33 Pigeonpea

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Pigeonpea [*Cajanus cajan* (L.) Millsp.] is grown in most tropical countries and has many common names, including red gram, tur, arhar, gandul, and pois d'Angole. India has over 90% of the hectarage and maximum variability for almost all the characters in the germplasm of pigeonpea and the genus *Atylosia,* a probable progenitor. The African origin proposed by de Candolle is controversial (De, 1974). Other important pigeonpea-growing countries are Burma, Uganda, Kenya, Dominican Republic, Panama, Puerto Rico, and the West Indies. Dry grain of the commonly grown cultivars contains 21 to 24% protein, and is usually consumed as dhal, a type of split peas, and as green peas.

I. PARENTAL MATERIAL

Pigeonpea belongs to the genus *Cajanus*, tribe Phaseoleae, subtribe *Cajaninae,* subfamily Papilionoideae, and family Leguminosae. Early subdivisions, *C. bicolor* DC. and *C. flavus* DC., based on variation for plant form, maturity, inflorescence structure, flower size, and color, are now considered the same species. *Cajanus indicus* Spreng., *C. luteus* Bello, *Cytisus cajan* L., *Cytisus pseudo-cajan* Jacq., and *Cajan cajan* (L.) Huth are synonyms (Pathak, 1970; Westphal, 1974; Morton, 1976; Huth, 1893). The *Cajanus kerstingii* Harms, found in Senegal, Togo, Ghana, and Nigeria, also listed by Hutchinson and Dalziel (1958) would have been placed in the genus *Atylosia* if Harms had known the strophioled seed (van der Maesen, 1977).

The genus *Atylosia* W. and A. forms a secondary gene pool of 34 known species. *Atylosia* and *Cajanus* are mainly distinguished by a persistent aril or strophiole on the seeds of *Atylosia.* The character is simply inherited and does occur in some cultivars of *Cajanus.* The two genera, however, are quite distinct because *Cajanus* is found only under cultivation and the *Atylosia* spp. are all uncultivated, wild, weedy forms. Van der Maesen (1975) reviewed the distribution of *Atylosia* and reported the occurrence of 22 out of 34 species in India, Sri Lanka, and Burma, one in Mauritius, seven in Australia, one in Malaysia, two in China, and one in Thailand.

Collections of 10 species, *A. lineata* W. and A., *A. scarabaeoides* (L.) Benth., *A. sericea* Benth. ex Baker, *A. platycarpa* Benth., *A. volubilis* (Blanco) Gamble (*A. crassa* Prain ex King), *A. trinervia* (DC.) Gamble (*A. candollei* W. and A.), *A. albicans* (W and A.) Benth; *A. rugosa* W. and A., *A. grandifolia* (F. von Muell. Benth.) and *A. cajanifolia* Haines are being maintained at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad, India.

Cytogenetic relationships of the *Atylosia* species have not yet been elucidated. Deodikar andThakar (1956) observed close affinity between *Cajanus* and some erect species of *Atylosia* and suggested the possibility of transferring wilt resistance to *Cajanus.* Three species *A. lineata, A. sericea,* and *A. scarabaeoides,* were successfully crossed with *Cajanus.* Cytological studies showed that all were close to *Cajanus,* but *A. lineata* was the closest (Kumar and Thombre, 1958; Kumar et al., 1966; Reddy, 1973; and De, 1974). Reddy (1973) and De (1974) concluded that *Cajanus* originated through selection of gene mutations without any change in chromosome number (n = 11) from an advanced *Atylosia* species, most likely *A. lineata.* However, it would appear that *A. cajanifolia,* only recently added to the ICRISAT collection, is the closest relative of *C. cajun.* Except for pod and seed characters, it is difficult to distinguish from *C. cajun.*

Recent crossing attempts were unsuccessful with *Cajanus* × *A. platycarpa* and *A. volubilis (A. crassa),* but apparently successful with *A. albicans* and *A. trinervia (A. candollei).* Success in crossing with *Cajanus* as female has varied from 0.0 to 32.9% (De, 1974). Reciprocal crosses have not been successful, except with *A. sericea.*

The Regional Pulse Improvement Project of USAID in India and Iran made the first comprehensive collection of 4,000 accessions in the 1960's. The bulk of this collection is now at ICRISAT, which has the responsibility of collecting and maintaining pigeonpea germplasm at the international level. Approximately 5,000 accessions from India and 300 from other countries are being maintained. Several small collections are being maintained at the national and regional level.

