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REVIEW ARTICLE

ORIGIN, DISTRIBUTION, TAXONOMY, BOTANICAL DESCRIPTION, GENETICS AND CYTOGENETICS, GENETIC DIVERSITY AND BREEDING OF SWORD BEAN

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ABSTRACT

Sword bean belongs to the family Fabaceae, subfamily Faboideae, genus *Canavalia* and species *Canavalia gladiata* (Jacq.) DC. and Jack bean belongs to the species *Canavalia ensiformis* (L.) DC. Although related, jack bean and sword bean are two different species beans. While Sword bean is *Canavalia gladiata*, Jack bean is *Canavalia ensiformis*. The seeds of Sword bean are reddish pink or light brown and seeds of Jack bean are white or light tan. *C. ensiformis* has numerous names in English *viz.*, Brazilian broad bean, "Coffee bean", Chickasaw lima bean, Ensiform bean, "Horse bean" (usually applied to *Vicia faba*), "Jack bean" (also applied to other species in the genus *Canavalia*), Mole bean, Overlook bean, Pearson bean, "Sword bean" (usually applied to *Canavalia gladiata*), Wonder bean. Common name in English: Sword Bean, Jack bean, Scimitar bean, Jamaican horse bean; Hindi: Khadsampal, Badi sem ; Manipuri: Tebi ; Tamil: Segapputampattai; Malayalam: Valpayar, Valaringha ; Telugu: Tamma ; Kannada: Tumbekonti, Shambi, Sambe, Shampe ; Bengali: Makhan shim and Sanskrit: Mahasimbi, Asisimbi. Leguminosae is one of the largest families of flowering plants with about 690 genera and 18,000 species of herbs, shrubs, trees and climbers. They are believed to have originated in the late Jurassic period and expanded and diversified in the Cretaceous. Although evidence of the cultivation and utilization of dry beans as food extends to prebiblical times, accurate records of legume cultivation go back only to the 16th century. In many of the less-developed countries and tropical areas, the food grain legumes are important sources of protein and calories. In addition, legumes are an important source of several B-complex vitamins, minerals and fiber. The genus *Canavalia* to which the plant *Canavalia gladiata*, commonly known as the sword bean, belongs is one of these genera with about 48 species. This genus is tropical and subtropical with two major pulses contributing to agriculture, namely jack (*Canavalia ensiformis*) and sword (*Canavalia gladiata*) beans, which have been exploited fully as food sources. The jack bean (*Canavalia ensiformis*) is very closely related to the sword bean. However, the seeds can be distinguished by the length of the hilum which is nearly as long as the seed in the sword bean, and less than half its length in the jack bean. The mature seeds of *Canavalia gladiata* were originally consumed by people of ancient India, and are now consumed even by the urbanized population. Jack and sword beans are advocated to be good sources for extending protein since the protein quality is similar to most edible food legumes. Sword bean (SB) is also a good source of medicinal properties. The *Canavalia gladiata* possess biological functions such as anti-inflammatory, haematopoietic improving, hepatoprotective and anti-angiogenic activity. Some studies have reported that *C. gladiata* efficient for protecting against bone loss, increase in antioxidant activity and improving cell profiles. Sword bean, the seed of the leguminous plant *Canavalia gladiate*, also has been treated as traditional medicine for containing canavanine, hemagglutinin, and concanavalin A. It has been reported that sword bean may exhibit antioxidant activity of eliminating free radicals and against oxidative stress. In addition, it also has strong anti-inflammatory and anticarcinogenic effects. India is often referred to as a predominantly vegetarian nation due to a combination of cultural, historical, religious and economic factors. While it's essential to note that not every individual in India is vegetarian, a significant portion of the population does follow a vegetarian diet. legumes are highly preferred in India for vegetarian diets due to their nutritional value, affordability, cultural significance, versatility, satiety, environmental considerations, and alignment with religious and cultural practices. These factors collectively make legumes an integral part of the Indian vegetarian diet and contribute to their widespread popularity. In this review article on Origin, Domestication, Taxonomy, Botanical Description, Genetics and Cytogenetics, Genetic Diversity, Breeding, Uses, Nutritional Value and Health Benefits of Sword Bean are discussed.

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INTRODUCTION

Sword bean belongs to the family Fabaceae, subfamily Faboideae/Papilionoideae, genus *Canavalia* and species *Canavalia gladiata* (Jacq.) DC. (Mia, 2016; Rojas-Sandoval, 2019; Pal and Pandey, 2023; Wikipedia,2024a; Wikipedia, 2024d) and Jack bean belongs to the species *Canavalia ensiformis* (L.) DC. (Ranjeet Patel *et al*., 2016; Wikipedia, 2024c). *C. ensiformis* has numerous names in English *viz.*, Brazilian broad bean, "Coffee bean", Chickasaw lima bean, Ensiform bean, "Horse bean" (usually applied to *Vicia faba*), "Jack bean" (also applied to other species in the genus *Canavalia*), Mole bean, Overlook bean, Pearson bean, "Sword bean" (usually applied to *Canavalia gladiata*), Wonder bean (Wikipedia, 2024c). Sword beans taste very similar to broad beans- earthy and nutty with some sweet and buttery taste. Not everyone has a palate for such tastes. When consumed in large quantities and also not cooked/consumed in the right way, sword beans can be poisonous. For instance, if you want to eat sword beans raw, then you should remove the sword beans seed coating and boil it many times in water. Note that everytime you boil, the water should be different (HND, 2023). Young leaves, pods, and stems of this fruit and vegetable can be eaten raw, steamed, or boiled. Because mature or dried seeds (sword beans) contain poisonous protein, they are often cooked in two or three changes of water before the tough seed coatings are removed. They are regarded as a necessary diet for expectant mothers in India (HND, 2023). Common Names for *Canavalia ensiformis* (L.) DC jack-bean, sword-bean, coffee bean, wonder-bean, giant stock-bean, horse-bean and horse gram (Sheahan, 2012). Other scientific names for jack bean are *Canavalia ensiformis* var. *truncata* Ricker and *Dolichos ensiformis* L. (Sheahan, 2012). Although related, jack bean and sword bean are two different species beans. While Sword bean is *Canavalia gladiata*, Jack bean is *Canavalia ensiformis*. The seeds of Sword bean are reddish pink or light brown and seeds of Jack bean are white or light tan (HND, 2023). Common names are as follows: Jack bean, Sabre bean, Brazilian Bean, Horse bean, Sword-leaf bean, Brazilian broad bean, Wild Bean, Chinese sword bean, Bell bean, Sword-lily bean, Indian sword bean, Mauritius bean, Bay bean, Catalina bean, Sikkim sword bean, Fiji bean, Sudan bean, Madagascar bean, Rongai bean, Sudanese bean, Mombasa bean, Manila bean, Kaffir bean, Macassar bean, Chinese long bean. The popular name for this plant comes from the way its leaves look like the blade of a sword (Sylvia, 2023). Common names of sword bean are Sword bean, dolic en sabre, pois sabre, pois sabre rouge, schwertbohne, feijão de porco, haba de burro, poroto sable (Feedipedia, 2015). Common name in English: Sword Bean, Jack bean, Scimitar bean, Jamaican horse bean; Hindi: Khadsampal, Badi sem ; Manipuri: Tebi ; Tamil: Segapputampattai; Malayalam: Valpayar, Valaringha ; Telugu: Tamma ; Kannada: Tumbekonti, Shambi, Sambe, Shampe ; Bengali: Makhan shim and Sanskrit: Mahasimbi, Asisimbi (Kasim and Valke, 2024).

Eight accessions of sword bean were collected from eight agroclimatic regions of Tamil Nadu, India. A portion of the collected seeds of accessions will be deposited in NBPGR, New Delhi. The most pronounced differences in agrobotanical characters were observed in seed germination percentage, plant height, number of branches per plant, number of leaves (180th day) per plant, leaf area (150th day), early flowering, fertility index and 100-seed-weight. Differences in the contents of crude protein and crude lipid in the seeds of different accessions also appeared to be significant. Performance of Lowerkodiyar and Mundanthurai accessions under test conditions was superior and suggested that breeders might exploit the genome of these accessions in current pulse crop improvement programmes (Vadivel *et al*., 1998). The wide prevalence of protein-calorie-malnutrition in developing countries including India is of great concern not only to agricultural scientists but also the concerned Governments. About 80% of the protein consumed by humans in developing countries is supplied by plants. The continuous increase in population growth and inadequate supplies of plant proteins lead to malnutrition among people in developing countries (Vadivel *et al*., 1998). The tribal sects of India live on a vast treasure of germplasm, which has hitherto remained untapped. Some of the under-utilized legumes/tribal pulses may fit well into subsistance agriculture as alternate protein sources. Unless collected accessions from different regions have been properly evaluated and their attributes become known to breeders, they will have little practical use (Vadivel *et al.,* 1998).

The literature related to the legume commonly known as sword beans that belongs to the genus *Canavalia* which is considered to be an underutilized legume, is reviewed. The legume seeds are considered to be a cheap source of good protein and calories that are easily available. However, even with this knowledge, the utilization of most legumes is apparently low. Sword beans have favorable agronomic features suitable for cultivation in the tropics and a high average yield comparable to that of soybeans (Ekanayake *et al*., 2000). The gap between the human population and the quantity of the food supply has already become a global threat. Therefore, to bridge the gap efforts are being made to identify and evaluate under exploited food sources. Legumes with high quality protein and calories that are not extensively utilized as food have become a primary target in this effort. It is critical to produce or introduce new foods that have high nutritional quality and are easy, for people with a low income, to purchase; foods that are less costly to produce and suitable to the environment as a function of desirable agronomic features need to be cultivated in the tropics where a large portion of the persons affected by food shortages reside. The bean *Canavalia gladiata* (sword bean) which is a leguminous plant is not eaten very frequently, but has a potential to become an important food source (Ekanayake *et al*., 2000).

Leguminosae is one of the largest families of flowering plants with about 690 genera and 18,000 species of herbs, shrubs, trees and climbers. They are believed to have originated in the late Jurassic period and expanded and diversified in the Cretaceous. Although evidence of the cultivation and utilization of dry beans as food extends to prebiblical times, accurate records of legume cultivation go back only to the 16th century. In many of the less-developed countries and tropical areas, the food grain legumes are important sources of protein and calories. In addition, legumes are an important source of several B-complex vitamins, minerals and fiber (Ekanayake *et al*., 2000). The genus *Canavalia* to which the plant *Canavalia gladiata*, commonly known as the sword bean, belongs is one of these genera with about 48 species. This genus is tropical and subtropical with two major pulses

contributing to agriculture, namely jack (*Canavalia ensiformis*) and sword (*Canavalia gladiata*) beans, which have been exploited fully as food sources. The jack bean (*Canavalia ensiformis*) is very closely related to the sword bean. However, the seeds can be distinguished by the length of the hilum which is nearly as long as the seed in the sword bean, and less than half its length in the jack bean (Ekanayake *et al*., 2000). The mature seeds of *Canavalia gladiata* were originally consumed by people of ancient India, and are now consumed even by the urbanized population. Jack and sword beans are advocated to be good sources for extending protein since the protein quality is similar to most edible food legumes (Ekanayake *et al*., 2000).

