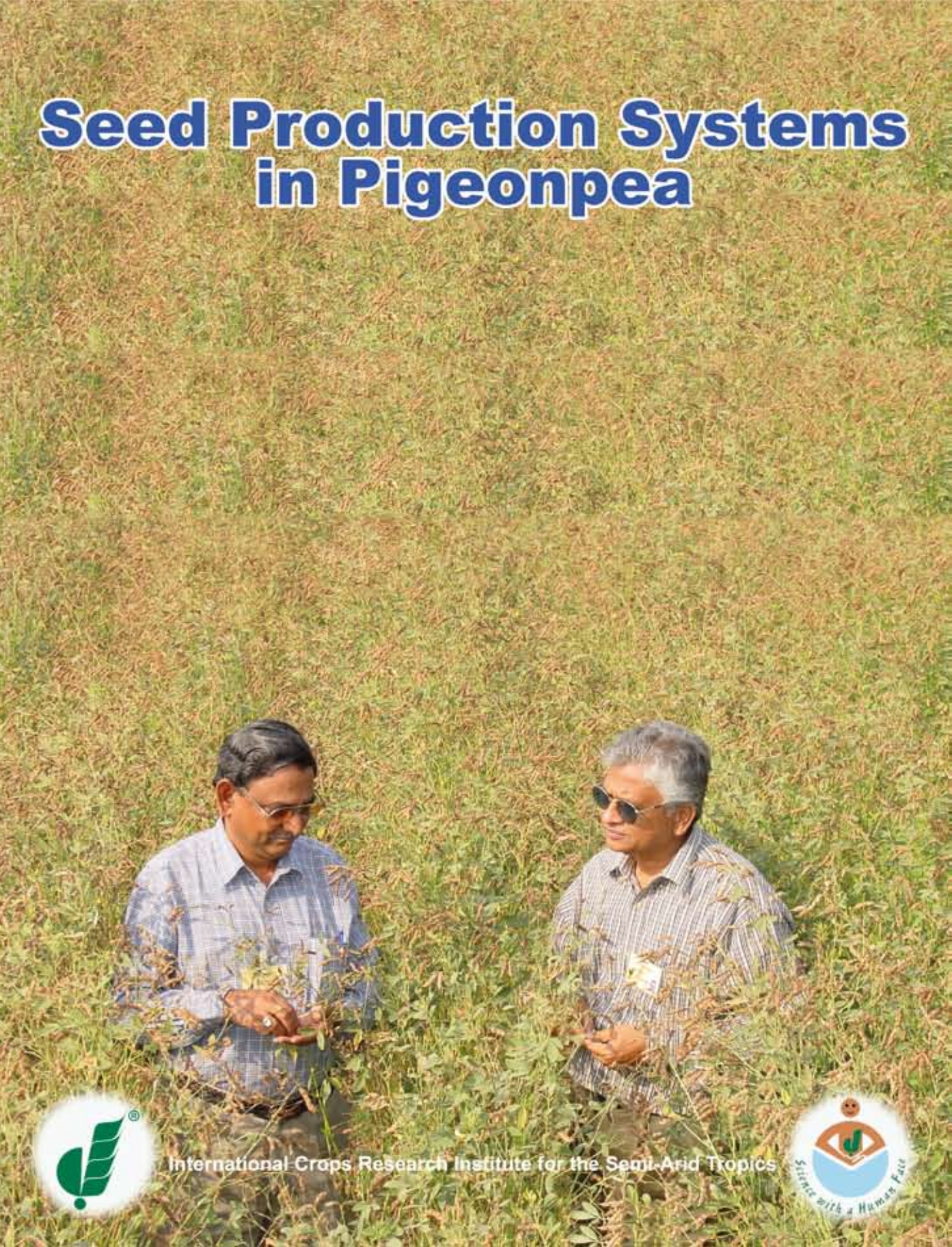
Seed Production Systems in Pigeonpea



International Crops Research Institute for the Semi-Arid Tropics

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Seed Production Systems in Pigeonpea

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Foreword

The Green Revolution of the 1960s and 70s saved millions of people from malnutrition and hunger. Its success was embedded in the seed that contained useful genes for dwarfing, fertilizer responsiveness, and high yield. The revolution predominantly benefited farmers in irrigated areas, leaving those inhabiting the semi-arid tropical regions devoid of any benefits.

The sustainability of agriculture in fragile rainfed environments primarily depends on crops such as legumes that can grow well with minimum inputs, and enhance soil structure and nutrition. Legumes also play a major role in meeting the protein needs of the populace. The stagnation in legume production and increasing population in rainfed areas have led to declining per capita availability of protein, with drastic consequences for the health and nutritional security of the poor, particularly growing children and expectant mothers. This is a matter of concern to policymakers as well as a challenge to the scientific community.

Among legumes, pigeonpea is an integral part of rainfed agriculture in Asia, southern and eastern Africa, Latin America, and the Caribbean. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and our partners in the national agricultural research systems (NARS) are committed to increasing pigeonpea production and productivity. The non-availability of quality seed and improved varieties to the farming community apart from a number of socioeconomic factors have been responsible for the marginal impacts that new technologies have had on pigeonpea productivity and on the incomes of poor farmers.

Seed is one of the most important agricultural inputs for maximizing yield. Hence, maintaining its genetic purity is vital. Given pigeonpea's low seed multiplication ratio and seed replacement rate, combined with the rapid genetic deterioration of varieties caused by natural outcrossing, scientific procedures involving maintenance of seed purity have gained primacy.

This book on seed systems in pigeonpea discusses all aspects of seed production, maintenance of purity, and distribution of hybrids and pure line varieties. Its author, Dr KB Saxena, is a highly experienced pigeonpea breeder who has lucidly and concisely dealt with a gamut of seed-related issues. I am sure the book will generate awareness about seed quality in pigeonpea and serve as a guide for farmers, scientists, and seed producers.

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1. Introduction

Among the legume crops of the tropics and sub-tropics red gram (tuar) or pigeonpea [C*ajanus cajan* (L.) Millsp.] is recognized as an important crop for subsistence agriculture due to its drought tolerance, ability to recover from the losses caused by various stresses, high-protein (20–22%) grains, quality fodder, and fuel wood. Its ability to enrich soils further adds to the value of the crop, and therefore, pigeonpea finds a valuable place among smallholding farmers in a number of developing Asian and African countries. According to van der Maesen (1980) the cultivated form of pigeonpea is believed to have originated in India from its wild relative Cajanus cajanifolius (Haines) van der Maesen comb. nov, through a single gene mutation (De 1974). Subsequently, it spread from India into other parts of the world at least two millennia B.C. Globally pigeonpea is commercially grown in over a dozen countries on about 5.25 million hectares (Table 1) and India accounts for over 80% of the total area and production. Pigeonpea is primarily consumed as de-hulled split grains in the form of a thick soup (dhal) eaten with rice and unleavened bread (roti or chapati). In Africa and Central America, whole dry seeds are cooked after soaking. Its immature but fully-grown seeds are consumed as a fresh vegetable that can also be processed for canning and freezing.

Table 1. Global pigeonpea scenario (FAOSTAT 2003).

Region	Area (Million ha)	Production (Million tonnes)	Yield (kg ha^{-1})
World	4.587	3.278	714
Asia	4.072	2.928	720
North and Central America	0.027	0.023	851
South America	0.002	0.002	800
Africa	0.485	0.325	670
India	3.500	2.400	686
Nepal	0.029	0.026	897
Uganda	0.084	0.084	1000
Tanzania	0.068	0.050	736
Malawi	0.123	0.079	642
Myanmar	0.540	0.500	926
Bangladesh	0.003	0.020	618

The availability of genetically pure seeds of improved cultivars is considered crucial for realizing their productivity and adoption in different agro-climatic conditions. In fact, the benefits of new improved varieties cannot be fully realized until sufficient quantities of genetically pure and healthy seeds are commercially produced and sold in the areas of its adoption. The problems encountered in the adoption of new varieties do not end with the initial distribution of improved varieties to the farmers. Therefore, appropriate provisions must be made to maintain the genetic purity of these varieties in their large-scale seed production programs year-after-after. It is in fact an exacting task that requires high technical skills and heavy financial investments. The good quality seed should have genetic purity and uniformity, and it should conform to the standards of the particular cultivar, be disease free, and have viable seeds, free from admixtures of other crop seeds, weeds, and inert matter.

In a recent review by Maruthi Shanker et al. (2004), the shortage of quality seed has been identified as one of the major constraints for increasing pigeonpea production in India. The genetically pure seed alone is known to account for at least 10–15% increase in the productivity. The lack of quality seed continues to be one of the greatest impediments to bridging the vast yield gap in India. Therefore, to approach the potentially realizable yield of a cultivar, the production and distribution of quality seed is essential.

In the mid sixties, the Government of India took a decision to make available high quality seed of different crops to farmers. To achieve this goal, a formal process began with the enactment of the Seed Act 1966. The provisions of this Act were enforced in 1969. To kick-off this seed mission, the provisions of Seed Act 1966 were systematically enforced and a number of important steps such as setting up of the Seed Certification Board and Certification Agencies, formulation of Minimum Seed Certification Standards etc. were undertaken. To meet the changing needs of seed production systems, various aspects of this technology were researched and over a period of time suitable amendments to the Seed Act 1966 were made.