II. PLANT CULTURE

A. Field

Pigeonpea is sensitive to photoperiod and is a short-day plant (Sen Gupta, 1955; Gooding, 1962; Spence and Williams, 1972). Cultivars differ widely in time from planting to flowering at different latitudes due to the

varying degree of sensitivity to day length and temperature. Most cultivars flower in day length of 11 to 11.5 hours (Akinola et al., 1975). In Puerto Rico, Riollano (1964) was successful in shortening the time from planting to flowering by 4 months in medium maturing and 7 weeks in late maturing cultivars by reducing the day length to 8 hours, but it did not effect an early maturing, all season cultivar. This so called all-season cultivar in Puerto Rico (18°N Lat) is not necessarily photoperiod insensitive. In India, all extra early cultivars flowered within a reasonable period of time when planted every month of the year at 17°N Lat, but they took much longer to flower when grown at 29°N Lat.

No study has been done under controlled temperature and photoperiod conditions to separate photoperiod and temperature effects. Preliminary observations made under field conditions indicate that no pigeonpea genotype is truely photoperiod insensitive. The degree of sensitivity varies quantitatively, however, with the earliest maturing types being the least sensitive. Monthly plantings of 21 cultivars of varying maturity at Hyderabad, India, indicated at least 4 major response groups.

Pigeonpea is successfully grown between 30°N and 30°S Lat. In India and Java, productive plants were found at altitudes up to 1,830 m, but seed set was adversely affected at 1,070 to 1,525 m in Hawaii where minimum night temperature was 10 C (Akinola et al., 1975). In Kenya, production has been successful at 2,000 m. Pigeonpeas generally are highly susceptible to frost. Pollination and pod setting is adversely affected at high temperatures in dry weather and low soil moisture conditions. At Hyderabad, pollinations can be successfully done until the end of March with maximum temperatures of 38 to 40 C, but in April when temperature exceeds 40 C, pod set is adversely affected.

Inflorescence development and pod setting is influenced by the availability of light. No pods are set under the crop canopy. Dry, bright days are favorable for fertilization, while cloudy, damp weather results in excessive flower drop (Howard et al., 1919; Mahta and Dave, 1931). Precise information on the quality, level, and the duration of light required for fertilization and seed setting is lacking.

Pigeonpea can grow and produce relatively good yield on fertile soils with a soil pH of 5 to 8 (Akinola et al., 1975). It is highly susceptible to waterlogging, and genetic differences exist for tolerance to temporary waterlogged conditions. The deep tap root system sustains the crop on residual moisture during dry periods.

Pigeonpeas grow slowly during the first 45 to 60 days, but become large bushy plants by flowering time. For seed production purposes, a wide range of plant densities from 6,000 to over 300,000 plants/ha are being used in different regions, depending on the maturity, determinate or indeterminate plant type, soil type, and time of planting (Abrams and Julia, 1973; Ariyanayagam, 1975; Saxena and Yadav, 1975).

Common spacings used in experimental plots in India are 0.75 × 0.25 m or 0.50 × 0.25 m for early types, 0.75 × 0.30 m or 0.90 × 0.30 m for medium cultivars, and 0.90 × 0.30 m or 1.50 × 0.30 m for late cultivars. Spacings of 0.76 × 1.53 m to 1.53 × 1.53 m were recommended for pedigree breeding by Krauss (1932).

In the crossing block, spacings of 1.50 × 0.50 m for medium and late and 0.75 × 0.30 m for early types have been found convenient. Where land is a limiting factor, medium and late types can be planted in paired rows 5 m long at 0.75 × 0.30 m spacing with a one row gap between the pairs. This provides satisfactory access for emasculating and crossing.

Tall growing plants should be cut back for easy handling of flowers for emasculation and pollination and for allowing sufficient penetration of light in the plant canopy, which is essential for floral initiation and development.

