984).

8. Processing and detoxification

Seed processing techniques such as soaking, germination, hydrothermal processing and fermentation increase cereal and legume enzyme activity. For instance, seed germination results in activation or synthesis of phytase, similarly, lactic acid fermentation is favorable for cereal phytase activity (Sandberg, 2002). Improved nutritive value of legume seeds by thermic treatments was first demonstrated by Osborne and Mendel (1917). Moist heat proved to be more effective than dry heat to inactivate hemagglutinins (pressure-cooking, 45 min) and trypsin inhibitors (pressure-cooking, 30 min) of *C. ensiformis* seeds (Carlini & Udedibie, 1997). Cracking of *C. ensiformis* seeds (3–7 pieces per seed) prior to cooking is the most effective means to totally eliminate hemagglutination activities (cooking, 1 h; pressure-cooking, 15 min) (Udedibie & Carlini, 1998b). However, cooking (2 h) or pressure-cooking (45 min) is effective in elimination of hemagglutination activity in whole seeds. Cooking and germination of seeds of *C. ensiformis* reduced trypsin inhibition activity to 38% and 12%, respectively (Akpapunam & Sefa-Dedeh, 1997). Germination of *Phaseolus vulgaris* seeds also showed similar results (Sathe, Deshpande, Reddy, Goll, & Salunkhe, 1983). Soaking (24 h) followed by cooking (20 min) destroyed trypsin inhibitors in seeds of *C. ensiformis* (Babar et al., 1988). However, prolonged cooking (3 h) of seeds of *C. ensiformis* resulted in toughening and unpleasant odor (Akpapunam & Sefa-Dedeh, 1997).

The in vitro starch digestibility of dry-autoclaved cotyledons of *C. gladiata* flours exhibited improved digestibility and weight gain in rats (Ekanayake et al., 2000b). Ekanayake et al. (2000b) found low protein digestibility and biological value on using *C. gladiata* seeds as a diet in rats. This necessitates further exploration of the effect of different processing methods on protein availability of *C. gladiata* seeds. Kessler, Belmar, and Ellis (1990) studied 1–8 or 5–8 weeks of growth period of chicks on offering commercial and thermally treated seeds of *C. ensiformis*. Reduction in growth rate (35–55%), feed intake and conversion efficiency; enlargement of pancreas and liver was evident on feeding chicks with 300 g kg^{-1} of autoclaved (30 or 60 min) seeds of *C. ensiformis*. Thus, alternate methods other than autoclaving of seeds are recommended for employing *C. ensiformis* seeds as chick feed.

Seeds of *C. ensiformis* processed in various ways have been employed in chick diets (300 g kg^{-1}) by Belmar and Morris (1994). Boiling is a satisfactory method for the inactivation of heat-labile lectins, soaking and shaking were effective in reducing Cav and hemolytic activity of saponins in *C. ensiformis* (Belmar & Morris, 1994). Chicks fed with boiled seeds (1 or 2 h) showed 50% weight gain compared to control diets, while combination of boiling followed by soaking and shaking of seeds was successful in removal of most of the antinutritional factors. However, residual toxic effects persisted in the processed seeds and caused a decline of 10% feed intake and growth rate. Rats (45–50 g, 21 days) fed with raw seeds of *C. gladiata* indicated low biological value and true digestibility and low liver, thymus and thyroid weights (Aguirre, Savon, Oramas, Dihigo, & Rodriguez, 1998). The highest protein nutritional quality of *C. gladiata* seed flours and grits was obtained by cooking or soaking and cooking (Ekanayake, Nair, Jansz, & Asp, 2003). One day soaking of *C. ensiformis* seeds prior to cooking (20 min) ensured complete inactivation of trypsin inhibitors (Babar et al., 1988). Therefore trypsin inhibitors are of little antinutritional consequence if the seeds are adequately heated.

The improvement of nutritive value of *C. ensiformis* by toasting of seeds was first reported by Borchers and Ackerson (1950). Toasted seeds of *C. ensiformis* (3 vs. 24 min, 190 °C) resulted in improvement of chick response vs. duration of toasting. Whole seeds of *C. ensiformis* roasted at various conditions completely diminished hemagglutination activity (Melcion et al., 1998). Léon, Vargas, Michelangeli, and Melcion (1998) demonstrated that roasting of seeds of *C. ensiformis* destroys the antinutritional factors without adverse effects on the biological value. Seeds of *C. ensiformis* consist of oligosaccharides that cause flatulence, rectal gas discharge, stomach crumbling, diarrhoea and nausea (Babar et al., 1988). Oligosaccharides of *C. ensiformis* seeds (1.8%) were eliminated by roasting (2 min) and there was a 30–40% reduction after germination (1–2 days) (Revilleza et al., 1990). Animal experiments were carried out on variously roasted seeds of *C. ensiformis* using chicks (acceptability test) and adult cockerels (nitrogen balance, true nitrogen digestibility) by Léon et al. (1990). The best results in relation to feed intake were obtained at roasting temperature 164–168 °C (medium) or 180–190 °C (high) for 24–26 min, which was attributed to decreased Cav and hemagglutinating activity.

Tepal, Castellanos, Larios, and Tejada (1994) conducted extrusion and extraction of *C. ensiformis* seeds to remove Cav. The Cav of raw *C. ensiformis* seeds (100 g kg^{-1}) subjected to 1-acid and 2-acid extraction (pH 5.5, 2 h) reduced to 8.5 and 4.9 g kg^{-1}. Effectiveness of extractability of antinutritional factors using the base and acid soluble protein fraction on feeding the chicken with *C. ensiformis* was examined by Ologhobo, Apata, and Oyejide (1993). Decrease in weight of liver; increase in weight of kidney, brain and pancreas; growth depression; elevation of serum urea and enzyme activity were noted. Histopathological examination revealed many pathological lesions in organs of chickens fed with base and acid soluble protein fractions, defatted *C. ensiformis* and raw *C. ensiformis* seed diets. Three feeding methods (ad libitum feeding, dry and wet force feeding) were con-

ducted for raw and extruded *C. ensiformis* seeds (Léon et al., 1990). Extrusion improved digestibility of nutrients (20% for amino acid, 30% for starch) of *C. ensiformis* seeds. Seed extraction followed by different treatments (e.g., heat treatments, dietary supplements of amino acids and potassium acetate) on the nutritive value of *C. ensiformis* was examined (D'Mello & Walker, 1991). Feeding the young chicks with processed seeds of *C. ensiformis* (aqueous solution of $KHCO_3$, 10 g g^{-1}; 80 °C for 48 h; followed by autoclaving, 1 h, 120 °C) reduced Cav to negligible quantities (D'Mello & Walker, 1991). Extrusion and pressure-cooking of *C. ensiformis* seeds with lime was found to be effective in improving the protein quality (Bressani & Sosa, 1990). Extruded products of *C. ensiformis* seed flour and semolina blend (30:70) had protein of moderate nutritive value and could be advocated in countries where *C. ensiformis* is cultivated (Vaidehi & Shivaleela, 1984).

Amendment of *C. ensiformis* seeds with calcium hydroxide (0.45%) followed by pressure-cooking (30 min) indicated beneficial effects (D'Mello, Acamovic, & Walker, 1985). Significant improvement in protein quality of *C. ensiformis* seeds was noticed on methionine supplementation, while arginine supplementation resulted in minor growth improvements of chick. Seeds of *C. ensiformis* ($KHCO_3$-treated and autoclaved) supplemented with lysine, arginine, tryptophan and potassium acetate in diets of chicks showed marked improvement in nitrogen utilization. Creatine supplementation of autoclaved *C. ensiformis* seed diets enhanced the food efficiency and nitrogen utilization in chicks, which was further enhanced on addition of 2-aminoisobutyric acid, arginine and lysine (D'Mello, Walker, & Noble, 1990). Potassium acetate also induced improvement in the nitrogen retention efficiencies of chicks fed with autoclaved *C. ensiformis* seed diets. Urea-treated and toasted *C. ensiformis* seed meals (10% and 20%) improved broiler performance compared to control (Udedibie, Esonu, Obaji, & Durunna, 1994). The inclusion of urea treated (40 h) and decorticated *C. ensiformis* seeds (20%) increased the nutritional quality of mash resulting in 134.7% increase in growth. Soaking of *C. ensiformis* seeds in kitchen soda (10 g l^{-1}; 1:3 w/v) significantly reduced Cav to 75–82% (Gupta, Yadav, Gupta, Sahoo, & Agrahar, 2001) which qualifies this method for amendment purposes. Thus, amended *C. ensiformis* seeds (e.g., urea, kitchen soda, methionine) can be safely incorporated in ration of livestock without any adverse physiological effects.