2. Floral Biology

2.1 Flower structure

The pigeonpea flowers (Fig 1), borne in short racemes, are predominantly yellow in color. The peduncles of pigeonpea are 1–8 cm long. Pedicels are thin, 7–15 mm long and covered with hairs. Bracts are 1–4 mm long and their margins curve inwards to form a boat like structure. The calyx tube is campanulate with numerous glandular hairs with bulbous bases. The tube is dorsally gibbous, about 5 mm in length. The corolla is highly zygomorphic, papilionaceous, and generally yellow in color. The petals are imbricate in the bud. The standard petal (vexillum flag) is erect and spreading more or less orbicular, 14–22 mm long, 14–20 mm wide with clawed base. The wing petals are obovate with a straight upper margin, clawed base, asymmetrically biauriculate, 15–20 mm long, and 6–7 mm wide with a callosity. Keel petals are boat-shaped, 14–17 mm long, 5–7 mm wide, clawed and dorsally split, and ventrally split near the base (Reddy 1990).

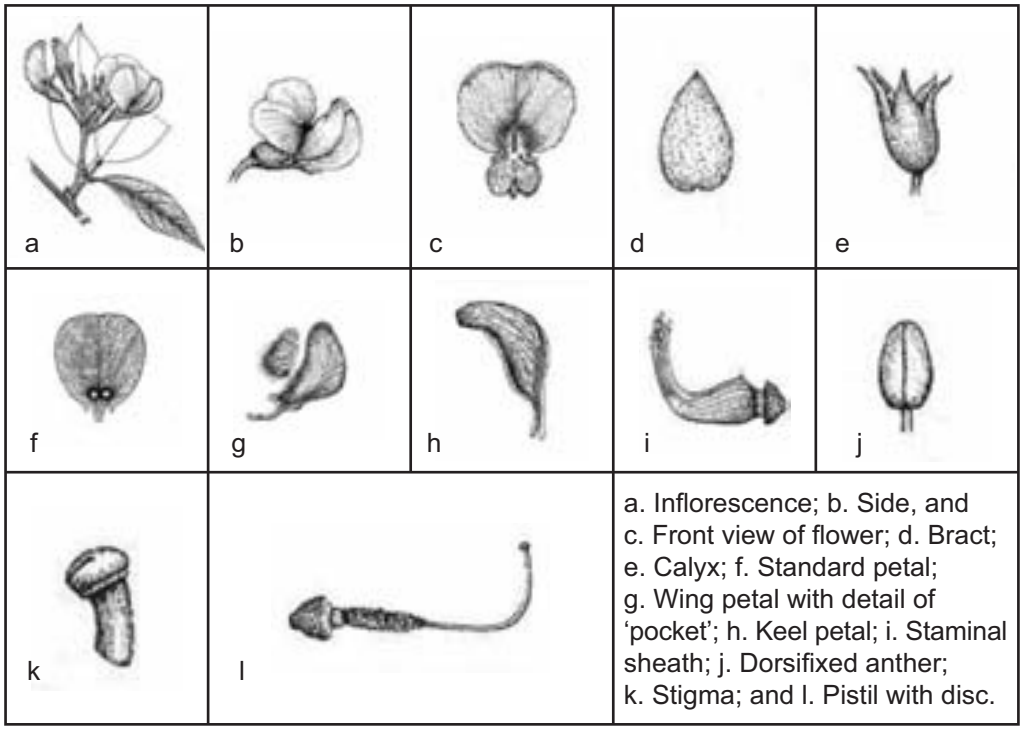

Fig 1. Pigeonpea flower and its major parts.

Stamens are 10, diadelphous (9+1), 15–18 mm long, with 4–7 mm free parts, flattening towards the base, tapering towards the top, and geniculate near the base. The staminal sheath is about 12 mm long. The anthers are ellipsoid, about 1 mm long, dorsifixed, and light or dark yellow in color. Of the 10 stamens, four have short filaments and six, including the odd posterior one, have long filaments. The odd stamen 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. Bahadur et al. (1981) reported that pigeonpea pollen grains exhibit dimorphism with regard to grain size and exine structure. In general, the pollen grains in the "short" stamens are larger than those in the "long" stamens.

2.2 Pollination and fertilization

Predominantly pigeonpea flowers are self-fertilized with 20–40% cross-fertilization. Bahadur et al. (1981) reported that growth and development of short stamens is faster than those of longer ones. The maturity period of short stamens coincides with that of stigma receptivity. They also postulated that the pollen grains produced by short stamens are predominantly responsible for self-fertilization, whereas those produced by long stamens are utilized in insect-aided out-crossing. Self-pollination occurs in the buds before their petals open while cross-pollination takes place at a later stage when the petals of the flowers unfold and insects visit the flowers to collect nectar. In general, the pigeonpea flowers are not truly cleistogamous and only part of their life cycle is cleistopetalous. In Lord's (1981) terminology such a condition is known as pre-anthesis cleistogamy.

At ICRISAT, however, a case of true cleistogamy has also been reported (Saxena et al. 1992a), where out-crossing is extremely low. This floral variant (Fig 2), where the petals are twisted and inter-locked with each other with an unusual cylindrical appearance, was selected from an inter-specific cross. This trait, controlled by a single recessive gene, ensures a high level of self-pollination in pigeonpea. Under different locations the level of out-crossing in this mutant has been reported to vary from zero to a maximum of 2.5%. Thus, the breeding behavior of an often cross-pollinated crop has been changed in this material to self-pollination. This trait is now being incorporated by breeders to develop high-yielding pure lines.

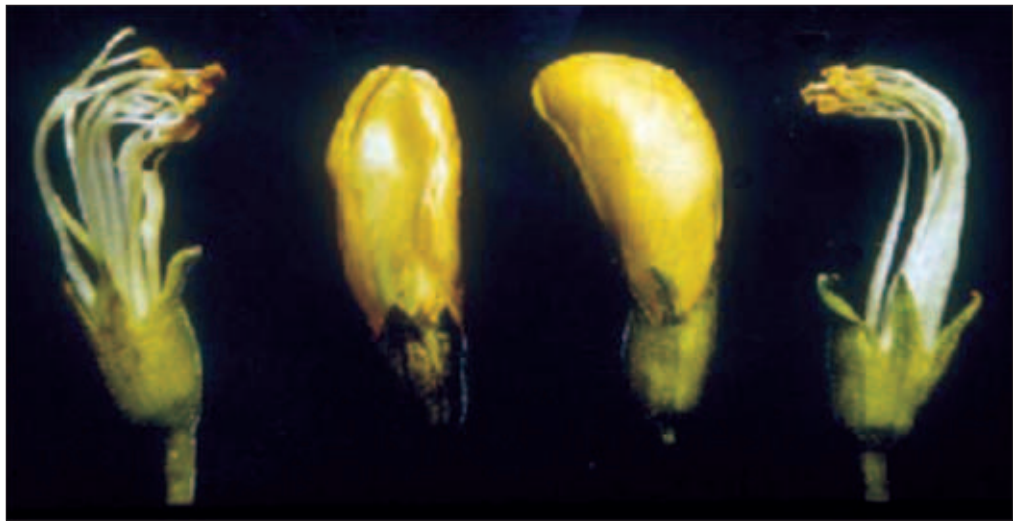

Fig 2. Cleistogamous floral **(left)** *and normal* **(right)** *bud of pigeonpea.*

Once a flower bud becomes visible, it takes about two weeks to bloom. In a young pigeonpea bud, the stigma is placed slightly above the level of anthers, and the style is curved at the tip in such a way that the stigmatic surface is directed towards the anthers. The anthers inside flower are arranged around the style in two groups, five above and five below. As the bud grows, the anther filaments elongate and bring the anthers to the level of the stigma. This growth is completed before the anthers starts dehiscing in the closed bud, ie, a day before the flower opens. The anthers dehisce in about 80–90% of the flowers before they open. The length of time the flower remains open depends on environmental conditions such as temperature, intensity of sunlight, and relative humidity. Mahta and Dave (1931) observed that the pigeonpea flowers remained open for 48 hours at Pusa (Bihar) while at Nagpur they remained open only for 6 hours. In West Bengal, Reddy (1973) found that the pigeonpea flowers began to open from 0630 onwards and remained open for 15 to 24 hours, and anthesis continued until 1400 with the maximum anthesis taking place between 1030 and 1230. Pathak (1970) reported that those flowers which open in the evening usually remain so throughout the night and close before noon on the following day.

It has also been found that the stigma becomes receptive for pollination 68 hours before anthesis, and remains in the same condition for about

20 hours after anthesis (Prasad et al. 1977). According to Onim (1981), although anthers dehisce during the bud stage the pollen grains do not start germinating until the flower starts to wither, ie, 24–28 h after dehiscence. Under Hyderabad (17°N) conditions, the fertilization in pigeonpea occurs on the day of pollination, and seeds mature within 45–50 days after pollination. In the first three weeks after anthesis, the pod wall grows more rapidly than the young seeds (Narayanan and Sheldrake, 1975). Datta and Deb (1970) reported that when pollinated with the pollen from the same flower, pollen tube growth within the style is very slow, taking 54 h to reach the base of the ovary. Reddy and Mishra (1981) reported that the percentage of "selfs" was negligible when flower buds were pollinated with foreign pollen without emasculation. This indicates that the foreign pollen has an advantage in affecting fertilization over the plant's own pollen. Such mechanisms in pigeonpea offer a sufficient time gap for foreign pollen to be introduced onto the stigma, and thus favoring out-crossing.