Winter nurseries are in use with short and medium duration cultivars. The chief constraint is photoperiod reaction, but most cultivars which have a short life cycle will flower within 80 to 100 days when planted after the normal season harvest date, and two generations can be obtained each year.

B. Growth Chamber and Greenhouse

Only limited work has been done on production of pigeonpeas in growth chambers and greenhouses. Satisfactory growth in greenhouses has been observed where light was adequate and temperatures were kept between 38 and 40 C. Summerfield et al. (1977) reported successful growth of pigeonpea to maturity in growth chambers, greenhouses, and under a plastic shelter in the field. They provide details on rooting substrate, nutrient solution, irrigation and light requirements but they are not included herein because it seems unlikely breeders would use so expensive a facility for making crosses.

III. FLORAL CHARACTERISTICS

The complete flower is similar in structure to that of other legumes. The raceme inflorescences form a terminal panicle in indeterminate and somewhat corymb shape bunch in determinate plant types. These are grouped together at the ends of the branches in late types, and distributed along the branches in early and medium, indeterminate types.

Individual flowers consist of a calyx with five sepals, and a corolla with a standard, two wings, and a keel. There are 10 stamens, 9 fused in a column and 1 free. The ovary consists of two to nine ovules. The long, club-shaped style curves upward toward the standard. Flower size is positively correlated with seed size and is larger in vegetable types than in grain types.

Flower opening in an individual inflorescence and within a branch begins at the base and progresses upward. There are exceptions where the first flower opens in the middle of a flowering branch and successive flowering proceeds in either direction. The size of the inflorescence varies in different types and there may be as many as 10 flowers in each inflorescence. Usually two flowers open at a time on the same inflorescence, but the process of flowering in a plant continues until pod maturation. An inflorescence may hold from two to eight pods; however, the number in successive inflorescences decreases progressively towards the apical end of the branch. If old

inflorescences and pods from the lower nodes are removed, pod setting on successive nodes improves and compensates for the loss. This compensatory mechanism helps in prolonging the growth of apical meristem and extends the flowering period.

Durga Prasad and Narsimha Murthy (1963) and Datta and Deb (1970) studied floral development in a few grain types at Hyderabad and a vegetable type at Calcutta and observed that a bud visible to the naked eye develops and blooms within 15 to 20 days time. In a fully developed bud, anthers surround the stigma and dehisce a day before the flower opens. This normally results in self pollination of all flowers, however, on an average 15 to 20% outcrossing is common.

Sen and Sur (1964) suggested that thrips (*Taeniothrips distalis*), which enter the mature buds in large numbers may be responsible for cross pollination. At ICRISAT, however, thrips were abundant on male-sterile plants bagged together with normal plants, but almost no pod set occurred. It seems that bees, *Megachile* spp. and *Apis* spp. are the main pollinating insects. Foreign pollen tube growth is probably faster than that of pollen from the same plant, which favors cross fertilization in the species. Datta and Deb (1970) studied pollen tube growth in a style pollinated with pollen from the same flower and observed it to be very slow, taking 54 hours to reach the base of the ovary.

Prasad et al. (1977) reported that receptivity of stigmas starts 68 hours before anthesis and continues for 20 hours after anthesis. The best time for stigma receptivity is a day before anthesis.

Flowers start opening early in the morning in the summer and by noon during winter, and continue opening throughout the day. The length of time flowers remain open is influenced by the weather. Mahta and Dave (1931) observed that the flowers remained open at Pusa (Bihar) in north east India as long as a day and a half, but at Nagpur in central India it was normally about 6 hours.

IV. ARTIFICIAL HYBRIDIZATION AND SELF-POLLINATION

A. Equipment

Emasculation is carried out with a fine forceps. Items used for pollination include a petri dish containing moist filter paper and threads of different colors. Muslin cloth bags, nylon stockings, or fine-mesh nylon bags are used to cover flowers for selfing.

B. Preparation of the Female

Flowering in pigeonpeas normally continues until 75 to 80% of the pods mature; however, only 10 to 20% of the buds develop into pods. At the onset and during peak flowering, 50% or more of the buds may set pods, while toward the end of the flowering period pod set diminishes to zero. Crossing success, therefore, is higher if early developing buds are

chosen on the female parent. Usually two flower buds should be selected for crossing, and all smaller buds should be removed to prevent competition within the inflorescence. Only 2 to 10 buds should be emasculated on a branch.