9. Pharmacological importance

Protein with complete sequence homology to bovine insulin (recognized by antihuman insulin antibodies) is present in *C. ensiformis* seed coats (Oliveira, Sales, Machado, Fernandes, & Xavier, 1999). It lowered the blood glucose levels of alloxanized mice indicating that it is biologically potent for treatment of diabetes. Seed proteins of *C. ensiformis* considerably lowered the cholesterol in hypercholesterolimic rats (Marfo, Wallace, Timpo, & Simpson, 1990) indicating the importance of PUFA of *Canavalia* spp. The viability of the liver cancer cells (HepG2) was reduced by 80% and 0% on treatment with fermented *C. gladiata* seed solution (Chen, Lu, Chan, & Lin, 2000). The leaves and pink colored seeds of *C. gladiata* are used to treat skin rashes in Chinese medicine (Kay, 1979). Aqueous extract of *C. cathartica* produced a number of CNS effects including potentiation of pentobarbitone hypnosis in mice (1 mg 100 g^{-1}) and morphine catalepsy in albino rats (1 mg 100 g^{-1}) (Mukhopadhyay et al., 1986). Alpha-mannosidase (220 kD) of *C. ensiformis* is known to stimulate the proliferation of B-lymphocytes of nude mice (Einhoff & Ruediger, 1988).

10. Pest control

Phytochemical investigations of raw seeds of *C. ensiformis* revealed the presence of several ANFs (Con A, saponins, cyanogenic glycosides, terpenoids, alkaloids and tannic acid), which render them free from insect attack (Oliveira, 1997; Udedibie & Carlini, 1998a; Udedibie & Nwaiwu, 1988). Oliveira et al. (1999) found that many proteins present in the seeds of *C. ensiformis* (trypsin inhibitors, canatoxin) are detrimental to the development of bruchid insect, *Callosobruchus maculatus*. Con A of *C. ensiformis* exhibited insecticidal property by affecting the function of soluble and brush border membrane enzymes in the mid gut of tomato moth larvae, *Lacanobia oleracea* (Fitches & Gatehouse, 1998). Gatehouse et al. (1999) studied the impact of Con A of *C. ensiformis* on insect crop pests of two orders (Lepidoptera and Homoptera). On feeding tomato moth larvae (*L. oleracea*) with con A, resulted in retarded development and decreased 90% survival. The peach–potato aphid (*Myzus persicae*) fed with 1–9 μM Con A in liquid artificial diet reduced its size (up to 30%) and reduced fecundity (over 30%) and retarded its development. Con A of *Canavalia* spp. is a protective agent against insect pests and it is useful in creating transgenic plants resistant to insect by genetic engineering (Sauvion et al., 2004). Cav of *C. ensiformis* retards the growth of *Spodoptera* larvae and also causes antifertility in *P. americana* (Koul, 1983, 1985). Leaf cutting ants (*Atta sexdens*) fed with leaves of *C. ensiformis* showed high mortality and decrease in fungal garden volume with depletion of nests after 11 weeks of treatment (Hebling, Bueno, Pagnocca, Silva, & Maroti, 2000). The inhibitory effects of leaf extracts of *C. ensiformis* on the development of symbiotic fungus of the leaf-cutting ants (*A.*

sexdens) was studied and the chromatographic separation of the leaf extract consisted of a mixture of fatty acids which showed the inhibitory effect (Monteiro et al., 1998). Morris and Walker (2002) mixed dried ground *C. ensiformis* tissues with soil (1%, 2%, 2.5% and 5% w/v) infected with nematode (*Meloidogyne incognita*) and found a reduction in nematode gall numbers on incubation of up to 1 week (21–27 °C).

11. Outlook

This review suggests that seeds of *Canavalia* spp. are a rich source of proteins, essential amino acids, carbohydrates and energy. Out of the four *Canavalia* spp., *C. maritima* and *C. cathartica* are shown to be a good source of sulphur amino acids. These species are least explored and can be exploited in breeding programmes for mass cultivation and conservation. *Canavalia* spp. also possesses a variety of antinutritional factors that can cause adverse effects on consumers. Various types of detoxification studies have been conducted and a few have been successful in the reduction or and elimination of antinutritional components. Concanavalin A has a variety of applications such as a blood grouping substance, immunomodulator and tissue marker. Canavanine is an anticancer agent and can be employed mainly in pancreatic cancer studies. However, more information pertaining to administration of antinutritional factors besides canavanine and concanavalin A is essential to assess the overall toxicity and intake of seeds of *Canavalia* spp. in test animals. There is a clear gap in the knowledge of vitamins of these gene pools. The use of various landraces of *Canavalia* as rotation crop, cover crop and plant growth promoters and secondary metabolites has to be further investigated.

Acknowledgements

Authors are grateful to Mangalore University for permission to carry out studies on *Canavalia* at the Department of Biosciences. We thank Damodar Shenoy Belle, University of Hong Kong for retrieval of some relevant literature.

References

Abbey, B. W., & Ibeh, G. O. (1987). Functional properties of raw and heat processed brown bean (*Canavalia rosea* DC.) flour. *Journal of Food Science, 52*, 406–408.

Acamovic, T. (1987). *Analysis and nutritional evaluation for young chicks of some toxic factors in three novel legumes*. Ph.D. Thesis, University of Edinburgh.

Addison, K. B. (1957). The effect of fertilizing espacement and date of planting of the yield of jack bean (*Canavalia ensiformis*). *Rhodesian Agricultural Journal, 54*, 521–532.

Adebowale, K. O., & Lawal, O. S. (2004). Comparative study of the functional properties of bambara groundnut (*Voandzeia subterranean*), jack bean (*Canavalia ensiformis*) and mucuna bean (*Mucuna pruriens*) flours. *Food Research International, 37*, 355–365.

Agbede, J. O., & Aletor, V. A. (2005). Studies of the chemical composition and protein quality evaluation of differently processed *Canavalia ensiformis* and *Mucuna pruriens* seed flours. *Journal of Food Composition and Analysis, 18*, 89–103.

Aguirre, L. A., Savon, L., Oramas, A, Dihigo, L. E., & Rodriguez, V. (1998). Protein quality of raw soybean (*Glycine max*), vigna (*Vigna unguiculata*) and *Canavalia* (*Canavalia gladiata*) meal in growing rats. *Cuban Journal of Agricultural Science, 32*, 75–81.

Akpapunam, M. A., & Sefa-Dedeh, S. (1997). Some physiological properties and antinutritional factors of raw, cooked and germinated jack bean (*Canavalia ensiformis*). *Food Chemistry, 59*, 121–125.

Ali, N. (2000). Report of the Asian Productivity Organization seminar. In *Processing and utilization of legumes* (pp. 116–145). Tokyo: Asian Productivity Organization.

Alves, E. W., Ferreira, A. T. D. S., Ferreira, C. T. D. S., & Carlini, C. R. (1992). Effects of canatoxin on the calcium-atpase of sarcoplasmic reticulum membranes. *Toxicon, 30*, 1411–1418.

Arinathan, V., Mohan, V. R., Britto, A. J., & Chelladurai, V. (2003). De Studies on food and medicinal plants of Western Ghats. *Journal of Economic and Taxonomic Botany, 27*, 750–753.

Arora, S. K. (1995). Composition of legumes grains. In J. P. F. D'Mello & C. Devendra (Eds.), *Tropical legumes in animal nutrition* (pp. 67–93). London: CAB International.

Arun, A. B., Beena, K. R., Raviraja, N. S., & Sridhar, K. R. (1999). Coastal sand dunes – a neglected ecosystem. *Current Science, 77*, 19–21.

Arun, A. B., Raviraja, N. S., & 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.

Arun, A. B., & Sridhar, K. R. (2005). Growth tolerance of rhizobia isolated from sand dune legumes of southwest coast of India. *Engineering in Life Sciences, 5*, 134–138.

Arun, A. B., Sridhar, K. R., Raviraja, N. S., Schmidt, E., & Jung, K. (2003). Nutritional and antinutritional components of *Canavalia* spp. seeds from the west coast sand dunes of India. *Plant Foods for Human Nutrition, 58*, 1–13.

Babar, V. S., Chavan, J. K., & Kadam, S. S. (1988). Effects of heat treatments and germination on trypsin inhibitor activity and polyphenols in jack bean (*Canavalia ensiformis* L. DC). *Plant Foods for Human Nutrition, 38*, 319–324.

Barja, F. C., Guimaraes, J. A., & Carlini, C. R. (1991). Canatoxin, a plant protein, induces insulin release from Isolated pancreatic islets. *Endocrinology, 128*, 675–679.

