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REVIEW ARTICLE

ORIGIN, DOMESTICATION, TAXONOMY, BOTANICAL DESCRIPTION, GENETICS AND CYTOGENETICS, GENETC DIVERSITY AND BREEDING OF PIGEONPEA [*Cajanus cajan* (L.) Millsp.]

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ABSTRACT

Pigeonpea [*Cajanus cajan* (L.) Millsp.] belongs to the genus-Cajanus, subtribe-Cajaninae, tribe-Phaseoleae. order-Fabales,family-Fabaceae and sub-family Faboideae. There are two types of pigeon pea viz., 1) *Cajanus cajan* variety bicolor:-the colour of the flower of this variety is yellow, the plant is bushy and tall, pods are of dark colour which contains approx four to five seeds, we do its cultivation all over the world and 2) *Cajanus cajan* variety flavus:- the color of the flower of this variety is also yellow as compared to variety bicolor the size of the plant is small, the pod also contain only two to three seeds, but this is an early maturing variety so it is cultivated more, it is also cultivated all over the world. The name pigeonpea was first used in Barbados where pigeon were fed the seeds of *Cajanus cajan* . Red gram (*Cajanus cajan* L.) belonging to Leguminosae family has several species that vary in height, habit, maturation period, colour, size, and form of pods and seeds. In India the plant is known by various different names such as; Assamese: arahar,• Bengali: arahar, mirai-maha, • Gujarati: tuver, • Hindi: arhar, tuvar, • Kannada: togari bele, togari kalu, • Konkani: tori, • Malayalam: adhaki, tuvara, • Manipuri: mairongbi, • Marathi: tur, • Oriya: har-har, kakshi, tubara, • Punjabi: dinger, • Tamil: adhaki, iruppuli, kaycci), and tuvarai, • Telugu: adhaki, kandi, togari, tuvaramu, and in Urdu: ।arhar, tuar. The centre of origin is the eastern part of peninsular India, including the state of Orissa, where the closest wild relatives occur. Pigeonpea being a leguminous plant is capable of fixing atmospheric nitrogen and thereby restore lot of nitrogen in the soil. Every Red gram plant is a mini-fertilizer factory as the crop has unique characteristics of restoring and maintaining soil fertility through fixing atmospheric nitrogen in symbiotic association with *Rhizobium* bacteria present in the root nodules. Red gram has a deep root system, and it extracts minerals, nutrients, moisture from the deep soil. In this process, it breaks the hardpans of the soil, which is helpful in improving the structural condition of the soil. Red gram is also useful for preventing soil from erosion. Nowadays, it is a major problem. It encourages the moment of water in the soil. Red gram is a very important source of protein, iron, iodine & some essential amino acids like lysine, tyrosine, cystine, protein percentage in red gram is approx 22.3% so we know it as a rich source of protein, it is consumed as dal and also used for preparing curries. We use the sweet green pod as a vegetable. Red gram crop is suitable for inter-cropping, with different crops (Cotton, Sorghum, Pearl millet, Green gram, Black gram, Maize, Soybean, Groundnut) for increasing production and maintaining soil fertility. It is an important pulse crop which is mainly grown in developing countries of the world. In India, red gram is widely cultivated and accounts for 15 to 20 per cent of the pulse production in the country. Globally, India is the largest producer and consumer of red gram. In India arhar is mostly grown in the states of UP, MP, Maharashtra, Bihar and Andhra Pradesh, Punjab, Haryana, West Bengal, Assam, Orissa, Rajasthan, HP, Gujarat, Jammu and Kashmir, Karnataka, Tamil Nadu, Kerala. However, the major area is restricted to north Indian states. In this review article on Origin, Domestication, Taxonomy, Botanical Description, Genetics and Cytogenetics, Genetic Diversity, Breeding, Uses, Nutritional Value and Health Benefits of Pigeonpea are discussed.

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INTRODUCTION

Pigeonpea [*Cajanus cajan* (L.) Millsp.] belongs to the genus-Cajanus, subtribe-Cajaninae, tribe-Phaseoleae, order-Fabales,family-Fabaceae and sub-family Faboideae (Singh et al., 2016). There are two types of red gram viz. (Singh, 2022): 1)

***Cajanus cajan* variety bicolor**:-the colour of the flower of this variety is yellow, the plant is bushy and tall, pods are of dark colour which contains approx four to five seeds, we do its cultivation all over the world and 2) ***Cajanus cajan* variety flavus**:- the color of the flower of this variety is also yellow as compared to variety bicolor the size of the plant is small, the pod also contain only two to three seeds, but this is an early maturing variety so it is cultivated more, it is also cultivated all over the world. Red gram (*Cajanus cajan* L.) has several species that vary in height, habit, maturation period, colour, size, and form of pods and seeds. The name pigeonpea was first used in Barbados where pigeon were fed the seeds of *Cajanus cajan*. Pigeon pea is a short-lived, erect, woody shrub growing about 4 metres tall with erect ribbed, densely pubescent stems. Not known in the wild, the plant is often grown in the tropics and subtropics for its wide range of uses, including food, medicine and fuel. It is also often used as a green manure and for soil stabilization. This species is believed to be one of the earliest of cultivated crops (TPD, 2023). In India the plant is known by various different names such as; Assamese: arahar,• Bengali: arahar, mirai-maha, • Gujarati: tuver, • Hindi: arhar, tuvar, • Kannada: togari bele, togari kalu, • Konkani: tori, • Malayalam: adhaki, tuvara, • Manipuri: mairongbi, • Marathi: tur, • Oriya: har-har, kakshi, tubara, • Punjabi: dinger, • Tamil: adhaki, iruppuli, kaycci), and tuvarai, • Telugu: adhaki, kandi, togari, tuvaramu, and in Urdu: ˈarhar, tuar (Wikipedia, 2023). It is the second most important pulse crop grown in India. The term 'pigeonpea' was coined in Barbados, where its seeds were considered an important pigeon-feed. Pigeonpea or red gram or tur is known by several vernacular names in India viz. Tur (Maharashtra and Gujarat), Arhar (Uttar Pradesh, Bihar, Madhya Pradesh), Aral (West Bengal), Kandi (Andhra Pradesh), Harad (Haryana and some parts of western Uttar Pradesh), Rahat (parts of Bihar), Tuvaraparippu (Kerala), Kokh-lan (tribes of Tripura), adhaki and tuvarika (Sanskrit) (Singh *et al*., 2016).

In English they are commonly referred to as pigeon pea which originates from the historical utilization of the pulse as pigeon fodder in Barbados. The term Congo pea and Angola pea developed due to the presence of its cultivation in Africa and the association of its utilization with those of African descent. The names no-eye pea and red gram both refer to the characteristics of the seed, with no-eye pea in reference to the lack of a hilum on most varieties, unlike the black-eyed pea, and red gram in reference to the red color of most Indian varieties and gram simply referring to the plant being a legume (Wikipedia, 2023). Pigeon pea, no-eye pea, no-eyed pea, tropical green pea, cajan pea [English]; pois d'Angole, pois cajan, pois-congo, ambrevade [French]; guandú, gandul, guandul, frijol de palo, quinchoncho [Spanish]; guandu, andu, anduzeiro, guandeiro, feijão boer [Portuguese]; Straucherbse [German]; pwa kongo [Haitian creole]; gude, kacang gude [Indonesian]; caiano [Italian]; umukunde [Kinyarwanda]; pī kula [Tongan]; Đậu triều [Vietnamese] (Heuzé et al., 2017). It is known as Pigeon Pea, Puerto Rico Bean, Gandul, Dhal, Congo Pea (PFAF, 2023). No-eye pea, tropical green pea, gungo pea in Jamaica, gandule bean, gandul / guandu in Latin America, ch'charo in Latin America, "kumanda yvyra'i" Guaran' name in Paraguay, arveja in Ecuador, mgb_mgb_. gungo pea / gunga pea / Congo pea in Africa, mzimbili mussa in Tanzania, nandolo in Malawi, fio-fio. mbaazi in Kenya, kadyos in Philippines, quinchoncho in Venezuela, "mbaazi" in Tanzania, tubarika in Sanskrit, togari bele in Kannada, thuvaram paruppu in Tamil, thuvaraparippu in Malayalam, tuver' in Gujarati, toor Dal in Marathi, toor dal or arhar dal, orhor dal in Bengali, rohor dail in Assamese, rahar daal in Nepali, harada dali in the Odia, kandi bedalu in Telugu, behliang in the Zomi/Mizo language, and Towar or Tovar or Tover ki dal (PFAF, 2023). Pigeonpea is known with various vernacular names in different countries (Table 1)

Table 1. Some vernacular names of pigeonpea used in different parts of the World

Country	Vernaculars ----------
Bangladesh	Arhar, Tur, Tuver
China	Muk tau, Tan Shue, Shan Tou Ken (Tree bean)
India	Red gram, Arhar, Tur, Kandulu, Thogari, Tuvari,Thuvarai, Thora-paerou, Paruppu IndonesiaSaupapa, Kachng bali, Kachng gude
Japan	Ki-mame
Malaysia	Kachang, Kachang dal
Nepal	Adhad, Arhar, Rar
Philippines	Tabios, Kardis, Kudis, Callos, Kadyos Sri LankaParippu (Pulse)
(General)	Pigeonpea, Pois d'Angole,Pois de Congo AngolaErvilha do Congo
Egypt	Ads sudani, Lubia hadjeri sudani
Ethiopia	Yeweof-ater, Ringa
Gabon	Oando, Ossanga, Osang-eli Kenya,TanzaniaMbaazi
Mozambique	Dozi, Feijao Boer
Nigeria	Aduwa, Olele, Orele, Alev a batur
San Tome	Feijao Congo
Senegambia	Cajan des Indes AMERICA:
(General)	Guandu, Angola pea, No eye pea, Gungo pea, BrazilFaijao andu, Feijao guandu
Cuba	Gandul, Gadul
Jamaica	Congo pea, Christmas pea, Guango
Puerto Rico	Gandul, Gandal
Venezuela	Qunichoncho, Quinchonchillo OCEANIA-HawaiiPuerto Rican pea
France	Embravade,Pois d' Angole, Pois de Bois,Pois cajan, Pois de congo
Germany	Angolische Erbse, Indischer Bohnenstrauch
Netherlands	Wandoe

The centre of origin is the eastern part of peninsular India, including the state of Orissa, where the closest wild relatives occur. (Singh *et al*., 2013). The initial domestication of pigeon pea was started in central India over 3,500 years ago, from its wild progenitor *Cajanus cajanifolius* (Jorrin *et al*., 2021). The pigeon pea (*Cajanus cajan*) is a perennial legume from the family Fabaceae native to the Old World. The pigeon pea is widely cultivated in tropical and semitropical regions around the world, being commonly consumed in South Asia, Southeast Asia, Africa, Latin America and the Caribbean (Wikipedia, 2023). Though pigeonpea has a narrow genetic base, vast genetic resources are available for its genetic improvement. The ICRISAT gene bank maintains about 13,216 accessions, whereas the Indian NBPGR bank maintains a total of about 12,900 accessions (Singh *et al.,* 2013).

Pigeonpea is a legume crop resilient to climate change due to its tolerance to drought. It is grown by millions of resource-poor farmers in semiarid and tropical subregions of Asia and Africa and is a major contributor to their nutritional food security (Jorrin *et al.,* 2021). Pigeonpea being a leguminous plant is capable of fixing atmospheric nitrogen and thereby restore lot of nitrogen in the soil (Google, 2023). Red gram is an important source of human food, also acts as animal feed, enriches the soil through atmospheric nitrogen fixation. Since red gram is a drought-resistant crop, it is mainly grown under rainfed conditions (Bhat *et al*., 2019). Every Red gram plant is a mini-fertilizer factory as the crop has unique characteristics of restoring and maintaining soil fertility through fixing atmospheric nitrogen in symbiotic association with *Rhizobium* bacteria present in the root nodules. Red gram crop is suitable for inter-cropping, with different crops (Cotton, Sorghum, Pearl millet, Green gram, Black gram, Maize, Soybean, Groundnut) for increasing production and maintaining soil fertility (Bhat *et al*., 2019). Diverse pigeon pea rhizobia have been reported in Indian soils and have a long history of usage as inoculants; nevertheless, rigorous diversity studies have not been performed on these endosymbionts (Jorrin *et al*., 2021).

Red gram has a deep root system, and it extracts minerals, nutrients, moisture from the deep soil. In this process, it breaks the hardpans of the soil, which is helpful in improving the structural condition of the soil. Red gram is also useful for preventing soil from erosion. Nowadays, it is a major problem. It encourages the moment of water in the soil (Singh, 2022**).** *Cajanus cajan* (L.) Millsp is a protein-rich legume species belonging to the Fabaceae family. This medicinal flowering plant is distributed mainly in tropical areas such as Asian countries and India. This medicinal species is also called different things depending on its location of growth (Tungmunnithum and Hano, 2020). Due to being rich in protein and interesting flavonoid and phenolic compounds, it is continuously studied and reported on nowadays (Tungmunnithum and Hano, 2020). Pigeon pea can be grown for seed production, forage production, or both. Some double purpose cultivars have been developed. Since its domestication in India at least 3,500 years ago, its seeds have become a common food grain in Asia, Africa, and Latin America. It is consumed on a large scale mainly in south Asia and is a major source of protein for the population of that subcontinent (Shirsath *et al.,* 2014).

Red gram is an important pulse crop which is mainly grown in developing countries of the world. In India, red gram is widely cultivated and accounts for 15 to 20 per cent of the pulse production in the country. Globally, India is the largest producer and consumer of red gram (Bhat *et al*., 2019). Further, red gram is also rich in lysine, riboflavin, thiamine, niacin and iron. Pigeonpea is a backbone of nutritional security of our country. India has virtual monopoly in its production by bagging 80 per cent of world's total production. Pigeonpea like other pulses is considered a subsidiary crop. It is often grown on marginal lands and is usually intercropped with crops as sorghum and cotton, etc. As a crop of secondary importance in many of these systems, it receives little or no purchased inputs. However, farmers in some red gram growing areas are growing more sole crops of pigeonpeas and the crop is increasingly gaining status as a cash crop. Besides, it supplements the important component of protein particularly to Indian population where their diet is based on cereal itself (Google, 2023). It is cultivated as a pulse crop, it is also important medicinally. Tender leaves ate reported to be chewed in case of aphthalmia and spongy gurns of the mouth. The poultice made by seeds is used to reduce swelling and treat snakebites **(**Mia, 2016**).** Red gram is a very important source of protein, iron, iodine & some essential amino acids like lysine, tyrosine, cystine, protein percentage in red gram is approx 22.3% so we know it as a rich source of protein, it is consumed as dal and also used for preparing curries. We use the sweet green pod as a vegetable (Singh, 2022**).**

In India arhar is mostly grown in the states of UP, MP, Maharashtra, Bihar and Andhra Pradesh, Punjab, Haryana, West Bengal, Assam, Orissa, Rajasthan, HP, Gujarat, Jammu and Kashmir, Karnataka, Tamil Nadu, Kerala. However, the major area is restricted to north Indian states (Google, 2023). Grains become hard, and moisture percent in grain at harvesting should be 20-22 %. Pod shattering is common problem in pulse. Harvest the whole plants with sickle when 80% of the pods mature. The pods or whole crop after complete drying should be threshed manually or by machine. 15-20 quintal/ ha as rainfed intercrop and 25-30 quintal/ha as irrigated monocrop can be obtained. Very early and early varieties yield 20-30 % less (Shirsath *et al.,* 2014). Pigeon pea is the sixth most important legume in the world, representing 5% of the total pulse production (4.92 M ha), with India contributing more than 70% of the total (3.6 M ha) and harbouring a wide variety of cultivars (218 making up 73% of the total). It was estimated by the Food and Agriculture Organisation (FAO) that the worldwide annual production of pigeon pea in 2019 was 5.6 Mt, of which ~59% was produced by India alone (Jorrin *et al.,* 2021). Pigeonpea is an important grain legume of the Indian subcontinent, Southeast Asia and East Africa. More than 85% of the world pigeonpea is produced and consumed in India, where it is a key crop for food and nutritional security of the people. (Singh *et al*., 2013). After gram, arhar is the second most important pulse crop in the country. It is mainly eaten in the form of split pulse as 'dal' (DPD, 2023). Pigeon pea (*Cajanus cajan* L. Millsp.) is grown by millions of resource-poor farmers in semiarid and tropical subregions of Asia and Africa as a major contributor to their food security (Jorrin *et al*., 2021). Pigeon pea is the sixth most important legume in the world, with India contributing more than 70% of the total production and harbouring a wide variety of cultivars (Jorrin *et al.,* 2021). Harvesting is done with the sickle. At the time of harvesting, the colour of the pod is brown. After harvesting, threshing starts where grains get separated from plants. After threshing, it should be sun-dried and then it should store. The yield of improved variety is 25- 30 q/ha and in inter-cropping yield maybe got 2-5 q/ha (Singh, 2022**).** Forage yield ranges from 20-40 t DM/ha. Levels as high as 24 t DM/ha of fodder and stalks have been reported from the Sahel, and it has been suggested that there should be further study on the use of pigeon pea as forage plant in this area. Up to 40 tons DM/ha could be expected under optimal conditions (Heuzé *et al.,* 2017). In this review article on Origin, Domestication, Taxonomy, Botanical Description, Genetics and Cytogenetics, Genetic Diversity, Breeding, Uses, Nutritional Value and Health Benefits of Pigeonpea are discussed.