Tightly closed buds, approximately two-thirds the size of mature buds, should be emasculated (Fig. 1). Buds at the correct stage should show a bright corolla color without any greenish hue. The selected bud should be firmly held between the thumb and the middle finger with the index finger used to support the flower (Fig. 2). The curved side of the standard is held toward the crosser and the sepal covering the keel is removed (Fig. 2A). The corolla is opened by inserting one of the tips of a fine pointed forceps at the base of the keel and moving upward to the tip of the standard (Fig. 2B). The bud will open with slight pressure of the supporting index finger, and the well-developed yellow anthers can be removed from the staminal column with forceps (Fig. 2C).

C. Pollination

The stigma is receptive before anthesis, and pollination can be done immediately after emasculation. Pollen source buds from male parent should be collected between 0800 and 1000 hours. These should be large, unopened buds in which the anthers will dehisce on the day collected (Fig. 1). They can be used throughout the day by keeping the buds in a covered petri dish on moist filter paper. When a flower has been emasculated, the staminal column of the pollen bud is used to brush pollen on the stigma of the female (Fig. 2D). If pollen buds are plentiful, the staminal column of the pollinator bud is left in contact with the pollinated stigma by trapping it between the edges of the corolla. Single flower buds can be used for two to three pollinations when necessary.

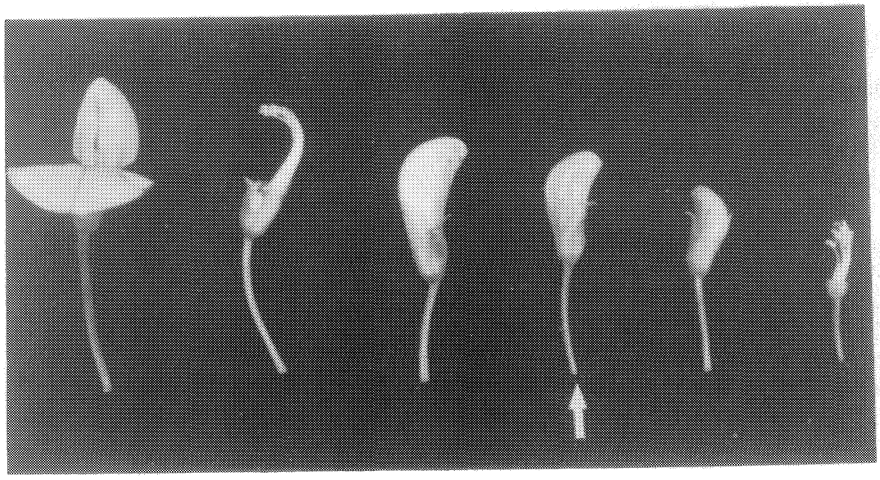

Fig. 1—Stages of flower development. Right to left. Flower before anthesis with calyx and corolla removed, an immature bud, bud at the stage for emasculation (arrow), bud at the stage for pollen collection, bud at the stage for pollen collection with calyx and corolla removed, and open flower.

Prasad et al. (1977) found that pollen in buds remained viable up to 42 hours at room temperature (25 to 28 C, 50.6% relative humidity) and up to 11 days in the refrigerator (10 C, 37.5% relative humidity). Successful pollinations have been made with *Cajanus* with detached mature flower buds of *Atylosia* spp. that had been stored up to 72 hours in polythene bags kept in a Thermos flask with ice.

For selfing, muslin cloth bags, reject nylon stockings, or fine-mesh nylon cloth bags have been found quite effective to exclude insect vectors. One can self the entire plant or an individual branch depending on the quantity of selfed seed required. At ICRISAT, bags 120 × 80 cm and 60 × 30 cm are used for entire plants and an individual branch, respectively. It is desirable to spray insecticide before bagging to control pod borers and avoid damage to the pods. Murthi (1977) obtained 15 to 18 selfed pods from a branch and over 200 pods from an entire plant. Kelkar and Pandya (1934) suggested smearing candle wax to seal individual flower buds in preference to muslin cloth bags and reported 15% success in obtaining selfed pods. The method has never been tried, however, on a large scale and does not seem practical.