Six accessions [three with maroon-coloured seed coat and three with white-coloured seed coat) of sword bean were collected from six different locations in south India. They were analysed for their proximate and mineral composition, amino acid profiles of total seed proteins, *in vitro* protein digestibility (IVPD) and certain antinutritional factors. The essential amino acid profile of total seed proteins compared favourably with FAO/WHO requirements, except that there were deficiencies of sulphur containing amino acids in all the six accessions and also the leucine, lysine and tryptophan contents were low in maroon-coloured seed coat accessions. The IVPD of the accessions ranged from 63.39 to 76.92%. Antinutritional substances like total free phenolics, tannins, L-DOPA (3,4-dihydroxyphenylalanine), trypsin inhibitor activity and phyto-haemagglutinating activity were also investigated. The antinutritional factors that were detected were thought to have little nutritional significance if the beans are properly processed (Vadivel and Janardhanan, 2004). The growing Third World population and its domestic animals need more protein. The most cost-effective proteins are those derived from plant materials which, although in abundance in many developing countries, are under-utilized. The search for novel high-quality but cheap sources of protein and energy has continued to be of major concern to governments and other bodies charged with the responsibility for food and nutrition in many parts of the developing world (Vadivel and Janardhanan, 2004). The jack bean (*Canavalia ensiformis* DC.) is very closely related to the sword bean. However, the seeds can be distinguished by the length of the hilum which is nearly as long as the seed in the sword bean, and less than half its length in the jack bean. Sword bean plants with pinkish flowers produce seeds with maroon-coloured seed coats and plants with white flowers produce seeds with white-coloured seed coats. Leaves are trifoliate, with large pubescent leaflets, which are acuminate with a short point at the apex. The petioles are shorter than the leaflets with a groove above and stout with a large pulvinus at the base of each leaflet. The seed-pods are usually broad and curved with strongly developed ridges. They are about 20–40 cm long and 3.5–5 cm broad, containing on average 8 to 16 seeds (Vadivel and Janardhanan, 2004).

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 (Sridhar and Seena, 2006). Tropical developing countries are facing an increasing demand for protein-rich food due to teeming population, cereal-based diet and scarcity of fertile land. 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. They are known to contain certain bioactive compounds whose beneficial effects need to be explored for exploitation (Sridhar and Seena, 2006).

The global production of food legumes in 1998 was 246 million tons. 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 (Sridhar and Seena, 2006). 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 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. (Sridhar and Seena, 2006).

Sword bean has been used in Asia and Japan as a vegetable while in the United States sword bean is used as a source of the lectin concanavalin A. The USDA, ARS, PGRCU maintains 27 sword bean accessions. Sword bean accessions were transplanted from approximately 45-day-old seedlings to the field. After 3–4months, 21 accessions were characterized for morphological traits and evaluated for regeneration. High quality plants regenerated from all accessions produced 19 to more than 1100 total seeds. Sword bean can be successfully grown and regenerated in Griffin, GA. Sword bean has potential to be used in numerous other ways including nutraceuticals, phytopharmaceuticals, and other agricultural products. Flavonoids such as rutin identified in sword bean seeds may decrease precancerous lesions in the large intestine while the phytochemical, beta-aminopropionitrile inhibits breast adenocarcinoma growth. Canatoxin, the potential pesticide from sword bean seeds showed toxicity to the cotton pest, Dysdercus peruvianus (Morris, 2007). Conventional legume seeds have been playing a key role as a source of protein in the diets of both human beings and animals, but their production is not sufficient to meet the increasing protein requirements, particularly in a developing country like India. To meet the inadequate supply of proteins in developing countries, where animal protein is grossly insufficient and also relatively expensive, recent research efforts are being geared towards finding out novel and economic sources of food proteins. Among the various alternative protein sources, the under-utilized legume seeds received more attention, whose protein potential remains under-developed (Vadivel *et al.,* 2010).

Sword bean (SB) is a tropical under-utilized food legume, wildly distributed in the Eastern and Western Ghats of South India and also cultivated as a fodder crop in Northern and Peninsular India. It has many desirable agronomic features such as high biomass production, resistance to drought, pest and diseases, high fertility index and high seed productivity (800-1000 Kg/ha) on fertile land, which enable them to grow well under tropical conditions. In India, the SB seeds are consumed by certain ethnic groups and poor village people. In Asia, the young pods and seeds of SB are used as a green vegetable. The SB seeds are often consumed as curries and as a substitute for mashed potatoes and the immature pods are made into a dish directly or often boiled with water in Sri Lanka. The roasted seeds are used to prepare a coffee-like drink in Latin America (Vadivel *et al*., 2010).

Canavalia species ranks well among the neglected crop species. The nutritional, pharmaceutical usefulness of this legume both to man and his livestock are outstanding; the seeds are used as food for man while foliage is important as meal for animals. The immature pod of most legumes is rich in protein, minerals and vitamins while the seeds are the most nutritious part. The fruits of *Canavalia* spp. have been reported as potential sources of nutritional, nutraceutical, and pharmaceutical benefits for humans and livestock. Both species of Sword bean (*Canavalia gladiata*) Jack bean (*Canavalia ensiformis*) are used in Nigeria as ornamental plants and in some places are believed to be "snake repellents". Sword bean contains gibberellin A-15, a growth-promoting hormone (Dada *et al*., 2013).

Jack bean (*Canavalia ensiformis* (L.) DC.) belongs to the family leguminosae is one of the underexploited tropical dry bean however, fairly widely distributed from West Indies (origin) to Central and South America. The Genus *Canavalia* consisting of 48 species of which, four species are reported from India, *viz*., *C. ensiformis, C. gladiata, C. maritima* and *C. virosa*. Out of these four species, *C. ensiformis* (Jack bean) and *C. gladiata* (Sword bean) were reported to cultivated in North East region of India for the edible pods (Lenkala *et al.,* 2015a). The exploitation of genetic variability is a pre-requisite for the effective screening of superior genotypes for improvement of yield and yield related characters. The progress in breeding for the yield and its contributing characters of any crop is polygenically controlled, environmentally influenced and determined by the magnitude and nature of their genetic variability. Hence, it is essential to partition the overall variability into its heritable and non-heritable components with the help of genetic parameters like variability, heritability and genetic advance. Knowledge of correlations among different characters and further partitioning them into direct and indirect effects help to understand the nature and extent of such relationship. Therefore, study of genetic variability, correlation and path coefficient are pre-requisite for improvement of any crop (Lenkala *et al*., 2015a).

Sword beans have been used as grain legumes and medicinal plants in China for thousands of years. To explore new natural antioxidant sources, the antioxidant capacity and phenolic composition in the soluble and bound fractions of three sword bean genotypes were evaluated *in vitro*. The red and black sword beans were found to have antioxidant capacity compared to the white sword bean, and this was attributed to their red and black bean coats, which possessed extremely high phenolic content. Gallic acid and its derivatives, such as methyl gallate, digalloyl hexoside and digallic acid, were the main phenolic compounds in the coats of red and black sword beans. Therefore, the red and black sword beans, especially their bean coats, are good sources of antioxidant phenolics and may have potential health benefits (Ren-You Gan *et al.,* 2015). At the green pod and shelled vegetable stage, the seeds contain vitamin A, vitamin C, calcium and iron (Ekanayake *et al.,* 2000). The coats of the bean *C. gladiata* contain good source of antioxidant phenolics having potential benefits against oxidative stress. The seeds of *C. gladiata* are known for several valuable phytochemicals such as anticancer agent, trigonelline, cytotoxic amino acids canavanine, antiviral lectin and concavalin A (Ren-You Gan *et al*., 2015).

Sword bean (SB) is also a good source of medicinal properties. The *Canavalia gladiata* possess biological functions such as anti-inflammatory, haematopoietic improving, hepatoprotective and anti-angiogenic activity. Some studies have reported that *C. gladiata* efficient for protecting against bone loss, increase in antioxidant activity and improving cell profiles (Ren-You Gan *et al.,* 2015). The seed coat possesses extremely high phenolic content which have antioxidant activity and may have potential health benefits. The gallic acid and its derivatives such as methyl gallate, digalloyl hexoside and digallic acid were main phenolic compounds in the coats of the bean. The lectins present in red sword bean have been reported as anticancer agent and used as biochemical tools due to their specificity and ability to recognize cancer cells (Ren-You Gan *et al*., 2015).

Canavalia ensiformis is a legume, mainly used for nutrition, especially in North-East India, South East Asian countries and South American countries. It is also a rich source of Concanavalin A and can also be used as an animal fodder. In North-east India this plant is cultivated mainly for domestic consumption. The aim of the present study was to evaluate the nutritional composition of pods of *Canavalia ensiformis* (Jack bean) with the help of proximate analysis. The proximate composition were determined in the form of moisture content (83.3%), reducing sugar (2.21%), total sugar (3.41%), acidity (0.19), vitamin C (8.087 mg/100g), protein (10.85 g/100g), fat (1.59 g/100g), carbohydrates (12.15 g/100g) and crude fiber (3.98 g/100g). Based on the result of this study, the pods of *Canavalia ensiformis* was found to be a potential source of protein, vitamin and energy supplements (Ranjeet Patel *et al.,* 2016). North-East India comprising of Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Tripura and Nagaland, and the Himalayan state of Sikkim has huge physiographical variations. This region is one of the richest reservoir of various kinds of fruits, vegetables, spices, medicinal & aromatic plants including ornamental plants. *Canavalia ensiformis* (Jack bean) is a legume crop, belonging to the family Fabaceae and is cultivated in North Eastern region of India. It is widely distributed in India, Argentina, China and United States and is mainly used for animal fodder and for human nutrition in a limited scale. The seeds of *Canavalia ensiformis* (Jack bean) are consumed in different parts of India (Ranjeet Patel *et al.*, 2016). It is a twining type of plant whose height may go upto 10 feet in North-East India. Moreover, its height may vary to some extent from region to region depending upon the topography and the climatic condition of the region. It is highly drought resistant and its roots penetrate deep into the soil. It can spread *via* long runners and its flowers are pink-purple in colour. The average length of the pod is 32 cm with

large white seeds. This legume is used as a cover crop and the roasted seeds are ground to prepare drink like coffee in western countries. Its cultivation is easy and produces high yields in low-altitude regions with high temperature and relative humidity. The environment of different locality plays an important role in the determination of quantity and quality of seed proteins (Ranjeet Patel *et al.,* 2016). The crop has high commercial value and has been widely produced in the Far East countries. It is primarily produced in China in the area of the Yangtze River basin and southern provinces: Anhui, Hubei, Guangdong, Guangxi, Jiangxi, Shanxi, Sichuan, Jiangsu and Taiwan. The crop is considered to be an underutilized legume and so far, it has been completely unknown in Poland and other Central European countries (Xianzong XIA *et al*., 2017). Sword bean is well adapted to tropical climates. Being a hardy crop, it can be grown in all types of soil and is well adapted to poor-quality soils. Sword bean is propagated by seed. Actually, sword bean is grown on a small scale only by the small holding farmers near houses, and the vines are allowed to climb on walls, fences and trees (Rana and Badiger, 2017). *Canavalia ensiformis* known as jack bean is the most economically important species in the genus *Canavalia*, with enormous potentials to serve as food for both humans and livestock. It is widely distributed in Africa, Asia, and America, with large-scale cultivation reported in Congo and Angola. It is rich in protein and thrives well in poor and acidic soils. Jack bean is mainly grown for its nutritious pods, seeds, and as fodder. It is a forage crop with high green manure capacity to enrich the soils and also to control soil erosion. The crop tolerates adverse environment, drought, heat, and leached soils; also it resists pest attacks. The leaf of jack bean contains crude proteins and fiber comparable to other legumes. Jack bean possesses deep root system which enables the plant to penetrate deeply into the soil which enables it to withstand very dry conditions. Raw jack bean contains toxic compounds such as tannin, phytate, saponins, canavanine, concanavalin A (hemagglutinin), and trypsin inhibitors (Popoola *et al.,* 20219). Sword bean (*Canavalia gladiata* L.) is another species in the genus *Canavalia* of the Fabaceae family with rich potentials likely to be adopted as an important source of food, leafy vegetable, medicine, forage, and as cover crop. It is a vigorous perennial climber plant usually cultivated as an annual. Reports indicated that sword bean originated from the Asian continent and is now known in the tropics as an introduced species. The red sword bean is one of the edible beans of China reportedly rich in antioxidant polyphenols with great medicinal uses. Furthermore, the seed coat of the bean is rich in gallic acid and its derivatives, mainly gallotannins, a common trait found in legume polyphenols. The chemical composition of seeds of sword bean has been reported and compares quite well with soybean (Popoola *et al*., 20219).