ORIGIN AND DOMESTICATION

The cultivation of the pigeon pea goes back at least 3,500 years. The centre of origin is probably peninsular India, where the closest wild relatives (*Cajanus cajanifolia*) occur in tropical deciduous woodlands. Archaeological finds of pigeon pea dating to about 3400 years ago (14th century BC) have been found at Neolithic sites in south India (Sanganakallu) and its border areas (Tuljapur Garhi in Maharashtra and Gopalpur in Orissa). From India it traveled to East Africa and West Africa. There, it was first encountered by Europeans, so it obtained the name Congo Pea. By means of the slave trade, it came to the American continent, probably in the 17th century (Shirsath *et al*., 2014). Pigeonpea is grown in

over 50 tropical countries of the world especially in more arid regions of Africa, Asia and the Americas. In India, it is cultivated as an annual crop, but in other countries, it is grown as perennial crop, where pods are harvested at regular intervals. Red gram is mainly cultivated and consumed in developing countries of the world. The major pigeonpea producing countries of world are India Myanmar Kenya Malawi Uganda and Tanzania. Pigeonpea is the second most important pulse crop in the country. India is the largest producer and consumer of Red gram in the world. India accounts for over ¾ of acreage and production of the globe. The crop is extensively grown in Maharashtra, Andhra Pradesh and Gujarat. Maharashtra has unique distinction of contributing about 30% of total pigeonpea production in the country (Shirsath *et al.,* 2014).

India is considered as the centre of origin for pigeonpea. Many evidences including occurrence of various wild relatives **(Table 2**) in nature, vast genetic variability in the gene pool, and a few historical as well as archaeological records have been offered to strengthen the view of Indian origin of pigeonpea. The alternate hypothesis suggesting Africa as the centre of origin does not seem to be viable as only one wild relative *C. kerstingii* is reported to occur in West Africa. In addition, *C. scarabaeoides* has also been found in Africa, but spread is restricted to the coastal areas only. Consequently, it was proposed Africa as the secondary centre of origin. Therefore, the most acceptable route of dispersion describes that the immigrants moved the crop up from India to East Africa, then the route followed to Egypt (via Nile valley), West Africa and finally to the America. Fifteen wild species have been reported in Australia also. Noticeably, majority of these species are endemic, therefore, Australia is considered as the centre of diversity for pigeonpea. However, it was contested that this view that considers Australia as the centre of diversity since they observed very low level of genetic diversity among the wild Australian species, which were used for SNP based genetic diversity analysis. *C. cajan* having a pantropical distribution is the only cultivated species belonging to the genus Cajanus. Pigeonpea underwent domestication around 3,500 years ago (Singh *et al.,* 2016).

Table 2. Wild species and their distribution in India

Species	Distribution	Reference(s)/Links
C. *scarabaeoides*	Widely distributed species across Andaman and Nicobar, Andhra Pradesh, Bihar, Chattisgarh, Himachal Pradesh, Jharkhand, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Tamil Nadu, Uttar Pradesh, Uttaranchal, West Bengal	Upadhyaya et al., 2013
C. *albicans*	Peninsular India	van der Maesen, 1990
C. *cajanifolius*	Andhra Pradesh, Arunachal Pradesh, Assam, Bihar, Chattisgarh, Gujarat, Haryana, Himachal Pradesh, Jammu-Kashmir, Karnataka, Kerala, Maharashtra, Manipur, Meghalaya, Mizoram, Nagaland, Orissa, Pondicherry, Punjab, Rajasthan, Sikkim, Tamil Nadu, Tripura, Uttar Pradesh, West Bengal	http://www.iucnredlist.org/details/full/19891613/0
C. *crassus* (King) Maesen var *crassus*	Assam, Central Indiaand NW Himalaya	van der Maesen, 1990
C. *elonagatus* (Bentham) Maesen	NE India	van der Maesen, 1990
C. *grandiflorus* (Bentham ex Baker) Maesen	Himalayn region	van der Maesen, 1990
C. *mollis*	Himalayn region	van der Maesen, 1990
C. *platycarpus*	Bihar, Gujarat , Haryana, Himachal Pradesh, Jammu-Kashmir, Madhaya Pradesh; Maharashtra, Orissa, Punjab, Rajasthan and Uttar Pradesh	http://www.legumes-online.net/ildis/aweb/td114/td_24020.htm

The origin of *Cajanus cajan* is either North-Eastern Africa or India. Its cultivation dates back at least 3000 years. It is now a pantropical and subtropical species particularly suited for rainfed agriculture in semi-arid areas due to its deep taproot, heat tolerance and fast growing habit. *Cajanus cajan* can be found in both hemispheres from 30°N to 30°S, and from sea level to an altitude of 2000 m (3000 m in Venezuela). It is very heat-tolerant and grows better in places where temperatures range from 20° to 40°C and which are frost-free. Though sensitive to frost, pigeon pea keeps growing at temperatures close to 0°C and tall plants can survive light frost. It does better where annual rainfall is above 625 mm but it is highly tolerant of dry periods. However, where the soil is deep and well-structured it continues to grow with rainfall as low as 250 to 375 mm. Pigeon pea can grow on a wide range of soils, from sands to heavy black clays, with variable pH. However, the best pH range is within 5-7. It has low tolerance of soil salinity, although some cultivars were reported to tolerate high (6-12 dS/m) salinity. *Cajanus cajan* is sensitive to salt spray and water logging. Under shade, it shows reduced growth and bears thin, pale green foliage with few pods (Heuzé *et al*., 2017).

According to the ancient research document, we are doing red gram cultivation for over three thousand years. We believe that red gram origin is near the Nile river, or Angola districts of Africa, but according to the scientist's, Vavilov in 1951 India is the origin of the red gram (Singh, 2022**).** We cultivate red gram all over the world, including southeast Asia, Africa, America, India. Major red gram farming growing countries are India and Africa (Singh, 2022**).** Pigeonpea is the most widely grown crop in the country and has been under cultivation for over three thousand years. It has been reported to occur in wild state in the upper region of Nile river and the coastal districts of Angola in Africa. Therefore, Africa may be its original place and from where it might have been introudced to India. However, according to Vavilov, India is the place of origin of pigeonpea (Ikisan, 2023).

Based on the wide genetic variability, Vavilov (1951) reported that India is the center of origin for cultivated pigeonpea and is also been widely cultivated in many African countries, Egypt, and a bunch of Asian countries since prehistoric times. Eastern Africa was considered as center of origin of pigeonpea by several workers owing to its occurrence in wild form. Based on the occurrence of wild relatives and diversity, it is inferred that India is the primary centre of origin and Africa is the secondary centre of origin for pigeonpea. Its actual place of origin is very controversial as some people believe it to originate in India while others say that red gram was found in the wild estate in Africa in regions of upper Nile and the coastal districts of Angola.

From Africa it spread to other parts of the world and to India. Australian people grow it for fodder and vegetable purposes. Now, it is being grown in Africa, America, Australia, Hawaii, Ceylon, Netherland, Malaya, East and West Indies, India, Indo-China, Pakistan (Google, 2023).

The closest relatives to the cultivated pigeon pea are *Cajanus cajanifolia, Cajanus scarabaeoides* and *Cajanus kerstingii,* native to India and the latter West Africa respectively. Much debate exist over the geographical origin of the species, with some groups claiming origin from the Nile river and Western Africa, and the other Indian origin. The two epicenters of genetic diversity exist in both Africa and India, but India is considered to be its primary centre of origin with West Africa being considered a second major centre of origin (Wikipedia, 2023). By at least 2,800 BCE in peninsular India, where its presumptive closest wild relatives *Cajanus cajanifolia* occurs in tropical deciduous woodlands, its cultivation has been documented. Archaeological finds of pigeon pea cultivation dating to about 14th century BC have also been found at the Neolithic site of Sanganakallu in Kalaburagi and its border area Tuljapur (where the cultivation of African domesticated plants like pearl millet, finger millet, and Lablab have also been uncovered), as well as in Gopalpur and other South Indian states. From India it may have made its way to North-East Africa via Trans-Oceanic Bronze Age trade that allowed cross-cultural exchange of resources and agricultural products. The earliest evidence of pigeon peas in Africa was found in Ancient Egypt with the presence of seeds in Egyptian tombs dating back to around 2,200 BCE. [56] From eastern Africa, cultivation spread further west and south through the continent, where by means of the Trans-Atlantic slave trade, it reached the Americas around the 17th century. Pigeon peas were reportedly introduced to Hawaii in 1824 by James Macrae with a few specimens reportedly becoming naturalized on the islands, but they wouldn't gain much popularity until later. By the early 20th century Filipinos and Puerto Ricans began to emigrate from the American Philippines and Puerto Rico to Hawaii to work in sugarcane plantations in 1906 and 1901, respectively. Pigeon peas are said to have been popularized on the island by the Puerto Rican community where by the First World War their cultivation began, to expand on the island where they are stilled cultivated and consumed by locals (Wikipedia, 2023).

TAXONOMY

Pgeonpea belongs to the Family Fabaceae, Subfamily Faboideae, Tribe Phaseoleae, Subtribe Cajaninae, Genus *Cajanus* and the Species *Cajanus cajan* **(**Mia, 2016; Singh *et al*., 2016; Wikipedia, 2023; Wikipedia, 2023a**).** The species name is *Cajanus cajan* (L.) Huth [Fabaceae] (Heuzé *et al*., 2017). The scientific name for the genus *Cajanus* and the species *cajan* derive from the Malay word *katjang* meaning legume in reference to the bean of the plant (Wikipedia, 2023). Pgeonpea (*Cajanus cajan* L.), a diploid legume crop species (2n = 2x = 22) (Shirsath *et al.,* 2014).

Taxonomical Hierarchy

The genus *Cajanus* has 11 related genera [(1) Rhynchosia Lour., (2) Dunbaria W., (3) Dunbaria A., (4) Eriosema D., (5) Eriosema C., (6) Reichenb, (7) Flemingia Roxb. Ex Aiton., (8) Paracalyx Roxb. Ali, (9) Adenodolichos, (10) Baukea, and (11) Carissoa] and 32 species; (18 species are endemic to Asia, 13 to Australia, and one to West Africa). It is postulated that the cultivated pigeonpea originated from *Cajanus cajanifolius* by selection for size and vigor of the plant, non-shattering pods, and larger seed size. However, the cultivated *Cajanus cajan* differs from *Cajanus cajanifolius* in floral morphology, pod and seed color, and 100 seed mass. Based on the genetic cross-compatibility the species of *Cajanus cajan* are distributed into primary gene pool (GP1), which includes the all available germplasm and *C. cajanifolius*. It is freely crossable with the cultivated types and produces fertile hybrids. While the 10 *Cajanus* species that are cross-compatible with *C. cajan* form the secondary gene pool (GP2), the rest of the species, which do not cross with *C. cajan*, are placed in the tertiary gene pool (GP3**) (Table3)**

Table 3. Species of *Cajanus cajan* are distributed into Primary, secondary and tertiary gene pool

Gene pool	Species
GP1	1) C. cajan (L.) Millsp., C. cajanifolius
GP2	1) C. acutifolius (F. von Muell.) van der Maese 2) C. albicans (W. & A.) van der Maesen 3) C. cajanifolius (Haines) van der Maesen 4) C. lanceolatus (W. V. Fitzg.) van der Maesen 5) C. latisepalus (Reynolds and Pedley) van der Maesen 6) C. lineatus (W. & A.) van der Maesen 7) C. sericeus (Benth. ex Bak.) van der Maesen 8) C. trinervius (D.C.) van der Maesen 9) C. scarabaeoides (L.) Thouars 10) C. reticulates (Dryander) F. von Muell
GP3	1) C. aromaticus van der Maesen 2) C. cinereus (F. von Muell) F. von Muell 3) C. crassicaulis van der Maesen 4) C. crassus (Prain ex. King) van der Maesen 5) C. elongatus (Benth.) van der Maesen 6) C. grandiflorus (Benth. ex Bak.) van der Maesen 7) C. goensis Dalz 8) C. heynei (W. & A.) van der Maesen 9) C. kerstingii Harms 10) C. lanceolatus (W. V. Fitzg.) van der Maese, 11) C. lanuginosus van der Maesen 12) C. mareebensis (Reynolds and Pedley) van der Maesen 13) C. marmoratus (R. Br. ex Benth.) F. von Muell 14) C. mollis (Benth.) van der Maesen 15) C. niveus (Benth.) van der Maesen 16) C. platycarpus (Benth.) van der Maesen 17) C. pubescence (Ewart & Morrison) van der Maesen 18) C. rugosus (W. & A.) van der Maesen 19) C. villous (Benth. ex. Bak.) van der Maesen 20) C. viscidus van der Maesen 21) C. volubilis (Blanco) 22) C. convertiflorus F. von Muell.