Bau, H. M., Vallaume, C. F., Evard, F., Quemener, B., Nicolas, J. P., & Mejean, L. (1994). Effect of solid state fermentation using *Rhizophus oligosporus* sp. T-3 on elimination of antinutritional substances and modification of biochemical constituents of defatted rape seed meal. *Journal of Science of the Food and Agriculture, 65*, 315–322.

Beena, K. R., Arun, A. B., Raviraja, N. S., & Sridhar, K. R. (2001). Association of arbuscular mycorrhizal fungi with plants of coastal sand dunes of west coast of India. *Tropical Ecology, 42*, 213–222.

Bell, E. A. (1960). Canavanine in the leguminosae. *Biochemistry Journal, 75*, 618–620.

Bell, E. A., & Janzen, D. H. (1971). Medical and ecological considerations of L-DOPA and 5-HTP in seeds. *Nature, 229*, 136–137.

Bell, E. A., Lackey, J. A., & Polhill, R. M. (1978). Systematic significance of canavanine in the Papillonoidae (Faboideae). *Biological Systematics and Ecology, 6*, 201–212.

Belmar, R., & Morris, T. R. (1994). Effects of the inclusion of treated jack beans (*Canavalia ensiformis*) and the amino acid canavanine in chick diets. *Journal of Agricultural Science, 123*, 393–405.

Belmar, R., Nava-Montero, R., Sandoval-Castero, C., & McNab, J. M. (1999). Jack bean (*Canavalia ensiformis* L. DC) in poultry diets: antinutritional factors and detoxification studies – a review. *World Poultry Science Journal, 55*, 37–59.

Betancur, A. D., Garcia, C. E., Cañizares, R. E., & Chel, G. L. (2002). Chemical modification of jack bean (*Canavalia ensiformis*) starch by succinylation. *Starch, 54*, 540–546.

Betancur, A. D., Peraza, M. G., Moguel, O. Y., & Fuertes, B. S. (2004). Physicochemical characterization of lima bean (*Phaseolus lunatus*) and Jack bean (*Canavalia ensiformis*) fibrous residues. *Food Chemistry, 84*, 287–295.

Bohlool, B. B., & Schmidt, E. L. (1974). Lectins: a possible basis for specificity in the *Rhizobium*-legume root nodule symbiosis. *Science, 185*, 269–271.

Borchers, R., & Ackerson, C. W. (1950). The nutritive value of legume seeds X. Effects of autoclaving and trypsin inhibitor test for 17 species. *Journal of Nutrition, 41*, 339–345.

Bressani, R., Braham, J. E., & Elias, L. G. (1983). Effects on nutritional effects of food legumes from chemical changes through processing and storage. In L. W. Shemilt (Ed.), *Chemistry and world food supplies: The new frontiers chemrawn II* (pp. 403–491). Oxfod: Pergamon Press.

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

Bressani, R., & Sosa, J. L. (1990). Effect of processing on the nutritive value of *Canavalia* Jack beans (*Canavalia ensiformis* L.). *Plant Foods for Human Nutrition, 40*, 207–214.

Brown, R. D., Koenig, S. H., & Brewer, C. F. (1982). Conformational equilibrium of demetalized concanavalin A. *Biochemistry, 21*, 465–469.

Brune, M., Rossander, L., & Hallberg, L. (1989). Iron absorption and phenolic compounds: importance of different phenolic structures. *European Journal of Clinical Nutrition, 43*, 547–558.

Brune, M., Rossander-Hulthén, L., Hallberg, L., Gleerup, A., & Sandberg, A. S. (1992). Human iron absorption from bread: inhibiting effects of cereal fiber, phytate and inositol phosphates with different numbers of phosphate groups. *Journal of Nutrition, 122*, 442–449.

Burkett, D. P., & Trowell, H. C. (1975). *Refined carbohydrates foods and diseases*. London: Academic Press.

Caldero, J., Campo, E., Ascaso, C., Ramos, J., Panades, M. J., & Rene, J. M. (1989). Regional distribution of glycoconjugates in normal, transitional and neoplastic human colonic mucosa: a histochemical study using lectins. *Vircghows Archiv A Patholgoical Anatomy and Histopathology, 415*, 347–356.

Campos, M. M., Carlini, C. R., Guimaraes, J. A., Marques, M. V. M., & Rumjanek, V. M. (1991). Effect of canatoxin on cell cultures. *Cell Biology International Reports, 15*, 581–594.

Carlini, C. R., Barcellos, G. B. S., Baeta, N. D. V., & Guimaraes, J. A. (1988). Immunorectivity for canatoxin and concanavalin A among protein of leguminous seeds. *Phytochemistry, 27*, 25–30.

Carlini, C. R., Gomes, C., Guimaraes, J. A., Markus, R. P., Sato, H., & Trolin, G. (1984). Central nervous effects of the convulsant protein canatoxin. *Acta Pharmacologica et Toxicologica, 54*, 161–166.

Carlini, C. R., & Guimaraes, J. A. (1981). Isolation and characterization of toxic protein from *Canavalia ensiformis* (jack bean) seeds, distinct from concanavalin A. *Toxicon, 19*, 667–676.

Carlini, C. R., & Guimaraes, J. (1991). Plant and microbial toxic proteins as hemilectins: emphasis on canatoxin. *Toxicon, 29*, 791–806.

Carlini, C. R., Guimaraes, J. A., & Ribeiro, J. M. C. (1985). Platelet release reaction and aggregation induced by canatoxin, a convulsant protein: evidence for the involvement of the platelet lipoxygenase pathway. *British Journal of Pharmacology, 84*, 551–560.

Carlini, C. R., Oliveira, A. E. A., Azambuja, P., Xavier, F. J., & Wells, M. A. (1997). Biological effects of canatoxin in different insect models: evidence for a proteolytic activation of the toxin by insect cathepsin-like enzymes. *Journal of Economic Entomology, 90*, 340–348.

Carlini, C. R., & Udedibie, A. B. (1997). Comparative effects of processing methods on hemagglutinating and antitryptic activities of *Canavalia ensiformis* and *Canavalia braziliensis* seeds. *Journal of Agricultural and Food Chemistry, 45*, 4372–4377.

Cheeke, P. R. (1971). Nutritional and physiological implications of saponins: a review. *Canadian Journal of Animal Science, 51*, 621–623.

Chel, G. L., Perez, F. V., Betancur, A. D., & Davila, O. G. (2002). Functional properties of flours and protein isolates from *Phaseolus lunatus* and *Canavalia ensiformis* seeds. *Journal of Agricultural and Food Chemistry, 50*, 584–591.

Chen, W. M., Lee, T. M., Lanm, C. C., & Cheng, C. P. (2000). Characterization of halotolerant rhizobia isolated from root nodules of *Canavalia rosea* from seaside areas. *FEMS-Microbiology-Ecology, 34*, 9–16.

Chen, C., Lu, F. J., Chan, Y. L., Lin, T. H. (2000). *Method of producing fermented sword beans*. Official Gazette of the United States Patent and Trademark Office Patents, 1239 (2).

Crine, P., & Lemieux, E. (1982). Incorporation of canavanine into rats pars intermedia proteins inhibits the maturation of pro-opiomelanocortin, the common precursor of adrenocorticotrophin and β-lipotropin. *Journal of Biological Chemistry, 257*, 832–838.

Dalkin, K., & Bowles, D. J. (1983). Analysis of inter-relationship of jack bean seed components by two-dimensional mapping of iodinated tryptic peptides. *Planta, 157*, 536–539.

Daloz, C. R. (1988). *Productivity of vegetable legumes in the special territory of Aceh* (pp. 317), Indonesia. Dissertation Abstracts, Cornell University, Ithaca, New York.

Prada, M., Keller, H. H., Pieri, L., Kettler, R., & Haefely, W. E. (1984). The pharmacology of Parkinson's disease: basic aspects and recent advances. *Experientia, 14*, 1165–1304.

DeOliveira, A. C., Vidal, B. D., & Sgarbieri, V. C. (1989). Lesions of intestinal epithelium by ingestion of bean lectins in rats. *Journal of Nutritional Science and Vitaminology, 35*, 315–322.

Diaz, M. F., Gonzalez, A., Mora, C., & Curbelo, F. (1998). Leaf protein concentrates (LPC) in *Canavalia ensiformis*. *Cuban Journal of Agricultural Science, 32*, 291–298.

Dixon, N. E., Riddles, P. W., Gazzola, C., Blakeley, R. L., & Zerner, B. (1980). Jack bean urease (EC 3.5.1.5) on the mechanism of action of urease and urea, formamide, acetamide, *n*-methyl urea and related compounds. *Canadian Journal of Biochemistry, 58*, 1534–1535.

D'Mello, J. P. F. (1989). Toxic amino acids. In J. P. F. D'Mello, C. M. Duffus, & J. H. Duffus (Eds.), *Antinutritional factors, potential toxic substances in plants, aspects of applied biology* (pp. 29–50). Wellesbourne, Warwick: Association of Applied Biologists.