Sword bean, the seed of the leguminous plant *Canavalia gladiate*, also has been treated as traditional medicine for containing canavanine, hemagglutinin, and concanavalin A. It has been reported that sword bean may exhibit antioxidant activity of eliminating free radicals and against oxidative stress. In addition, it also has strong anti-inflammatory and anticarcinogenic effects. It is reported that soybean paste containing sword bean exhibits higher ACE inhibitory effects than other soybean pastes (Zhang *et al*., 2018). Sword bean (Canavalia gladiata L.) is a tropical under-utilized food legume. It is rich in proteins and is cultivated as a vegetable and fodder crop. Sword bean is wildly distributed in the Eastern and Western Ghats of South India and also cultivated as a fodder crop in Northern and Peninsular India. It has many desirable agronomic features such as high biomass production, resistance to drought, pest and diseases, high fertility index and high seed productivity on fertile land, which enable them to grow well under tropical condition. The seeds are not extensively utilized as food/feed mainly due to the presence of certain antinutritional compounds such as total free phenolics, tannins, Concanavalin A (Con A) lectin, L-Canavanine (a non-protein amino acid), phytic acid, oligosaccharides, protease inhibitors and α-amylase inhibitors (**V**ikaspedia, 2020). June - July (Rainfed), September - October (Rabi), February - March (Summer). It can be grown throughout the year and gives good response to irrigation (**V**ikaspedia, 2020). There are two types of sword bean. White seeded varieties are bushy in nature whereas red seeded varieties are trailed over pandals. Pole type varieties are to be planted at a spacing of 4 x 3 m whereas bush type varieties are to be planted at 60 x 60 cm. May-June and September-October are the usual sowing time and the seed rate followed is one or two seeds per pit. This can also be grown as border crop, intercrop and a shade crop. SBS 1 is a variety of Sword bean grown in Tamil Nadu (**V**ikaspedia, 2020). FYM is applied at the rate of 5 t/ha. The $N:P_2O_5: K_2O$ mixture (7:10:5) may be applied as basal dose and top dressing at several splits (**V**ikaspedia, 2020). Sword bean matures in 110 - 120 days. Tender pods are ready for harvest from 75 days after sowing. As a pure crop it gives an average grain yield of 1356 kg/ha and green pod yield of 7500 kg/ha (**V**ikaspedia, 2020). *Canavalia gladiata* and *Canavalia ensiformis* are the two species of the genus *Canavalia*, and are commonly known as the sword bean and jack bean, respectively. They have the potential to be used as an important food source. There are about 48 species belonging to the genus *Canavalia*, however the two species of the genus *Canavalia ensiformis* (jack) and *Canavalia gladiata* (sword) are very popular (Ekanayake *et al*., 2000). These species are closely related to each other and have been exploited for human food. Young green pods of this plant are used as a vegetable in Asian countries with reported use in India, Sri Lanka, and Indonesia. In some places, the pods and seeds are eaten raw or are cooked or fermented. In non-Asian countries like the West Indies, Africa, and South America, the plant is grown on a small scale. The plants are relatively resistant to various pathogen attack, although there is evidence of root rot and scab in a few cases (Nayak *et al*., 2020). Nutritionally, *Canavalia* spp. are rich in protein (17%–30%) and carbohydrate (24%–68%) content, but fat content is minimal with 0.2% in fresh seeds. Minerals like potassium, calcium, and iron are found in good quantities along with vitamin C (Ekanayake *et al*., 2000). *Canavalia* varieties have a wide range of nutritional and medicinal properties. Although the plant is not grown on a large scale, but its potential in terms of nutrition is beneficial in terms of low fat content, which could be beneficial for people looking for low-fat and high protein fortified diet (Nayak *et al.,* 2020). Sword Bean (*Canvalia gladiate* L.) is underutilized vegetable crop propagated through seeds belongs to the Fabaceae family and widely distributed in South and Southeast Asia. Sword bean is self-pollinated photo-insensitive crop and climbing in nature. Flowers are white in colour. Sword bean seeds are rich in protein. Seeds are elliptical in shape with 3 cm long and reddish in color (Kumarasamy *et al*., 2020). Seed maturity is the crucial factor in determining the seed quality and it is a gradual preparation for germination of seeds. Quality of the seed is basically depending upon the nature of seed filling and metabolic as well as synthetic activities during seed developmental and maturation which in turn is reflected upon the germination and vigorous growth of seedlings. A study on tracing the pattern of seed development and maturation is highly essential to fix the optimum stage for seed harvest from the mother plant so as to obtain good quality seeds

with assured germination and vigour (Kumarasamy *et al*., 2020). Early harvesting of crop before physiological maturity leads to reduction in yield and quality of seed and also favours development of immature seeds. Delaying of harvest after physiological maturity leads to decrease in viability and vigour and lower performance during storage (Kumarasamy *et al.,* 2020). As you can see, there's a lot to love about the Sword Bean. It's big, nutritious, delicious, and isn't grown commercially, so growing it yourself is one of the only ways to try it out. If you hope to enjoy Sword beans or other beans, visit our beans page page for all our legume-related blog posts! (Coblentz, 2023). Some species of the genus *Canavalia,* including *Canavalia ensiformis* and *Canavalia gladiata*, are known as sword bean. Tropical perennial legumes, known as sword beans, are popular companion plants. These species are thought to be most beneficial for fixing nitrogen and controlling weeds, even if they constitute a minor food crop. Additionally, it has been discovered that ensiformis inhibits several plant diseases. Although it might be challenging to find seeds, there are various commercial sources (HND, 2023). Sword bean (*Canavalia gladiata* L.), a tropical food legume, is underutilised. It is a vegetable and a fodder crop and is high in proteins. Sword bean is widely farmed as a crop for fodders in the peninsular and northern parts of India and the Eastern and Western Ghats of South India. Numerous advantageous agronomic characteristics, including high biomass output, tolerance to pests, diseases, drought, good fertility index, and productive seed yield on fertile ground, enable them to thrive in tropical environments (HND, 2023). Antinutritional substances are the primary reason the seeds are not widely used as food or feed. Sword bean comes in two varieties. Red-seeded variants trail over pandals, and white-seeded versions are bushy in characters. While bush-type types should be planted at 60 x 60 cm, pole-type varieties should be planted at a spacing of 4 x 3 meters. Tamil Nadu is the sword bean type home, SBS 1 (HND, 2023).Young leaves, pods, and stems of this fruit and vegetable can be eaten raw, steamed, or boiled. Because mature or dried seeds (sword beans) contain poisonous protein, they are often cooked in two or three changes of water before the tough seed coatings are removed. They are regarded as a necessary diet for expectant mothers in India (HND, 2023). Sword beans taste very similar to broad beans- earthy and nutty with some sweet and buttery taste. Not everyone has a palate for such tastes. When consumed in large quantities and also not cooked/consumed in the right way, sword beans can be poisonous. For instance, if you want to eat sword beans raw, then you should remove the sword beans seed coating and boil it many times in water. Note that everytime you boil, the water should be different (HND, 2023). Although related, jack bean and sword bean are two different species of beans. While Sword bean is *Canavalia gladiata*, Jack bean is *Canavalia ensiformis*. The seeds of Sword bean are reddish pink or light brown and seeds of Jack bean are white or light tan (HND, 2023).

The most distinguishing feature of the Sword Bean is its unusual size. However, there's more to this bean than meets the eye. The best way to describe the taste of these beans is that they're very similar to broad beans. They have a very earthy and nutty flavor with subtle hints of sweetness and butter. Sword beans are the type of bean you can tell is fresh from the earth. It tastes like a stereotypical green vegetable with a flavor that isn't for everyone. Sword beans are contained in pods that are long and green. Inside the pods, however, you'll find seeds that vary in color but are usually somewhere between brown and pink, ending up close to red. The bean pods grow on climbing vines that are green and leafy. The leaves are just as green as the pods, but they don't get quite as big. You can also find white flowers on the plant at certain times of the year. Like we said before, the beans found inside the pods are reddish or brown, and there are typically between ten and fifteen beans in a pod. While the individual beans are nowhere nearly as large as the pods, they're bigger than a typical bean. The most pronounced feature of these beans is their incredible size. The pods themselves can grow up to or over one foot in length, which is why it gets its fitting name. In addition to growing a foot long, the pods are also several inches wide. Contained inside the bean pod, you can find up to fifteen seeds. These incredible specimens grow (Coblentz, 2023).

India is often referred to as a predominantly vegetarian nation due to a combination of cultural, historical, religious and economic factors. While it's essential to note that not every individual in India is vegetarian, a significant portion of the population does follow a vegetarian diet. legumes are highly preferred in India for vegetarian diets due to their nutritional value, affordability, cultural significance, versatility, satiety, environmental considerations, and alignment with religious and cultural practices. These factors collectively make legumes an integral part of the Indian vegetarian diet and contribute to their widespread popularity (Debbarma *et al*., 2023). Sword bean is perennial in nature but are often cultivated as annual crop. The plant requires warm and sunny weather and grows well under organic rich well-drained soil. The plant is adapted to adverse environmental conditions and can thrive under extreme stress conditions. The genotypes of underutilized vegetables unless collected from different regions are properly evaluated and their attributes become known to breeders, will have little practical use (Debbarma *et al.,* 2023). Sword beans are mostly consumed by rural peoples of North-Eastern hill region. The diversity in sword bean observed based on morphological characters in the present study could be of interest to the breeders in breeding programme (Debbarma *et al*., 2023).

Canavalia comes from the Portuguese word "canaval," which means "bean" or "plant with edible seeds." The plant was given this name because it is in the family of legumes (Fabaceae) and has seeds that can be eaten. Gladiata is a specific name that comes from the Latin word "gladius," which means "sword." It has to do with the way the leaves of the Sword Bean look, which are long and shaped like a sword (Sylvia, 2023). It is used as a food in the central interior and south central parts of India, but it is not grown on a large scale. In Africa and Asia, the green pods are consumed as a veggies. The title"sword bean" is also utilized for other legumes, common jack bean. They are a good source of protein, fiber, vitamins (like thiamine and niacin), and minerals (like iron and potassium). They also have little fat, which makes them a healthy part of a well-balanced diet. It is sometimes grown as a flower because its flowers, which look like pink and white peas, are very pretty (Sylvia, 2023). Regular consumption of legume reduces the risk of cardiovascular diseases, coronary heart diseases and also helps in prevention of cancer, type II diabetes, obesity and osteoporosis. The seeds of sword bean was mostly consumed by some tribal groups of India but now it is also been utilized by urban people as a vegetable (Pal and Pandey, 2023). Investigation of phytochemicals in *C. gladiata* have indicated the presence of alkaloids, tannins, flavonoids, cardiac glycosides and reducing sugars. *In vitro* evaluation of phytochemical constituents showed the biological activity *viz.*, antioxidant, antimicrobial, anti-inflammatory, antidiabetic activities etc.

Sword bean has profitable characters like high biomass production, drought resistant, pest and disease resistant, high fertility index and high seed production *i.e*. 800-1000 kg seeds per hectare of crop land (Pal and Pandey, 2023). The protein content in the mature seed of sword bean is comparatively higher than that in any other legumes. However, other than protein, the starch, fat and mineral profile also indicated sword bean to be good supplement to cereal based diet (Pal and Pandey, 2023).