There are 37 species in the genus *Cajanus*, mainly distributed across Africa, Asia and Australasia. Species include the pigeon pea (*C. cajan*), which is a significant food crop. Species include (Wikipedia, 2023a):

1) *Cajanus acutifolius*
2) *Cajanus albicans*
3) *Cajanus aromaticus*
4) *Cajanus cajan* - pigeon pea, Congo-pea
5) *Cajanus cinereus*
6) *Cajanus confertiflorus*
7) *Cajanus crassicaulis*
8) *Cajanus crassus*
9) *Cajanus elongatus*
10) *Cajanus goensis*
11) *Cajanus grandiflorus*
12) *Cajanus kerstingii*
13) *Cajanus lanceolatus*
14) *Cajanus lanuginosus*
15) *Cajanus latisepalus*
16) *Cajanus mareebensis*
17) *Cajanus marmoratus*
18) *Cajanus mollis*
19) *Cajanus platycarpus*
20) *Cajanus pubescens*
21) *Cajanus reticulatus*
22) *Cajanus scarabaeoides*
23) *Cajanus sericeus*
24) *Cajanus viscidus*

Synonyms (Tungmunnithum and Hano, 2020):

1) Cajan indorum Medik.,
2) Cajan inodorum Medik.,
3) Cajanus cajan (L.) Huth,
4) Cajanus cajan var. flavus (DC.) Purseglove,
5) Cajanus cajan var. bicolor (DC.) Purseglove,
6) Cajanus striatus Bojer,
7) Cajanus obcordifolia Singh,
8) Cajanus pseudo-cajan (Jacq.) Schinz and Guillaumin,
9) Cajanus indicus Spreng.,
10) Cajanus indicus var. flavus (DC.) Kuntze,
11) Cajanus indicus var. bicolor (DC.) Kuntze,
12) Cajanus indicus var. maculatus Kuntze,
13) Cajanus luteus Bello,
14) Cytisus guineensis Schumach. and Thonn.,
15) Cytisus pseudocajan Jacq.,
16) Cytisus cajan L.,
17) Phaseolus balicus L.

The genus *Cajanus* has 32 species, most of them being distributed in India and Australia. About 17 *Cajanus* species including the most probable progenitor of pigeonpea [*C. cajanifolius* (Haines) Maesen] occur in India. The variability available within the cultivated species *C. cajan* forms the primary gene pool, while 11 species that are cross compatible with *C. cajan* constitute the secondary gene pool. These cross-compatible species are (Singh *et al.,* 2016):

1) C. acutifolius (F. Muell.) Maesen,
2) C. albicans (Wight & Arn.) Maesen,
3) C. cajanifolius (Haines) Maesen,
4) C. confertiflorus F. von Muell,
5) C. lanceolatus (W. Fitzg.) Maesen,
6) C. latisepalus Maesen,
7) C. lineatus (Wight & Arn.) Maesen,
8) C. sericeus (Baker) Maesen,
9) C. trinervius (DC) Maesen,
10) C. scarabaeoides (L.) Thouars Maesen,
11) C. reticulatus (Dryand.) F. Muell.

The following species are reported to be rich sources of various desirable traits:

C. goensis Daiz,
C. heynei (W & A) Maesen,
C. kerstingii Harms,
C. mollis (Benth) Maesen,

C. platycarpus (Benth) Maesen,
C. rogosus (W & A) Maesen,
C. volubilis (Blanco)
Blanco do not cross with the cultivated pigeonpea and form the tertiary gene pool (Singh *et al*., 2016)*:*

Classification pigeon pea

The *Cajanus cajan* differs in plant character, pod character and maturity duration, but most of the cultivated types belong to two categories. 1) *Cajanus cajan* var. *bicolour:* They are late maturing, plants grow very tall or probably they are tallest of both the types which are freely branched and bear flowers at the end of the branches. The pods are relatively longer and use to contain 4 to 5 seeds in them. 2) *Cajanus cajan* var. *flavus:*

They have shorter duration and accordingly they fall in early maturing category of plants. Plants are shorter, bushy having flowers at several points along the branches. The pods are also shorter which bear two to three seeds in them. **Table 4** gives the classification based on growth habit

Table 4. Classification of pigeonpea based on growth habit

Classes	Basis of classification
Very erect (30") Erect (40") Semi-erect (50°) Spreading (60°)	Angle of branching
Erect (30-40°) Semi-erect (40-50°) Spreading (60 -70°)	Angle of branching
Erect and compact Semi-spreading Spreading Trailing	Angle of branching
Tall compact Tall open Medium-height compact Medium-height open Dwarf bushy	Plant height and angle of branching
Compact Spreading Semi-spreading	Spreading Semi-spreading Angle of branching and number of branches

Synonyms (Heuzé *et al*., 2017).
Cajanus bicolor DC.,
Cajanus flavus DC.,
Cajanus indicus Spreng.,
Cytisus cajan L.

Synonyms (Wikipedia, 2023a)
Atylosia Wight & Arn. 1834
Cajan Adans. 1763
Cantharospermum Wight & Arn.
Endomallus Gagnep. 1915

Synonyms (Singh *et al*., 2016)
Cytisus cajan L.;
C. bicolor DC.;
C. flavus DC.;
C. indicus Spreng.;
C. striatus Bojer (van der Maesen, 1990).

BOTANICAL DESCRIPTION

Morphology of *Cajanus cajan*
The morphological variation in pigeonpea (*Cajanus cajan*) is greatest in Asia especially in India, its place of origin. Several researchers working in India have described the morphology and studied the variation available within pigeonpea. On the basis of flower colour, seed numbers per pod, length of stipples, de Candolle distinguished two species under *Cajanus viz*., *C.bicolor* and *C.flavus*. Later workers reduced these two species to botanical varieties. Variety *flavus* (DC) is characterised by early maturity with shorter stature, yellow standard petals, green glabrous pods, lighter in colour when ripe, and usually 3 seeded. Variety *bicolor* (DC) is characterised by late maturity, large bushy stature, red or purple streaked standard petals, and hairy pods blotched with maroon, or dark coloured with 4 to 5 seeds, that are darker coloured or speckled when ripe. The above varietal distinctions appear to be of doubtful taxonomic validity since the two varieties are readily crossable, and a range of combinations of the above distinguishing features occurs in the present-day varieties. Based on the morphology, distinguished 86 different pigeonpea types from collections throughout India, while it was recognized 36 types from Madhya, Pradesh State alone (Ikisan, 2023).

The root system in pigeonpea consists of a deep, strong, woody tap root with well developed lateral roots in the superficial layers of the soil. Under certain conditions the roots can go more than 2 m deep, but the most extensive development takes place in the upper 60 cm of the soil. Normally root depth ranges from 30 to 90 cm and is influenced by the date of sowing and the availability of moisture in the soil profile. Root

growth continues during the reproductive phase and the total root length approximately doubles after the onset of flowering. The root system appears to be closely related to plant habit. Tall, compact varieties produce longer and more deeply penetrating roots, whereas spreading types produce shallower, more spreading, and denser root systems. In a dormant seed, the radical measures 0.2 cm below the cotyledonary node. Before the first pair of simple leaves unfolds, the radical grows to a sufficient length with a clear demarcation between the tap root and the hypocotyl region. The radical comes out through the hilum within 1.5 to 2.0 days. In about 5 days the radical attains a length of 4-6 cm. From the third day onwards, lateral roots make their acropetal appearance. The primary structure of both the tap root and secondary roots is tetrarch. Young roots posses parenchymatous pith that is disorganised at the onset of secondary growth. The epidermis of the young root is single-layered with a thin layer of cuticle. The wide cortex is parenchymatous, and consists of numerous rhomboidal crystals. The endodermal cells do not show casparian thickening on their radial walls. The pericycle is multilayered. Older roots with secondary growth appear more or less eccentric. Secondary growth occurs through the activity of a vascular combium. The development of this cambium is typically dicotyledonous. The cork consists of a few layers. In the secondary pholoem region, secretary ducts containing a tannin-like material are present, these ducts are also present in stems and other aerial organs. Mycorrhizae are often present in cortical cells of the roots, and occassionally mycorrhizal fruiting bodies can be observed. The first two leaves are simple, opposite, and caducous. They are narrowly ovate with a cordate to truncate base, and an acute to acuminate apex. The apices may have a small macro. The stipules are lanceolate and conspicuously forked. Rarely, the second and third nodes, show either a simple leaf or a compound leaf with only two leaflets. Subsequent leaves are compound, pinnately trifoliate, and arranged in a 2/5 type of spiral phyllotaxy. A pair of free lateral, lanceolate stipules is present at the pulvinate base of the petiole that bears the leaflets. In a fully developed leaf, petiole length ranges from 2.4 to 6.0 cm and is prominently grooved on the adaxial side. Lateral leaflets possess one stiped each, whereas the terminal leaflet has a pair of stiples. The leaflets are lanceolate or elliptic, with acute or obtuse apices. Terminal leaflets are mostly symmetrical, but the side leaflets are broader at the side furthest away from the terminal leafs. Terminal leaflets are usually bigger than lateral leaflets. Genotypic differences exist for leaf size and shape and are also influenced by the environment. Under extended day length conditions the leaflet size considerably increases. The leaf surface area varies from 13.0 to 93.5 cm2 in various genotypes, whereas in a minute leaf variant the total leaf surface for three leaflets only measures 6 cm2. The lengths of the petiole and rachis also vary greatly, but the petiolule length is not so variable. The stipellae vary from traces to 4 mm. In the midrib region of the leaf, the vascular tissue in the ventral half occurs in a continuous arched band with phloem on the outside and xylem inside. Two distinct strands mostly consisting of phloem are seen on the ventral side. The centre of the dorsal part of the midrib is occupied by fibres capped by collenchymatous cells. The leaf lamina comprises a distinct palisade layer, and in the lower part of the leaf a spongy mesophyll with large air filled intercellular spaces. There are far more stomata on the lower surface of the leaf than on the upper surface. Stomata are distributed between and over the minor veins, but not over the major veins. Mature stomata are either anomocytic, diacytic, or paracytic. Paracytic stomata are predominant. The venation pattern consists of the mid vein and conspicuously arranged secondaries which end at the leaf margins. The major veins from regular meshes, each of these are further divided several times with free vein endings. The vein ends have tracheids that are often forked. The petiole contains a number of distinct vascular strands above which lie fibre bands. Occassionally some of the xylem vessels of the petiole are filled with a darkly stained tanin-like substance. Pulvini are found at the bases of the petiole and the leaflets. These are responsible for leaf and petiole movements. Under drought stress conditions when the sunlight is intense the leaflets exhibit paraheliotropy i.e., they take up a position parallel to the incident light. Similarly, during the night the leaflets are folded vertically upwards into the "sleeo" position. Most of the pulvinus consists of cortical tissue. Changes in the turgor of these cortical cells are responsible for the movements of the pulvini. As the leaves approach senescence, an abscission zone develops at the junctions between the leaflets and the petiole, and between the petiole and the stem. The cells in the abscission zone show divisions parallel to the plane of abscission. The weakening of the walls of these cells results in an early separation of the abscission zone, and consequently the leaflet or petiole falls (Ikisan, 2023).

Germination is hypogeal, and the cotyledons remain underground. Under suitable field conditions the seedlings appear above the ground in about 5-6 days. On the second day, the tests splits open near the micropyle, and the tip of the radical elongates and emerges from the seed coat. On the third day the hypocotyl appears as an arch and continuous to grow upwards. The hypocotyl develops a light purple colour and becomes straight. The seedling epicotyl is light green, green, or purple in colour . The first pair of leaves are simple and opposite. The epicotyl elongates to 47 cm before the first isolate leaf emerges. The first pair of leaves generally drops off within 30 to 40 days, but they may remain longer. When the young plumes or axillary shoots are damaged, secondary shoots develop from the cotyledonary axils of the seeds, resulting in multiple shoots. This phenomenon helps the plant to overcome germination and establishment problems under harsh environmental conditions. The occurrence of secondary shoots is often mistaken for twin seedlings in pigeonpea. Variation in maturity, leaf size, flower, pod and seed size, and plant pigmentation between secondary shoots developed from the same seed. Large-seeded varieties produce bigger seedlings than those of the small seeded types, but these differences disappear as the plant grows (Ikisan, 2023).

Stem is ribbed, upto 15 cm diameter, show enormous secondary growth and become woody with age. In early maturing types stem girth seldom reaches 3 cm, whereas in late-maturing types it ranges from 4 to 10 cm at the base of the plants. Four different stem colour, dark purple, purple, sun red and green (the most common) are recognized. The internodes of the stem developed by elongation of the tissue between the leaf initials tin the apical meristem. The primary vascular tissue of the stem is organised in strands connecting the nodes. Each strand is associated with a ridge on the stem that is distinctly visible even in old, secondarily thickened stems. Collenchymatous bundle caps underlie the epidermis of the ridges. Photoperiod and temperature exert profound influence on days to 50 per cent flowering and maturity duration in pigeonpea, which is considered to be a quantitatively short-day plant. Genotypes differ in their response to photoperiod (Ikisan, 2023).

The flowers are borne in short racemes. In the world germplasm collections the number of racemes per plant ranged from 6 to 915. Peduncles are (0 - 1.8 cm) long. Pedicels are thin, 7-15 mm long, downy and covered with hairs. Flowers are predominantly yellow. Bracts are small with a thick medium nerve, triangular or ovate-acuminate scales, 1-4 mm long; their margins curve inwards to form a boat-like structure, and enclose 1-3 very young flower buds. The calyx tube is companulate with numerous glandular hairs with bulbous bases, the tube dorsally gibbous, about 5 mm long, with five subequal, narrowly triangular lobes 4-7 mm long. The smaller upper lobes are paired, free or partly connate, and the lower one is the longest. The corolla is highly zygomorphic, papilionaceous, and generally yellow in colour. The petals are imbricate in the bud. The standard petal (vexillum, flat) is erect and spreading, more or less orbicular, 14-22 mm long, 14-20 mm wide, base clawed, biauriculate, with two callosities. Both right and left handed flowers in pigeonpea with regard to contortion of the vexillum petal either to the right or to the left. Wing (aloe) petals are obviate with a straight appear margin, clawed base, asymmetrically biauriculate, 15-20 mm long, 6.7 mm wide, with a callosity. Keel petals are boatshaped, 14-17 mm long, 5-7 mm wide, clawed, entirely split dorsally, ventrally split near the base, left and right lengthwise furrowed, glabrous and more greenish than other petals. Stamens are 10, diadelphous (9+1), 15-18 mm long, with 4-7 mm free parts, flattening towards the base, tapering towards the top, geniculate near the base, the staminal sheath is about 12 mm long. Anthers are ellipsoid, about 1 mm long, dorsifixed and light or dark yellow in colour. Pigeonpea stamens exhibit dimorphism. Of the 10 stamens, four have short filaments and six, including, the odd posterior one, have long filaments. The odd stamesn has a groove for the passage of nectar that is secreted from the base of the

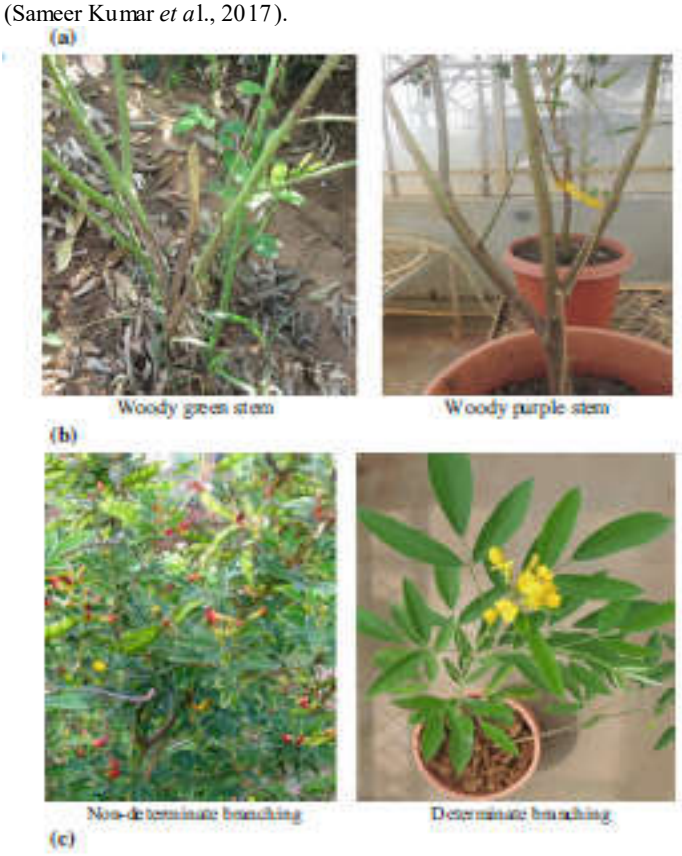
filaments. The long stamens are antisepalous, and the short ones antipetalous. The anther lobes also exhibit dimorphism, those of the shorter stamens have blunt lobes, and the longer ones pointed lobes. The filaments of shorter stamens are thicker than those of the longer growth and development in short stamens is faster than the longer ones. The maturity of short stamens coincides with that of the stigma. The pollen produced by short stamens is used for self fertilization, whereas that produced by long stamens is used for outcrossing. The ovary is superior 5-8 mm long, sub-sessile, since it has a very short stalk, densely pubescent and glandular-punctuate, with 2-9 ovules. The stigma is capitate and glandular papillate. The style is long, filiform, upturned beyond the middle, 10-12 mm long and glabrous (Ikisan, 2023).