3. Important Considerations

3.1 Maturity range

The traditional pigeonpea cultivars and most landraces are of long (>250 d) to medium (160–180 d) maturity durations. However through breeding efforts, some early maturing types have also been developed recently and the earliest maturing line MN 8 flowers in 45 d and matures in 85 d at Patancheru (17°N). Thus, almost continuous variation for maturity from 85 to over 250 d exists at present (Table 2). This variation not only plays a major role in diversification of cropping systems involving pigeonpea but also provides an opportunity to extend pigeonpea cultivation to new production niches. The plants of early maturing varieties are relatively short in height and produce less biomass, therefore require high plant population per unit area (330,000 plant ha^{-1}) for maximizing yield. Such types are generally cultivated as a sole crop. On the contrary, individual plants of the longer maturing cultivars produce greater biomass and are traditionally grown either as an intercrop or as perennial hedges. Therefore, in any commercial hybrid breeding program, the cross combinations involving diverse maturity

Table 2. Pigeonpea maturity groups established on the basis of days to 50% flowering of the mid-June planted crop at Patancheru (17°N).

ICRISAT maturity group	Popular maturity group	Days to 50% flowering	Reference cultivar
0	Extra short	< 60	ICPL 88039
I	Extra short	61–70	Prabhat
II	Early short	70–80	UPAS 120
III	Early short	81–90	Pusa Ageti
IV	Early short	91–100	ICP 6
V	Early short	101–110	BDN 1
VI	Medium	111–130	C 11
VII	Medium	131–140	ICP 7035
VIII	Medium	141–160	ICP 7065
IX	Long	>160	NP (WR) 15

group parents must be avoided, as the large-scale seed production of their hybrids will be difficult and uneconomical.

3.2 Photo-period sensitivity

Pigeonpea is a short-day plant and flowering in this species is induced by long periods of darkness. The photo-period sensitive reaction in pigeonpea germplasm is positively linked to their maturity duration and biomass production. The recently developed early maturing genotypes are relatively less sensitive to photo-period and the long-duration types are most sensitive (Wallis et al. 1981). For efficient seed production a general understanding of this phenomenon is necessary to maximize the seed productivity by adjusting the plant population of the parental lines, cultivars, or hybrids in accordance with their planting dates. For example, if a photo-sensitive genotype is planted during the long days of mid-June, then the plants will produce greater biomass, more branching, more pods, and therefore, a population of about 66,600 plants ha^{-1} will be sufficient for realizing optimum yield levels. On the contrary, in the late (September–October) sowings the plants of the same variety will be short in height (Fig 3), flower quickly, and produce only a few branches and pods. Therefore, to establish an optimum biomass canopy per unit area and to record high yields, over 330,000 plants ha^{-1} would be necessary.

3.3 Life cycle and ability to ratoon

Fig 3. Variation on the phenology of ICPA 2039 planted on three dates at Patancheru (17°N) in 2005.

Pigeonpea is a perennial shrub and this unique trait of the species helps in its adaptation to stress environments because it has a strong deep root system, large food reserves, and some undefined built-in stress compensation mechanisms. These factors encourage regeneration of vital plant parts. For example, if there is a sudden loss of flowers due to severe insect damage or short spells of drought or low temperature, then the plants will produce a second flush of flowers and pods as soon as the environmental conditions become conducive for growth and development. Similarly, when pigeonpea plants are harvested by cutting the main stem and branches at about 2–3 feet from the ground level, then too a second flush of vegetative and reproductive growth will be observed, provided the available soil moisture is sufficient. This ability to regenerate (or ratooned growth) can be exploited to our benefit especially in seed multiplication of important genetic stocks. Using this system, under a good cultural management at ICRISAT, a total of 5.2 t ha^{-1} seed (Table 3) of a short-duration cultivar, ICPL 87, was recorded in three harvests by Chauhan et al. (1987). Breeders can use this production

Table 3. Seed yields (t ha^{-1}) of short-duration varieties ICPL 87 and Prabhat in multiple harvests at Patancheru, 1982–83.

Harvest	ICPL 87	Prabhat
First flush	2.21	2.15
Second flush	2.04	0.67
Third flush	0.97	0.23
Total yield	5.22	3.05

Source: Chauhan et al. 1987.

technology to multiply precious nucleus and foundation seed of pigeonpea with a little additional cost of irrigation and insect management.

4.4 Natural cross-pollination

For consistency in the expression of any trait of a given variety, it is essential that its genetic purity be maintained. In most pulses, the genetic contamination of varieties through natural out-crossing is not an issue as their flowers are cleistogamous with high levels of self-pollination, and the genetic drifts due to natural out-crossing are minimum. In contrast, pigeonpea is grossly different in its pollination behavior and a considerable level (25–30%) of natural out-crossing is observed. Since pigeonpea is a perennial plant, its flowering continues until an optimum pod load on an individual plant under specific environmental conditions is achieved. This characteristic behavior of pigeonpea exposes its flowers for a longer period to insect visits. The large yellow flowers of pigeonpea attract various insect species (Fig 4), particularly bees. The frequent visits of pollen-carrying insects across various genotypes lead to natural cross-pollination, resulting in sharp deterioration of genetic purity of cultivars and genetic stocks.

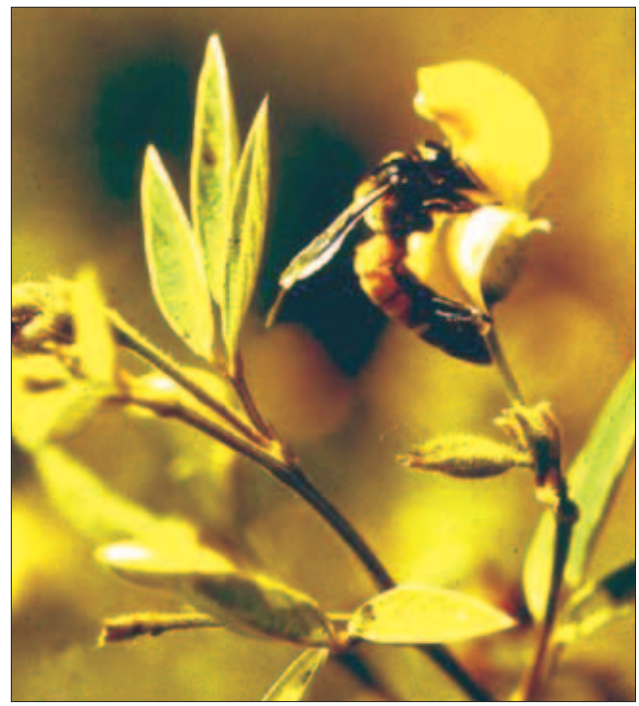

Fig 4. A honey bee foraging on a pigeonpea flower, which helps in out-crossing.

Pathak (1970) was the first to report *Megachile bicolor* and *Apis florea* as cross-pollinating agents in pigeonpea. At ICRISAT's Patancheru campus, although 48 different insect species were found visiting an unsprayed plot of pigeonpea, *Apis dorsata* and *Megachile*

spp. were the main pollinators (Williams, 1977). In Kenya also, 24 insect species visited pigeonpea flowers, and each insect visit lasted between 15–55 seconds (Omin, 1981). In the pollen basket (corbiculae) of a single pollinating insect, approximately 5000–100,000 pigeonpea pollen grains were reported by Williams (1977). Since in pigeonpea, natural cross-pollination is the direct consequence of insect visitation, its extent may vary from location-to-location and year-to-year. It is also observed that besides the density of pollinating insects, some external factors such as location of the plot, wind velocity, crop growth, floral morphology etc, also influence the extent of natural out-crossing at a particular location.

The first report of natural out-crossing in pigeonpea was documented by Howard et al. (1919) and subsequently, a number of papers were published (Table 4) on this subject (Saxena et al. 1990). This review shows that the natural out-crossing in pigeonpea is a common event in almost all the pigeonpea growing areas and it is considered an important constraint in pure line breeding and variety maintenance. Although the natural out-crossing in pigeonpea was known to occur for decades, the breeders unfortunately ignored this important fact while breeding new varieties and always treated pigeonpea as a self-pollinated crop

Table 4. Natural out-crossing in pigeonpea reported from various locations/countries.

Country/place	% Out-crossing	
	Mean	Range
In India		
Pusa	-	1.6–12.0
Nagpur	25.0	3.0–48.0
Niphad	16.0	11.6–20.8
West Bengal	30.0	-
Ranchi	-	3.8–26.7
Coimbatore	13.7	-
Varanasi	-	10.3–41.4
Badnapur	-	0.0–8.0
Coimbatore	-	10.0–70.0
Hyderabad	27.9	0.0–42.1
In Kenya		
Katumani	17.7	-
Kibos	12.6	-
Makueni	21.0	-
Mtwapa	22.0	-
Kabete	45.9	23.3-45.9
In other countries		
Hawaii	15.9	5.9-30.0
Puerto Rico	-	5.5-6.3
Trinidad	26.4	-
Australia	-	2.0-40.0
China	24.6	15.0-30.0

Source: Saxena et al. (1990).

while deploying various mating and selection schemes. Thus, the ill effects of natural out-crossing such as selection of out-crossed vigorous plants in segregating generations always had its share in reducing the breeding efficiency. On the contrary, pigeonpea breeders at ICRISAT are deploying this natural phenomenon of out-crossing to enhance yield levels of the crop by exploiting hybrid vigor at a commercial level (Saxena et al. 2005).

4. Crop Production Technology

The first and foremost pre-requisite for a good crop production is timely procurement of quality seeds of the given variety or hybrid parents for sowing. The reliability of the seed source should be of the highest order. Also, it is essential that the contract growers identified for seed production should be willing to cooperate with the seed producing agency.