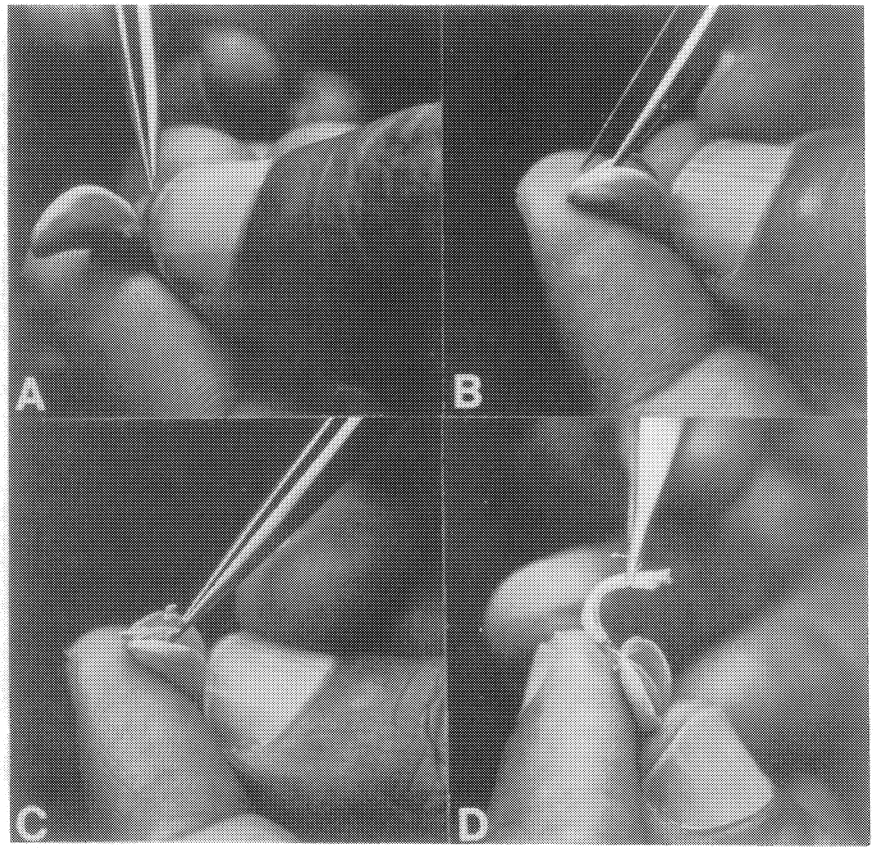

Fig. 2—Artificial hybridization of pigeonpea. A. Removing the sepal in front of the keel; B. Opening the flower; C. Removing the anthers; D. Brushing pollen on the stigma of the emasculated flower.

To identify cross-pollinated flowers, colored thread is better than a jeweller's tag commonly used for cereals and plants with bigger flowers. Different colored threads can be used to identify different crosses. Pollinated buds are generally not bagged because pod setting is greatly reduced under glassine bags. Our experience shows that outcrossing, if any, is negligible in unprotected pollinated buds. In a large crossing program, covering individual pollinated buds is not practical.

Success of crossing is influenced by the environment and skill of the pollinator. An average pod set of 20% was obtained at ICRISAT by skilled laborers who made 447,000 pollinations over a period of 8 months.

D. Factors Affecting Efficiency

The time of initiation and duration of flowering is influenced by the degree of perenniality of the cultivars, and by their photoperiod and temperature responses. Monthly plantings of early, medium, and late cultivars at Hyderabad (17°N Lat) have shown that by planting in September, the difference in days to flowering between the early and the late types is reduced to about 68 days compared with 85 days when planted in July. With plantings in September and October, there is overlap in the flowering period of early and medium, and medium and late. Successive plantings are needed to match flowering dates of early and late parents.

Some degree of perenniality is present in almost all pigeonpea cultivars and provides an opportunity to prolong the flowering period by 1 to 2 months in any cultivar if flowers are removed as they appear. Ratooning of early and medium maturing types and utilization of flowers on regenerated growth has been successfully used to cross divergent maturity types by Saxena et al. (1976).