Description: When pigeonpea seed is sown under optimal moisture and temperature (29 °C–36 °C), the testa of the seed splits open near the micropyle on the second day. The tip of the radical elongates and emerges from the seed coat. Hypocotyl appears as an arch on the third day and continues to grow upward. The hypocotyl turns light purple. The seedling epicotyl elongates three to seven centi meters before the first trifoliate leaf Emerges. Likewise, the tender seedling grows and gives rise to an erect woody shrub. The plant shows considerable variations in height, ranging from one to four meters with taproots that extend up to two meters into the soil. In most of the types, branching begins from the sixth to the tenth node, *i.e*., from 15 to 20 centi meters above the ground and covers with full-fledged lush green foliage. The comprehensive botanical description of main parts of pigeonpea plant is given below.

Under optimal conditions, root growth starts on second day after sowing. Splitting of the testa takes place near the micropyle and radicle emerges and elongation starts from the seed coat.Cambial activity results in secondary thickening. Pigeonpea root system possesses taproot in central with numerous lateral and secondary branches. The taproot becomes thick and woody. The length and spread of the root system is governed by the varietal characters. The erect types produce deeper and penetrating roots where as the spreading ones have shallower and spreadingroot system. Depending on the varieties, roots may grow deep more than two meters in the soil (Sameer Kumar *et a*l., 2017).

Pigeonpea is nodulated by the cowpea group of rhizobia (*Brady rhizobium* spp.) and forms rhizobia-symbiotic system, mainly on the upper 30 cm of the root system takes active participation. Nodulation starts approximately 15 days after sowing and continues up to 120 days. It declines toward pod filling stage. Meristematic zone anchors the development of nodules. The shape of nodules may be oval, elongate, or spherical, and the size varies from 2 to4 mm. The rhizobia-symbiotic systems play asignificant role in improving the fertility and productivity of low nitrogen (N) soils of arid andsemi-arid regions and in turn act as a biological factory for N. The nodes are connected by the primary vascular tissues organized into strands, and each strand is associated with a ridge on the stem. Starch accumulation will be noticed in xylem parenchyma and medullary raysduring vegetative phase, and during reproductivephase, these will be mobilized for pod development (Sameer Kumar *et al*., 2017).

Fig.1 shows woody stem pigmentation, growth habit type and trifoliate leaf in pigeonpea. The branching pattern in pigeonpea depends on genotype, habitat, and spacing of the plants. Wider spacing may form a bush and at narrow spacing may remain compact and upright. For agronomic purposes, pigeonpea plants can be grouped as compact (erect), semi-spreading (semi-erect), and spreading types. Based on the flowering pattern, it may be determinate or non-determinate **(Fig. 1b)**. The determinate type completes the vegetative phase and thenenters into the reproductive phase. In this type, the apical bud of the main shoot develops into aninflorescence, and the sequence of inflorescence production is basipetal (developing in the direction of base). The non-determinate type shows continuous vegetative and reproductive phases. In this type, the flowering starts at nodes behind the apex and proceeds both acropetally and basipetally. Another group is semi-determinate between the determinate and non-determinate types. It includes late-maturing genotypes wherebranching starts from different angles, but most of the pods are at the upper region of the plant (Sameer Kumar *et a*l., 2017).



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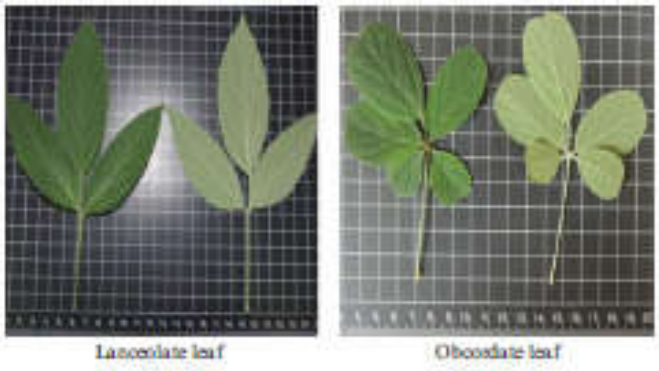


Fig. 1: a) Woody stem of pigeonpea. b) Different growthhabit types in pigeonpea. c) Trifoliate leaf of pigeonpea

The leaf shape in pigeonpea varied form lance- olate to elliptical in shape. The leaflets are borne on a rachis, which is swollen at the base (pulvinus). The leaf sizes vary from 6 to 17 cm in length and are about the same width. The rachis varies from 2 to 4 cm, and the terminal leaflets are 4–8 cm by 2–3.5 cm. The lateral leaflets are slightly smaller. There is genetic variability in the size, shape, and color of the leaves. The leaves are pubescent with more on the lower than the upper surface. The hair types are simple or glandular. The latter are spherical and contain a yellow oily material, probably responsible for the fragrance of pigeonpea plants (Sameer Kumar *et al*., 2017).

In most cultivars, flowers are borne on terminal or auxiliary racemes (4–12 cm) and are carried on a long peduncle **(Fig. 2a)**. The raceme inflorescence forms a terminal panicle in non-determinate types and as corymb-shape bunch in the determinate types. These are grouped together at the end of branches in late types and distributed along the branches in early, medium, and indeterminate types. The number of racemes plant^{-1} in the pigeonpea world collections ranged from 6 to 915. Flowering pro- ceeds acropetally (in the direction of apex) both within the raceme and on the branch. The flowers **(Fig. 2a, b)** are clustered at the top of the peduncle. The peduncles are 1–8 cm long. Flowers are normally yellow, however, the main color of the petals could be ivory (green–yellow group 1), light yellow (yellow group 6D), yellow (yellow–orange group 14A), and orange–yellow (orange–red group 31A). Color of streaks on dorsal side of the vexillum (flag) and second color of the wings and keel petals could be red (red group 45 A) or purple (grayed–purple group 186A) (Royal Horticultural Society). The streaks pattern of second color on the dorsal side of the flag (standard petal) ranges from no/sparse streaks to dense/uniform coverage of streaks **(Fig. 2c).**The bracts **(Fig. 2d)** are small with a thick middle nerve. They are ovate-lanceolate withhairy margins and curved inward to form a boat-like structure to enclose one-to-three young lateral buds. The pedicel is thin, 5–15 mm long, and covered with hair. The flowers are mostly yellow and papilionaceous or completely bisexual and zygomorphic. The calyx is gamosepalous with five lobes. The calyx tube is campanulate (bell-shaped) withnerved teeth. The upper two teeth are sub-connate. The lower three are free and spreading **(Fig. 2e)**. The upper lobes are paired, free or partly free, and the lower one is the longest (Sameer Kumar *et al*., 2017).

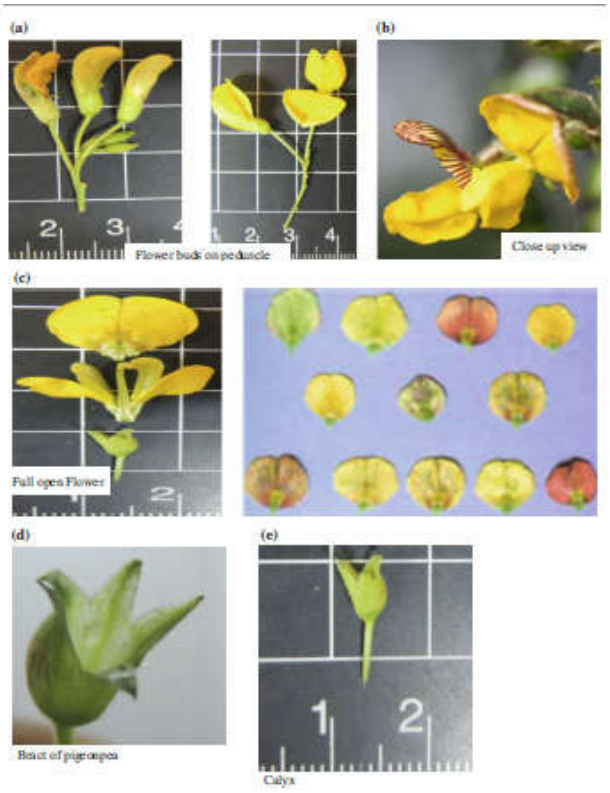


Fig. 2: a) and b) Flower buds and Full bloom flower of pigeonpea. c) Dissected flower and Streak pattern of standard petal. d Bract of pigeonpea. e) Calyx

***Corolla*:** The corolla is zygomorphic (yoke-shaped flowers symmetrical about one plane) and bright yellow. The petals are imbri- cate and of three prominent types; the standard, wings, and a keel. The standard is broad, large, auricled, and erect (Fig. 3a). The wings areobliquely obovate with an incurved claw (Fig. 3b). The keel petals are obtuse (round) incurved and boat shaped (Fig. 3c). The keel covers the androecium (stamens) and gynoecium(female organs) of the flower (Sameer Kumar *et al*., 2017).

***Androecium*:** The two halves of the anthers arejoined by a relatively large, sterile connectivetube that is basi fixed. The anthers are light or dark yellow, dorsi fixed. Of the 10 stamens, fourhave short filaments and six, including a posterior one, have long filaments. The short anthers have blunt lobes and the long ones pointed lobes. The pollen produced by short stamens is generally used for self-fertilization.

***Gynoecium*:** The ovary is superior, subsessile,flattened dorsoventrally along with style **(Fig. 3e**). It has a very short stalk, densely pubescent, and glandular punctate (dotted or pitted) with two to nine ovules, marginal placentation, monocarpellary, and unilocular. The style is long, filiform, upturned beyond the middle region, and glabrous. It is attached to a thickened, incurved, and capitate (swollen) stigma.

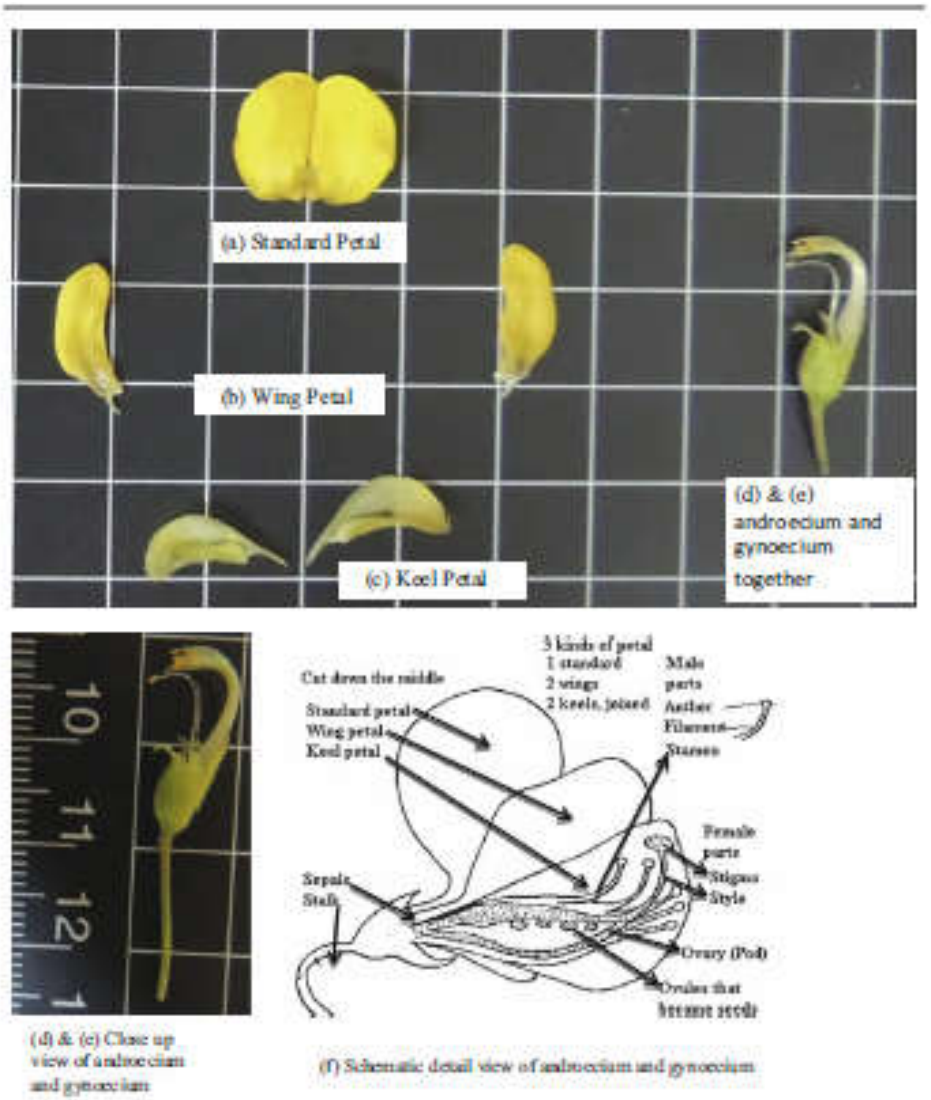


Fig. 3: a) Standard Petal. b) Wing Petal. c) Keel Petal. d) and e) androecium and gynoecium together. d) and e) Close upview of androecium and gynoecium. f) Schematic detail view of androecium and gynoecium

Pigeonpea is anoften cross-pollinated crop ranges from 3 to 40%. In a fully developed bud, anthers surround the stigma and dehisce a day before the flower opens. Anthesis in pigeonpea starts from 06.00 h and continues till 16.00 h. The peak anthesis period recorded is between 09.00 and 10.00 h. The duration of flower opening also depends on the weather and environment. This varies from 6 to 36 h. Fertilization occurs on the day of pollination. The fruit of pigeonpea is a pod. During the first week of anthesis, the endosperm undergoes rapiddevelopment. The nuclei take up a parietal position, forming a large vacuole in the center of the embryo sac. The embryo sac elongates at thechalazal region and forms a haustorium. The haustorium penetrates into the nucellar tissue. This is instrumental in absorbing food material that is used by the developing embryo. In the cotyledons, synthesis of starch and protein starts about 17 days after pollination and continues for14 days. In each raceme, 1–5 pods may mature, rarely up to 10. Pods are of various colors **(Fig. 4);** green, purple, dark purple, or mixed green and purple. The seeds per pod range from two to seven, and sometimes up to nine. The seeds are in separate locules, and thecross-walls develop during the first week after fertilization. The pod wall develops more rapidlythan the young seeds. Seed development is visible 7 days after pollination. A pod is formed 15–20 days after fertilization. Seeds reach physiological maturity in 30 days and are ready for harvest at lower moisture content in 40 days. There is little orno shattering of mature pods in the field (Sameer Kumar *et al.,* 2017).