D'Mello, J. P. F, Acamovic, T., & Walker, A. G. (1985). Nutritive value of jack beans (*Canavalia ensiformis* (L.) DC.) for young chicks. *Tropical Agriculture, 62*, 145–150.

D'Mello, J. P. F., & Walker, A. G. (1991). Detoxification of jack beans (*Canavalia ensiformis*): studies with young chicks. *Animal Feed Science and Technology, 33*, 117–127.

D'Mello, J. P. F, Walker, A. G., & Acamovic, T. (1988). Concentrations of total amino acids including canavanine during germination of *Canavalia ensiformis* (L.) DC. *Tropical Agriculture, 65*, 376–377.

D'Mello, J. P. F., Walker, A. G., & Noble, E. (1990). Effects of dietary supplements on the nutritive value of jack beans (*Canavalia*

ensiformis) for the young chick. *British Poultry Science, 31*, 759–768.

DOES (2000). Directorate of Economics and Statistics. *Agricultural statistics at a glance*. Ministry of Agriculture, Government of India, New Delhi, India.

Dominguez, B. M. G., & Stewart, C. S. (1990). Effects of feeding *Canavalia ensiformis* on the rumen flora of sheep, and of the toxic amino acid canavanine on rumen bacteria. *Systematic and Applied Microbiology, 13*, 388–393.

Downum, K. R., Rosenthal, G. A., & Cohen, W. S. (1983). L-Arginine and L-canavanine metabolism in jack bean, *Canavalia ensiformis* and soybean, glycine max. *Plant Physiology, 73*, 965–968.

Einhoff, W., & Ruediger, H. (1988). The alpha-mannosidase from *Canavalia ensiformis* seeds: chemical and kinetic properties and action on animal lymphocytes. *Biological Chemistry, 369*, 165–170.

Ekanayake, S., Jansz, E. R., & Nair, B. M. (1999). Proximate composition, mineral and amino acid content of mature *Canavalia gladiata* seeds. *Food Chemistry, 66*, 115–119.

Ekanayake, S., Jansz, E. R., & Nair, B. M. (2000a). Literature review of an underutilized legume: *Canavalia gladiata* L.. *Plant Foods for Human Nutrition, 55*, 305–321.

Ekanayake, S., Jansz, E. R., & Nair, B. M. (2000b). Nutritional evaluation of protein and starch of mature *Canavalia gladiata* seeds. *International Journal of Food Sciences and Nutrition, 51*, 289–294.

Ekanayake, S., Nair, B., Jansz, E. R., & Asp, N. G. (2003). Effect of processing on the protein nutritional value of *Canavalia gladiata* seeds. *Nahrung, 47*, 256–260.

Ellis, N., Belmar, R. (1985). La compositión qu'mica del grano de *Canavalia ensiformis*: suvalor nutrito y sus factores tóxicos. In: *Memorias: I Reunion sobre la produccion y utilizacion del grano de Canavalia ensiformis en sistemas pecuarios de Yucatán F.M.V.Z-U.A.D.Y.*, Yucatán, México.

Emken, E. A., Adlof, R. O., & Gulley, R. M. (1994). Dietary linoleic acid influences desaturation and acylation of deuterium-labeled linoleic and linolenic acids in young adult males. *Biochemica Biophysica Acta, 1213*, 277–288.

Ensgraber, A. (1958). Seed hemagglutinins. *Economic Botany, 18*, 27–38.

Enyikwola, O., Addy, E. O., & Adoga, G. I. (1991). Hypoglycaemic effect of *Canavalia ensiformis* 1. (leguminosae) in albino rats. *Discovery and innovation, 3*, 61–63.

Esonu, B. O. (1996). *Studies on the methods of improving the nutritive value of the jack bean (C. ensiformis)*. Ph.D. Thesis, Federal University of Technology, Owerri, Nigeria.

Estruch, R., & Damjanov, I. (1986). Lectin histochemistry applied to human nerves. *Archives of Pathology and Laboratory Medicine, 110*, 730–735.

FAO (1970). *Amino acid content of foods and biological data on proteins* (pp. 295). Rome: Food and Agricultural Organization of United Nations.

FAO (1998). *Production year book 52*, Rome, Italy.

FAO/WHO (1991). Protein quality evaluation. *Reports of a Joint FAO/WHO Expert Consultation, Food and Agriculture Organization of the United Nations*. (pp. 1–66). FAO, Rome, Food and Nutrition paper No. 51.

Faye, L., & Chrispeels, M. J. (1987). Transport and processing of the glycosylated precursor of concanavalin A in jack-bean. *Planta, 170*, 217–224.

Faye, L., Greenwood, J. S., & Chrispeels, M. J. (1986). Urease in jack-bean (*Canavalia ensiformis*) seeds is a cytosolic protein. *Planta, 168*, 579–585.

Ferreira, D. C. T., Gombarovits, M. E. C., Masuda, H., Oliveira, C. M., & Carlini, C. R. (2000). Proteolytic activation of canatoxin, a plant toxic protein, by insect cathepsin-like enzymes. *Archives of Insect Biochemistry and Physiology, 44*, 162–171.

Fitches, E., & Gatehouse, J. A. (1998). A comparison of the short and long term effects of insecticidal lectins on the activities of the soluble and brush border enzymes of tomato moth larvae (*Lacanobia oleraceae*). *Journal of Insect Physiology, 44*, 1213–1224.

FNB/NRC (1989). *Food and Nutrition Board/National Research Council Recommended Dietary Allowances* (pp. 58–68). Washington, DC: National Academy of Sciences.

Follmer, C., Barcellos, G. B. S., Zingali, R. B., Machado, O. L. T., Alves, E. W., Barja, F. C., Guimaraes, J. A., & Carlini, C. R. (2001). Canatoxin, a toxic protein from jack beans (*Canavalia ensiformis*), is a variant form of urease (EC 3.5.1.5): biological effects of urease independent of its ureolytic activity. *Biochemical Journal, 360*, 217–224.

Fujihara, S., Nakashima, T., Kurogochi, Y., & Yamaguchi, M. (1986). Distribution and metabolism of sym-homospermidine and canavalamine in the sword bean *Canavalia gladiata* cultivar Shironata. *Plant Physiology, 82*, 795–800.

Fujimura, S., Terada, S., Jayavardhanan, K. K., Panikkar, K. R., & Kimoto, E. (1993). Primary structures of concanavalin A-like lectins from seeds of two species of *Canavalia*. *Phytochemistry, 33*, 985–987.

Gansera, R., Schurz, H., & Ruediger, H. (1979). Lectin-associated proteins from the seeds of Leguminosae. *Hoppe Seyler's Zeitschrift fuer Physiologische Chemie, 360*, 1579–1585.

Gatehouse, A. M. R., Davison, G. M., Stewart, J. N., Gatehouse, L. N., Kumar, A., Geoghegan, I. E., Birch, A. N. E., & Gatehouse, J. A. (1999). Concanavalin A inhibits development of tomato moth (*Lacanobia oleracea*) and peach–potato aphid (*Myzus persicae*) when expressed in transgenic potato plants. *Molecular Breeding, 5*, 153–165.

Ghazaleh, F. A., Araujo, C. F., Barja, F., & Carlini, C. R. (1992). Canatoxin induces activation on mice peritoneal macrophages. *Brazilian Journal of Medical and Biological Research, 25*, 1033–1035.

Ghosh, B. N., Dasgupta, B., & Sircar, P. K. (1985). Lectin concanavalin A distribution at different stages in the tissues of *Canavalia gladiata*. *Current Science, 54*, 80–82.

Graham, H. D., & DeBravo, E. N. (1985). Chemical composition of the seeds, leaves and pods of *Canavalia maritima*. *Caribbean Journal of Science, 21*, 163–168.

Green, M. H., Brooks, T. L., Mendelsohn, L., & Howell, S. B. (1980). Antitumor activity of L. canavanine against L1210 murine leukemia. *Cancer Research, 40*, 535–537.

Gross, C. L. (1993). The reproductive ecology of *Canavalia rosea* (Fabaceae) on Anak Krakatau, Indonesia. *Australian Journal of Botany, 41*, 591–599.

Gulati, A. K., Zalewski, A. A., Sharma, K. B., Ogrowsky, D., & Sohal, G. S. (1986). A comparison of lectin binding in rat and human peripheral nerve. *Journal of Histochemistry and Cytochemistry, 34*, 1487–1494.

Gupta, Y. P. (1982). Nutritive value of food legumes. In S. K. Arora (Ed.), *Chemistry and biochemistry of legumes*. New Delhi, India: Oxford & IBH Publishing Company.