In pigeonpea there exists a large variation for maturity and plant type, leading to the development of markedly different phenologies. Therefore, a uniform agronomic package cannot be adopted or recommended for optimizing the grain productivity of all types of genetic materials and for different pigeonpea growing areas. The short-duration determinate types have small plants while the long-duration non-determinate plants produce about 8–10 times more biomass. Also due to variable photo-periods and temperatures in different regions, both the plant growth and the rate of biomass production are vastly different at different planting dates and latitudes. For example, a variety like UPAS 120 will mature in about 125 d and attain a height of about 1.25 m at Patancheru (17°N) while at Hisar (29°N), at the same planting date, this variety will mature in about 150 d and grow about 3.0 m in height and produce about 3–4 times more biomass. Hence, for optimizing yield in different agro-ecological zones specific agronomic practices need to be worked out. It is, therefore, improper to recommend a single production package of practices for all the locations. However, some general guidelines for developing specific packages of practices for different locations and plant types are given below:

4.1 Field preparation

To select a field for large-scale seed production of pigeonpea, it is essential to ensure the availability of recommended isolation distance and irrigation.

Also, the field should have a known history of good soil fertility. Since pigeonpea cannot withstand water-logging, low-lying fields should never be selected for seed production. In Vertisols, where the probability of water-logging is always high, the sowings on raised beds or ridges with appropriate slopes offer greater probability of raising a healthy crop. Timely field preparation with the recommended basal doze of 100 kg ha^{-1} of di-ammonium phosphate and other recommended soil amendments for the known soil deficiencies is also advisable. It has been observed that a substantial delay in the planning activity often leads to problems in seedbed preparation due to early rains, particularly in Vertisols.

4.2 Sowing

Sowing should be undertaken at the onset of the rainy season. This will ensure good plant growth and canopy development. For short-duration types, the row-to-row spacing of 30 cm at lower latitudes, and 45 to 60 cm at higher latitudes with plant-to-plant spacing of 10 to 20 cm is recommended. For this spacing, a seed rate of 25–30 kg ha^{-1} is sufficient. For medium and long-duration types, the seed should be mechanically sown to maintain row-to-row and plant-to-plant spacing of 75–90 cm and 25–30 cm, respectively. This would result in approximately 66,000 plants ha^{-1}, and a seed rate of 10–15 kg ha^{-1} will be sufficient. The seeds are placed about 5 cm deep and covered firmly with soil to ensure a good contact between seed and soil particles and ultimately germination. Planting of pigeonpea on ridges is known to enhance drainage and productivity in Vertisols and high rainfall areas.

4.3 Weed control

The slow initial seedling growth of pigeonpea makes it prone to weed competition particularly during the first six weeks of growth. In general, three hand weedings, the first at 25–30 d, the second about 50–60 d, and the third at 80–90 d after sowing are sufficient to get rid of most weeds. Alternatively, spraying of a mixture of pre-emergence herbicide such as *Basalin* or *Prometryn*, each @1.5 L ha^{-1}, followed by two-hand weedings has also been found effective in controlling weeds. Under certain situations, the cultivation of early maturing short stature *Vigna* crops such as

V. unguiculata, *V. mungo*, and *V. radiata* in the inter-row spaces of pigeonpea also suppresses the weeds. These short-duration pulses are harvested before the on-set of flowering in pigeonpea, and the space left by these crops generally facilitates the insecticide spraying operation.

4.4 Irrigation

Irrigation is generally not recommended if the crop is grown for domestic consumption on deep Vertisols. However, if the crop is grown for seed purposes, either on light Vertisols or Alfisols, an irrigation during the early growth stage and another at the early podding stage is considered beneficial.

4.5 Insect management

Pod borers (*Helicoverpa armigera* and *Maruca vitrata)* (Fig 5), pod fly (*Melanagromyza obtusa*) and blister beetle (*Mylabris pustulata*) (Fig 6) are major pigeonpea insects. These may cause severe reduction in yields and grain quality. Also, sometimes a total crop loss is also observed. To control the pod borers in pigeonpea, the following insecticides have been found effective at ICRISAT.

Endosulfan	35 EC @.1.0 L ha^{-1}
Monocrotophos	36 EC @ 1.0 L ha^{-1}
Quinalphos	25 EC @ 2.0 L ha^{-1}
Dimethoate	30 EC @ 1.0 L ha^{-1}

Fig 5. Two major pod borers of pigeonpea.

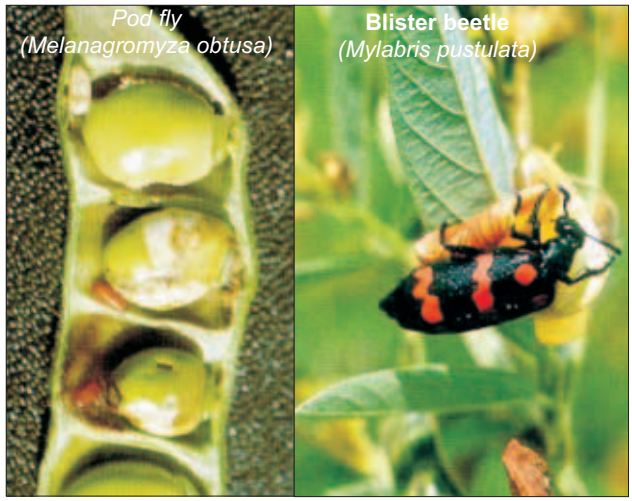

Fig 6. Two other important insects of pigeonpea.

The first insecticide spray is recommended at flower initiation, and the second and third sprays should be done at 10–15 d intervals. If pest incidence persists, then one or two additional sprays can also be done. If Knapsack sprayers are used, then 500 L of spray liquid is recommended to cover one hectare of a pigeonpea field.

It has often been observed that farmers apply insecticides after the onset of insect devastation. Grown larvae are not killed by normal insecticide sprays and damage continues at a rapid pace. Consequently, the growers loose both the yield as well as money spent on insecticide application. Therefore, timely application of the appropriate combination of insecticides is essential. It is advisable that selected chemicals not be sprayed repeatedly. Our experience shows that the first insecticide application should be done at an early flowering stage and this will kill the young larvae more easily, keeping the insect population low. In general the sprays of Monocrotophos 36 EC (0.04%) @ 1 mL L^{-1} of water, followed by Nimbicidine (0.3%) have been found the best for controlling pigeonpea pests. Cypermethrin (0.004%), and Endosulfan 35 EC (0.07%) @ 2 mL L^{-1} of water are also effective against pod borers. Spraying should be done @ 600–1000 L of water ha^{-1} with a knapsack sprayer, or 200–300 L of water ha^{-1} with a power sprayer. It is always advisable to consult a local expert before finalizing the spray schedule. Also, the quality of insecticides should be ensured before purchase.

ICRISAT has recently developed some integrated pest management (IPM) practices to reduce pod borer damage in pigeonpea. An outline of such practices is given below:

(i) Monitoring the pests with pheromone trap. The septa of a pheromone trap consist of a chemical that attracts the male moths. Therefore, the

use of sex pheromone traps at village or block level will unfailingly predict the time when the pest population is likely to reach the threshold so that chemical/biological pesticide sprays can be planned.

(ii) Growing of trap crops such as marigold (C*hrysanthemum* spp.) on the borders of the field and in between rows as an inter-crop also helps in reducing pod borer damage.

(iii) Planting of tall sorghum on the borders of the pigeonpea field acts as perches for birds that eat pod-borer larvae. The border also harbors natural enemies of pigeonpea pests.

(iv) Use of neem seed kernel extract (5%) against pod borers is quite effective.

(v) On noticing the eggs and first instar larvae of *H. armigera*, spraying of HNPV (hydro nuclear polyhedrosis virus that infects *H. armigera*) is recommended @ 250 LE (larval equivalent) ha^{-1}.

(vi) Manual shaking of plants helps in dislodging the grown Helicoverpa pod borer larvae from the plants. These larvae are collected on the ground on a plastic sheet and are physically destroyed.

(vii) Since the blister beetles are large in size and slow moving insect, they can be controlled manually by hand picking or by using small insect catching nets and later crushing them. Use of hand gloves in catching insects is always advisable for these operations. This will protect the skin from blisters caused by this insect.

4.6 Disease management

Fusarium wilt, sterility mosaic, and phytophthora blight are major pigeonpea diseases (Fig 7); Wilt is caused by a soil-borne fungus *Fusarium udum* Butler. The pathogen can survive in the field for three years or more. Therefore, to control the losses caused by wilt, we recommend the following:

(i) Use wilt resistant varieties.

(ii) Use disease free fields with no previous record of wilt.

(iii) Do not grow pigeonpea after pigeonpea in the same field; follow appropriate crop rotations.

Sterility mosaic disease is caused by a virus, which is transmitted through the eriophide mite (*Aceria cajani)*. The virus-carrying insects survive on a number of alternative hosts, pigeonpea plants and stubble left in the field after harvesting the main crop.

Fusarium Wilt (*Fusarium udum* Butler) | Sterility mosaic | Phytophthora blight (*Phytophthora drechsleri* Tucker f. sp. *cajani)*

Fig 7. Major pigeonpea diseases observed in India.

The simple disease management options are:

(i) Grow sterility mosaic resistant cultivars.
(ii) Select a field well away from perennial or ratooned pigeonpea.
(iii) Uproot infected plants at an early stage of disease development and destroy them.
(iv) Spray acaricides such as Kelthane, Morestan or Metasystox @ 0.1% to control the mite vectors in the early stages of plant growth.

Phytophthora blight, caused by *Phytophthora drechsleri* f. sp. C*ajani* is not a very common pigeonpea disease. Its incidence is seen in patches during the rainy season. The pathogen can survive for several years in the soil.