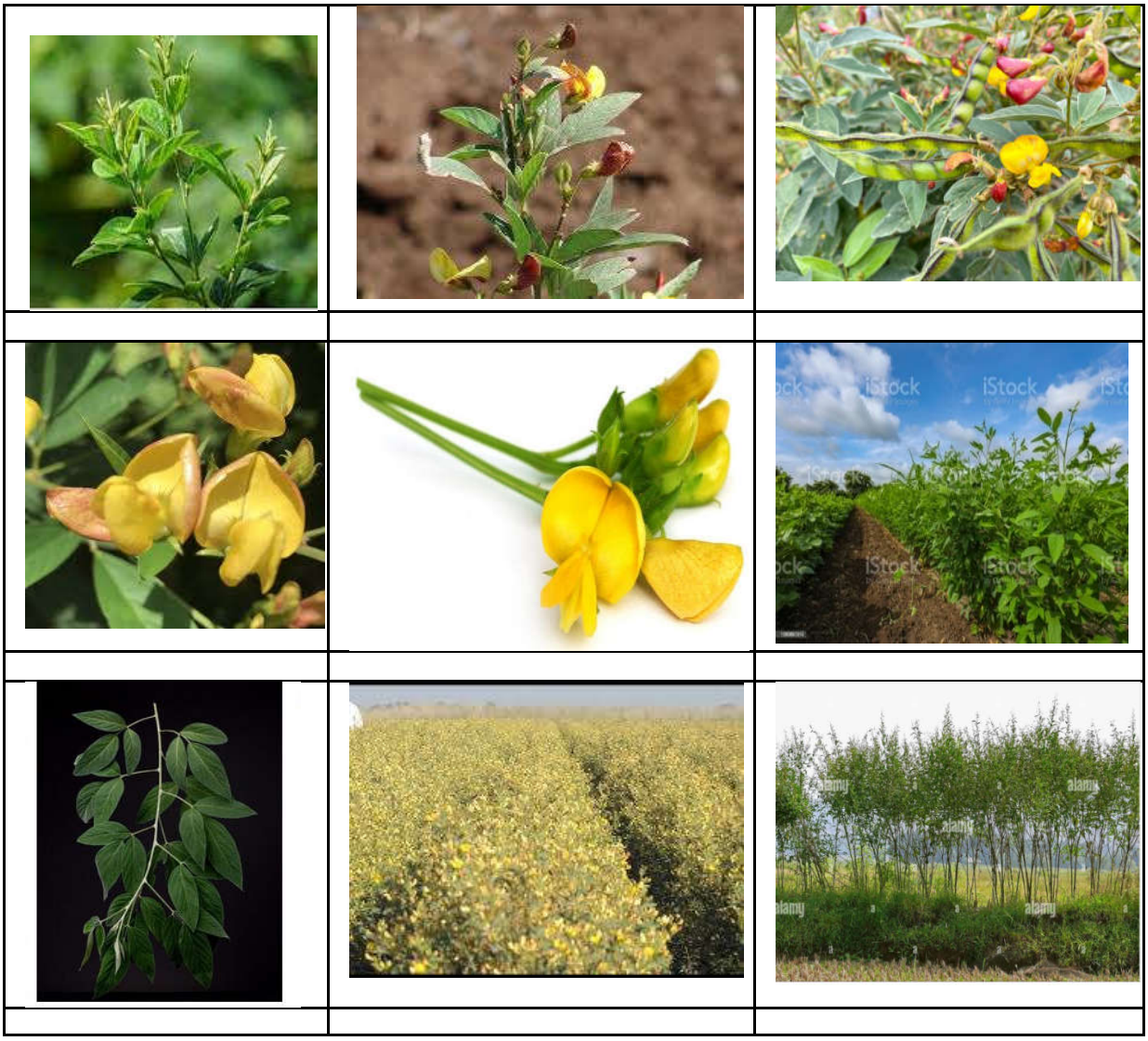
Seeds are round or lens shaped, the color of the seed coat varies from dirty white to silver white, light brown to chestnut brown, dark mottled brown and pinkish black, and the cotyledons are yellow colored (**Fig 5**). The seed is orthodox and can be stored for long term under frozen

condition. The seed coat color is relatively trivial character, but it is a consistent feature of pigeonpea evolution that lighter colored testae have consistently been favored in selection. This is frequently the case even when the testa is removed as in the preparation of split peas (Sameer Kumar *et al.,* 2017).

Fig. 4: Pigeonpea pods are of various colors and sizes

Fig. 5: Different colors andsizes of pigeonpea seeds

C. cajan is a perennial shrub, stem: erect, 1–3.5 m., branchlets green to gray with pubescent. Leaf: stipulate, pinnately 3-foliolate, ovate to lanceolate, abaxial densely pubescent with inconspicuous yellow glands, adaxial pubescent, apex acute or acuminate; petiole 1–5 cm long. Inflorescence: raceme 3.5–8 cm long; peduncle 1.5–4 cm; bracts ovate or ovate-elliptic. Flowers: calyx campanulate, 5–7 mm, green, pubescent; corolla papilionaceous form, yellow, standard suborbicular with auricle, wings obovate with auricle; keel apex obtuse. Ovary: pubescent; style slender, linear, glabrous; stigma capitate, ovule numerous. Fruit: Legume, oblong or linear-oblong. Seeds: subspherical, 3–6 mm in diameter, gray with brown spots (Tungmunnithum and Hano, 2020) (Fig. 6).



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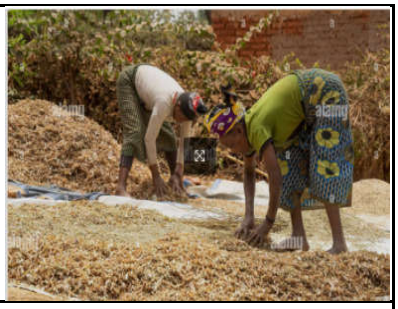

Fig. 6: Botanical Description

A young pod of about one centimetre length is visible after about a week. Such pods grow rapidly and achieve their full length in about 25 day. Pegion pea is an erect shrub. The plant show considerable variations in height, ranging from 1-4 meters. In most of the types branching begins from the sixth to the tenth node, *i.e*. from 15-20 centi meters above the ground. The botanical description of main parts of pigeon pea plant is given below:

Root system of pigeon pea consists of a central tap root with numerous lateral and secondary branches. The length of the lateral roots differs with the variety; usually tall, upright varieties produce longer and more deeply penetrating roots, whereas spreading types produce shallower, more spreading and deeper roots. Leaves are trifoliately compound; central leaflet longer than lateral ones. The leaflets are entire and densely silky on the lower surface. Stipules are small; lamina hairy with the under surface grayish due to dense hairs. The total length of the leaf, as also the size, shape and texture of leaflets also differ with the varieties. The inflorescence is an axillary raceme often forming a terminal panicle. The size of inflorescence varies in different types. The flowers are distinctly papallionaceous. In the late maturing varieties, the flowers are usually grouped together at the ends of the branches, but in early maturing varieties, the flowers are produced at several points along the branches. Usually flowers open at a time on the same inflorescence, but the process of flowering continuous in each plant almost up to the time of harvest. The flowers are self pollinated, pollination takes place before the flowers open. Cross fertilization may also occur to some extent. The fruit of pigeon pea is a pod. These vary in length, width and nature of markings. The length of pod varies from 5 to 10 centimetre, width from 0.6 to 0.9 centimetre. The pods vary in color from green to dark brown. In some types, they are broad and pendant with their tips pointing downwards while in others they are quiet erect. The seed in the pod may vary in number, but there are usually four to five in each pod in late maturing varieties and two to three in early maturing varieties. Seeds are differing in great deal in size, shape and color. Seeds are round or lens shaped, the color of the seeds coat being dirty white to silver white, light brown to chestnut brown, dark mottled brown and pinkish black and the cotyledons yellow colored (Shirsath *et al.,* 2014).

The growth habit is predominantly indeterminate but some genotypes show determinate growth. The branching pattern varies from erect to spreading. Pigeonpea is a predominantly photoperiod sensitive short day plant and exhibit wide variation in days to flower among genotypes (Singh *et al.,* 2016). Pigeonpea has deep tap roots which extend vertically up to 2 meters and spread horizontally through lateral roots. The Root is well developed in upper 60 cm soil profile. The root roliferation is correlated with the duration of crop and growth habit. An angular and woody stem originates from three ribs starting from the base of each petiole. Starch present in xylem parenchyma and the medullary rays are mobilized to the pod and seed. Branching pattern (compact or semi spreading or spreading) is determined by the genetic constitution. Pigeonpea plant show great plasticity by adjusting its branching behavior depending on the available space between plants. Leaves are spirally arranged, pinnately trifoliate and lanceolate to oblong in shape. The terminal petiole is highly variable and attains a length of 10-20 mm while the lateral petiole is usually 2-3 mm long. Leaf size varies from 6-17 cm; lateral leaflets are smaller than the terminal leaflet which varies from 4-8 cm. Leaves are pubescent due to the presence of simple or glandular hairs. Figure 1 represents piegonpea plant. The inflorescence is raceme which contain up to ten flowers per panicle and usually two flowers open at a time on a single inflorescence. Flowering is acropetal (in the direction of apex), both within the raceme and on the branch. A single plant can hold up to 915 racemes. The terminal or auxillary raceme is usually 4-12 cm long. In most of the long duration genotypes the racemes are grouped together at the end of branches, while in early, medium and indeterminate genotypes the racemes are distributed along the branches. The flowers are bisexual, zygomorphic and predominantly yellow. More flowers are seen on the top of the peduncle. Small flowers, normally about 2 cm in length are borne on thin, hairy pedicel. The flower size is very small in wild species. Flower size is correlated with seed size. The calyx is gamosepalous with five lobes. The corolla is zygomorphic and petals are imbricate. The largest, auricled and erect petal forms the standard; two lateral, obliquely obovate and incurved clawed petals are known as wings; the two innermost obtuse, incurved and boat shaped petals are fused to form the keel to protect the stigma and style. The standard and the wings are generally of bright yellow colour, whereas keel is greenish yellow. A lot of variation in petal colour can be observed in the germplasm collections. The androecium has 10 stamens bunched into two groups (diadelphous) of 9 and a single free stamen that is attached at the base of androecium. The grouped filaments are fused at the base and cover the gynaecium, while the upper part is free and bear uniform anther of about 1 mm length. Six filaments are long, while the remaining four stamens including the free posterior have short filaments which are supposed to encourage self fertilization. The dorsifixed anthers, consisting of two halves, are pale yellow to yellow in colour. The placement of subsessile, dorsoventrally flattened, punctuates and densely hairy ovary is superior. The long, filliform and glabrous style of gynaecium bears a thick, incurved and capitate stigma. The short stalked glandular ovary is unilocular and monocarpellary bearing 2-9 ovules with marginal placenta. P od size is highly variable. The vegetable types have long pods with 4-7 seeds per pod. Depending on the genotype, 2-7 seeds develop in each pod. Seeds are produced in separate locules and the pod may be highly constricted in certain genotypes giving beaded appearance. Pod colour varies from green to dark purple with varying degrees of brownish or purplish streaks. Pod is generally pubescent with varying degrees of simple or glandular hairs. Pod shattering at maturity is uncommon in cultivated varieties as it is an undesirable trait for grain harvest. The germplasm of pigeonpea show a variety of seed colour (white, creamy white, silvery, fawn, dark purple which appear as black, pink, red to purple, straw, brown) with or without specks and blotches of different shades. The 100 gram seed weight varies considerably from 5 to 22 g in germplasm materials. The 100 seed weight of short duration cultivated varieties are low (generally 6-8 grams) as compared to long duration varieties (9-13 g). Seed weight of medium duration varieties lie between early and late maturing varieties. The 100 seed weight of vegetable types may reach up to 22 g. Seed do not show dormancy and germination is hypogeal (Singh *et al*., 2016).

Pigeonpea is an erect perennial shrub much branched. Pigeonpea has a tap root system. Stem is pubescent. It has compound leaf, pinnately compound, trifoliate, leaflet elliptical to lanceolate, acute. Inflorescnce is a terminal panicle. Flower is zygomorphic, complete, hermaphrodite and paplinaceous. Calyx is tubuler, sepal 5, gamosepalous. Corolla bright yellow in color, papilinaceous composed three types of petal viz. standard, wing and keel, aestivation vexillary. Androecium cosists of stamen 10, diadelphous (9)+1. Gynoecium cosists of carpel one, ovary superior, placentation marginal. Fruit is a pod, linear oblong. Seed is rounded, compressed, non-endospermic (Mia, 2016). Pigeonpea is an erect, short-lived perennial leguminous shrub that usually grows to a height of about 1-2 m, but can reach up to 2-5 m high. It quickly develops a deep (2 m depth) poisonous taproot. The stems are woody at the base, angular and branching. The leaves are alternate and trifoliate. The leaflets are oblong and lanceolate, 5-10 cm long x 2-4 cm wide. Leaves and stems are pubescent. The flowers (5 to 10) are grouped in racemes at the apices or axils of the branches. The flowers are papilionaceous and generally yellow in colour. They can also be striated with purple streaks. The corolla is about 2-2.5 cm. The fruit is a flat, straight and pubescent pod, 5-9 cm long x 12-13 mm wide. It contains 2-9 seeds that are brown, red or black in colour, small and sometimes hard-coated (Heuzé *et al*., 2017).

Red gram [*Cajanus cajan* (L.) Millsp.] belongs to family Leguminosae. Numerous nodules are present on roots, these nodules contain *Rhizobium* bacteria, which fixes atmospheric nitrogen. The flowers are self-pollinated but cross-fertilization may also occur to some extent. The fruit of the Red gram is a pod. Seeds are round or lens shaped. Numerous species of *Cajanus* are known, differing in height, habit, time of maturity, colour, size and shape of pods and seeds. All these cultivated types belong to two categories:

i) *Cajanus cajan* var. *bicolor*: This group includes late maturing varieties, having tall bushy plants and bear flowers at the end of the branches. The pods are relatively longer and contain 4-5 seeds.

ii) *Cajanus cajan* var. *flavus*: This group includes early maturing varieties, having smaller plants and flowers at several points along the branches. The pods are also shorter which bear 2-3 seeds (Agropedia, 2009; Bhat *et al*., 2019).