India is often referred to as a predominantly vegetarian nation due to a combination of cultural, historical, religious and economic factors. While it's essential to note that not every individual in India is vegetarian, a significant portion of the population does follow a vegetarian diet. Legumes are highly preferred in India for vegetarian diets due to their nutritional value, affordability, cultural significance, versatility, satiety, environmental considerations, and alignment with religious and cultural practices. These factors collectively make legumes an integral part of the Indian vegetarian diet and contribute to their widespread popularity (Debbarma *et al*., 2023). 20 genotypes of sword bean were collected from various parts of North-Eastern hill region of India. Sword bean, scientifically known as *Canavalia gladiata* Jacq., is a tropical and sub-tropical legume plant that is primarily grown for its edible beans and attractive flowers. The most notable feature of the sword bean plant is its long, flat and somewhat sword-shaped pods. These pods measure about 20 to 40 cm in length and are typically green, turning yellow or brown as they mature. Each pod contains several large, flat and oval-shaped or kidney shaped seeds or beans. The sword beans, which are the seeds found inside the pods are edible. These are consumed when young and tender, similar to other green beans. The pods become tough and less palatable when mature. Therefore, it is essential to harvest the pods when young and tender for the best flavour and texture. The beans have mild and nutty flavour thus making them suitable for various culinary preparations (Debbarma *et al.,* 2023). Sword beans can be prepared and cooked in a similar manner to other beans. They can be steamed, stir-fried, boiled or included in a variety of dishes like salads, stews and curries. The young, tender beans are preferred for consumption. Sword beans are a good source of plant-based protein making them an excellent choice for vegetarians and vegans. The pod is high in dietary fiber, which aids in digestion and helps maintain bowel regularity and also good source of vitamin C, vitamin A and minerals like potassium and iron. The beans also contain antioxidants that help to protect cells from damage caused by free radicals (Debbarma *et al.,* 2023**).**

Sword beans are a versatile and nutritious addition to the diet and their cultivation can serve both culinary and ornamental purposes. Sword bean is perennial in nature but are often cultivated as annual crop. The plant requires warm and sunny weather and grows well under organic rich well-drained soil. The plant is adapted to adverse environmental conditions and can thrive under extreme stress conditions (Debbarma *et al*., 2023). Sword beans are mostly consumed by rural peoples of North-Eastern hill region. The diversity in sword bean observed based on morphological characters in the present study could be of interest to the breeders in breeding programme. Therefore, the present investigation was undertaken with the objective of exploring the lesser-known neglected sword bean grown in North-Eastern hill region and analysis was done based on 6 morphological characters (Debbarma *et al*., 2023).Sword bean (*Canavalia gladiata* L.), a tropical food legume, is underutilised. It is a vegetable and a fodder crop and is high in proteins. Sword bean is widely farmed as a crop for fodders in the peninsular and northern parts of India and the Eastern and Western Ghats of South India. Numerous advantageous agronomic characteristics, including high biomass output, tolerance to pests, diseases, drought, good fertility index, and productive seed yield on fertile ground, enable them to thrive in tropical environments (HND, 2023).

The sword bean or scimitar bean, is a domesticated plant species in the legume amily Fabaceae. It is used as a vegetable in interior central and south central India, though not commercially farmed. The unripe pods are also eaten as a vegetable in Africa and Asia. From the Japanese agricultural encyclopedia *Seikei Zusetsu* (1804). The term "sword bean" is also used for other legumes, notably the common jack bean *Canavalia ensiformis* (Wikipedia, 2024a). *Canavalia ensiformis* (jack bean) is a legume which is used for animal fodder and human nutrition, especially in Brazil where it is called *feijão-de-porco* ("pig bean"). It is also the source of concanavalin A (Wikipedia, 2024c). The sword bean or scimitar bean, is a domesticated plant species in the legume family Fabaceae. It is used as a vegetable in interior central and south central India, though not commercially farmed. The unripe pods are also eaten as a vegetable in Africa and Asia. The term "sword bean" is also used for other legumes, notably the common jack bean *Canavalia ensiformis* (Wikipedia, 2024d).

Sword Beans are impressive vines that produce bean pods that can be up to 35cm long and 6cm wide, resembling the blade of a sword. Young pods, leaves and stems can be eaten raw, steamed or boiled. Mature beans can also be eaten but should be boiled in at least two changes of water and have their seed coats removed due to toxic proteins within the mature seeds (**G**ardeningsg, 2024). Some authors consider the species *C. gladiata, C. africana* and *C. ensiformis* as a single species as they cross freely and their uses and chemical composition are similar. Furthermore, DNA analyses could not find differences between *C. gladiata* and *C. ensiformis*. These two species are very similar in growth habit, but they can be distinguished by the following morphological traits. seed colour: red or pink in *C. gladiata* and white in *C. ensiformis;* hilum length: in *C. gladiata,* the hilum covers most of the upper margin of the seed while in *C. ensiformis,* the hilum covers only a quarter of the seed. *C. gladiata* also appears to be closely allied to *C. africana,* but the main difference is in the pod size: up to 60 cm long in *C. gladiata* vs. up to 17 cm long in *C. Africana* (Rojas-Sandoval, 2024).

Green pods are produced in 80–120 days and mature seeds produced after 180–300 days. Jack bean can produce up to 4,105 lb/ac dry seed (Sheahan, 2012). During the vegetation period, additional watering, staking and chemical control against aphids and bean weevils were applied. On average, one pod had 7.3 seeds. The early cultivar gave good seed yield - 2,067.00 kg ha-1. The germination capacity of the produced seeds was over 90%. The mean germination time was shorter at 25 °C than at 15 °C. Water absorption capacity curves, although different for the 1 hour time point, were basically the same for both Chinese and Polish seeds. The total proteins content for both cultivars was almost 25% (Xianzong XIA *et al*., 2017).

Average yield ranges from 720 to 1500 kg/ha which can be compared with soybean yield of 600–1000 kg/ha. The fruits mature in 6–10 months after planting. The sword bean is relatively resistant to attack from pests and diseases (Popoola *et al.,* 20219).

Physiological maturity stages: The experiment to trace the pattern of seed development and maturation in Sword bean conducted at the Department of Vegetable Science, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore revealed that the pods and seeds attained physiological maturity on 80 days after anthesis as evidenced by the maximum dry weight of the pod (183.3g) and seed (2.92g) combined with minimum moisture content of the pod (18.63%) and seed (14.77%). The change in colour of pod from green to brown and seed from green to dark red could be considered as a visible index of maturity. The seed quality parameters *viz*., germination (93%), dry weight of seed (2.92g), root length (20.87cm), shoot length (22.43cm), vigour index (4038.67), drymatter accumulation (8.11g) and protein content (14.75%) were also maximum at 80 days after anthesis (Kumarasamy *et al*., 2020). The changes in pod development and maturation process might be due to development of zygote to matured seed. Pod length and pod width was maximum at 65 days after anthesis and thereafter no increase in length and width of pod was recorded (Fig.1). The seed colour was initially green in colour and thereafter colour changes into red and finally seed became dark red in colour due to accumulation of pigments. Once the seed attained physiological maturity, the photosynthetic material reduced and there after chlorophyll content started to disappear and appearance of pigments and characteristics colour in seed (Fig. 2) (Rojas-Sandoval, 2019).

Fig 1. Physiological maturity stages of pods

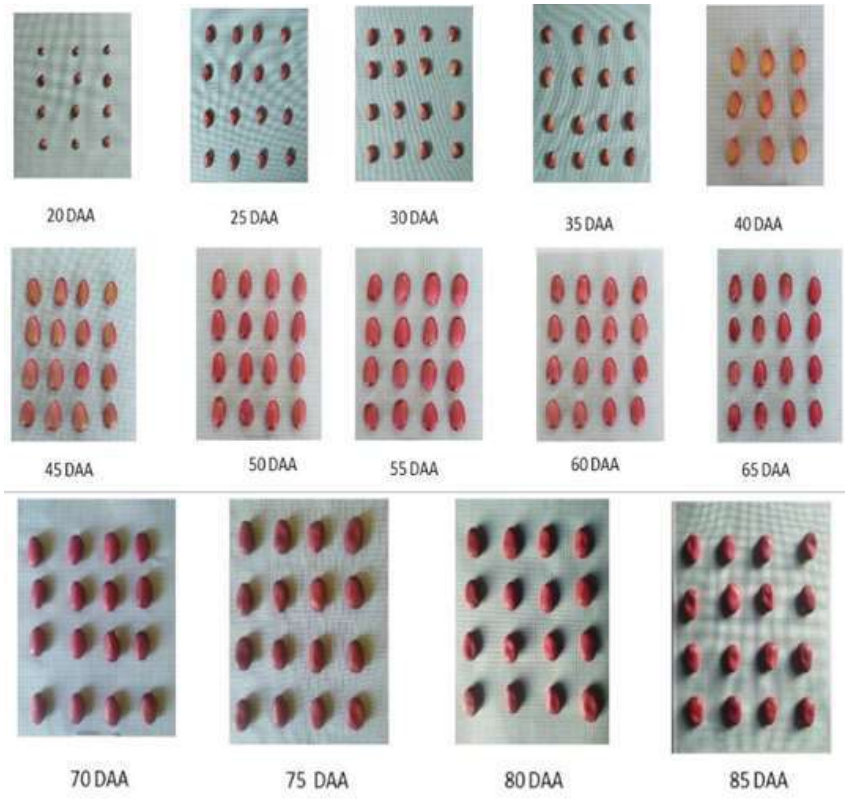

Fig. 2. Physiological maturity stages of seeds

Propagation of Sword Beans: Some species of the genus Canavalia, including *Canavalia ensiformis* and *Canavalia gladiata*, are known as sword bean. Tropical perennial legumes, known as sword beans, are popular companion plants. These species are thought to be most beneficial for fixing nitrogen and controlling weeds, even if they constitute a minor food crop. Additionally, it has been discovered that *ensiformis* inhibits several plant diseases. Although it might be challenging to find seeds, there are various commercial sources. In temperate areas, sword beans are used as companion plants for tree crops, particularly in the nursery stage. Farmers that grow trees (either for a nursery company or as crop plants) frequently struggle with weed control around the base of the trees. Canavalia may be the answer. The weeds and grass that would otherwise rob a growing tree of essential water and nutrients may be effectively suppressed by only one plant. These plants are particularly interesting to study subjects due to their capacity to fix nitrogen, their potential allelopathic (inhibitory) effects on numerous plant pests, and their use as food crops (HND, 2023).

Harvesting: Sword bean seed pods need at least 100 days to completely mature; however, picking immature pods reduces the risk of becoming sick from eating them. Ripe pods are 10 to 12 inches long, waxy in appearance, and have a few indentations all over the skin where the beans have developed. To harvest the beans, pinch off the pod just above the plant's blooming end (HND, 2023).

Problems faced by Sword Beans: It is necessary to peel and then boil fresh sword bean seeds before using them in dishes. Their toxic outer skin is removed by peeling. Although these poisons are not strong, they can nevertheless make you sick if you overindulge. Sword beans are a great dietary option for vegans due to their high protein content. Keep in mind that seeds cannot be peeled after they have dried, preventing them from being detoxified for use as food. To plant next year, save your best-dried seed. Let the pods finish drying on the vine if one wants to collect seeds. Pre-soak seeds in water for at least one night before planting to ensure complete hydration. When the seedlings have developed their first or second pair of genuine leaves, sow them directly where they will grow or separately in pots to be put outside (HND, 2023). In this review article on Origin, Domestication, Taxonomy, Botanical Description, Genetics and Cytogenetics, Genetic Diversity, Breeding, Uses, Nutritional Value and Health Benefits of Sword Bean are discussed.