Some of the suggested management options are:

(i) Select fields with no previous history of blight.
(ii) Avoid sowing pigeonpea in fields with low-lying areas prone to water-logging.
(iii) Prepare raised seedbeds to ensure good drainage.
(iv) Seed dressing with Ridomil MZ @ 3 g kg^{-1} seed.
(v) If there are continuous rains leading to the risk of disease infection, use two foliar sprays of Ridomil MZ at 15 day intervals starting from the 15th day after germination.

4.7 Harvesting and threshing

The crop can be harvested by picking pods, cutting the pod-bearing branches, or by cutting the whole plant at ground level when about 75–80% pods are mature. The harvested materials should be left in the field for a few days to dry in the sun. Threshing can be done as per the local practices. If suitable harvesters are available, then the top half of the plants may be harvested mechanically.

5. Emasculation and Pollination

To breed new varieties, or transfer specific trait into the adapted cultivars, artificial hybridization is undertaken. Since pigeonpea is a perennial plant, its flowering generally continues until about 80% of the pods are mature. This provides an extended period in which to complete the targeted crosses in a breeding program.

The first step in hybridization is to identify appropriate parental lines and purify them by removing obvious off-types and mixtures. It is always better to acquire genetically pure seed for hybridization. Based on the characteristics of the parents and mating scheme, specific cross combinations should be identified. To avoid difficulties in handling the seeds and breeding records, it is advisable to allocate an identification number to each cross with male and female parents properly identified. At ICRISAT, a five-digit code is used for the cross number. The first two digits indicate the year in which the cross was made and the next three digits represent the serial number. A prefix of a specific combination of letters may also be used to further strengthen its identity. For example, the first cross made at ICRISAT in 1998 is identified as ICPX 98001. The identity of parents of the cross, listed at serial number 001, is separately maintained in a cross register. In the hybrid program, where a number of experimental hybrids are made for evaluation each year, the hybrids are allocated serial numbers over the years with prefix ICPH. The identity of female and male parents are recorded in the hybrid cross register.

The land for the crossing block should always be selected near an irrigation source and be protected from stray animals. The parental lines should be planted at row-to-row spacing of 75–100 cm. This will allow a person to sit comfortably between the two rows while making crosses. The

plant-to-plant spacing is kept at 30–50 cm. Each parental row should be labeled properly and purified by removing off-type plants, if any. Within each row of female parents each plant should be given an identification number. This will help in keeping an effective crossing record. This should be followed by the selection and identification of individual plants to be used as a male and a female parent in each combination. If a large number of crossed seed is required then more than one plant can be used as parents for crossing. The pollinating buds harvested from the male parent should be kept in a labeled petri plate with moist filter paper in the base.

Emasculation of male fertile buds in the female rows is carried out with a fine sharply-pointed forceps. The other materials required for hybridization include about 3″ long pieces of thick colored cotton thread for easy identification of crossed buds and a notebook or card to record the day-to-day progress of hybridization. It has been observed that the crossing success is higher if the early developing floral buds are chosen on the female plant for crossing. Generally, each bunch contains 5–6 floral buds of different sizes. Of these, only two buds should be retained for emasculation and the remaining very young or over-grown buds are removed before emasculation (Fig 8).

For emasculation, tightly closed buds, approximately two thirds the size of mature buds, are selected. Such buds have a bright yellow corolla without any greenish hue. The selected bud is firmly held between thumb and the middle finger with the index finger used to support the bud from behind in such a way that the curved side of the standard petal faces the crosser. The sepal covering the keel is removed first then the corolla is forced open by inserting one of the tips of the forceps at the base of the keel and moving it upward to the distal end of the bud. This bud will open with a slight pressure of the supporting index finger and thumb exposing its stamen column. At this point, the anther filaments are carefully held with forceps without touching the stigma and they are removed from the stamen column with gentle sideways (left or right) movement of the hand. It is essential to ensure that no anther is retained inside the dissected bud. This emasculated bud is now ready for pollination. The selected pollinator bud should be fully grown but still closed. For pollination, the entire stamen column is removed with the pair of forceps and the pollen-bearing anthers are brushed on the stigma of the emasculated bud to effect fertilization.

1. Opening a floral bud

2. Removing anthers from the bud

3. Pollinating an emasculated bud

4. Tagging a pollinated floral bud

Fig 8. Manual emasculation and pollination in pigeonpea.

Tying a piece of colored thread around the pedicle of the pollinated bud will help in distinguishing the hand-pollinated bud on the female plant (Fig 8). If the female plants are limited in number and more crosses need to be made, then more than one cross can be made on a single plant. In such a situation, different colored threads can be used to identify different crosses. The success of crossing is determined primarily by the skill of the pollinator and environment. It has been observed that success in hybridization is low on

a cloudy or foggy day. At ICRISAT, on average a pod set of 20–30% has been observed over the seasons. Since emasculation is not carried out on the male-sterile plants, the probability of mechanical damage to the stigma is low and the success of hybridization can be as high as 48% (Table 5).

In a breeding program it sometimes becomes essential to transfer certain gene(s) from the wild relatives of pigeonpea. In these inter-specific hybridizations, the crossing success is less in comparison to inter-varietal crosses. For successful inter-specific crosses it is advisable to use the wild species as male parents. It has been observed that when the wild species are used as female parent, the rate of success is less than 1% and in the reciprocal crosses the success rate is about 10%.

Table 5. Percentage of pod-set in inter-varietal crosses of pigeonpea made by hand emasculation and pollination at Patancheru

Cross no. (ICPX)	Number of		Pod set (%)
	pollinations	pods	
75070	1840	545	29.6
75071	1650	505	30.6
75072	1550	560	36.1
75073	1970	945	48.0
75074	1970	810	41.1
75075	1900	760	40.0
75076	1800	810	45.0
75077	1500	485	32.3
75078	1550	618	39.9
75079	1840	525	28.5
75080	1560	690	44.2
75081	1010	36	3.6
75082	1010	68	6.7
75083	1050	54	5.1
75084	1000	103	10.3
75085	763	52	6.8
75086	933	85	9.1
75087	1015	63	6.2
75088	790	107	13.5
75089	865	40	4.6
75091	1006	135	13.4
75092	1020	75	7.4
75093	720	144	20.0
75094	1070	146	13.6
75095	1020	295	28.9
75096	1005	193	19.2
75097	1000	152	15.2
75098	410	10	2.4
75099	1060	5	0.5
75100	825	5	0.6

The perennial nature of pigeonpea provides an opportunity to prolong the flowering period both in the male as well as in female plants. In pigeonpea, great variation (45–170 d) exists in the character and days to

flower, and breeders have difficulty in making crosses between very diverse maturity groups. To affect such cross combinations, staggered planting is often recommended. In staggered planting, the parents planted late in the season (September–October) remain dwarf and produce few flowers. Much better results are obtained when pruning prolongs the blooming period of the parents planted at the normal date. Pruning the plants above the height of the basal branches after harvest of the first crop results in rapid re-growth.

The pruning or ratooning (or cutting back) of plants and utilization of their flowers in the regenerated growth has been successfully used to cross the very divergent maturity types by Saxena et al. (1976). From crosses made at ICRISAT it was possible to compare the degree of success of the same parents before and after ratooning. Where both parents of the cross were early, success was 14.39% (46,097 pollinations) and 35.50% (600 pollinations) on non-ratooned and ratooned plants respectively. Where early × medium parents were used, the average success was 20.08% (8116 pollinations) for ratooned and 9.63% (38,034 pollinations) for non-ratooned parents. Within these crosses the percent success on the early parents was 29.02 (6,838 pollinations) for ratooned and 8.26 (12,094 pollinations) for non-ratooned, and on the medium maturity parents 11.13 (1,278 pollinations) for ratooned and 11.00 (25,940 pollinations) for non-ratooned. On ratooned plants, particularly with early maturing types, comparatively less flower drop was observed than on non-ratooned plants, which was reflected in the high rate of success in crossing. An additional advantage of using ratooned plants in crossing is that they can be observed throughout the season and then be used in crosses after harvest of the normal crop.

6. Seed Production of Elite Genetic Stocks

For a successful long-term breeding program, it is always essential to maintain genetically pure seed of elite genetic stocks, advanced breeding lines, and potential parental lines. Small quantities of such seed is produced first by roguing off-type plants and then selfing of individual plants or branches using the recommended quality and size of bags, mosquito nets, or bee-proof nylon nets.

To produce genetically pure (selfed) seeds of individual plants, three types of selfing bags are generally used to cover the inflorescence at the time of flower initiation. These include glassine bag (13 cm × 8 cm), small muslin cloth bag (60 cm × 20 cm), and large muslin cloth bags (135 cm × 90 cm). On an average the pod set inside the selfing bags is not very encouraging and it is determined by the extent of foliage growth and availability of sunlight inside the bags. In general the large selfing bags produce maximum number of selfed pods (Fig 9), the small bags come next and glassine bags the least. In addition, to produce moderate amounts of selfed seeds, varying sizes of bee-proof cages made with nylon mosquito nets are used. Over the years it has been observed that the pod set in these cages is quite high.

Fig 9. Pod set observed in a selfing bag prepared from synthetic mosquito net at Patancheru.