Pigeonpea is a perennial shrub in the family Fabaceae grown for its edible pods and seeds. Pigeonpea is a highly branched shrub with a woody base, slender stems and trifoliate leaves. The plant leaflets are oblong or elliptical in shape and the leaves are alternate and arranged spirally on the stems. The plant usually produces yellow flowers, but they can be yellow with streaks of purple or red. The flowers are produced on racemes of 5–10 flowers. The seed pods are flat and either straight or sickle shaped and measure 5–9 cm (2–3.5 in) in length. Each pod can contain between 2 and 9 seeds which can be white, cream, brown, yellow, purple or black or mottled with any combination of these colors. Pigeonpea can reach 0.5–4.0 m (1.6–13.1 ft) in height and is usually grown as an annual, harvested after one season. It may also be referred to as red gram or congo pea and originates from India (Plantvillage, 2023). Arhar is grown as annual but tur varieties grow like perennial plants. The plants are bushy, densely branched having a height of about 150 cm to 300 cm depending upon type and management practices. It bears tap root with well developed lateral or secondary roots that consist nodules on them like any other leguminous plants. The stem is strong, woody, round but slightly ridged during active growth period having numerous branches. The leaves are pinnately compound and trifoliate with oblong, lanceolate leaflets. The flowers are arranged in racemes order. They open in the evening and remain open whole night and upto noon time of the text day. The structure of flower, nature of pollination, pod setting and pod characters are similar to that of any other papilionaceous plants (Google, 2023).

Floral biology/ Reproduction: The basic floral arrangement in pigeonpea is typical of fabaceae family exhibiting terminal or auxiliary raceme inflorescence. The panicles are either terminal, as in the case of indeterminate types, or corymb-shape bunch in the determinate types. The inflorescence has a long peduncle and flowers are concentrated at the end of branches in late maturing and determinate genotypes, whereas flowers are borne along the branches in most of the early, medium and non-determinate genotypes. In general, flowering starts from the base and proceeds acropetally towards the apex both within the raceme and on the branch. In some cases the first flower appears in the middle of the flowering branch and then move, in either directions. The flowers are papileonaceous (completely bisexual and zygomorphic). Generally the stigma of a mature flower bud is surrounded by anthers which dehisce a day before the opening of flower **(Fig. 7).** On a bright sunny day, anthesis starts in the early morning, peaks at 9-10 AM and continues till 4 PM. The duration of flower opening varies from 6 to 36 hours depending upon the climate and environmental conditions (Singh et al., 2016). Self pollination is the rule in Red gram and natural crossing extents up to 65 per cent. Therefore it is also known as often cross pollinated crop. For selfing mature flower buds are to be covered with paper bags for one or two days. For crossing hand emasculation followed by artifical cross pollination is essential. Emasculation should be done in the previous day evening and the emasculated buds are protected by covers. Early morning on the next day, pollination is done using pollen collected from the protected flowers of the selected male parents (**TNAU, 2015**). Pigeonpea possesses cleistogamous flowers which favour self pollination. However, 14-20 % natural outcrossing was observed in pigeonpea. Pigeonpea is often-cross pollinated through entomophily. Self-pollination occurs in the bud before the flowers open, while cross pollination is effected with the help of insects. Low frequency of self fertilization when flower buds were pollinated with foreign pollen without emasculation. It was observed that anthers dehisce during the bud stage but they start germinating 24-28 hours after dehiscence when flowers start to wither. Pigeonpea is protogynous and the stigma becomes receptive 68 hours before anthesis and stigma receptivity is maintained even 20 hours post anthesis. Fertilization occurs within 48-54 hours after pollination. Several factors like flowering habit of a genotype, presence of insect population, temperature, humidity, wind velocity and wind direction affect natural outcrossing at a given time and space.

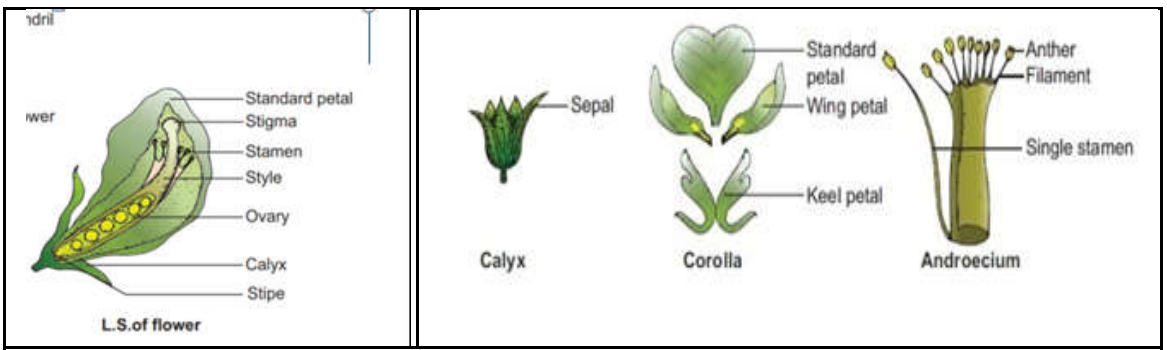

Fig. 7. Red gram flower parts

Most important pollinators are *Apis* spp . (*A.dorsata, A.laboriosa, A. florae* and *A. cerana*), *Megachile* spp. (*M. lanata* and *M. flavipes*) and *Xylocopa* spp. The rate of outcrossing varies from place to place depending on the extent of pollinator bees and climatic conditions. Outcrossing ranged from 20 to 70 % at various locations. High rate of out crossing in pigeonpea creates problems in the maintenance of varietal purity (Singh *et al.,* 2016).

GENETICS AND CYTOGENETICS

Genome sequence: The pigeonpea is the first seed legume plant to have its complete genome sequenced. The sequencing was first accomplished by a group of 31 Indian scientists from the Indian Council of Agricultural Research. It was then followed by a global research partnership, the International Initiative for Pigeon pea Genomics (IIPG), led by ICRISAT with partners such as BGI–Shenzhen (China), US research laboratories like University of Georgia, University of California-Davis, Cold Spring Harbor Laboratory, and National Centre for Genome Resources, European research institutes like the National University of Ireland Galway. It also received support from the CGIAR Generation Challenge Program, US National Science Foundation and in-kind contribution from the collaborating research institutes. It is the first time that a CGIAR-supported research center such as ICRISAT led the genome sequencing of a food crop. There was a controversy over this as CGIAR did not partner with a national team of scientists and broke away from the Indo American Knowledge Initiative to start their own sequencing in parallel. The 616 mature microRNAs and 3919 long non-coding RNAs sequences were identified in the genome of pigeon pea (Wikipedia, 2023).

Genetics: For effective plant breeding, a good understanding of various genetic systems controlling important qualitative and quantitative characters is essential. In comparison to many field crops, genetic research in pigeonpea is rather limited and fragmentary. For most qualitative characters, there are large differences in the reported traits, and sometimes the observed phenotypic segregation ratios cannot be interpreted confidently. Also, in most cases only a limited number of crosses have been studied, making it difficult to generate information on their allelic relationships. The genetic interpretations in such studies are also greatly influenced by parental materials used in the study; therefore, any generalization about this information will be unrealistic. Both additive and non-additive gene actions of various degrees for yield and other characters have been reported by several pigeonpea researchers.

Genetics of Pod color: Studied variation for pod color **(Fig.8)** and reported an F_2 ratio of 3 maroon blotched:1 light tinted. It was reported that streaked pod color was dominant over green pod color, and that a single gene was responsible for streaked pods. A dihybrid F_2 segregation(9 dark:3 maroon blotched:4 green) was reported. An F_2 ratio of 15 blotched:1 green was observed. The color developmentin unripe pigeonpea pods was due to the interaction of four genes.

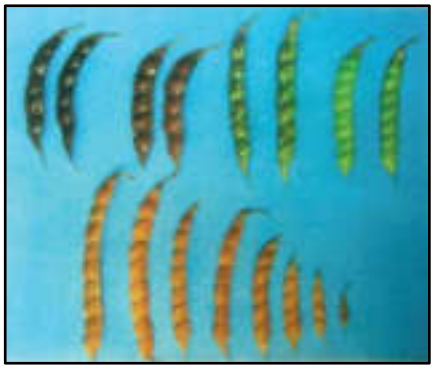

Fig. 8. Range in pod length and color.

The genetics of seed color in pigeonpea is also complicated. The variation in seed coat color **(Fig.9)** can be controlled by some basic, inhibitory genes and modifier genes, and their interactions.

Fig. 9. Seed color variation

GENETIC DIVERSITY

There are two major growth patterns in pigeonpea; the determinate types **(**Fig.10**)** have pods in clusters at the top of the canopy.

Fig. 10: Growth patterns in pigeonpea – determinate (left) and non-determinate (right)

Pods are of various colors ; green, purple, dark purple, or mixed green and purple. The seeds perpod range from two to seven, and sometimes up to nine. Seeds are round or lens shaped, the color of the seed coat varies from dirty white to silver white, light brown to chestnut brown, dark mottled brown and pinkish black, and the cotyledons are yellow colored (**Fig. 11-14**).

Fig. 11. Variability for pod color of pigeonpea

Fig. 12. Variability for immature seeds color, shape and size of pigeonpea

Fig.13. Varibilyfor pigeonpea seeds color, shape and size

Fig.14. Variabilityfor Pigeonpea splits /Tur dal

Pigeonpea is an important grain legume crop grown in tropical and subtropical regions of the world. Though pigeonpea has a narrow genetic base, vast genetic resources are available for its genetic improvement. Evaluation of small subsets, such as core (10% of the whole collection) and mini-core collections (about 1% of the entire collection), has resulted in the identification of promising diverse sources for agronomic and nutrition-related traits as well as resistance/tolerance to important biotic/abiotic stresses for use in pigeonpea improvement programmes. Wild relatives of pigeonpea are the reservoir of many useful genes, including resistance/tolerance to diseases, insect pests and drought and good agronomic traits, and also have contributed to the development of cytoplasmic male sterility systems for pigeonpea improvement. Availability of genomic resources, including the genome sequence, will facilitate greater use of germplasm to develop new cultivars with a broad genetic base (Singh *et al.,* 2013). Evaluation of small-sized subsets such as core (10% of whole collection) and mini-core (about 1% of the entire collection), developed at the ICRISAT, has resulted in identification of promising diverse sources for agronomic and nutrition-related traits, as well as resistance to major biotic and abiotic stresses for use in pigeonpea improvement programs. Wild relatives of pigeonpea are the reservoir of several useful genes, including resistance to diseases, insect pests and drought, as well as good agronomic traits, and have contributed to the development of cytoplasmic male sterility systems for pigeonpea improvement. Availability of genomic resources, including the genome sequence, will facilitate greater use of germplasm to develop new cultivars with a wider genetic base (Singh *et al.,* 2013).

Pigeonpea, a diploid (2n = 22) legume crop with a genome size of 852 Mbp, serves as an important source of human dietary protein especially in South East Asian and African regions. In this study, the draft chloroplast genomes of *Cajanus cajan* and *Cajanus scarabaeoides* (L.) Thouars were generated. *Cajanus scarabaeoides* is an important species of the *Cajanus* gene pool and has also been used for developing promising CMS system by different groups. A male sterile genotype harboring the *C. scarabaeoides* cytoplasm was used for sequencing the plastid genome. The cp genome of *C. cajan* is 152,242bp long, having a quadripartite structure with LSC of 83,455 bp and SSC of 17,871 bp separated by IRs of 25,398 bp. Similarly, the cp genome of *C. scarabaeoides* is 152,201bp long, having a quadripartite structure in which IRs of 25,402 bp length separates 83,423 bp of LSC and 17,854 bp of SSC. The pigeonpea cp genome contains 116 unique genes, including 30 tRNA, 4 rRNA, 78 predicted protein coding genes and 5 pseudogenes. A 50 kb inversion was observed in the LSC region of pigeonpea cp genome, consistent with other legumes. Comparison of cp genome with other legumes revealed the contraction of IR boundaries due to the absence of *rps19* gene in the IR region. Chloroplast SSRs were mined and a total of 280 and 292 cpSSRs were identified in *C. scarabaeoides* and *C. cajan* respectively. RNA editing was observed at 37 sites in both *C. scarabaeoides* and *C. cajan*, with maximum occurrence in the *ndh* genes. The pigeonpea cp genome sequence would be beneficial in providing informative molecular markers which can be utilized for genetic diversity analysis and aid in understanding the plant systematics studies among major grain legumes (Kaila *et al.,* 2016).

Pigeonpea is grown in differtent agroclimatic regions of India on a variety of soil and diverse physiographic situations. Wide range of variability has been documented for various botanical and agronomic traits viz. plant growth habit, plant height, days to 50% flowering, days to physiological maturity, branching pattern, number of primary branches, branching length, crop duration, photoperiod sensitivity, number of pods per plant, pod length, number of seeds per pod, flower number, flower colour, inflorescence size, pod colour and seed size, seed color, taste, pod dehiscence, seed dormancy, seedling vigour, habitat preferences and biochemical constitution. Most of the pigeonpea genotypes are photo-thermo sensitive and a few behave like photoperiod insensitive. Therefore, days to 50% flowering and physiological maturity do not correspond across the North-South region. Grossly, as mentioned earlier Indian pigeonpea genotypes have been classified into distinct maturity groups i.e. early, mid-early, medium and late. Vegetable types (tall, large flower, bigger pods and seed) are distributed in the North East Hill region, Gujarat, Karnataka, Chhattisgarh and Andhra Pradesh. Genotypes with non-branching habit (single stem) have also been identified among collections from Madhya Pradesh and other parts of Central and Northern India. Large amount of variability exists for growth habit (determinate and non-determinate) and branching pattern (erect to spreading). Flower colour is predominantly yellow among the accessions of grain type, while purple flower is predominant among the vegetable types collected from Chhattisgarh and Tripura. Wide scale variation is observed for seed size and seed colour among the germplasm collections. Considerable diversity was observed in pigeonpea germplasm accessions of Bastar Region. Forty nine pigeonpea genotypes originating from different eco-geographical regions exhibited considerable genetic diversity for 12 characters. Variability for SSR alleles was shown among 36 pigeonpea lines with varying degrees of resistance against Fusarium wilt (Singh *et al.,* 2016).

BREEDING

Germplasm: There are 13,771 accessions of pigeonpea conserved at ICRISAT. ICRISAT has developed a composite collection of pigeonpea containing 1000 accessions representative of the diversity of all germplasm collection. Furthermore, a mini core collection comprising 146 accessions (Singh *et al.,* 2016).:

Breeding Objectives: In the pre independence time all cultivated pigeonpea genotypes were landraces or local types which were either long duration type (>180 days) in the Northern plains or medium late in the central and southern zone. With the creation of AICPIP, pigeonpea breeding efforts were initiated simultaneously at 31 locations in different agroclimatic zones of the country for developing early, medium and long duration varieties suitable for different zones. Multilocation testing of genotypes for yield and biotic stresses paved the way for the identification of more stable varieties. Varieties were bred either through hybridization followed by pure line selection or by selecting desirable plants from the heterogeneous germplasm followed by pure line selection. During this time a need for reducing the crop duration was felt. UPAS120 was the first high yielding short duration (120-140 days) crop released in 1976. ICRISAT has played an important role in the introduction of medium and short duration varieties for the Central and Southern zone. About 40% of the varieties bred so far have evolved through selections made from landraces or heterogeneous population or spontaneous mutations. Vishakha 1 (TT 6) was the first variety developed through mutation breeding by BARC. Subsequently, three more varieties were developed through mutation breeding. Inspite of long and continued breeding efforts, the average productivity of pigeonpea has not increased significantly in the last five decades (Singh *et al.,* 2016).