ORIGIN AND DISTRIBUTION

The naturally pantropical genus *Canavalia* is the source of four domesticated species, of which *C. plagiosperma* and *C. ensiformis* evidently evolved under aboriginal New World cultivation. Their exact origins are uncertain because the archaeological record is concentrated in dry regions where they arrived as irrigated crops. Prehistoric cultivation of *C. plagiosperma* is known only from coastal Peru where it has been grown continuously for at least 4,000 years. The earliest secure record of *C. ensiformis* is from about A.D. 900 in Oaxaca, but charred seeds from about 300 B.C. in Yucatán probably belong to this species. Later archaeological records of *C. ensiformis* are available from a few Arizona sites and from Peruvian sites occupied in the early Colonial period. *Canavalia* and *Phaseolus* beans are generally associated in prehistoric cultures (Sauer and Kaplan, 1969). Found in the tropics, subtropics, West Africa, Asia, Latin America, South America, India, and South Pacific—mainly in cultivation. It is also grown in the southwestern United States and Hawaii. Canavalia is a pantropical genus that is believed to have originated in the New World based on the large genetic diversity of species in the fossil record (Sheahan, 2012). The plant *C. gladiata* is believed to have originated in the Asian continent and spread throughout the tropics. They are now cultivated on a limited scale throughout Asia, the West Indies, Africa and South America and have been introduced into tropical parts of Australia (Ekanayake *et al*., 2000). *Canavalia ensiformis* is a common, under-exploited legume and potentially rich protein source. *C. ensiformis* has been found at archaeological sites in Mexico dating from approximately 3000 B.C. It is widely distributed in Asia, the West Indies, Africa, and South America (Ming-qian Liu *et al*., 2014). Sword bean (*Canavalia gladiata* (Jacq.) DC.), sometimes also called Jack bean or beach bean, originates from India and China and has spread throughout the tropics (Xianzong XIA *et al*., 2017). Sword bean is native to the Indo-Malayan region (Rana and Badiger, 2017).

Canavalia gladiata is native to Asia. It was probably domesticated in eastern Asia and it is only known in cultivation, except as an escape. It is widely cultivated across tropical and subtropical regions. It can currently be found cultivated and naturalized across Asia, Africa, Australia, North, Central and South America and the Caribbean (Rojas-Sandoval, 2019). Sword beans are predominantly found in Indonesia, near the residential areas. Experts believe that Sword bean in Indonesia are introduced plants as traces of them in the primary Indonesia forests are not found (HND, 2023). Sword beans were initially found primarily in parts of India and China. Over the years, however, they have become popular in other parts of the world, including Madagascar, Japan, Indonesia, and Korea. Because of how exotic a plant it is, it's unknown when these beans were first planted or who had the honors. However, we know that it originated somewhere in the tropics of the Old World and has been around for centuries (Coblentz, 2023). The plant comes from warm areas of Central and South America. It is grown a lot in South and South-East Asia, especially in Brazil, India, Thailand, Sri Lanka, Burma, Nigeria, the Philippines, and Indo-China. It is now found all over the tropics, and in some places it has become a native species (Sylvia, 2023).

People think that the Sword Bean came from Africa, especially the tropical and subtropical parts of the continent. It is one of the oldest crops that have been grown. There is proof that it has been tamed for thousands of years. No one knows for sure when or where it was first domesticated, but it is thought to have been grown in old societies in Africa and Asia. Several different ancient cultures grew the Sword Bean. Ancient Egyptians grew it in Africa because they liked to eat it and because it was good for them. The crop also went to Asia, where it was grown in India, China, and Southeast Asia, among other places. It's possible that trade routes and cultural exchanges brought it to these places. As trade and exploration grew, the Sword Bean was brought to places outside of its natural range. Explorers and settlers from Europe did a lot to spread the crop to different parts of the world. It was brought to the Americas during the time of colonization, and it is now grown in many tropical and subtropical countries around the

world (Sylvia, 2023). *C. gladiata* is native to Asia and distributed throughout the world *viz*., Africa, Asia, Australia, Latin America, North America and South America. Sword bean is cultivated all throughout India in very limited scale where as tribal community of Indian states like Arunachal Pradesh , Nagaland, Manipur, Mizoram, Tripura and Megahalaya in North East, the Kadar, Mannan and Muthuvan tribal state of kerala, South India respectively are reported to be readily cultivating and utilizing this plant species (Pal and Pandey, 2023). Sword beans are predominantly found in Indonesia, near the residential areas. Experts believe that Sword bean in Indonesia are introduced plants as traces of them in the primary Indonesia forests are not found. Antinutritional substances are the primary reason the seeds are not widely used as food or feed. Sword bean comes in two varieties. Red-seeded variants trail over pandals, and white-seeded versions are bushy in characters. While bush-type types should be planted at 60 x 60 cm, pole-type varieties should be planted at a spacing of 4 x 3 meters. The typical planting seasons are May–June and September–October, and one or two seeds are sown per pit. Additionally, this may be produced as a shade crop, an intercrop, and a border crop. Tamil Nadu is the sword bean type home, SBS 1 (HND, 2023).

Sword bean growing countries are Africa, Angola, Argentina, Asia, Australia, Bangladesh, Benin, Brazil, Burundi, Cambodia, Central Africa, Central America, China, Congo DR, Cuba, East Africa, Fiji, Ghana, Guadeloupe, Guatemala, Guianas, Haiti, Hawaii, Honduras, India, Indochina, Indonesia, Jamaica, Japan, Korea, Laos, Madagascar, Malaysia, Mauritius, Mexico, Mozambique, Myanmar, Nigeria, North America, Northeastern India, Pacific, Panama, Papua New Guinea, PNG, Paraguay, Philippines, SE Asia, Seychelles, Singapore, Solomon Islands, South Africa, Southern Africa, South America, Sri Lanka, Suriname, Taiwan, Tanzania, Thailand, United States, Vietnam, West Africa, West Indies, Zambia, Zimbabwe (Edible Plants, 2024). *Canavalia ensiformis* is native to the West Indies and Central America. It closely resembles Sword Bean, *C. gladiata*, and the predominantly African wild species, *C. virosa*. *C. ensiformis* is widely distributed in the tropics and subtropics although it is regarded as a minor vegetable rather than a major crop species (Echocommunity, 2024). Assam, Bangladesh, Cambodia, China South-Central, China Southeast, East Himalaya, Hainan, India, Japan, Laos, Myanmar, Nicobar Is., Panamá, Taiwan, Thailand, Vietnam, West Himalaya (*RBG, 2024*). Andaman Is., Argentina Northeast, Borneo, Burundi, Congo, Cuba, Florida, Guinea, Haiti, Hawaii, Honduras, Jamaica, Jawa, Korea, Leeward Is., Lesser Sunda Is., Madagascar, Malaya, Mauritius, Mexico Northwest, Mozambique, New Guinea, New South Wales, Northern Provinces, Paraguay, Philippines, Rwanda, Réunion, Sri Lanka, Suriname, Tanzania, Texas, Trinidad-Tobago, Venezuela, Windward Is., Zambia, Zaïre, Zimbabwe (*RBG, 2024*). The genus name *Canavalia* was, as recently as 1913, known as *Canavali* (Wikipedia, 2024b). *Canavalia gladiata* is native to Asia. It was probably domesticated in eastern Asia and it is only known in cultivation, except as an escape. It is widely cultivated across tropical and subtropical regions. It can currently be found cultivated and naturalized across Asia, Africa, Australia, North, Central and South America and the Caribbean (Rojas-Sandoval, 2024).

TAXONOMY

Sword bean belongs to the family Fabaceae, subfamily Faboideae, genus *Canavalia* and species *Canavalia gladiata* (Jacq.) DC. (Mia, 2016; Pal and Pandey, 2023; Wikipedia,2024a; Wikipedia, 2024d) and Jack bean belongs to the species *Canavalia ensiformis* (L.) DC. (Ranjeet Patel *et al*., 2016; Wikipedia, 2024c). *C. ensiformis* has numerous names in English *viz.*, Brazilian broad bean, "Coffee bean", Chickasaw lima bean, Ensiform bean, "Horse bean" (usually applied to *Vicia faba*), "Jack bean" (also applied to other species in the genus *Canavalia*), Mole bean, Overlook bean, Pearson bean, "Sword bean" (usually applied to *Canavalia gladiata*), Wonder bean (Wikipedia, 2024c). *Canavalia gladiata* and *Canavalia ensiformis* are very close species. Though they have always been distinguished in Floras, genetical assessment failed to show differences between the two species (Feedipedia, 2015). Jack bean [*Canavalia ensiformis* (L.) DC.] belongs to the family leguminaceae is one of the underexploited tropical dry beans however, fairly widely distributed from West Indies (origin) to Central and South America (Lenkala *et al.,* 2015). 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* (Sridhar and Seena, 2006). The Genus *Canavalia* consisting of 48 species of which, four species are reported from India, *viz*., *C. ensiformis, C. gladiata, C. maritima* and *C. virosa*. Out of these four species, *C. ensiformis* (Jack bean) and *C. gladiata* (Sword bean) were reported in North East region of India and are being cultivated for the edible pods (Lenkala *et al.,* 2015). Jack bean (*Canavalia ensiformis* (L.) DC.) belongs to the family leguminosae is one of the underexploited tropical dry bean however, fairly widely distributed from West Indies (origin) to Central and South America. The Genus *Canavalia* consisting of 48 species of which, four species are reported from India, *viz*., *C. ensiformis, C. gladiata, C. maritima* and *C. virosa*. Out of these four species, *C. ensiformis* (Jack bean) and *C. gladiata* (Sword bean) were reported to cultivated in North East region of India for the edible pods (Lenkala *et al*., 2015). The genus *Canavalia* comprises approximately 60 species of lianas that are mostly distributed not only across tropical and subtropical America, but also in Asia and Africa. Taxonomic revisions have divided this genus into four subgenera: *Canavalia (*including species with a pantropical distribution), *Catodonia* (including species with a neotropical distribution, excepting one species also found in the Old World), *Maunaloa* (including species occurring in Hawaii) and *Wenderothia* (including species with a neotropical distribution) (Rojas-Sandoval, 2019)

Canavalia is a genus of plants in the legume family (Fabaceae) that comprises approximately 62 species of tropical vines. Members of the genus are commonly known as jack-beans. It has a pantropical distribution. The species of *Canavalia* endemic to the Hawaiian Islands were named *ʻāwikiwiki'* by the Native Hawaiians. The name translates to "the very quick one" and comes from the Hawaiian word for "fast". The genus name is derived from the Malabar word for the species, *kavavali*, which means "forest climber." (Wikipedia, 2024b). The genus *Canavalia* comprises approximately 60 species of

lianas that are mostly distributed not only across tropical and subtropical America, but also in Asia and Africa. Taxonomic revisions have divided this genus into four subgenera. *Canavalia (*including species with a pantropical distribution), *Catodonia* (including species with a neotropical distribution, excepting one species also found in the Old World), *Maunaloa* (including species occurring in Hawaii) and *Wenderothia (*including species with a neotropical distribution) (Rojas-Sandoval, 2024)

Species include (Wikipedia, 2024b).