7. Seed Production of Contaminated Genetic Stocks

Development of elite genetic stocks and parental lines is a resource consuming activity and requires several years of inter-disciplinary research efforts. The benefits of this endeavor will be realized only if their genetic purity is maintained year-after-year. Although there are established quality seed production systems for pigeonpea, sometimes due to reasons such as non-availability of selfing materials, isolations, or financial resources, it is not possible to produce self-seeds. Consequently, the purity of such precious genotypes deteriorates rapidly (Fig 10) and it becomes

Fig 10. Wilted plants observed in a wilt resistant variety Maruti in farmer's field in Maharashtra State.

essential to purify them before using again in the breeding program. In doing so, it is always possible that the purified version of a particular genotype may not have the full original genetic complement, however, with careful sampling, selection, and evaluation it is possible to recover them to a great extent. The following methodology could be used to purify a contaminated pure line genotype. At ICRISAT this procedure has been successfully used to purify important genetic resources for traits such as plant type, disease resistance, seed size, seed color, and pod size. However, depending on the degree of contamination and the genetic nature of the trait, this method could be modified appropriately.

7.1 Year 1

- Critically study the available original data and acquire the best possible seed lot of the genotype identified for purification. To start the purification program, the first step is to purify the acquired seed lot for seed traits such as color, size, and shape admixtures. For example, in a white seeded variety any other seed color should be discarded.
- Grow about 1000 plants under recommended package of agronomic practices. If the genotype is known to be resistant to one or more diseases, a part of this seed lot should be grown in the respective disease sick nursery and its level of resistance should be recorded. Take the help of a pathologist to monitor the disease reaction.
- Identify about 100 plants, which one can find closest to the line description at early podding stage. At this time both flower and pod traits can be examined. Remove all the open flowers and immature pods from these plants and self them using muslin cloth or nylon net selfing bags of an appropriate size.
- At maturity, harvest selfed pods from each plant separately. Examine their seed traits again and reject off-type selections.

7.2 Year 2

- Grow 50–75 single plant progenies (1 row/selection) and reject segregating progenies, first at early growth (for vegetative traits) and then at early podding (for reproductive traits) stages.
- Identify 10–15 uniform progenies best matching with the target genotype. In each progeny select five plants and self them. Reject the

progenies showing inter-plant variation for any noticeable trait. Further assess these selections for seed traits, select a final 30–40 single plants and keep their seed separately.

7.3 Year 3

- Grow the single plant progenies (one row each) and based on uniformity of various traits select the best five progenies and self five plants in each progeny. Harvest selfed and open-pollinated seed from each plant separately.

7.4 Year 4

- Grow 25 (5x5) selfed single plant progenies for evaluation and bulk 10 best progenies resembling the original variety traits. Also, grow part of the seed of each selection inside a selfing cage. Identify the best progeny rows and bulk harvest their selfed seed from the selfing cage. Reject the rest. Plan to multiply breeder seed from the above nucleus seed in isolation in the subsequent season.

8. Seed Production of Germplasm Lines

In any breeding program genetic variation is the key to success. Greater variability for economic traits will provide an opportunity to breeders to select parental lines and design mating and selection schemes. For pigeonpea, ICRISAT has the global responsibility of collection, maintenance, and distribution of germplasm, and at present, 13,632 germplasm accessions are preserved in gene bank. The seed production of pigeonpea germplasm for the purpose of periodical rejuvenation is a critical activity because one has to be careful while maintaining the original inter and intra-accession variability. To achieve this, 180 plants of each accession are grown in the field. For selfing, either a few branches on each plant or the whole plant is bagged. An equal number of selfed seeds from each plant are pooled to conserve the existing genetic variability of a given accession. Since most pigeonpea accessions are tall, bushy and produce a lot of biomass, the selfing by bagging is a tedious and less productive job. Therefore alternatively,

the seed production of germplasm accessions is carried out with delayed sowings in shortening day-lengths that reduce its plant height and biomass considerably. This allows whole plants to be conveniently covered with muslin cloth bags. The selfing of the whole plot is carried out by using dismountable steel frames and covering it with insect-proof nylon nets (Fig 11).

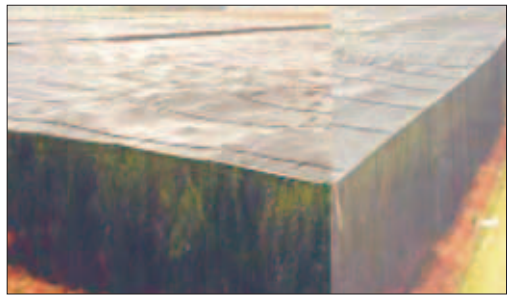

Fig 11. Pigeonpea germplasm multiplication inside a large nylon cage at Patancheru.

To regenerate germplasm, two nine-meter long rows of each accession are planted. At Patancheru (17°N) the seeds are sown during mid August. About five seeds are sown in holes at a distance of 20 cm on ridges. The seedling stand is reduced to one or two plants hole^{-1} by thinning after three weeks. The selfing, with muslin cloth bags or cages is done 2–3 weeks before flowering.

It is important to eliminate off-types and verify accession identification by comparing the traits such as flowering pattern, flower color, pod color, and primary seed color. Harvesting is done when about 90% of the pods turn dry. The selfed pods are hand picked from each plant and placed in labeled paper bags. All the bags collected from a plot (accession) are kept together inside a labeled jute sack (63 × 33 cm). The pods are further dried under shade for 2–3 days to reduce the seed moisture content to about 12%. The pods are then threshed on a tarpaulin by gentle beating, and seeds are collected into paper packets. Ensure that spillover and seed mixing do not occur during threshing. If a limited number of pods are harvested, then manual threshing is advisable. An equal number of seeds from each plant are pooled and kept in a muslin cloth bag labeled within and outside with tear-off tags. These bags should be stored properly (Fig 12).

Fig 12. Long term preservation of germplasm in the cold storage at Patancheru.

9. Seed Production of Wild Relatives of Pigeonpea

In general, the wild relatives of crop species harbor many beneficial genes, which are not present in the cultivated types. Such genes have been conserved by nature for centuries and the breeders need to mine them for use in their crop improvement programs. At ICRISAT a total of 555 accessions of wild relatives of pigeonpea, representing 64 species, are conserved. The seeds of all the wild relatives of pigeonpea have a hard coat, and therefore take a relatively long time to germinate, as the imbibition of water from soil to seed is extremely slow. Therefore, to improve germination, the individual seeds are scarified with a fine sharp blade. For germination, these seeds are sown in small plastic/paper cups with a hole at the bottom to drain excess water. The cups are filled with a mixture of of soil and farmyard manure in the ratio 3:4. To avoid seedling mortality the soil mixture is sterilized and seeds are treated with Benlate @ 3 g kg^{-1} seed. Two seeds are sown in each cup at about 2-cm depth. The seedlings are ready for transplanting when they have 3–4 leaves or are 2–5 cm in height. The creeping type of wild species such as C. *platycarpus*, C. *scarabaeoides*, and *Rhyncosia* are generally transplanted in large-size (30 cm diameter) pots, while the perennial shrubs like C. *albicans*, C. *crassus*, C. *goensis*, C. *heynei* and C. *mollis* are transplanted in the field. To transplant, turn the cup upside down while holding the seedlings with the fingers. A gentle tap on the cup will bring the seedlings along with soil onto the palm. Transplant the seedlings in the desired pot or field and water them with a rose can. Keep these pots in the shade for 3–4 days. If transplanted in the field, place the seedlings at a distance of 25 cm or more depending on growth habit, and provide light shade for 2–3 days. For better establishment the transplanting should be done in the evening and the cups should not be watered the day before transplanting. For regeneration of the wild relatives of pigeonpea, a sample size of 8–10 plants per accession is used. It is necessary to provide bamboo stakes to support the climber species. Collect the ripe pods from individual plants into paper envelopes before they shatter. Bulk equal number of seeds from each plant to reconstitute the accession.

10. Seed Production of Transgenic Varieties

The transgenic in food crops have now become a reality. In most crops there are some important biotic and abiotic stresses for which genetic resistance in the germplasm is limited, and the probability of developing a variety with a high level of resistance is minimum. Therefore to overcome such stresses, the genetic material is transferred from unrelated species using various biotechnological tools. In many field, fruit, and vegetables crops it has conclusively been shown that at present the technology of recombination DNA is the only solution to overcome the stress problems. A similar situation exists in pigeonpea, and to control the damage caused by the *Helicoverpa* pod borer, incorporation of insecticidal genes is being strongly advocated. Genetically transformed materials are popularly known as GMOs (genetically modified organisms). This technology, besides overcoming the constraints and enhancing yield, carries some harmful risk factors. These potential safety issues are grouped in a broader category called 'bio-safety risks'. Among these, the major environmental concern is the escape of alien genes from the transgenic plants to other cultivars/ species through dissemination of pollen grains by wind, insects or any other agent. When these pollen grains land on the receptive stigma of another variety they may pollinate it, resulting in the production of hybrid seed involving transgenic plants with a pollen parent. Such an uncontrolled gene flow is dangerous and it needs to be contained while producing the seeds of transgenic varieties. The extent of such gene flow generally depends on the duration of pollen viability and the distance between the two varieties. Once the transgenic varieties are released for cultivation, there will not be any control on bio-safety aspects such as prevention of flower production and pollen transfer to another species. Therefore, critical information about the invasiveness of transgenic plants in the wild habitats, their ability to propagate sexually or asexually, the possibility of transferring the transgenic to the same or related species, or to micro-organisms, and the consequences of gene transfer (Sharma et al. 2002) is essential. Since the behavior of a transgenic plant in the open environment cannot be predicted in a generalized way, its seed production at different levels of testing and the mass seed production should always be done with strict bio-safety regulations enforced under the direct supervision of the national authority.