Heterosis Breeding: Existence of high natural out crossing and identification of genetic male sterility offered new avenues for expoiting heterosis leading to the initiation of ICAR sponsored programme on "Promotion of Hybrids in Selected Crops" in 1989. Heterosis breeding was tried for breaking the yield barrier through exploitation of hybrid vigour. Initially genetic male sterility (GMS) was utilised for the development of hybrids and, as a result an early maturing hybrid ICPH 8, which showed more than 40 % superiority over the best check UPAS 120, was released for commercial cultivation (Saxena *et al.,* 1992). Subsequently, 5 more GMS based hybrids were released for general cultivation. Though ICPH 8 and other hybrids had substantial yield advantage, they could not survive due to difficulties in seed production associted with GMS system that led to very high cost of hybrid seed (Saxena *et al*., 2010b). In order to overcome the lacuna of GMS, cytoplasmic genetic male sterility (CGMS) system was adopted for the production of hybrid seed. The hybrid programme was further strengthened through the National Agricultural Technology Project (NATP) in 1998 and the Integrated Scheme on Oilseeds, Pulses, Oilpalm and Maize (ISOPOM) in 2005. In 2004, the first CMS based medium duration hybrid GTH 1 was released in India (Varshney et al., 2010). Subsequently, using A4 cytoplam a medium duration hybrid RVICPH 2671 was released in Madhya Pradesh (Singh *et al*., 2016).

Major Traits of Interest and Priorities in Breeding: The important agronomic and yield attributing traits of pigeonpea for enhancing productivity are: days to 50% flowering, days to 75 % maturity, plant height, plant type, branching pattern, number of pods per plant, number of seeds per pod, pod length, number of primary branches, number of secondary branches, branching length, 100 seed weight, seed yield per plant and seed yield per plot. Tolerance against biotic and abiotic stresses is an important parameter for selection. The objectives of the breeding programme depend on the local needs of the cultivators, prevailing cropping system, climatic condition and constraints of production. Though breeding objectives vary in different agroclimatic zones as per the local needs, varieties are generally bred keeping in view appropriate maturity and enhanced harvest index through manipulating plant architecture for different cropping situations. Attention is also given to induce photo insensitivity, enhancing yield and ensure stability of the released varieties by incorporating resistance against Fusarium wilt, SMD and Phytopthora blight and tolerance against abiotic stresses like drought, heat and cold. Identification of potential donors and incorporation of disease resistance into newly developed cultivars remains the most sustainable, ecomically attractive and ecofriendly strategy to reduce yield losses in crop plants. With the aim of identifing the Fusarium wilt resistant sources, multi-location and multi-year screening of genotypes led to the identification of promising wilt resistance genotypes in pigeonpea like IPA 16 F, IPA 8 F, IPA 9 F and IPA 12 F. Several varieties have been developed in pigeonpea like ICP 8863, ICPL 87119, BDN 1, BDN 2, BSMR 736, IPA 203 which are known to exhibit resistance against Fusarium wilt (Singh *et al*., 2016).

Pigeonpea is a key source of some of the vital nutritive components such as proteins, carbohydrates, vitamins, and minerals. Its split dehusked grains form an important portion of diet when consumed with cereals, especially among the small and marginal farmers who earn their livelihoods from subsistence agriculture. Pigeonpea is blessed with wide genetic variability for maturity duration, and this allows its cultivation in diverse environments and cropping systems including sole and intercropping. For sustainable production of pigeonpea, it is imperative that some high-yielding cultivars are developed and the crop is protected from various biotic and abiotic yield reducers. The conventional plant breeding approaches have been used in the past to breed new disease-resistant varieties; but breaking the yield plateau still needs focused efforts and deployment of new technologies is warranted. The expansion of genetic diversity using wild species, adoption of hybrid technology, application of genomic tools, and improvement of seed systems are the key identified areas that should be addressed on priority (Sultana *et al*., 2021).

Some of the important varieties of pigeon pea released in India for the different maturity groups are given in **Tables 5- 8** (Shirsath et al., 2014).

Table 5. Extra-short-duration varieties of pigeonpea released in India:

Variety	Maturity(days)	Characteristics
UPAS-120	120-140	Nondeterminate, yield 1.5-1.8 t ha
Pant A3	120-130	Semierrect, determinate, dwarf, 3-4 seeds/ pod
Prabhat	110-120	Determinate, dwarf, clustered fruiting, yield 1.2-1.5 t/ha
ICPL 87 (Pragati)	120-130	Determinate, 10.5 g test weight, brown seeded, yield 2.5-3.0 t ha
ICPL 151 (Jagriti)	120-130	Determinate, 10.5 g test weight, cream color, yield 2.5-3.0 t ha

Table 6 :Short-duration varieties of pigeonpea released in India:

Variety	Maturity (days)	Characteristics
Pusa Ageti	150-160	Dwarf, determinate, bold seeded 9 g test wt., 4-5 seeds/pod, yield 2.5 t ha
T21	150-170	Semi-spreading, indeterminate branching, Small seeded, 7 g (100 seed)
HY2	140-150	Semi-erect tall, purple stem, white seed, bold, yield 2.5-2.7 t ha
Pusa 84	140-150	Medium tall, semi-spreading, 3-4/pod, 7.5 g test weight, brown seeded.
C01	135-140	Photoinsensitive, brown seeded, 7 g test weight, average yield 1.5 t ha-1.

Table 7: Medium-duration varieties of pigeonpea released in India:

Variety	Maturity (days)	Characteristics
HY 1	160-170	Spreading, purple stem, white seed, yield1.9-2 t ha average 1.2-1.5 t ha
HY 3A	160-170	Erect tall, green stem, white bold seeded, test wt. 18-20 g yield 3.0-4.0 t ha
HY 5	160-170	Semi-erect, purple stem, medium height (170 cm) , brown seeded,
AS 71-37	165-195	Medium tall (172-194 cm),potential yield 3.0 t ha, ave. 1.65 t ha
BDN 1	160-179	Semi-spreading, wilt resistant height (200-220 cm)
S20	180-190	Semi-compact, Potential yield 2.5 t ha average yield 1.7 t ha

Table 8: Late-duration varieties of pigaonpaa released in India

Variety	(days)	Characteristics
C11	200-220	Medium tall, profuse branching, spreading, brown seed,
Bahar	220-240	Compact, semi-erect plant,brown round, 4-5 seeds/pod- yield 3 t ha
Laxmi	180-220	Perennial, semi-spreading,field tolerant to wilt,potential yield 2 t ha
Gwalior 3	270>	Tall 250-300 cm, spreading, light brown seed, 7-8 g (100 seed)

As we know, red gram is one of the most important crops, so many of the new varieties for different environmental conditions, maturity periods, hybrids. Something mostly cultivated short duration high yielding crops as rabi crops. Short-duration crops take approx 130-180 days. Longer duration crops take up to 240 – 300 days (Singh, 2022**):**

Hybrid Varieties: ICPH 8, COH-1, COH-2, PPH 4, etc.
Short varieties: BDN-1, CO-3, Prabhat, Pusa Ageti, Pusa 74, Pusa 84, etc
Medium Varieties: Laxmi, Mukta, etc…
Late Varieties: Bahar, Gwalior-3, etc.
Red Gram Varieties (Krishijagran, 2023**):**
Medium duration: LRG-41, ICP-8863, ICPL-332, ICPL-87119, MRG-66, ICPL-85063, WRG-27, PRG-158, MRG-1004, WRG-53, WRG-65, TDRG-4, ICPH-2740 (hybrid)
Short duration: ICPL-84031 (Durga), ICPL-85010 and CORG-9701, PRG176
Wilt resistant varieties (hybrid): ICPL-87119, ICP-8863, WRG-65, TDRG-4, ICPH-2740

State-wise recommended Varieties (DPD, 2023).

Andhra Pradesh: Laxmi, LRG-41, LRG-38, WRG-27, WRG-53, Bahar, Pusa-9, NDA 1, WRG 65, Surya (MRG 1004)
Bihar: MA-6, Ajad, DA-11, IPA-203, Bahar, Pusa-9, Narendra Arhar-2
Madhya Pradesh: JKM-189, TJT-501, JKM-7, TT-401, BSMR-175, ICPL-87119, BSMR-736
Chhattisgarh: Rajiv Lochan, MA-3, ICPL-87119, Vipula, BSMR-853, Gujarat GT-100, GT-101, Banas, BDN-2, BSMR-853, AGT 2
Haryana: Paras, Pusa-992, UPAS-120, AL-201, Manak, Pusa-855, PAU-881
Karnataka: Vamban-3, CORG-9701, ICPL-84031, BRG-2, Maruti (ICP-8863), WRP-1, Asha (ICPL 87119), TS-3, KM 7

John Spence, a botanist and politician from Trinidad and Tobago, developed several varieties of dwarf pigeon peas which can be harvested by machine, instead of by hand (Wikipedia, 2023).

The Improved Vegetable Varieties: The three Pigeon pea varieties, Kudrat 3, Chamatkar, Karishma were developed from Asha and Malviya. Kudrat *3* is a perennial variety while the other two are annuals. The number of pods per plant in cases of Kudrat 3, Chamatkar and Karishma are 500-1000, 400-600 and 450-650 respectively while the yield per acre is 12-15 quintals, 10-12 quintals and 10-12 quintals respectively. These varieties possess bold seeds, robust stem and more number of pods per plant (Raghuwansi, 2021).

In southern India farmers grow the large-seeded lines Hy 3C and TTB 6, and there are other tribal areas, particularly in the hills, where large seeded landraces are traditionally grown. An example is ICP 7035 (Fig.15), which has large and sweet seeds and a high level of disease resistance. Scientists at ICRISAT have bred some large-seeded lines such as ICPL 87091, which also have a good yield potential. In selection, earliness in maturity is a character considered appropriate for vegetable pigeonpea, although some medium maturing lines have performed well, and some late maturing large seeded genotypes can be grown for a few years as a hedge around or in gardens.

There are also some early maturing cultivars that continue to produce pods for a long time and can, therefore, produce more than one crop in a year, of which ICPL 87091 and ICPL 87 (Fig. 16) are good examples. In a survey conducted in Gujarat state of India, where immature pigeonpea seeds is a popular vegetable, it was observed that in spite of extensive cultivation of a green podded pigeonpea variety, T 15-15, the rural consumers preferred cultivars that had purple streaks on the pod surface. On the contrary, city consumers preferred fresh pods that were green in color (Fig.17). In another consumer survey conducted, cultivar ICP 7979 was found to be the best because it had good taste, green colored pods and was easy to shell.

Fig. 15: ICP 7035 plant and pods.

Fig. 16: ICPL 87

Fig. 17: Green colored pods

USES

Though mainly cultivated for its edible seeds, *Cajanus cajan* can be considered a multipurpose species. Pigeon pea stems are a good fuel source, valued for pigeon pea's fast growing habit, though their energy value is half that of charcoal. Stems and branches of pigeon pea are also used for basketry. Among other uses of pigeon pea, trials have shown a potential use as a raw material for paper pulp. Pigeon pea also contributes to the environment through its use in alley cropping and as a windbreak, cover crop, shade plant and green manure (Heuzé *et al.,* 2017). *Cajanus cajan* has numerous uses in animal feeding. The leaves and pods are valuable and palatable protein-rich fodder. Leaves are sometimes used to replace alfalfa in ruminant diets where alfalfa cannot be grown. Seed processing by-products, and sometimes the whole seeds, are used as livestock feed. The seeds can be fed to poultry and, in Hawaii, mixtures of pigeon pea with maize grain were successful. Bees actively feed on pigeon pea and produce a honey with a distinctive colour (greenish) in the comb. Pigeon pea is also a good host for lac insects and silkworms. Plant breeders have bred varieties adapted to drier conditions, more resistant to disease and suited to different production systems and cropping cycles. Since the 1990s there has been an increase in varieties available, allowing selection of cultivars with not only higher grain yields but also higher forage yields and crude protein (Heuzé *et al*., 2017). Red gram is a healthy protein-rich staple food, and it contains about 22 per cent protein. Red gram is consumed in the form of dal (dehusked split pulse) along with cereals such as rice (dal-chawal or chawal-sambar) and wheat (dal-roti). The combinations of dal-chawal or sambar-rice and/or dal-roti form the main ingredients of an average Indian vegetarian diet (Bhat *et al.,* 2019).

Pigeon peas are both a food crop (dried peas, flour, or green vegetable peas) and a forage/cover crop. In combination with cereals, pigeon peas make a well-balanced meal and hence are favored by nutritionists as an essential ingredient for balanced diets. The dried peas may be sprouted briefly, then cooked, for a flavor different from the green or dried peas. Sprouting also enhances the digestibility of dried pigeon peas via the reduction of indigestible sugars that would otherwise remain in the cooked dried peas (Wikipedia, 2023). Harvested pods of pigeon peas in Benin. It is an important ingredient of animal feed used in West Africa, especially in Nigeria, where it is also grown. Leaves, pods, seeds and the residues of seed processing are used to feed all kinds of livestock. In the Congo pigeon peas are utilized as one of the main food forest and soil improvement crops after using a slash-and-burn fire technique called *maala* . Pigeon peas are in some areas an important crop for green manure, providing up to 90 kg nitrogen per hectare. The woody stems of pigeon peas can also be used as firewood, fencing, thatch and as a source for rope fiber (Wikipedia, 2023). In the Republic of Congo the Kongo, Lari, and Dondo people use the sap of the leaves as an eyedrop for epilepsy. In Madagascar the branches have been used as a teeth cleaning twig (Wikipedia, 2023).

Very young seeds can be cooked and eaten like peas, going well in rice dishes. Mature seeds are dried and added to soups and stews. Small but flavourful. The seed may be used instead of soya bean to make tempeh or tofu, and can also be sprouted and eaten when about 25mm long. The seed is usually round or oval and up to 8mm in diameter. The unripe pods are eaten in curries. The pods are up to 10cm long and 14mm wide. Leaves and young shoots are cooked and used as a vegetable. A strong, spicy odour, with a new flavour that is not agreeable to everyone. A good source of protein. The leaves contain up to 9% protein. The leaves quickly become fibrous. Widely cultivated in all tropical and semitropical regions. An important legume crop of rainfed agriculture in the semiarid tropics. The Indian subcontinent, eastern Africa and Central America are the World's three main pigeon pea-producing regions. Pigeonpeas are cultivated in more than 25 countries, either as a sole crop or intermixed with cereals, such as sorghum (*Sorghum bicolor*), pearl millet (*Pennisetum glaucum*), or maize (*Zea mays*), or with other legumes, such as peanuts (*Arachis hypogaea*) (PFAF, 2023).

Pigeonpea is one of the most important legumes grown in semi-arid tropical regions and young seeds are consumed fresh as a vegetable or can be allowed to mature before drying and eating as a pulse. The seed pods are also edible and are eaten as a vegetable. The leaves and seed husks of the plant can be used as an animal feed (Plantvillage, 2023**).** Pigeonpea is mainly used as a dal, while the tender green seeds are consumed as vegetable, crushed dry seeds as animal feed and green leaves as fodder. The stems are used as fuel wood and to make buts, baskets, etc. The leaves can be used to seed feed silkworms and plants are used to culture the lac producing insect. On maintain slopes, it reduces soil erosion and permits multiple harvests and browsing. It serves as a wind break and live fence or as green manure and has immense potential in the agroforestry system. Redgram can be processed by canning and freezing for export purpose. In Venezuela, a local soft drink known as 'Chicha' is made from pigeonpea. Most recent evidence indicates the possibility of its use for paper pulp (Google, 2023).