Gupta, R., Rauf, A., Ahmad, M. A., Ahmad, F., & Osman, S. M. (1983). Chemical screening of seed oils. *Journal of Oil Technologists Association of India, 15*, 6–7.

Gupta, J. J., Yadav, B. P. S., Gupta, H. K., Sahoo, S. K., & Agrahar, D. (2001). Nutritive value of detoxified jack bean (*Canavalia ensiformis*) seed for young chicks. *Indian Journal of Animal Sciences, 71*, 1169–1171.

Hallberg, L., Brune, M., & Rossander, L. (1989). Iron absorption in man: ascorbic acid and dose-dependent inhibition by phytate. *American Journal of Clinical Nutrition, 49*, 140–144.

Hamblin, J., & Kent, S. P. (1973). Possible role of phytohemagglutinins in *Phaseolus vulgaris* L.. *Nature New Biology, 245*, 28–30.

Hebling, M. J. A., Bueno, O. C, Pagnocca, F. C., Silva, O. A., & Maroti, P. S. (2000). Toxic effects of *Canavalia ensiformis* L.

(Leguminosae) on laboratory colonies of *Atta sexdens* L. (Hym., Formicidae). *Journal of Applied Entomology, 124*, 33–35.

Hennig, M., Jansonius, J. N., Terwisscha, V. S. A. C., Dijkstra, B. W., & Schlesier, B. (1995). Crystal structure of concanavalin B at 1.65 A resolution: an "inactivated" chitinase from seeds of *Canavalia ensiformis*. *Journal of Molecular Biology, 254*, 237–246.

Herklots, G. A. C. (1972). *Beans and peas: vegetables in South East Asia* (pp. 225–236). London: George Allen and Unwind Ltd.

Herman, E. M., & Shannon, L. M. (1984). Immunocytochemical localization of concanavalin A in developing jack-bean (*Canavalia ensiformis*) cotyledons. *Planta, 161*, 97–104.

Herrera, F. G. (1983). Effect of planting density on the seed yield of *Canavalia ensiformis*. *Tropical Animal Production, 8*, 153–156.

Hoshikawa, K. (1981a). Natamame (sword bean). In *Shokuyou sakumotu (food crops)* (pp. 547–548). Tokyo: Yokendo.

Hoshikawa, K. (1981b). Tachi natamame (jack bean). In *Shokuyou sakumotu (Food crops)* (pp. 548–549). Tokyo: Yokendo.

Hurrel, R. F., Reddy, M., & Cook, J. D. (1999). Inhibition of non-heme iron absorption in man by polyphenolic-containing beverages. *British Journal of Nutrition, 81*, 289–295.

Hwang, I. D., Kim, S. G., & Kwon, Y. M. (1996a). Canavanine metabolism in tissue cultures of *Canavalia lineata*. *Plant Cell Tissue and Organ Culture, 45*, 17–23.

Hwang, I. D., Lee, Y., Kim, S. G., Lee, J. S., & Kwon, Y. M. (1996b). Enzyme activities of canavanine metabolism in *Canavalia lineata* L. callus. *Journal of Plant Physiology, 149*, 494–500.

Jaffe, W. G. (1980). Hemagglutinins (lectins). In I. E. Liener (Ed.), *Toxic constituents of plant food stuffs* (pp. 525–552). New York: Academic Press.

Jayavardhanan, K. K, Padikkala, J., & Panikkar, K. R. (1996). Lectin biosynthesis in callus culture established from seeds of *Canavalia virosa*. *Biologia Plantarum, 38*, 329–334.

Jayne-Williams, D. J. (1973). Influence of dietary jack bean (*Canavalia ensiformis*) and of concanavalin-A on the growth of conventional and gnotobiotic Japanese quail (*Coturnix japonica*). *Nature, 243*, 150–151.

Johnson, L. T., Gee, J. M., Price, K. R., Curl, C. L., & Fenwick, G. R. (1986). Influence of saponins in gut permeability and active nutrient transport in vitro. *Journal of Nutrition, 116*, 2270–2272.

Karnboj, S. S., Khanna, A., Arora, J. S., Sandhu, R. S., Kaur, K., Sangary, S., & Forrester, J. A. (1992). Purification and characterization of a lectin from the seeds of *Canavalia obtusifolia* DC. *Journal of Plant Science Research, 8*, 83–86.

Kathiravan, K., & Ignacimuthu, S. (1999). Micropropagation of *Canavalia virosa* (ROXB.) Wight & Arn. A medicinal plant. *Phytomorphology, 49*, 61–66.

Kay, E. D. (1979). *Food legumes*. Digest No. 3, Tropical Products Institute, London.

Kessler, C. D. J. (1990). An agronomic evaluation of jackbean (*Canavalia ensiformis*) in Yucatan, Mexico: II. Defoliation and time of sowing. *Experimental Agriculture, 26*, 23–30.

Kessler, M., Belmar, R., & Ellis, N. (1990). Effects of autoclaving on the nutritive value of the seeds of *Canavalia ensiformis* (jackbean) for chicks. *Tropical Agriculture, 67*, 16–20.

Kitagawa, M., & Tomiyana, T. (1929). A new amino acid compound in the jack bean and the corresponding new ferment. *Journal of Biochemistry, 11*, 265–271.

Kojima, K., Ogawa, H., Seno, N., & Matsumoto, I. (1991). Purification and characterization of *Canavalia gladiata* agglutinin. *Carbohydrate Research, 213*, 275–282.

Koratkar, R., & Rao, A. V. (1997). Effect of soya bean saponins on azoxymethane-induced preneoplastic lesions in the colon of mice. *Nutrition and Cancer, 27*, 206–209.

Koul, O. (1983). L-Canavanine from *Canavalia ensiformis* seeds: effects on fertility of *Periplaneta americana* (Orthoptera, Blattidae). *Zeitschrift fuer Angewandte Entomologie, 96*, 530–532.

Koul, O. (1985). Foliage spray tests with L-canavanine for control of *Spodoptera litura*. *Phytoparasitica, 13*, 167–172.

Kruse, P. R., & McCoy, T. A. (1958). The competitive effect of canavanine on utilization of arginine in growth of Walker carcinosarcoma 256 cells in vitro. *Cancer Research, 18*, 279–282.

Kumari, N. N., & Pattabiraman, T. N. (1990). Natural plant enzyme inhibitors: isolation and properties of a trypsin inhibitor from jack bean (*Canavalia ensiformis*). *Indian Journal of Biochemistry and Biophysics, 27*, 332–338.

Kuzayali, M. V., Cowan, J. W., & Sabry, Z. I. (1966). Nutritive value of middle eastern foodstuffs – II. Composition of pulses, seeds, nuts and cereal products of Lebanon. *Journal of the Science of Food and Agriculture, 17*, 82–84.

Larue, A. C., Picard, M., & Louis, S. J. (1992). Feeding behavior in rats on a complete diet containing Concanavalin A. *Reproduction Nutrition Development, 32*, 343–350.

Laurena, A. C., Rivilleza, M. J. R., & Mendoza, E. M. T. (1994). Polyphenols, phytate, cyanogenic glycosides and trypsin inhibitory activity of several Philippine indigenous food legumes. *Journal of Food Composition and Analysis, 7*, 194–202.

Laviada, A. E. (1983). *Estudios preliminaries del efecto de diferentes tratamientos destoxificantes sobre la semilla de Canavlia ensiformis y su utilización en la alinentacion de las aves*. M.Sc. Thesis, F.M.V.Z.-U.A.D.Y.

Lavin, M. (1986). The occurrence of canavanine in the seeds of the tribe Robiniae. *Biochemical Systematic Ecology, 14*, 71–74.

Lee, M. C., & Damjanov, I. (1984). Anatomic distribution of lectin-binding sites in mouse testis and epididymis. *Differentiation, 27*, 74–81.

Lee, Y., & Kwon, Y. M. (2000). Identification of an isoform of ornithine carbamoyltransferase that can effectively utilize canaline as a substrate from the leaves of *Canavalia lineata*. *Plant Science, 151*, 145–151.

Léon, A., Carre, B., Larbier, M., Lim, F., Ladjali, T., & Picard, M. (1990). Amino acids and starch digestibility and true metabolizable energy content of raw and extruded jack beans (*Canavalia ensiformis*) in adult cockerels. *Annales de Zootechnie, 39*, 53–61.

Léon, A. M., Caffin, J. P., Plassart, M., & Picard, M. L. (1991). Effect of concanavalin A from jackbean seeds on short-term food intake regulation in chicks and laying hens. *Animal Feed Science and Technology, 32*, 297–312.