At present strict bio-safety regulations do exist in several countries. In the seed multiplication of transgenic cultivars, therefore, extra care and special seed production regulations are needed to ensure a high level of bio-safety of the eco-system. At present there is no transgenic pigeonpea variety available for cultivation. However, at ICRISAT and some other institutions, transgenics are being bred for pod borer resistance. ICAR has developed stringent biosafety regulations for generation advance, field testing and seed multiplication of transgenics, and every institute involved in this research needs to observe these regulations very strictly.

11. Seed Production Regulations in India – a Summary

To increase productivity and meet the changing needs of farmers in India, crop improvement research is receiving high priority, and new varieties are being released for cultivation at regular intervals. Transferring the varietal technology from research laboratories to farmers' fields, while maintaining its genetic purity, is indeed a difficult task. This requires well-planned quality control measures at different stages of the long seed production and distribution processes (Fig 13).

A national level organization for seeds, ie, the National Seeds Corporation Limited (NSC), was established in 1963 with the objective of developing a sound seed industry in the country. Initially, it started production of foundation and hybrid seeds of maize, sorghum, and pearl millet. It also undertook certification of seed in the country. The NSC also developed field inspection norms, seed standards for certification, and seed-class labeling procedures. They, however, were unable to meet the huge seed requirements of the country. To develop infrastructure facilities to cope up with the seed demand, a National Seed Project (NSP) was implemented in 1976 with the assistance of the World Bank. Under this project, a number of State Seed Corporations (SSCs) and State Seed Certification Agencies (SSCAs) were established in the country during 1976–1990. At present there are 13 SSCs and 22 SSCAs in India. In addition to the public sector seed organizations, over 250 private seed companies are also producing and marketing seeds in the country. Some of the companies also export seeds to some Asian and African countries. Subsequently, the crop seeds were included in the Essential Commodities Act, 1955 through the seed

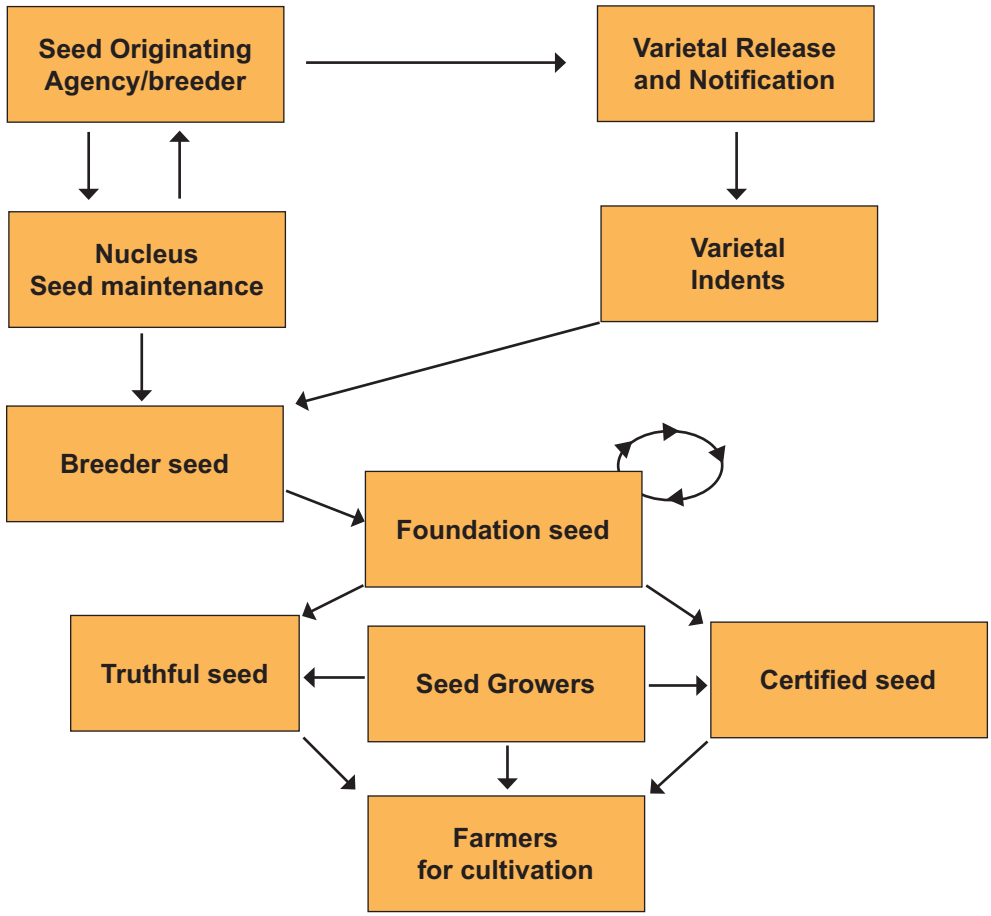

Fig 13. A generalized view of seed production and distribution channels in India.

control order 1983 and in 1964, the official variety release system came into existence and Central Variety Release Committee (CVRC) at the national level under ICAR; and State Variety Release Committee (SVRC) at state level were formulated. In 1966, The Seed Act was developed by the Government of India, and under this Act, various seed rules were constituted. Later, under the Ministry of Agriculture and Cooperation, a Central Seed Committee (CSC) was formulated and the functions of CVRC were taken over by CSC in 1969.

At present the seed regulatory framework operates both at national as well as state levels. Both these organizations are authorized to release

varieties, but the notification of a variety is under the control of the central system. Over the years, the seed industry in India has grown considerably and its benefits are reaching the farmers. In this process a number of research and development organizations (Table 6) work together. For the release of a variety the breeder needs to ensure the availability of enough seed for at least 10 hectares. After the release of new varieties, the seed multiplication and quality control is carried out by a number of agencies.

Table 6. Variety identification, release, seed producing, and distributing organizations in India.

Sl. No.	Activity	Organization/Agency
1.	Breeding and variety development	International and National Institutes, State Agricultural Universities, ICAR Research Centers, and Private Seed Companies
2.	Variety identification for release	ICAR
3.	Variety release and notification	Central/State Seed Sub-committees
4.	Nucleus seed production	The Institute which developed the variety
5.	Breeder seed production	International and National Institutes, State Agricultural Universities, State Seed Corporations, ICAR Research Centers, Public and Private Seed Companies
6.	Foundation seed production	International and National Institutes, State Agricultural Universities, State Seed Corporations, ICAR Research Centers, Public and Private Seed Companies
7.	Certified seed production	International and National Institutes, State Seed Corporations, State Agricultural Universities, ICAR Research Centers, Public and Private Seed Companies
8.	Truthfully-labeled seed production	State Agricultural Universities, Public and Private Seed companies, and Progressive Farmers.
9.	Seed certification	Central / State Seed Certification Agencies
10.	Seed distribution	National Seed Corporation, State Farms Corporation, State Seed Corporations, State Agricultural Universities, Private Seed Companies, Farmers' Organizations, Co-operatives, and NGOs.

At present the private sector is also actively involved in developing new varieties, and the regulations described above also apply to them for any official variety release. However, the private sector is not forced to release their varieties through CVRC or SVRC. The private sector has been given an option to sell their seeds under the category 'Truthfully Labeled Seed'. The seed under this category is not field certified but the seed standards are *at par* with the certified class of seed.

Since the breeder seed production is not a part of any seed certification scheme, it does not contain any prescribed certification standards. However, as per the Indian Minimum Seed Certification Standards "breeder seed should be genetically so pure as to guarantee that in the subsequent generation (certified foundation seed class) it conforms to the prescribed standards of genetic purity" (Shanmugam 2003). A breeder seed monitoring team is entrusted with the responsibility of maintaining the seed quality. To regulate the breeder seed production, inspection, and allocation, five levels of Breeder Seed Proforma (BSP I–V) have been created. The activities covered under each proforma are summarized in Table 7.

Table 7. Various Breeder Seed Proforma (BSP) used in India and their purposes.

Proforma Number	Activity	Responsibility
BSP I	Allocation of breeder seed production	Crop Coordinator of ICAR
BSP II	Time table of production activities and expected level of produce	Crop Breeder
BSP III	Crop status report of monitoring team	Crop Breeder
BSP IV	Final report of breeder seed production	Crop Breeder
BSP V	Supply of breeder seed against authorized ICAR allocations.	Crop Breeder

The monitoring team generally consists of a breeder and one representative each of crop coordinator, NSC, and the State Seed Certification Agency. This team submits the report to the Ministry in the prescribed format of BSP III. The other important quality parameters of breeder seed such as purity, contents of inert matter, and germination etc. necessarily

need to be indicated on a standard Breeder Seed Production label (Fig 14), in a characteristic Golden Yellow Color No. 356. (IS: 5-1978), size 12 × 6 cm on an actual basis (Tunwar and Singh 1988). Also, the breeder is required to maintain a record of each and every yellow colored label issued.

Fig 14. A Breeder Seed tag.

12. Seed Production of Released Varieties

12.1 Isolation specifications

Since the extent of natural out-crossing in pigeonpea dependent on insect activity may vary from one place to another (section 3.4), it is difficult to specify a uniform isolation distance that would be effective across locations. However, some safe and standard guidelines are essential to maintain the crop purity standards of the cultivars identified for mass seed multiplication. A summary of isolation distances recommended by various scientists / organizations is given in Table 8.

Table 8. Isolation distance (meters) recommend for seed production of various seed classes of pigeonpea.