Synonyms include (*RBG, 2024*):
Homotypic Synonyms
- *Canavalia ensiformis* var. *gladiata* (Jacq.) Kuntze in Revis. Gen. Pl. 3(2): 55 (1898)
- *Dolichos gladiatus* Jacq. in Collectanea 2: 276 (1789)

Heterotypic Synonyms
- *Canavalia ensiformis* var. *alba* Makino
- *Canavalia gladiata* var. *alba* (Makino) Hisauti
- *Canavalia gladiata* f. *alba* (Makino) H.Ohashi
- *Canavalia gladiata* f. *erythrocarpa* Taub.
- *Canavalia gladiata* var. *erythrosperma* Voigt
- *Canavalia gladiata* var. *machaeroides* DC.
- *Canavalia incurva* (Thunb.) DC.
- *Canavalia incurva* Thouars
- *Canavalia loureiroi* G.Don
- *Canavalia lunareti* Carrière
- *Canavalia machaeroides* (DC.) Steud.
- *Canavalia maxima* Thouars
- *Cryptophaseolus anamensis* Kuntze
- *Dolichos faba-indica* Forssk.
- *Dolichos incurvus* Thunb.
- *Malocchia gladiata* Savi

Synonyms include (Edible Plants, 2024):
Canavalia ensiformis (L.) DC. var. *alba* Makino
Canavalia ensiformis auct. non (L.) DC.
Canavalia ensiformis (L.) DC. var. *gladiata* (Jacq.) Kuntze
Canavalia gladiata (Jacq.) DC. var. *alba* (Makino) Hisauti
Canavalia gladiata (Jacq.) DC. var. *machaeroides* DC.
Canavalia gladiolata J. D. Sauer
Canavalia incurva (Thunb.) DC.
Canavalia incurva Thouars
Canavalia loureirii G. Don.
Canavalia machaeroides (DC.) Steudel
Canavalia maxima Thouars
Dolichos gladiatus Jacq.
Dolichos incurvus Thunb.
Malocchia gladiata (Jacq.) Savi

Synonyms include (Rojas-Sandoval, 2024):

Canavalia foureiri G.Don
Canavalia gladiolata J.D.Sauer
Canavalia incurva (Thunb.) DC.
Canavalia loureirii G.Don
Canavalia lunareti Carriere
Canavalia machaeroides (DC.) Steud.
Canavalia maxima Thouars
Dolichos gladiatus Jacq.
Dolichos incurvus Thunb.
Malocchia gladiata (Jacq.) Savi

Synonyms include (Nparks, 2024):

Canavalia foureiri,
Canavalia gladiolata,

Canavalia incurva,
Canavalia loureirii,
Canavalia machaeroides,
Canavalia maxima,
Canavalia plagiosperma

BOTANICAL DESCRIPTION

Jack bean is an annual or weak perennial legume with climbing or bushy growth forms. It is woody with a long tap root. The 8 in (20 cm) long and 4 in (10 cm) wide leaves have three egg-shaped leaflets, are wedge-shaped at the base, and taper towards the tip. The 1 in (2.5 cm) long flowers are rose-colored, purplish, or white with a red base. It has a 12 in (30 cm) long, 1.5 in (3.8 cm) wide, sword-shaped seedpod. Seeds are white and smooth with a brown seed scar that is about one-third the length of the seed. Its roots have nodules which fix nitrogen (Sheahan, 2012). The *Canavalia gladiata* is a vigorous perennial climber often cultivated as an Annual. The height may vary from 4.5 to 10 m. The degree of twining, the size of the seed pods, the number and the color of the seed pods show considerable variation. In some areas semi-erect forms are found. Leaves are trifoliate, with large pubescent leaflets (10–18 × 6–14 cm) which are acuminate with a short point at the apex. The petioles are shorter than the leaflets with a groove above and stout with a large pulvinus at the base of each leaflet. Inflorescence is an axillary, long stalked raceme bearing several flowers in succession. The flowers are inverted, the standard being at the bottom. Flowers are 3.5 to 4 cm long and are white or pinkish. The seed pods are usually broad and curved with strongly developed ridges. They are about 20 to 40 cm long and 3.5 to 5 cm broad, containing on average 8 to 16 seeds. Seeds are 2.5–3.5 cm long, white or red in color with a dark brown hilum extending the entire length of the seed. Germination of the seed is epigeal (Ekanayake *et al.,* 2000).

C. ensiformis is a shrub with upright or climbing growth. Its leaves are trifoliolate, with small trichomes and petioles. The petioles are grooved above with a large pulvinus at the base and at the base of each leaflet; the leaflet is elliptic to ovate. The inflorescence has a curved pseudoraceme with 2–4 flowers on swollen and shortened pedicellar knobs; each inflorescence has 30 or more flowers. Usually, only the lowest 2–4 flowers of each inflorescence produce pods. The flowers are pink and 1.5–3 cm in length, and ten stamens encircle the simple pistil. The pods are yellow and 20–35 cm long when mature. The seeds are white, tawny, or red and 1.8–2.6 cm in length. The 100-seed weight ranges from 130 to 260 g (Ming-qian Liu *et al*., 2014).

Vigorous woody perennial climber with twining stems, up to 10 m long; leaflets ovate or ovate-elliptic, acuminate at the apex, 80-200 × 75-150 mm, sparsely pubescent; petiole (50) 145-175 mm long; stipules ±2 mm long. Peduncles 100-300 mm long, with 8-10 flowers, flowers 25-30 mm long; bracteoles ±1 mm long. Calyx sparsely pubescent, upper lip large, 12-15 mm long, lower lip much smaller, 8-10 mm long. Corolla white or pink; standard broadly obovate, 25-35 × 15-20 mm, claw 3-4 mm long; wings oblong, 14-18 × 4-5 mm, smaller than keel, claw 3-5 mm long; keel obovate,16-22 × 6-8 mm, claw 3-5 mm long. Ovary narrowly oblong, 8-10 mm long. Pod linear-oblong, very large, slightly compressed, 160-400 (-600) × 35-50 mm, with two longitudinal ribs near the upper suture, 8-16-seeded; seeds very large, brick red, pink or reddish brown, with hilum extending most of the upper margin elliptic-oblong, ca. 3.5 × 2 cm; hilum ca. 1.5 cm. Cultivars vary widely, particularly in the degree of twining, the size of the pods and the number and colour of the seeds. In some areas semi-erect forms are found. Forms with red or reddish to blackish seeds are sometimes classified as *C. gladiata* var. *gladiata* and forms with white seeds as var. *alba* (Makino) Hisauchi (Rojas-Sandoval, 2019). Sword bean belongs with jack bean to the *Canavalia* genus, a neglected group of legumes that has however many valuable characteristics. A tropical perennial legume, it is mainly cultivated as an annual. Sword is a perennail legume mainly cultivated as an annual (Ekanayake *et al*., 2000)/ Sword bean has a vigorous climbing or trailing habit and can be up to 10 m long. Some cultivarrs may also be semi-erect. Sword bean root system is deep. Its stems are woody . The leaves are alternate, large, trifoliolate. Sword bean leaflets are oval-shaped, 7.5–20 cm long × 5–14 cm broad, shortly pubescent on both faces. The inflorescence is a large axillary raceme (7 to 12 cm long) bearing several flowers. The flowers are papillonaceous, inverted, white to pink in colour. The fruits are long (20-40 (-60) cm, straight, rough-surfaced and slightly compressed dehiscent pods containing 8 to 16 seeds. The seed are 2-3.5 cm -1.5-2 cm, oblong-ellipsoid in shape, very variable in colour. They range from red, red-brown to white or black. The hilum is as long as the seed, dark brown in colour (Feedipedia, 2015). It is a herbaceous climbing plant that, under ideal circumstances, may reach a length of up to 10 meters. Stems contain three oval leaflets make up its compound leaves. It has a raceme-shaped inflorescence with 10–20 white or light purple blooms in them. Each blossom is around 3 cm long. Its fruit, which is sward-shaped pods, measures 20 to 35 cm in length and 3 to 6 cm in width. Many reddish seeds are seen in each pod (HND, 2023).

Sword bean is a vigorous, deep-rooted, fast-growing, heavy-yielding, annual or permanent climbing legume plant that can grow up to 10 meters (33 feet) long. When given the right support, like trellises, poles, or fences, the plants can grow several meters long or more, making a thick and lush growth. Since it grows in a twining way, it can climb and wrap itself around other plants or buildings for support. They have long, flexible roots that wind their way up, allowing the plant to grow to heights of several meters or more (Sylvia, 2023). Plants of *C. gladiata* are fast growing vine with winding stem. The stem height varies from 4.5 to 10 m. Leaves are trifoliate. Leaflets are large pubescent. The sword bean show a peculiar inflorescence being inverted, the standard being at bottom and keel on the top. The size of flowers ranges from 3.5 to 4 cm long white or pinkish in colour. The fruit of *C. gladiata* is simple dry fruit called pod. The mature pod is large and its size varies from 25-30 cm in length and shape is sword like hence also called as sword bean. Each pod contains 10 seeds. The seed of *C. gladiata* is elliptical in shape and measure around 3 cm. The mature seed is divided into three parts: the seed coat, the cotyledon and the embryo. The external structures of the seed are the testa (*i.e.,* seed coat), hilum, micropyle, and raphe (Pal and Pandey, 2023).

It is a herbaceous climbing plant that, under ideal circumstances, may reach a length of up to 10 meters**. Stems-** Three oval leaflets make up its compound leaves. Flowers– It has a raceme-shaped inflorescence with 10–20 white or light purple blooms in them. Each blossom is around 3 cm long. Fruits**-** Its fruit, which is sward-shaped pods, measures 20 to 35 cm in length and 3 to 6 cm in width. Many reddish seeds are seen in each pod (HND, 2023). Sword Bean is a twining, nearly erect annual herb, growing to 6 ft. Flowers are pink and white, 2.5-4 cm across. Leaves are shiny, trifoliate. Pod becomes 30 cm long and 5cm wide. It contains 10-14 seeds. Seeds are elliptical and reaches 3cm long. The bean is eaten in many parts of India. It is sometimes grown as an ornamental with very attractive pink-white pea-like flowers **(**Kasim and Valke, 2024**).** *C. ensiformis* is a twining plant up to 1 metre (3.3 ft) in height. It has deep roots, which makes it drought resistant. The plant can spread via long runners. The flowers are pink-purple in colour. The pods are up to 36 centimetres (14 in) long with large white seeds (Wikipedia, 2024c). It is a climbing herbaceous plant that can grow up to 10 m long under optimal condition. Its compound leaves have 3 ovate leaflets. Its inflorescence is a raceme, consisting of 10 -20 flowers which are white or light purple. The individual flower measures about 3 cm long. Its fruit are pods, sword-shaped, and grow about 20 - 35 cm long and 3 - 6 cm wide. Each pod contains many reddish seeds. Its fruit are pods, sword-shaped, and grow about 20 - 35 cm long and 3 - 6 cm wide. Each pod contains many reddish seeds (Nparks, 2024).

Sword beans is a vigorous climbing plant to 10 m tall, with large leaves and pink flowers followed by giant pods to 30 cm long with huge, white seeds inside. These are edible but like all beans, the pods and seeds are toxic when raw and must be soaked and boiled before consumption. *Canavalia gladiata* is best adapted to tropical climates. *Canavalia gladiata* is a perennial, fast-growing, heavily producing, climbing legume. It is widely cultivated in the humid tropics of Southeast Asia, but remains a minor vegetable elsewhere. Plants can reach 10 m in length with a deep, penetrating root system. Leaves are trifoliate, similar to other legumes, with white, butterfly-like flowers also similar to other legumes. Mature pods reach 40 cm in length. Sword Bean is a twining, nearly erect annual herb, growing to 6 ft. Flowers are pink and white, 2.5-4 cm across. Leaves are shiny, trifoliate. Pod becomes 30 cm long and 5cm wide. It contains 10-14 seeds. Seeds are elliptical and reaches 3cm long (**Gardenhunt,** 2024). Vigorous woody perennial climber with twining stems, up to 10 m long; leaflets ovate or ovate-elliptic, acuminate at the apex, 80-200 × 75-150 mm, sparsely pubescent; petiole (50) 145-175 mm long; stipules ±2 mm long. Peduncles 100-300 mm long, with 8-10 flowers, flowers 25-30 mm long; bracteoles ±1 mm long. Calyx sparsely pubescent, upper lip large, 12-15 mm long, lower lip much smaller, 8-10 mm long. Corolla white or pink; standard broadly obovate, 25-35 × 15-20 mm, claw 3-4 mm long; wings oblong, 14-18 × 4-5 mm, smaller than keel, claw 3-5 mm long; keel obovate,16-22 × 6-8 mm, claw 3-5 mm long. Ovary narrowly oblong, 8-10 mm long. Pod linear-oblong, very large, slightly compressed, 160-400 (-600) × 35-50 mm, with two longitudinal ribs near the upper suture, 8-16-seeded; seeds very large, brick red, pink or reddish brown, with hilum extending most of the upper margin elliptic-oblong, ca. 3.5 × 2 cm; hilum ca. 1.5 cm. Cultivars vary widely, particularly in the degree of twining, the size of the pods and the number and colour of the seeds. In some areas semi-erect forms are found. Forms with red or reddish to blackish seeds are sometimes classified as *C. gladiata* var. *gladiata* and forms with white seeds as var. *alba* (Makino) Hisauchi (Rojas-Sandoval, 2024). Botanical Description is given in Fig. 3.