Léon, A., Vargas, R. E., Michelangeli, C., & Melcion, J.-P. (1998). Detoxification of jackbean (*Canavalia ensiformis* L.) with pilot scale roasting II: Nutritional value for poultry. *Animal Feed Science and Technology, 73*, 231–242.

Liener, I. E. (1953). Soyin, a toxic protein from the soybean 1. Inhibition of rat growth. *Journal of Nutrition, 49*, 527–539.

Liener, I. E. (1974). Phytohemagglutinins: their nutritional significance. *Journal of Agriculture and Food Chemistry, 22*, 17–22.

Liener, I. E. (1976). legume toxins in relation to protein digestibility – a review. *Journal of Food Science, 41*, 1076–1081.

Liener, I. E. (1981). Factors affecting the nutritional quality of soy products. *Journal of American Oil and Chemical Society, 58*, 406–415.

Livsmedelsverk, S. (1988). *Energi och näringsämnen*. Stockholm, Sweden: The Swedish Food Administration.

Lorenzo, P., Tovar, J., Pinelli, E., & Seidl, D. S. (1989). Subtilisin inhibitors in *Canavalia* and Vicia faba seeds: a comparative study. *Journal of the Science of Food and Agriculture, 47*, 181–190.

Marcus, S. E., Burgess, J., Maycox, P. R., & Bowles, D. J. (1984). Maturation events in jack beans (*Canavalia ensiformis*). *Biochemical Journal, 222*, 265–268.

Marfo, E. K., Wallace, P., Timpo, G., & Simpson, B. K. (1990). Cholesterol lowering effect of jackbean (*Canavalia ensiformis*) seed protein. *General Pharmacology, 21*, 753–758.

Martinez, M. L., Vazquez, G., White, D. A., Thivet, G., & Brengues, M. (2002). Effects of burial by sand and inundation by fresh- and

seawater on seed germination of five tropical beach species. *Canadian Journal of Botany, 80*, 416–424.

Matsuzaki, S., Hamana, K., Okada, M., Niitsu, M., & Samejima, K. (1990). Aliphatic pentaamines found in *Canavalia gladiata*. *Phytochemistry, 29*, 1311–1312.

Mattei, E., Damasi, D., Mileo, A. M., Delpino, A., & Ferrini, U. (1992). Stress response, survival and enhancement of heat sensitivity in a human melanoma cell line treated with L-canavanine. *Anticancer Research, 12*, 757–762.

Melcion, J.-P., Kodaira, M., Leon, A., Michelangeli, C., Vargas, R. E., & Picard, M. (1998). Detoxification of the jackbean (*Canavalia ensiformis* L.) with pilot scale roasting I: technological conditions and analytical data. *Animal Feed Science and Technology, 73*, 217–230.

Mendez, A., Vargas, R. E., & Michelangeli, C. (1998). Effects of concanavalin A, fed as a constituent of Jack bean (*Canavalia ensiformis* L.) seeds, on the humoral immune response and performance of broiler chickens. *Poultry Science, 77*, 282–289.

Merck (1989). *The Merck index: An encyclopedia of chemicals* (pp. 263). Rahway, NJ, USA: Drugs and Biologicals, Merck & Co.

Michelangeli, C., & Vargas, R. E. (1994). L-Canavanine influences feed intake, plasma basic amino acid concentration and kidney arginase activity in chicks. *Journal of Nutrition, 124*, 1081–1087.

Mohan, V. R., & Janardhanan, K. (1994). The biochemical composition and nutrient assessment of less known pulses of the genus Canavalia. *International Journal of Food Sciences and Nutrition, 45*, 255–262.

Molina, M. R, Argueta, C. E., & Bressani, R. (1974). Extraction of nitrogenous constituents from the jack bean (*Canavalia ensiformis*). *Journal of Agriculture and Food Chemistry, 22*, 309–312.

Molina, M. R., & Bressani, R. (1975). Protein starch extraction and nutritive value of jack bean and jack bean protein isolate. In W. G. Jaffe & D. J. E. Olivera (Eds.), *Nutritional aspects of common beans and other legume seeds ad animal and human foods* (pp. 153–163). Caracas, Venezuela: Archivos Latinoamericanos de Nutricion.

Molina, M. R., Bressani, R., & Elias, L. G. (1977). Nonconventional legume grains as protein sources. *Food Technology, 31*, 188–190.

Monteiro, M. R., Torkomian, V. L. V., Pagnocca, F. C., Vieira, P. C., Fernandes, J. B., Silva, M. F., Das, G. F. D., Bueno, O. C., & Hebling, M. J. A. (1998). Activity of extracts and fatty acids of *Canavalia ensiformis* (*Leguminosae*) against the symbiotic fungus of the leaf-cutting ants *Atta sexdens*. *Anais da Academia Brasileira de Ciencias, 70*, 733–736.

Morris, J. B., & Walker, J. T. (2002). Non-traditional legumes as potential soil amendments for nematode control. *Journal of Nematology, 34*, 358–361.

Mukhopadhyay, M., Sarkar, M. K., Biswas, M., Pathak, N. K. R., Ghosal, S., Singh, N. K., & Das, P. K. (1986). Some pharmacological studies on *Canavalia virosa*. *Indian Journal of Pharmacology, 18*, 84–88.

Murofushi, N., Takahashi, N., Yokota, T., Kato, J., Shiotani, Y., & Osaka, S. (1969). Gibberellins in immature seeds of *Canavalia*. *Agricultural Biology and Chemistry, 33*, 592–597.

Nair, S. S. D., Leitch, J. W., Falconer, J., & Garg, M. L. (1997). Prevention of cardiac arrhythmia by dietary (n-3) polyunsaturated fatty acids and their mechanism of action. *Journal of Nutrition, 127*, 383–393.

Nakajima, N., Hiradate, S., & Fujii, Y. (2001). Plant growth inhibitory activity of L-canavanine and its mode of action. *Journal of Chemical Ecology, 27*, 19–31.

Nakanishi, H. (1988). Dispersal ecology of the maritime plants in the Ryukyu Islands, Japan. *Ecological Research, 3*, 163–174.

Nakatsu, S., Matsuda, M., Sakagami, T., Takahashi, T., & Yamatato, S. (1996). Decomposition of canavanine in process of germination in the seeds of *Canavalia gladiata*. *Seikagaku, 38*, 67–71.

Natelson, S. (1985). Canavanine to arginine ratio in alfalfa (*Medicago sativa*), clover (*Trifolium*) and jack bean (*Canavalia ensiformis*). *Journal of Agriculture and Food Chemistry, 33*, 413–419.

Novus (1994). *Raw material compendium: a compilation of worldwide data sources* (II ed.). Brussels: NOVUS.

NRC/NAS (1989). *Recommended dietary allowances*. Washington: National Academic Press.

Oakenfull, D. G., Topping, D. L., Illuman, R. J., & Fenwick, D. E. (1984). Prevention of diatory hypercholesterolaemia in the rat by soya and quillaja sapnonis. *Nutrition Research International, 29*, 1039–1041.

Obizoba, I. C., & Obiano, N. (1988). The nutritive value of jack bean (*Canavalia ensiformis*). *Ecology, Food and Nutrition, 21*, 265–270.

Okolie, N. P., & Ugochukwu, E. N. (1989). Cyanide content of some Nigerian legumes and th effect of simple processing. *Food Chemistry, 32*, 209–216.

Oliveira, A. E. A. (1997). Defence proteins of legume seed testa are homologous to vicilin storage protein. *Abstract volume of 26th Annual Conference of Brazilian Society of Biochemistry and Molecular Biology*, Caxambu, Brazil, May 3–6.

Oliveira, A. E. A., Sales, M. P., Machado, O. L. T., Fernandes, K. V. S., & Xavier, F. J. (1999). The toxicity of Jack bean (*Canavalia ensiformis*) cotyledon and seed coat proteins to the cowpea weevil (*Callosobruchus maculatus*). *Entomologia-Experimentalis-et-Applicata, 92*, 249–255.

Ologhobo, A. D., Apata, D. F., & Oyejide, A. (1993). Utilisation of raw jackbean (*Canavalia ensiformis*) and jackbean fractions in diets for broiler chicks. *British Poultry Science, 34*, 323–337.

Onuegbu, B. A., Zibokere, D. S., Chinah, M., & Ukata, D. (1993). Unconventional food sources: effects of *Canavalia ensiformis* seeds on growth and development of domestic rats and effects of fungal infection on nutritional composition of the seeds. *Journal of Dairy Foods and Home Science, 12*, 62–66.

Orru, A., & Demel, V. C. (1941). Physiological and anatomical–pathological observations on rats fed with the seeds of *Canavalia ensiformis*. *Quanderni Nutrizione, 7*, 272–275.

Osborne, T. B., & Mendel, L. B. (1917). The use of soybean as food. *Journal of Biological Chemistry, 32*, 369–387.