Dehulling

Various methodologies exist in order to remove the pulse from its shell. In earlier days hand pounding was common. Several traditional methods are used that can be broadly classified under two categories: the wet method and the dry method. The Wet method Involves water soaking, sun drying and dehulling. The Dry method Involves oil/water application, drying in the sun, and dehulling. Depending on the magnitude of operation, large-scale commercial dehulling of large quantities of pigeon pea into its deskinned, split version, known as toor dal in Hindi, is done in mechanically operated mills (Wikipedia, 2023).

NUTRITIONAL VALUE

The pigeonpea *dal* is superior to vegetable type with respect to starch and protein **(Table 9),** while the vegetable pigeonpea grains had higher crude fiber, fat, and protein digestibility. As far as mineral and trace elements are concerned, green pigeonpea was better in phosphorus by

28.2%, potassium by 17%, zinc by 48.3%, copper by 20.9%, and iron by 14.7%(**Table 10**). On the other hand, the *dal* had 19.2% more calcium, and 10.8% more manganese (Saxena *et al.,* 2010).

Table 9. Comparison of green pigeonpea seeds and *dal* for important quality constraints

Constituent	Green seeds	*Dal*
Starch content (%)	48.4	57.6
Protein (%)	21.0	24.6
Protein digestibility (%)	66.8	60.5
Soluble sugars (%)	5.1	5.2
Crude fiber (%)	8.2	1.2
Fat (%)	2.3	1.6

(Saxena et al., 2010)

Table 10. Mean values for trace and mineral elements (mg 100 g^{-1}) in green seeds of a vegetable variety ICP 7035 and *dal* of a popular variety C 11.

Element (ICP 7035)	Green seeds	*Dal*	SEm (C 11)	Superiority over dal (%)
Phosphorus	264*	206	± 3.95	28.2
Potassium	1,498*	1,279	± 12.74	17.1
Calcium	92.3	114.3*	± 1.98	-19.2
Zinc	3.07*	2.07	± 0.01	48.3
Copper	1.39*	1.15	± 0.08	20.9
Iron	5.16*	4.50	± 0.06	14.7
Manganese	0.99	1.11*	± 0.02	-10.8
Magnesium	108.3	108.5	± 0.86	-

Red gram is a protein rich staple food. It contains about 22 percent protein, which is almost three times that of cereals. Red gram supplies a major share of protein requirement of vegetarian population of the country. Red gram is mainly consumed in the form of split pulse as dal, which is an essential supplement of cereal based diet. The combination of dal-chawal (pulse-rice) or dal-roti (pulse-wheat bread) is an important ingredient in the average Indian diet. The biological value improves greatly, when wheat or rice is combined with Red gram because of the complementary relationship of the essential amino acids. It is particularly rich in lysine, riboflavin, thiamine, niacin and iron (Shirsath *et al*., 2014).

Nutritional value of edible portion per 100 g of Red gram is given in **Table 11** (Shirsath *et al*., 2014).

Table 11. Nutritional value of edible portion per 100 g of Red gram

Energy (cal)	335
Protein (g)	22.3
Fat (g)	1.7
Ca (mg)	7.3
Fe (mg)	5.8
Thiamin (mg)	0.45
Riboflavin (mg)	0.19
Niacin (mg)	2.9
Vit.A value (mcg)	132

Nutrient composition of green seeds, mature seeds, and dal of pigeon pea are given in **Table 12** (Sameer Kumar et al., 2017).

Table 12. Nutrient composition of green seeds, mature seeds, and dal of pigeonpea

Constituent/cooking time	Green seed	Mature seed	*Dal*
Protein (%)	21.0	18.8	24.6
Protein digestibility (%)	66.8	58.5	60.5
Trypsin inhibitor (units mg^{-1})	2.8	9.9	13.5
Soluble sugars (%)	5.1	3.1	5.2
Flatulence factors (g 100 g^{-1} soluble sugar)	10.3	53.5	–
Crude fiber (%)	8.2	6.6	1.2
Fat (%)	2.3	1.9	1.6
Minerals and trace elements (mg 100 g^{-1})			
Calcium	94.6	120.8	16.3
Magnesium	113.7	122.0	78.9
Copper	1.4	1.3	1.3
Iron	4.6	3.9	2.9
Zinc	2.5	2.3	3.0
Cooking time (min)	13	53	18

Nutritional value of raw immature pigeon pea seeds and raw mature pigeonpea seeds is given in Table 13, 14 (Wikipedia, 2023).

Table 13. Pigeonpeas, immature, raw

Nutritional value per 100 g (3.5 oz)	
Energy	569 kJ (136 kcal)
Carbohydrates	23.88 g
Sugars	3 g
Dietary fiber	5.1 g
Fat	1.64 g
Protein	7.2 g
Vitamins	**Quantity %DV**†
Thiamine (B1)	35% 0.4 mg
Riboflavin (B2)	14% 0.17 mg
Niacin (B3)	15% 2.2 mg
Pantothenic acid (B5)	14% 0.68 mg
Vitamin B6	5% 0.068 mg
Folate (B9)	43% 173 µg
Choline	9% 45.8 mg
Vitamin C	47% 39 mg
Vitamin E	3% 0.39 mg
Vitamin K	23% 24 µg
Minerals	**Quantity %DV**†
Calcium	4% 42 mg
Iron	12% 1.6 mg
Magnesium	19% 68 mg
Manganese	27% 0.574 mg
Phosphorus	18% 127 mg
Potassium	12% 552 mg
Sodium	0% 5 mg
Zinc	11% 1.04 mg

Table 14. Pigeonpeas, mature, raw

Nutritional value per 100 g (3.5 oz)	
Energy	1,435 kJ (343 kcal)
Carbohydrates	62.78 g
Sugars	n/a
Dietary fiber	15 g
Fat	1.49 g
Protein	21.7 g
Tryptophan	212 mg
Threonine	767 mg
Isoleucine	785 mg
Leucine	1549 mg
Lysine	1521 mg
Methionine	243 mg
Cystine	250 mg
Phenylalanine	1858 mg
Tyrosine	538 mg
Valine	937 mg
Arginine	1299 mg
Histidine	774 mg
Alanine	972 mg
Aspartic acid	2146 mg
Glutamic acid	5031 mg
Glycine	802 mg
Proline	955 mg
Serine	1028 mg
Hydroxyproline	0 mg
Vitamins	**Quantity %DV**†
Thiamine (B1)	56% 0.643 mg
Riboflavin (B2)	16% 0.187 mg
Niacin (B3)	20% 2.965 mg
Pantothenic acid (B5)	25% 1.266 mg
Vitamin B6	22% 0.283 mg
Folate (B9)	114% 456 µg
Choline	0% 0.000000 mg
Vitamin C	0% 0 mg
Vitamin E	0% 0.000000 mg
Vitamin K	0% 0.000000 µg
Minerals	**Quantity %DV**†
Calcium	13% 130 mg
Iron	40% 5.23 mg
Magnesium	52% 183 mg
Manganese	85% 1.791 mg
Phosphorus	52% 367 mg
Potassium	30% 1392 mg
Sodium	1% 17 mg
Zinc	29% 2.76 mg

Pigeonpeas contain high levels of protein and the important amino acids methionine, lysine, and tryptophan. The Table 15 indicates completeness of nutritional profile of various amino acids within mature seeds of pigeonpea (Wikipedia, 2023).

Table 15. Nutritional profile of various amino acids within mature seeds of pigeonpea

Essential Amino Acid	Available mg/g of Protein	Min. Required mg/g of Protein
Tryptophan	9.76	7
Threonine	32.34	27
Isoleucine	36.17	25
Leucine	71.3	55
Lysine	70.09	51
Methionine+Cystine	22.7	25
Phenylalanine+Tyrosine	110.4	47
Valine	43.1	32
Histidine	35.66	18

Methionine + Cystine combination is the only limiting amino acid combination in pigeon pea. In contrast to the mature seeds, the immature seeds are generally lower in all nutritional values, however they contain a significant amount of vitamin C (39 mg per 100 g serving) and have a slightly higher fat content. Research has shown that the protein content of the immature seeds is of a higher quality.

Nutritional composition of mature pigeonpea seeds is given in Table 16 (Singh *et al.,* 2016).

Table 16. Nutritional composition of mature pigeonpea seeds

Nutritional value per 100 g	
Energy	343 kcal
Carbohydrates	62.78 g
Dietary fiber	15 g
Fat	1.49 g
Protein	21.7 g
Thiamine (vit. B1)	0.643 mg (56%)
Riboflavin (vit. B2)	0.187 mg (16%)
Niacin (vit. B3)	2.965 mg (20%)
Pantothenic acid (B5)	1.266 mg (25%)
Vitamin B6	0.283 mg (22%)
Folate (vit. B9)	456 µg (114%)
Calcium	130 mg (13%)
Iron	5.23 mg (40%)
Magnesium	183 mg (52%)
Manganese	1.791 mg (85%)
Phosphorus	367 mg (52%)
Potassium	1392 mg (30%)
Sodium	17 mg (1%)
Zinc	2.76 mg (29%)

Pigeonpea seeds are known to contain 18-26 % protein and in case of wild *Cajanus* species up to 30% protein content has been observed. The nutritional value of pigeonpea is evident from the information provided in Table 16. Additionally, a range of major anti-nutritional factors which are reported in pigeonpea. These anti-nutritional factors include phenolic compounds, tannins, phytolectins, oligosaccarides like raffinose and stachyose and a variety of inhibitors that negatively affect the digestive enzymes including trypsin, chymotrypsin and amylase. Compounds like phytolectins are heat-labile hence get destroyed easily while cooking (Singh *et al*., 2016). *Cajanus cajan* (aka pigeon pea) is a terrestrial medicinal plant native to Asian and African countries before being introduced to the American continent. This protein-rich legume species, belonging to the Fabaceae family, has been traditionally used to cure various ailments in many traditional medicines. Recent works have highlighted it as a rich source of a wide array of flavonoids and other phenolic compounds. The major biological activities that are currently reported on are mainly focused on antioxidant and anti-inflammatory activities which are relevant for the cosmetic field. For example, hydroalcoholic extract from *C. cajan* has been highlighted as a particularly effective antioxidant in various scavenging assays for both reactive oxygen or nitrogen species. One of its constituents, cyanidin-3-monoglucoside, has been reported to suppress inflammatory cytokine production (e.g., TNF-α, IL-1β, and IL-6 in murine RAW264.7 macrophages) (Tungmunnithum and Hano, 2020). Seeds of arhar are also rich in iron, iodine, essential amino acids like lycine, threonine, cystine and arginine. Protein - 22.3 %, Calcium - 73 mg/100 g, Fat - 1.7 %, Phosphorus - 304 mg/100 g, Minerals - 3.5 %, Iron - 5.8 mg/100 g, Fiber - 1.5 %, Moisture - 13.4%, Carbohydrate - 57.6 %, Calorific value - 335 Kcal/100 g

(DPD, 2023). It is rich in iron, iodine and the essential amino-acids like lycine, cystine and arginine. It is also used as ration for milch cattle. Its straw is also palatable and green leaves may be used as fodder. Sticks of pigeonpea are used for various purposes such as thatch and basket making (Ikisan, 2023). Pigeonpea is rich in iron, iodine and the essential amino acids like lysine, cystine and arginine (Google, 2023).

HEALTH BENEFITS

Concerning its therapeutic uses, consumption of immature pigeonpea seeds has been considered to have ameliorating effects in case of kidney related disorders. Similarly, leaf extracts from pigeonpea are reported to have noticeable impact in curing diverse diseases such as malaria, diabetes, dysentery and hepatitis. The flavonoids found in pigeonpea leaves have important pharmacological properties such as anti-cancer and anti-inflammatory. Similarly, the anti-cancer properties of cajanol (an isoflavanone isolated from pigeonpea roots) were also demonstrated *in vitro* against human breast cancer cells. Experimental evidences showing the hypocholesterolemic effect of stilbenes-containing extracts from pigeonpea have also been reported (Singh *et al.*, 2016).

Pigeonpea is a terrestrial medicinal plant native to Asian and African countries before being introduced to the American continent. This species, a member of the Fabaceae family, has been used for protein-rich food and medicines since prehistoric times in Asia, Egypt and African regions. This herbal species was also called the meat of poor people because of its seeds that consist of high protein content. In the past, *C. cajan* has been used mainly as food and traditional medicines. For example, people in some areas of Tamil Nadu, India use young stems, leaves and seeds to cure gingivitis, stomatitis and also as a toothbrush. In addition, the leaf of pigeon pea is also applied to treat oral ulcers and inflammations. For the traditional use in Oman, people use *C. cajan* seeds for treatment of various chronic diseases. Interestingly, ancient people used juice from the leaves of pigeon pea to treat various skin problems even inside the human mouth. This may be the fundamental evidence to reveal the potential of *C. cajan* in skin care research and development. Nowadays, the research interest in flavonoids and other phenolics from this medicinal plant is increasing, suggesting that more potential biological activities from these phytochemical compounds are waiting to be investigated (Tungmunnithum and Hano, 2020). Red gram regulates blood pressure. Because of potassium present in the red gram, it is very helpful for those who have hypertension or cardiovascular disease. It is very useful in the growth and development of the human body it contains a large amount of protein & as we know that protein is body building element it is very necessary for the growth and development of muscles, bones it is also important for healing and regeneration of tissue. It is useful to prevent anaemia because it contains an outrageous amount of folate and folate deficiency can cause anaemia. It is very useful for Weight Loss because it contains an in-considerable amount of saturated fat and cholesterol. It increases the rate of metabolism in our body and decreases the rate of weight gain in the human body. It is useful for Immune System it helps in strengthening the immune system of the body, it contains an enormous amount of Vitamin C and as we know Vitamin C is helpful in producing white blood cells which act as an antioxidant in the body (Singh, 2022**).**

A woody shrub that reaches only up to 4 m high upon maturity, Pigeonpea is grown in the tropics and subtropics for various uses. It is short-lived and believed to be one of the earliest of cultivated plants. It has deep tap roots hence it can tolerate drought and poor soil conditions. Edible parts of pigeonpea are the seeds, seedpods, leaves, and young shoots. Pigeonpea is as well known for its medicinal uses. Leaves are used as treatment of coughs, bronchitis, diarrhoea, haemorrhages, sores, and wounds. Diabetes and sore throats can likewise be treated using other plant parts of pigeon pea. Pigeon pea is planted as green manure. The stems are used as material in making baskets and in thatching. The wood is used in light construction (PFAF, 2023). The roots are anthelmintic, sedative, expectorant and vulnerary. An infusion of the leaves is used as a treatment for pulmonary conditions such as coughs and bronchitis. The leaf juice is taken internally in the treatment of haemorrhages, coughs and diarrhoea. An infusion of the leaves, combined with *Dactyloctenium aegyptium* or Egyptian crowfoot grass, is used to accelerate childbirth. Young leaves are chewed to treat boils on the tongue. A decoction is used for washing ulcers. The boiled leaves are applied to sores and wounds to hasten cicatrisation. Young shoots and the green seedpods are used to make a good pectoral infusion. An infusion of the flowers and leaves is diuretic and is used as a diabetes remedy. An infusion of the flowers is pectoral. A decoction of the plant is diuretic and laxative. It is used in the treatment of sore throats. An infusion of the seeds is diuretic. A flour made from the seeds is resolutive. Leaf contains cholesterol. The root bark contains numerous flavones including cajaflavanone and cajanone, and triterpenes. The root contains cajanone, an antimicrobial agent. An enzyme called 'urease' can be extracted from the plant. It has medicinal applications (PFAF, 2023).

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