Floral biology and Pollination: The flower's general structure is "papilionaceous," the same as most flowers in the Bean Family, except that the Sword Bean turns its flowers upside-down. Its large "banner" or "standard" petal, which on flowers of most Bean Family members rises above the blossom to attract pollinators, here flairs out at the flower's base. As such, it serves as a pollinator landing pad equipped with white-stripe "nectar guides" pointing to the flower's throat where nectar is available. The scoop-shaped "keel," which in most papilionaceous flowers lies at the blossom's bottom, in this flower rises above the blossom like a curving crest. A side view of the flower showing its two-lipped calyx. It's the Sword Bean's huge, legume-type fruits that really catch attention. An opened pod with beans inside it (Coleby-Williams, 2012). We monitored three marked carpenter bees – one female and two males – on the sword bean for 25 straight days of flowering to examine whether (1) the bee is consistent on the time of its first visit and the number of foraging bouts and (2) the number of flowers on the plant predicts foraging bouts of the bees. The female bee was consistent on the first arrival time and the number of visitation bouts, but the male bees were not. The median first arrival time of the female bee was 06:22 h. Number of visitation bouts of female bee was unaffected by the crop size. The duration the bees spent on the plant on subsequent visits increased with the duration they spent on the first visit. This study suggests that the carpenter bee, in particular the female, has a consistent visitation pattern to the flowers**.** The present study on three marked bees under typical field conditions provides some evidence for a carpenter bee species' consistency in flower visitation pattern. The female bee visited the plant all the 25 days of observation, maintained time for its maiden visit, and made similar number of bouts across the days. Although successful observations could be made only on three bees (the only individuals from *Xylocopa latipes*), we monitored the bees for a considerable amount of time during the peak flowering phase of the plant, which gave consistent and reliable results. Carpenter bee is the predominant pollinator of sword bean flowers in the Asia-Pacific region. The sword bean is a climbing annual with papilionaceous blue flower in axillary racemes, a trait typical for *Xylocopa* bees' visits13. It secretes 10–30 □l nectar of sugar concentration, about 50 Brix. The nectar secretion started by anther dehiscence in the mature bud and half opened flowers at around 06:00 h (LUX 50) in our study. The flowers completely opened by around 09:00 h (LUX 900). We recorded the light intensity by holding a LUX meter (Sigma-Aldrich) in an open field close to the focal plant. The stigma turned receptive in completely opened flowers. The nectar secretion continued until flower senescence (24 h after anthesis) or pollination. The visitors made bouts to both half-opened and completely opened flowers. *X. latipes* was responsible for 95–100% of the visits across days. *Xylocopa bryorum*, two species of butterflies – *Pelopidas mathias* and *Jamides celeno*, and an unidentified sphingid moth contributed to the remaining number of visits to the flowers (Sinu and Sinu, 2022).

The next barrier was how to arrange cross pollination. Most legumes (especially domesticated ones) are predominantly self-pollinating. This is probably an adaptation from when the original wild species were moved into regions where they lack suitable

pollinators. Interestingly I observed a species of native solitary bee enthusiastically working the flowers, but I couldn't rely on them to do outcrossing for me. I scrounged around for a piece of gauzy cloth, cut it into handkerchief sized squares, and started wrapping spikes of flowers that were at a convenient height on the trellis (held in place with a wooden clothes peg). Using a set of tweezers, I applied the technique used for hand pollinating sweet peas. Anthers start to develop in the late afternoon in unopened flowers. The petals are squeezed open, often using the tweezers to split them apart. Then a gentle downward motion will knock off the ends of the anthers while usually leaving the female stigma intact. I found the easiest method was to collect whole flowers from one species in my pocket, then peel back the petals off the anthers. With my other hand I could squeeze open the anther free flower of a different species from the day before, then dab the anthers from one species onto the stigma of another. In the end I think I got around a 10-20% rate of pod setting, with no indication that any crosses were more or less incompatible (Zeroinputagriculture, 2023). *C. gladiata* has bisexual flowers that are visited and pollinated by insects, mostly bees. This species is self-compatible but out-crossing rates greater than 20% have been reported. Seeds germinate readily and the plant is a fast-growing species. Young pods for vegetable use can be harvested 3-5 months after sowing while mature seeds can be harvested 5-10 months after sowing. *C. gladiata* is a perennial plant but it is also cultivated as an annual crop (Rojas-Sandoval, 2024).

		
Seeds	**Pentration of radicle from soil**	**Emergence of leaves**
		
Seedling	**Seedling**	**Plant**
		
Flowers	**Flowers**	**Flowers**
		
Flowers	**Flowers**	**Pod**

Continue ….

		
Plant with pods	**Pods**	**Pods, Open pods**
		
Pods	**Pods**	**Pods**
		
Mature pods	**Mature pods**	**Mature pods**
		
Seeds	**Seeds**	**Seeds**

Fig. 3. Botanical Description

GENETICS AND CYTOGENETICS

Sword bean (*Canavalia gladiata*) belongs to the genus *Canavalia* and family Fabaceae with chromosome number (2n) 22 and 44, indicating the presence of polyploids (Rana and Badiger, 2017). *C. ensiformis* has a diploid chromosome number of $2n = 2x = 22$ (Ming-qian Liu *et al*., 2014). The chromosome number reported for *C. gladiata* is $2n = 22$. Hybrids of *C. gladiata* with *C. africana* and *C. ensiformis* occur in the wild from natural crosses (Rojas-Sandoval, 2024). Underutilised crops suffer from under-investigation relative to more mainstream crops, but often possess improved stress tolerance and/or nutrition, making them potentially important for breeding programmes in the context of climate change and an expanding human population. Developing basic genome resources for underutilised crops may therefore catalyse analyses to facilitate their use, through improved understanding of population structure, phylogeny, candidate genes, and linkage mapping. We carried out nuclear and plastid genome sequencing and assembly for five underutilised legumes: jack bean, sword bean, Kersting's groundnut, moth bean, and zombi pea. Using only 'off-the-shelf', free-to-use bioinformatic tools, we also developed a simple but effective pipeline to identify thousands of markers, which could be applied in other species. We assembled 53–68% of the genome and 73–95% of the gene space in the five legumes. The assemblies were fragmented but nevertheless useful for identifying between 34,000—60,000 microsatellites. Examination of 32 markers in zombi pea revealed 16 primer pairs which amplified in at least half of the eight accessions tested and were polymorphic. We also present nuclear genome size estimates for 17 legume taxa (12 for the first time), comprising the above five species as well as other domesticated legume species and crop wild relatives (Diakostefani *et al.,* 2024). The two cultivated *Canavalia* (Adanson, 1763) species, *Canavalia gladiata* (N. J. von Jacquin, 1788) A. P. de Candolle, 1825 and *Canavalia ensiformis* (Linnaeus, 1753) A. P. de Candolle, 1825 are closely related based on morphological and molecular phylogenetic data. However, the similarities and differences in genome organization between them have not been evaluated at

molecular cytogenetic level. Here, detailed karyotypes of both species were constructed using combined PI and DAPI (CPD) staining, rDNA-FISH and self-genomic *in situ* hybridization (sGISH). For further comparison, comparative genomic *in situ* hybridization (cGISH) and sequence analysis of 5S rDNA were applied. Their chromosomes were accurately identified by sGISH and rDNA-FISH signals. Both species had the karyotype formula 2n = 22 = 18m + 4m-SAT, but the karyotype of *C. ensiformis* was shorter and more asymmetric than that of *C. gladiata*. They displayed similar CPD bands at all 45S rDNA sites and centromeres. *C. gladiata* had ten centromeric 5S rDNA loci and two SC (secondary constriction)-associated 45S rDNA loci. *C. ensiformis* had nine centromeric and one interstitial 5S loci, two SC-associated and one proximal 45S loci. Their sGISH signal patterns displayed both basic similarities and distinct differences. Reciprocal cGISH generated prominent signals in all pericentromeric regions and 45S sites. There was lower level of sequence identity of the non-transcribed spacer between their 5S rDNA repeats. These data confirmed the evolutionary closeness between *C. gladiata* and *C. ensiformis* and demonstrated obvious differentiation between their genomes, and supported the opinion that *C. ensiformis* is more advanced in evolution than *C. gladiate* (Chao-Wen She *et al*., 2017).

GENETIC DIVERSITY

Genetic variability for seed shape, color and size of sword bean (Fig.4).

Continue ….

Fig.4. Vasriability for seed shape, color and size of sowrd bean

Canavalia are large seeded and structurally similar, but differ to each other in size, shape, color and thickness of the seed coat. *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%) (Sridhar and Seena, 2006). *Canavalia ensiformis* is an under-exploited legume that has been used as forage, green manure, and a cover crop. Thus far, studies of the *C. ensiformis* germplasm have focused on morphological traits, which cannot be used to distinguish all known accessions or to evaluate their genetic diversity precisely. In this study, sequence-related amplified polymorphism (SRAP) markers were used to assess the genetic diversity and relationships among 29 *C. ensiformis* accessions originating from 16 countries. In total, 274 clear bands were amplified and 144 of them (52.6%) were polymorphic. The polymorphism information content values (PIC) ranged from 0.10 to 0.43, with an average of 0.27. An analysis of molecular variance (AMOVA) revealed that the most significant variation (92.0% of the total) occurred among accessions; the remaining 8.0% was attributed to variation within accessions. A cluster analysis and principal coordinates (PCoA) analysis produced similar results, whereby the 29 *C. ensiformis* accessions were divided into 5 clusters, each of which was composed of different accessions with different phenotypic traits (Ming-qian Liu *et al*., 2014).

Progress in plant breeding requires strong genetic variation to enable effective selection programs. However, few studies have investigated the *C. ensiformis* germplasm; thus, the genetic basis of, and relationships among, accessions are unclear. Bush and climbing types were identified in a field comparison of 18 accessions of *C. ensiformis*, and differences in seed yield were recorded. It was evaluated that the phenotypic variability of 13 morphological traits among 15 accessions of two *Canavalia* species, but some accessions of different *Canavalia* species were classified into one group. There are no molecular studies of *C. ensiformis* for the purpose of evaluating genetic diversity and species relationships. Molecular markers, as an important tool for evaluating genetic diversity among species and genera, have been increasingly used in recent years (Ming-qian Liu *et al*., 2014). The results showed that the values of phenotypic variance and phenotypic coefficient of variation were higher than genotypic variance and genotypic coefficient of variance for all the characters studied but the difference was very narrow indicating the low influence of environment for their expression. The phenotypic and genotypic variances were higher (>20) for the traits *viz*., marketable pod yield per plant (24045.14 P, 23091.38 G), plant height at last harvest (12231.78 P, 11593.01 G), plant height at first harvest (10780.83 P, 9892.75 G), 100 seed (Lenkala *et al*., 2015a). The experiment was conducted at NBPGR Regional Station, Rajendranagar during 2013-14 (August 2013 to February 2014) to study the genetic variability and association among the quality characters in jack bean. The results revealed that significant variation was observed for all the characters. Among the characters studied, the highest heritability coupled with genetic advance as percent of mean was observed for magnesium followed by calcium and iron contents. However, heritability alone was found to be highest for iron content followed by magnesium, calcium and protein contents. Calcium content had significant positive association with protein content whereas magnesium, calcium and iron content recorded the positive direct effect on protein content while sodium content have negative effect (Lenkala *et al*., 2015).