Oski, F. A. (1997). What we eat may determine who we can be. *Nutrition, 13*, 320–321.

Perez, G., Perez, C., Sousa, C. B., Moreira, R., & Richardson, M. (1991). Comparison of the amino acid sequences of the lectins from seeds of *Dioclea lehmanni and Canavalia maritima*. *Phytochemistry, 30*, 2619–2621.

Price, K. R., Curl, C. L., & Fenwick, G. R. (1986). The saponin content and sapogenol composition of the seed of 13 varieties of legume. *Journal of the Science of Food and Agriculture, 37*, 1185–1191.

Purseglove, J. W. (1968). *Canavalia gladiata* (Jacq.) DC. Tropical crops: dicotyledons 1 (p. 245). London: Longmans, Green and Co. Ltd.

Purseglove, J. W. (1974). *Tropical crops: dicotyledons* (pp. 242–246). London: Longman.

Putsztai, A. (1989). Biological effects of dietary lectins. In Huismay et al. (Eds.), *Recent advances of research in antinutritional factors in legume seeds* (pp. 244–245). Wageningen: Pudoc.

Rajaram, N., & Janardhanan, K. (1992). Nutritional and chemical evaluation of raw seeds of *Canavalia gladiata* (Jacq) DC. and *C. ensiformis* DC: the under utilized food and fodder crops in India. *Plant Foods for Human Nutrition, 42*, 329–336.

Rao, C. N., & Rao, B. S. N. (1978). Influence of starches from different sources on protein utilization in rats. *British Journal of Nutrition, 40*, 1–8.

Raychaudhuri, M., Nayogim, K., & Singh, M. (1987). Temporal regulation in the synthesis of concanavalin A and alpha-mannosidase in the seeds of *Canavalia ensiformis*. *Phytochemistry, 26*, 3201–3206.

Raychaudhuri, M., & Singh, M. (1986). A concanavalin a-like lectin in the developing seed of *Canavalia ensiformis*. *Phytochemistry, 25*, 793–798.

Reano, A., Faure, M., Jacques, Y., Reichert, U., Schaefer, H., & Thivolet, J. (1982). Lectins as markers of human epidermal cell differentiation. *Differentiation, 22*, 205–210.

Revilleza, M. J. R., Mendoza, E. M. T., & Raymundo, L. C. (1990). Oligosaccharides in several Philippine indigenous food legumes: determination, localization and removal. *Plant Foods for Human Nutrition, 40*, 83–94.

Ribeiro, D. G., Carlini, C. R., Pires, B. R., & Guimaraes, J. A. (1986). Blood glucose alterations induced in rats by canatoxin, a protein isolated from jack bean (*Canavalia ensiformis*) seeds. *Toxicon, 24*, 775–782.

Ribeiro, D. G., Prado, J. F., Collaresm, C. B., & Siste, C. M. (1992). Further studies on the hypoxia produced by canatoxin in rats. *Brazilian Journal of Medical and Biological Research, 25*, 849–852.

Robertson, A. T., Bates, R. C., & Stout, E. R. (1984). Reversible inhibition of bovine parvovirus DNA replication by aphidicolin and L-canavanine. *Journal of General Virology, 65*, 1497–1505.

Rockland, B. L., & Nishi, K. S. (1979). Tropical grain legumes. In G. E. Inglett & G. Charalambous (Eds.), *Proceedings of an international conference on tropical foods: Chemistry and nutrition, March 28–30* (pp. 547–574). Hawaii: Honolulu.

Rodrigues, B. F. (1993). Gamma irradiation induced variabilities in *Canavalia virosa*. *Journal of Ecobiology, 5*, 65–67.

Rodrigues, B. F., & Torne, S. G. (1990a). Seed mycoflora of two *Canavalia* species in Goa. *Indian Journal of Mycology and Plant Pathology, 20*, 164–165.

Rodrigues, B. F., & Torne, S. G. (1990b). Epidermal features in three Canavalia species. *Agricultural and Biological Research, 6*, 73–79.

Rodrigues, B. F., & Torne, S. G. (1990c). Lectin activity in the seeds of three *Canavalia species*. *Comparative Physiology and Ecology, 15*, 123–124.

Rodrigues, B. F., & Torne, S. G. (1991a). Root nodule morphology of *Canavalia ensiformis (L.)* DC. plant. *Biojournal, 3*, 43–46.

Rodrigues, B. F., & Torne, S. G. (1991b). Fruit rot disease of *Canavalia ensiformis* (L.) DC. (jack bean). *Tropical Pest Management, 37*, 100–102.

Rodrigues, B. F., & Torne, S. G. (1991c). A chemical study of seeds in three *Canavalia* species. *Tropical Science, 31*, 101–103.

Rodrigues, B. F., & Torne, S. G. (1991d). Characteristics of starch grains in three *Canavalia* species. *Agricultural and Biological Research, 6*, 73–79.

Rodrigues, B. F., & Torne, S. G. (1992). Estimation of canavanine in the seeds of three Canavalia species. *Tropical Science, 32*, 319–320.

Rosenthal, G. A. (1970). Investigation of canavanine biochemistry in the jack bean, *Canavalia ensiformis* (L.) DC. 1. Canavanine utilization in the developing plant. *Plant Physiology, 46*, 273–276.

Rosenthal, G. A. (1972). Investigations of canavanine biochemistry in jack bean plant *Canavalia ensiformis* (L.) DC. *Plant Physiology, 50*, 328–331.

Rosenthal, G. A. (1974). The interrelationship of canavanine and urease in seeds of the lotoidee. *Journal of Experimental Botany, 25*, 609–613.

Rosenthal, G. A. (1977). The biological effects and mode of action of L-canavanine a structural analogue of L-arginine. *Quarterly Review of Biology, 52*, 155–178.

Rosenthal, G. A. (1981). A mechanism of L-canaline toxicity. *European Journal of Biochemistry, 114*, 301–304.

Rosenthal, G. A. (1982). L-Canavanine metabolism in jack bean, *Canavalia ensiformis* (Leguminosae). *Plant Physiology, 69*, 1066–1069.

Rosenthal, G. A. (1988). The protective action of a higher plant toxic product. *Bioscience, 38*, 104–108.

Rosenthal, G. A. (1990). Metabolism of L-canavanine and L-canaline in leguminous plants. *Plant Physiology, 94*, 1–3.

Rosenthal, G. A. (1991). The biochemical basis for the deleterious effects of L-canavanine. *Phytochemistry, 30*, 1055–1058.

Rosenthal, G. A. (1992a). Purification and characterization of the higher plant enzyme L-canaline reductase. *Proceedings of the National Academy of Sciences of the United States of America, 89*, 1780–1784.

Rosenthal, G. A. (1992b). The biochemical basis of the insecticidal properties of L-canavanine, a higher plant protective allelochemical. In D. Otto & B. Weber (Eds.), *Insecticides: Mechanisms of action and resistance* (pp. 35–46). Andover, England: Intercept Ltd.

Rosenthal, G. A., Berge, M. A., & Bleiler, J. A. (1989). A novel mechanism for detoxification of L-canaline. *Biochemical Systematics and Ecology, 17*, 203–206.

Rosenthal, G. A., Berge, M. A., Bleier, J. A., & Rudd, T. P. (1987). Aberrant, canavanyl protein formation and the ability to tolerate or utilize L-canavanine. *Experientia, 43*, 558–561.

Rosenthal, G. A., Berge, M. A., Ozinskas, A. J., & Hughes, C. G. (1988). Ability of L-canavanine to support nitrogen metabolism in the Jack bean, *Canavalia ensiformis* (L.) DC. *Journal of Agricultural and Food Chemistry, 36*, 1159–1163.

Rosenthal, G. A., & Rhodes, D. (1984). L-Canavanine transport and utilization in developing jack bean, *Canavalia ensiformis* (leguminosae). *Plant Physiology, 76*, 541–544.

Ruediger, H., & Gabius, H. J. (2001). Plant lectins: occurrence, biochemistry, functions and applications. *Glycoconjugate Journal, 18*, 589–613.

Sadik, N. (1991). Population growth and the food crisis: food, nutrition and agriculture/alimentation. *Nutrition and Agriculture, 1*, 3–6.

Salunkhe, D. K. (1982). Legumes in human nutrition: current status and future research needs. *Current Science, 51*, 387–394.

Salunkhe, D. K., Kadam, S. S., & Chavan, J. K. (1985). Processing and utilization. In *Post harvest biotechnology of food legumes* (pp. 109–140). Boca Raton, Fl: CRC Press.

Sandberg, A. S. (2002). In vitro and in vivo degradation of phytate. In N. R. Reddy & S. K. Sathe (Eds.), *Food phytates* (pp. 139–155). Boca Raton, Fl: CRC Press.