Hybrids can be easily identified at flowering and pod formation by comparing various plant characteristics with the parents. For early detection of hybrids, stem pigmentation and obtuse leaf shape are good seedling markers. Deep purple pigmentation of the stem is partially dominant over green (F_1 is intermediate) and is monogenically inherited (Kumar and Haque, 1973). Normal lanceolate leaf with acute leaf apex is partially dominant over obtuse leaf (F_1 has broad leaf and acute apex).

V. NATURAL HYBRIDIZATION

Natural hybridization has been recognized as a major source of variability in released cultivars, as well as in landraces in farmers' fields. Both sources of variability have been extensively used by breeders for selection of improved types. In the absence of male sterility, Rachie and Gardner (1975) proposed a dual population system for effecting large-scale natural hybridization for population improvement. The system involves utilization of a simply inherited character like seedling coloration, plant growth habit (determinate or indeterminate), or leaf shape. The recessive condition of these characters is used in the female parent, so that the F_1 hybrids are quickly detected. Plantings of the female and male parent are made in alternate rows

or hills to maximize outcrossing. A bulk hybrid population constituted by compositing equal quantities of seed from each female parent row is planted in isolation. In F_1 seed is harvested only from plants with the dominant marker (hybrid plants). In F_2 seed is harvested only from plants with the recessive marker and in succeeding generations alternate selection for the dominant and recessive marker ensures intermating. After 2 to 3 generations of intermating, S_1 testing can be used to evaluate lines and selected ones can be used to reconstitute two populations, one with the recessive and the other with the dominant marker. The system depends heavily on insect pollination which may vary from location to location and from one season to another, and the desired level of intermating may not be achieved in each generation.

Reddy et al. (1977) recently reported five types of male-sterile plants from 35 sources among the germplasm collections, and from F_4 derivatives of *Cajanus cajan* × *Atylosia* spp. crosses. Of the five types, translucent male-sterile seems to be most promising for use in the natural hybridization, either for population improvement or for the production of hybrid seed because male sterility is complete and stable, phenotypic identification by anther color is easy, and monogenic recessive inheritance permits relatively easy maintenance (Reddy et al., 1978). Preliminary observations have indicated that in a population of fertile and sterile sibs, seed set on sterile plants under natural conditions with insect cross pollination was 84% of the normal fertiles.

Isolation distance for maintaining cultivar purity will depend on the pollinating agents. Published recommendations vary widely. Sen and Sur (1964) suggested a distance of 5.5 m while FAO recommended an isolation distance of 126 to 360 m (Akinola et al., 1975). Bhatia (1980) observed only 3% outcrossing at 100 m isolation. More detailed work on isolation distance, field layouts, and proportion of male and female rows required in a hybrid seed production block is in progress at ICRISAT.

VI. SEED DEVELOPMENT, HARVEST, AND STORAGE

Fertilization occurs in 48 to 54 hours after pollination (Datta and Deb, 1970). Preliminary observations to check the success of pollination can be made after 1 week, when petals dry and the young developing ovary can be clearly seen. There is substantial abscission of young pods, particularly in windy wet weather. Pod development ordinarily is completed in about 20 days after blooming. Seeds attain physiological maturity in 30 days and are ready for normal harvesting in about 40 days with 18 to 20% moisture (Rao and Rao, 1974).

Seed can be harvested and germinated in petri dishes at room temperature of 30 C after 20 to 30 days, when they are pale green or pale white in color. Germination of about 35% has been increased to 60% when a small portion of the cotyledons was cut or the testa was ruptured. Dry pods generally are harvested by hand into cloth bags and are kept for further drying in the sun or in a drier before being shelled by hand.

Information on drying and storage of pigeonpea seeds is limited. Seeds with 10% moisture have been stored at room temperature (21 to 37 C) for about a year, and in a cool room at 14 to 18 C and 50 to 70% relative humidity for up to 3 years without affecting seed viability (Murthi, 1977).

Pigeonpeas are highly susceptible to stored grain pests and the primary infection of *Callosobruchus chinensis* and *C. maculatus* starts in the field. Napthalene balls placed in individual seed packets or bottles are highly effective against these pests and ensure safe storage.

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