Fifteen genotypes of Jack bean were studied for variability, correlation and path analysis. The characters *viz.,* plant height at first harvest, number of primaries per plant at first harvest, plant height at last harvest, number of primaries per plant at last harvest, pod weight, number of pods per plant, number of seeds per pod, 100 seed weight and pod yield per plant were observed with high genetic variability, high heritability in conjunction with higher genetic advance as percent mean indicating the predominance of additive gene action on the expression of these traits and hence direct selection will be rewarding for improvement of these traits in Jack bean. This complex set of association between various yield components clearly indicated that selection of early genotypes would be reliable to increase the pod length, pod weight, number of pods and ultimately pod yield per plant (Lenkala *et al.,* 2015).

The exploitation of genetic variability is a pre-requisite for the effective screening of superior genotypes for improvement of yield and yield related characters. The progress in breeding for the yield and its contributing characters of any crop is polygenically controlled, environmentally influenced and determined by the magnitude and nature of their genetic variability. Hence, it is essential to partition the overall variability into its heritable and non-heritable components with the help of genetic parameters like variability, heritability and genetic advance. Knowledge of correlations among different characters and further partitioning them into direct and indirect effects help to understand the nature and extent of such relationship (Lenkala *et al*., 2015). In order to investigate the genetic diversity present in the underutilized legume sword bean genotypes of North-Eastern hill region of India 20 native sword bean (*Canavalia gladiata* Jacq.) genotypes were collected from different agroclimatic region of North-Eastern hill region of India. The wide genetic diversity found in sword bean genotypes collected from North-Eastern hill region of India based on morphological characters The morphological characters were observed in days to seed germination *i.e*. (3-6 days), pod length (16.45-32.87 cm), pod width (2.28-4.33 cm), pod weight (17.92-31.93 g), pod girth (7.75-12.64 mm) and seed weight (0.75-2.35 g). Performance of CHF SB-1, CHF SB-18, CHF SB-11, CHF SB-19, CHF SB-15, CHF SB-4 and CHF SB-10 genotypes under test conditions was superior and suggested that breeders might exploit the genome of these genotypes in current pulse crop improvement programmes (Debbarma *et al*., 2023). In order to investigate the genetic diversity present in the underutilized legume sword bean genotypes of North-Eastern hill region of India 20 native sword bean (*Canavalia gladiata* Jacq.) genotypes were collected from different agroclimatic region of North-Eastern hill region of India. The morphological characters were observed in days to seed germination i.e. (3-6 days), pod length (16.45-32.87 cm), pod width (2.28-4.33 cm), pod weight (17.92-31.93 g), pod girth (7.75-12.64 mm) and seed weight (0.75-2.35 g). Performance of CHF SB-1, CHF SB-18, CHF SB-11, CHF SB-19, CHF SB-15, CHF SB-4 and CHF SB-10 genotypes under test conditions was superior and suggested that breeders might exploit the genome of these genotypes in current pulse crop improvement programmes (Debbarma *et al*., 2023).

BREEDING

C. gladiata prefers a tropical climate. It grows best in areas with mean annual temperatures in the range 15-30°C (tolerates 12-36°C) and mean annual rainfall in the range 800-1800 mm (tolerates 600-2600 mm). This species thrives at elevations from sea level up to 1500 m; it is adapted to nutrient-depleted soils and acid soils with a pH of 4.5-7.0 (tolerates 4.3-7.5). *C. gladiata* also tolerates some salinity in the soil and some waterlogging but does not tolerate frost. It has a deep root system that allows it to resist drought when established. Information on species, varietal diversity, their origin, distribution and evolution of crop and its related species are very important prerequisites for genetic improvement of any crop. Information on genetics and genetic resources is pre-requisite to choose the appropriate breeding strategies to fulfill the objectives. Origin, evolution, genetics, genetic resources, breeding methods and varieties/hybrids developed, molecular breeding, genomics wherever available are presented in crisp on each of the crops, in the present book. The book 'Breeding of Leguminous Vegetable Crops' brings together the progress in genetics and breeding aspects of leguminous vegetable crops. Chapters describe genetic backgrounds, cytogenetics, germplasm and molecular resources, current breeding objectives, major breeding methods and OPV and hybrid varietal achievements for most of the leguminous vegetable crops. In addition, intellectual property rights, molecular breeding and ideotype characters of leguminous vegetables are also provided for comprehensive understanding of the recent updates in the vegetable legume crops *(Pidigam Saidaiah and Neeraja Prabhakar, 2023).*

The differences in morphological characters among the 20 sword bean genotypes have been enlisted in Table 1 (Debbarma *et al*., 2023).

Table 1. Morphological characters of different sword bean genotypes

Genotypes	Days to seed germination (days)	Pod length (cm)	Pod width (cm)	Pod weight (g)	Pod girth (mm)	Seed weight (g)
CHF SB-1	3	17.60	2.28	22.15	8.17	0.75
CHF SB-2	4	20.47	2.34	30.78	10.98	1.39
CHF SB-3	5	25.19	2.57	23.01	9.24	1.52
CHF SB-4	5	24.21	2.56	31.93	11.93	1.37
CHF SB-5	4	26.20	2.75	24.50	9.37	1.43
CHF SB-6	4	30.05	2.73	24.51	9.28	1.72
CHF SB-7	5	18.23	2.35	23.26	10.12	2.16
CHF SB-8	5	26.72	2.72	25.10	9.27	1.58
CHF SB-9	4	30.17	2.84	26.01	7.75	1.64
CHF SB-10	5	23.02	2.57	21.82	8.49	1.49
CHF SB-11	4	31.10	2.95	25.20	9.26	1.62
CHF SB-12	3	28.17	2.59	24.60	9.34	1.57
CHF SB-13	4	29.20	2.55	25.10	9.21	2.18
CHF SB-14	6	25.35	2.89	21.78	9.06	2.03
CHF SB-15	5	16.45	4.33	17.92	12.64	1.61
CHF SB-16	4	28.26	2.94	23.20	8.52	2.26
CHF SB-17	6	28.09	3.25	23.63	8.94	1.59
CHF SB-18	4	32.87	2.33	27.41	12.31	1.70
CHF SB-19	5	31.27	2.79	26.02	11.32	2.13
CHF SB-20	4	28.80	2.83	24.60	9.51	2.35

Fifteen genotypes of Jack bean were studied for variability, correlation and path analysis. The characters *viz.,* plant height at first harvest, number of primaries per plant at first harvest, plant height at last harvest, number of primaries per plant at last harvest, pod weight, number of pods per plant, number of seeds per pod, 100 seed weight and pod yield per plant were observed with high genetic variability, high heritability in conjunction with higher genetic advance as percent mean indicating the predominance of additive gene action on the expression of these traits and hence direct selection will be rewarding for improvement of these traits in Jack bean. This complex set of association between various yield components clearly indicated that selection of early genotypes would be reliable to increase the pod length, pod weight, number of pods and ultimately pod yield per plant (Lenkala *et al*., 2015a).

Varieties: The seed has a tough, thick coat which makes it unpopular among other beans. Three varieties in India are described in 1939; plants with red flowers and seeds, white flowers and red seeds and white flowers and seeds. The white seeded variety is the commonly consumed variety and is reported to have less antinutritional factors. Depending on the region, these three varieties are also commonly found in different regions of Sri Lanka (Ekanayake *et al*., 2000). Sword bean is classified into two variant species, namely the white sword bean (WSB; *Canavalia gladiata var. alba* MAKINO) and red sword bean (RSB; *Canavalia gladiata var. gladiata*). For the present study, dried WSBs and RSBs were purchased from Morika Kometen (Nara, Japan). RSBs were larger and heavier than WSBs (Nishizawa and Arii, 2018)

Varieties (Sylvia, 2023).

- Purple Seed
- Variegated
- Dwarf
- Multicolor
- Golden
- Gigante
- Black Pod (*Canavalia gladiata* var. *gladiata*)
- Green Pod (*Canavalia gladiata* var. *ensiformis*)
- Blue Pod (*Canavalia gladiata* var. *ensiformis*)
- Chinese Sword Bean (*Canavalia gladiata* var. *gladiata*)
- White Flower (*Canavalia gladiata* var. *gladiata*)
- Red Flower (*Canavalia gladiata* var. *gladiata*)

Varieties (Sylvia, 2023)

- **Red Flower (Canavalia gladiata var. gladiata):** This type can be recognized by its bright red flowers, which give the plant a striking look. After the flowers come long, curved pods that can be up to 60 centimeters long. Most of the time, the seeds of the 'Red Flower' type is beige or light brown.
- **White Flower (Canavalia gladiata var. gladiata):** In comparison to the 'Red Flower' variety, the 'White Flower' variety has white flowers that bloom before the pods form. Like other types of Sword Bean, these pods are long and bent. The seeds of the 'White Flower' type are usually a light beige or cream color.
- **Chinese Sword Bean (Canavalia gladiata var. gladiata):** This kind is used a lot in Chinese cooking. It gets its name from the long, flat pods that look like swords and are what make the plant stand out. The pods can be 30-45 centimeters long. The seeds of the 'Chinese Sword Bean' type are usually big and round.
- **Blue Pod (Canavalia gladiata var. ensiformis):** The 'Blue Pod' type stands out because its pods are blue. This gives the plant a unique look. The beans are long and curved, like those of other types of Sword Beans. Most of the time, the seeds of 'Blue Pod' are beige or light brown.
- **Green Pod (Canavalia gladiata var. ensiformis):** This type of Sword Bean is known for its green pods, which are shorter and bigger than those of other types. The pods can be 20–30 centimeters long. Most of the time, the seeds of the 'Green Pod' type are light beige or cream-colored.
- **Black Pod (Canavalia gladiata var. gladiata):** The 'Black Pod' type is known for its dark purple or black pods, which make the plant, stand out visually. The beans are long and curved, like those of other types of Sword Beans. Most of the time, the seeds of the 'Black Pod' type are black or dark brown.
- **Gigante**: This type is known for having seeds and pods that are big. The pods can get as long as 50 centimeters and hold big, round seeds. The large size of "Gigante" Sword Beans makes them popular, and they can be used in many ways in the kitchen.
- **Golden**: The 'Golden' type of Sword Bean has pods that are golden in color. These pods add color and visual charm to gardens and other outdoor spaces. Most of the time, the seeds of the 'Golden' type are cream to pale yellow in color.
- **Multicolor**: The 'Multicolor' Sword Bean is special because its pods have a variety of colors. When the plant is in full growth, the pods can be green, purple, or even yellow or red, which makes for an interesting sight.
- **Dwarf**: As the name suggests, the 'Dwarf' Sword Bean is a smaller version of the plant that usually only grows 60–90 centimeters tall. This variety can grow in small gardens or pots, making it a good choice for people who don't have much room.
- **Variegated**: The 'Variegated' variety of Sword Bean has leaves that are generally a mix of green and white or cream-colored leaves. This ornamental variety adds visual interest to gardening and can be grown for its looks instead of its taste.

- **Purple Seed**: People know the 'Purple Seed' type because its seeds are a deep purple color. These brightly coloured seeds can be used in a variety of ways, both in cooking and as decorations.

Description of Variety - SBS 1 is given in Table 2 (Anon., 2024). Sword bean SBS 1 is an introduction and is one of the vegetables with photo-insensitivity. It matures in 110 - 120 days. It can be grown throughout the year and gives good response to irrigation. Tender pods are ready for harvest from 75 days after sowing. As a pure crop it gives an average grain yield of 1356 kg/ha and green pod yield of 7500 kg/ha. This can also be grown as border crop, intercrop and a shade crop (Anon., 2024).

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