Sastrapradja, S., Lubis, S. H., Lubis, I., & Sastrapradja, D. (1981). Studies on the Javanese species of *Canavalia*: 4. An artificial hybrid of *Canavalia ensiformis* × *Canavalia microcarpa*. *Annales Bogoriensis, 7*, 129–136.

Sathe, S. K., Deshpande, S. S., Reddy, N. R., Goll, D. E., & Salunkhe, D. K. (1983). Effects of germination on proteins, raffinose oligosaccharides and antinutritional factors in the great northern beans (*Phaseolus vulgaris* L.). *Journal of Food Science, 48*, 1796–1800.

Sato, A., Barcellos, G. B. S., Riedel, E. C., Carneiro, J. A., Carlini, C. R., & Esquibel, M. A. (1993). The presence of concanavalin A and canatoxin in *Canavalia ensiformis* DC. tissue culture. *Plant Cell Reports, 12*, 233–236.

Sauer, T., & Kaplan, L. (1969). *Canavalia* beans in American pre history. *American Antiquity, 34*, 417–424.

Sauvion, N., Charles, H., Febvay, G., & Rahbe, Y. (2004). Effects of jackbean lectin (ConA) on the feeding behaviour and kinetics of intoxication of the pea aphid, *Acyrthosiphon pisum*. *Entomologia Experimentalis et Applicata, 110*, 31–44.

Schlesier, B., Nong, V. H., Horstmann, C., & Hennig, M. (1996). Sequence analysis of concanavalin B from *Canavalia ensiformis* reveals homology to chitinases. *Journal of Plant Physiology, 147*, 665–674.

Sharon, N., & Lis, H. (1972). Lectins: Cell agglutinating and sugar specific proteins. *Science, 177*, 949–959.

Sheldon, P. S., Keen, J. N., & Bowles, D. J. (1998). Purification and characterization of N-glycanase, a concanavalin A binding protein from jackbean (*Canavalia ensiformis*). *Biochemical Journal, 330*, 13–20.

Siddhuraju, P., & Becker, K. (2001). Species/variety differences in biochemical composition and nutritional value of Indian tribal legumes of the genus *Canavalia*. *Nahrung, 45*, 224–233.

Siegenberg, D., Baynes, R. D., Bothwell, T. H., Macfarlane, B. J., Lamparelli, R. D., Car, N. G., et al. (1991). Ascorbic acid prevent the dose-dependent inhibitory effect of polyphenols and phytates on non-heme iron absorption. *American Journal of Clinical Nutrition, 53*, 537–541.

Simopoulos, A. P. (1999). Essential fatty acid in health and chronic disease. *American Journal of Clinical Nutrition, 70*, 560S–569S.

Smartt, J. (1976). *Canavalia gladiata* (Jacq.) DC. (sword bean) tropical pulses (pp. 58). London: Longman Group Ltd.

Smartt, J. (1985). Evolution of grain legumes II. Old and new world pulses of lesser economic importance. *Experimental Agriculture, 21*, 1–18.

Smartt, J. (1990). *Grain legumes* (pp. 301–309). Cambridge: Cambridge University Press.

Spoladore, D. X., & Teixeria, J. P. F. (1987). Chemical composition of seeds of *Canavalia gladiata* DC. *Bragantia, 46*, 133–139.

Staples, S. J., & Reithel, F. J. (1976). Evidence for an active–inactive subunit complex in jack bean urease. *Archives of Biochemistry and Biophysics, 174*, 651–657.

Su, C. M., Chen, A. C., & Tung, Y. C. (1980). The saccharide-binding specificity and the molecular weight of the lectin purified from the bean meal of *Canavalia lineata*. *Journal of the Chinese Biochemical Society, 9*, 14–24.

Sumner, J. B., & Howell, S. F. (1936). Identification of the hemagglutinin of jack bean with con A. *Journal of Bacteriology, 32*, 227–237.

Surolia, A., Prakash, N., Bishayee, S., & Bachhawat, B. K. (1973). Isolation and comparative physicochemical studies of concanavalin A from *Canavalia ensiformis* and *Canavalia gladiata*. *Indian Journal of Biochemistry and Biophysics, 10*, 145–148.

Swaffar, D. S., & Ang, C. Y. (1999). Growth inhibitory effect of L-canavanine against MIA PaCa-2 pancreatic cancer cells is not due to conversion to its toxic metabolite canaline. *Anti Cancer Drugs, 10*, 113–118.

Swaffar, D. S., Ang, C. Y., Desai, P. B., & Rosenthal, G. A. (1994). Inhibition of the growth of human pancreatic cancer cells by the arginine antimetabolite L-canavanine. *Cancer Research, 54*, 6045–6048.

Tepal, J. A, Castellanos, R., Larios, A., & Tejada, I. (1994). Detoxification of jack beans (*Canavalia ensiformis*): I. Extrusion and canavanine elimination. *Journal of the Science of Food and Agriculture, 66*, 373–379.

Terada, S., Fujimura, S., Kino, S., & Kimoto, E. (1994). Purification and characterization of three proteinase inhibitors from *Canavalia lineata* seeds. *Bioscience Biotechnology and Biochemistry, 58*, 371–375.

Thangadurai, D., Viswanathan, M., & Ramesh, N. (2001). The chemical composition of *Canavalia virosa*: a wild perennial bean from Eastern Ghats of Peninsular India. *European Food Research and Technology, 213*, 456–459.

Thomas, F. A., Rosenthal, G. A., Gold, D. V., & Dickey, K. (1986). Growth inhibition of a rat colon tumor by L-canavanine. *Cancer Research, 46*, 2898–2903.

Udedibie, A. B. I. (1990). Nutritional evaluation of jack bean (*Canavalia ensiformis*) for the Nigerian poultry industry. *Ambio, 19*, 361–365.

Udedibie, A. B. I., & Carlini, C. R. (1998a). Questions and answers to edibility problem of the *Canavalia ensiformis* seeds – a review. *Animal Feed Science and Technology, 74*, 95–106.

Udedibie, A. B. I., & Carlini, C. R. (1998b). Crack and cook: a simple and quick process for elimination of concanavalin A (Con A) from *Canavalia* seeds. *Animal Feed Science and Technology, 74*, 179–184.

Udedibie, A. B. I., Esonu, B. O., Obaji, C. N., & Durunna, C. S. (1994). Dry urea treatment prior to toasting as a method of improving the nutritive value of jack beans (*Canavalia ensiformis*) for broilers. *Animal Feed Science and Technology, 48*, 335–345.

Udedibie, A. B. I., & Nwaiwu, J. (1988). The potential of jack bean (*C. ensiformis*) as animal feed. *Nigerian Agricultural Journal, 23*, 130–143.

Vadivel, V., & Janardhanan, K. (2001). Diversity in nutritional composition of wild jack bean (*Canavalia ensiformis* L. DC.) seeds located from south India. *Food Chemistry, 74*, 507–511.

Vadivel, V., Janardhanan, K., & Vijayakumari, K. (1998). Diversity in sword bean (*Canavalia gladiata* (Jacq.) DC.) collected from Tamil Nadu, India. *Genetic Resources and Crop Evolution, 45*, 63–68.

Vaidehi, M. P., & Shivaleela, H. B. (1984). The protein efficiency ratio of extrusion cooked blends of jack bean (*Canavalia ensiformis*) and semolina. *Nutrition Reports International, 30*, 1173–1182.

Vasconcelos, I. M., Trentim, A., Gulmaraes, J. A., & Carlini, C. R. (1994). Purification and physicochemical characterization of soyatoxin, a novel toxic protein isolated form soybeans (glycine max). *Archives of Biochemistry and Biophysics, 312*, 357–366.

Vecchi, M., Torgano, G., Monti, M., Berti, E., Agape, A., Primignani, M., et al. (1987). Evaluation of structural and secretory glycoconjugates in normal human jejunum by means of lectin histochemistry. *Histochemistry, 86*, 359–364.

Weaver, L. T. (1994). Feeding the weanling in the developing world: problems and solutions. *International Journal of Food Sciences and Nutrition, 45*, 127–134.

Yamauchi, D., & Minamikawa, T. (1986). In vivo studies on protein synthesis in developing seeds of *Canavalia gladiata*. *Plant and Cell Physiology, 27*, 1033–1042.

Yamauchi, D., & Minamikawa, T. (1987). Synthesis of *canavalin and concanavalin* A in maturing *Canavalia gladiata seeds*. *Plant and Cell Physiology, 28*, 421–430.

Yu, G. H., & Kwon, Y. M. (1992). Alteration of arginase activity in leaf protoplasts of *Canavalia lineata*. *Korean Biochemical Journal, 25*, 196–202.