Source	Seed Class			
	Breeder	Foundation	Certified	Truthfully labelled
FAO (Ariyanayagam 1976)	-	-	180–360	-
Agrawal (1994)	-	400	200	-
Bhatia et al. (1981)	300	-	200	-
Tunwar and Singh (1988)	-	200	100	100
Sudewad et al. (2004)	200	200	100	-

12.2 Nucleus seed production

Nucleus seed is a genetically pure seed lot of a particular variety, which is maintained by the originating plant breeder or the institute. It matches well in all the morphological parameters listed in the variety release document. In each cycle of regeneration, the population is monitored for these traits. In general, the available quantities of this valuable nucleus seed are limited and are used to produce breeder seed. To produce nucleus seed, the pure seed stock available with the breeder is grown under recommended agronomy and about 100 representative plants are bagged before flowering to obtain selfed seed. Each plant is harvested separately. In the subsequent season single plant progenies (2 rows/selection) are grown along with bulk seed in every fifth plot as a check plot for field assessment of progenies for various morphological traits. Any progeny showing significant deviation for any trait is rejected and its plants uprooted. About 20 plants from the uniform progenies, flowering along with the original seed lot, are selfed and harvested separately. This seed is assessed for its physical appearance (size, shape, color) and the seed from similar looking plants from a single progeny are bulked. Rigid criteria always need to be adopted while selecting the progenies because this seed lot will be used to produce the breeder's seed for future use.

According to Indian Minimum Seed Certification Standards (Tunwar and Singh 1988) the following two classes and sources of bulk seed production have been recognized.

Breeder Seed: Breeder Seed is the seed directly controlled by the originating or sponsoring plant breeder of the breeding program or institute. This seed production activity is supervised by a qualified plant breeder and the seed lot becomes the source for the initial and recurring increases of Foundation Seed. The Breeder Seed label shall be of a Golden Yellow color No. 356 (IS: 5-1978).

Certified Seed: Certified Seed is produced under the supervision of SSCA, notified under section 8 of the Seed Act 1966. The Certified Seed falls into two categories viz., Foundation and Certified Seed and each class shall conform to the standards.

Certified Foundation Seed: This seed is the progeny of Breeder Seed or produced from Foundation Seed Stage-I, which can be clearly traced to the

Breeder Seed. For these two categories of Foundation, ie, Foundation seed Stage-I directly produced from Breeder Seed and Foundation Seed, and the Stage-II Seed produced from Foundation Seed Stage-I, the Minimum Seed Certification Standards are the same. The tag for Foundation Seed is white in color. The seed production of Foundation Seed Stage-I and II must be supervised by SSCA.

Certified Seed: This is the progeny of Foundation Seed, and its production is so handled that it maintains the specific genetic identity and purity as per the prescribed standards fixed for the crop. Certified Seed may also be progeny of Certified Seed, provided the reproduction does not exceed three generations beyond Foundation Seed Stage-I. The color of the tag for the Certified Seed is blue (Shade ISI No. 104 AZURE BLUE).

12.3 Breeder seed production

Breeder seed is produced with high quality control standards under the direct supervision of the breeder (Fig 15) or institute who developed the variety. The planting material for breeder seed production is obtained from the nucleus seed lot. The breeder seed crop is grown in isolation with the recommended package of practices. Periodic inspection of the field, both before and after flowering, is essential, and all the off-type plants should be removed as soon as they are identified. Adequate measures should be taken to avoid mechanical mixtures during harvesting, threshing, cleaning, and packing. The Breeder Seed indents of the private companies for notified varieties/hybrids should be sent to the Seed Association of India, (SAI) New Delhi. The SAI, after consolidating crop/variety-wise Breeder

Fig 15. Inspection of a Breeder seed production plot of pigeonpea variety Asha at Patancheru.

Seed indents, will send the list to the Joint Secretary (Seeds), Ministry of Agriculture and Cooperation, Government of India. The indents can also be sent directly to the Joint Secretary (Seeds). The Government of India will forward the indent to ICAR, who will arrange for production and supply of breeder seed. Finally, the Joint Secretary (Seeds) will communicate the allotments to different organizations. The ICAR then, through the crop coordinator, will allocate the breeder seed production programs to its various ICAR centers and agricultural universities, which produce and deliver the breeder seed to NSC.

12.4 Foundation seed production

The direct large-scale progeny of breeder seed, produced either by government or private seed agencies, results in the production of Foundation Seed. Since yield is an important factor for profitable seed business, the production of Foundation Seed should be done in its area of adoption. In this class of seed production also, roguing of off-types should be exercised before flowering to avoid out-crossing. If sighted at a later stage, off-types should be removed then too. In general, the NSC and various other seed producing agencies multiply the Foundation Seed.

12.5 Certified seed production

The requirement for certified seed in the country is high. Certified seed is produced from foundation seed. Mainly, the National and State Seed Corporations are responsible for producing certified seed. In addition, various other seed producing agencies of public or private origin and progressive farmers can also produce certified seed from the stock of foundation seed obtained from NSC and other agencies. The seed lots have to meet specific standards of purity and germination, and these are monitored and certified under the 'Seed Act, 1966'. For this purpose, a number of independent State Seed Certification Agencies have been set up in almost all the states where seed production programs are undertaken.

12.6 Truthfully labeled seed production

To meet the expanding demand for quality seed of new varieties in the country, yet another seed class, called 'Truthfully Labeled Seed', has

evolved. Some progressive seed growers, capable of maintaining a sufficient level of variety purity by adopting the recommended isolation and other seed purity standards, can sell their seed, identified as 'Truthfully Labeled Seed' to other farmers. Similarly, private seed companies can also breed high-yielding varieties and sell the seed under their own trade name in this category. This option enhances the process of variety adoption by reducing the time involved in the formal 3–4 years multi-location testing required for the formal release of cultivars through the standard ICAR system.

12.7 Community-based seed production

In a crop such as pigeonpea, natural out-crossing is a strong force that can spoil the genetic purity of an adopted cultivar in a short span of two-three years if appropriate seed production guidelines are not followed. At present pigeonpea is a popular crop and in a village, the majority of farmers grow it for domestic use of seed and fuel wood. Therefore, it is very difficult in a village to find large isolated fields to multiply seed of a given variety. To overcome this seed production constraint, a "seed village" concept has evolved over a period of time where all the pigeonpea growing farmers are persuaded to cultivate only one variety, and their produce may be purchased by any voluntary organization or sold by farmers themselves. To achieve this, it is however, essential that all the farmers of a village be provided good quality seed. A pre-sowing meeting should be organized with farmers to explain the benefits of this seed village approach. Periodic instructions on various field operations, including rouging of odd plants, are also essential to maintain high quality seed health.

12.8 Seed production and dissemination by farmers

It has been observed that when a good pigeonpea variety is released and performs well in a particular area, the news about its performance spreads quickly to the surrounding areas. This generally leads to uncontrolled spread of seed from farmer to farmer. Initially, the new variety is grown by a few progressive farmers without any consideration about seed quality norms, particularly the isolation distance. This invariably leads to a certain degree of out-crossing with neighboring local cultivars. Therefore, this type of seed dissemination results in rapid deterioration of cultivars and undermines the

breeding objectives for which the variety was bred. There are a few very conspicuous examples. Bahar, an excellent widely adapted long-duration sterility mosaic disease resistant cultivar now exhibits variable extents of sterility mosaic disease incidence in farmers' fields. Similarly, the highly wilt resistant cultivar 'Maruti' is now showing a fair proportion of wilt susceptible plants. This type of contaminated seed lot is like a dangerous 'software virus' which spreads rapidly along with its usage.

If the farmers aim to sell their produce as seed, a lot of care should be taken to avoid contamination due to out-crossing or mechanical mixing. Unfortunately, in most cases it does not happen and quality continues to deteriorate season-after-season. A study conducted by the National Seed Project at 13 centers over six years revealed that in most cases the farmer-saved seeds were sub-standard with respect to physical (about 15–100%) and genetic purity (37–80%), ability to germinate (15–100%), and seed health. Also, farmers' seeds gave 2 to 80% lower yield than the certified seed in different crops (ICAR 1993).

In spite of the poor quality of seed, its exchange among farmers will continue to remain in practice. It is therefore essential to salvage the situation. To achieve this, the farmers should be educated to follow simple procedures to maintain seed purity at farm level through leaflets, videos, seminars, and meetings. These activities can be organized by '*Krishi Vigyan Kendras'*, the important centers for disseminating agricultural technology in India. Pigeonpea, being a partially out-crossing crop, requires extra-precautions to maintain variety purity. Some of the important steps that would help maintain variety purity and minimize the contamination of farmers' seed are listed below:

- Always purchase good quality seed from a reliable source.
- Avoid delayed sowing for seed production as it may produce low yield and poor quality seed.
- Select a field in which pigeonpea was not sown in the previous season. This will avoid emergence of dormant seeds of the previous season.
- Certified Seed production plots should be isolated from other pigeonpea cultivars by at least 100 m.
- The farmers should be advised to refrain from selling their seed if its quality is visibly inferior.
- Remove all off-type and late flowering/maturing plants as soon as they are spotted in the field.

- Prevent mechanical mixing and physical injury to the seeds.
- Soon after threshing and cleaning remove off-colored and small and over sized seeds.
- Sun dry the seed for a few days to bring the seed moisture level to 9.0%.
- Treat the seed with fungicides and pack it in small polythene bags for storage and distribution.

13. Male-Sterility Systems in Pigeonpea

13.1 Genetic male-sterility (GMS) system

Reddy et al. (1977) made the first serious attempt at ICRISAT to search for a stable male-sterile system that could be used in hybrid breeding technology. In 1974, they examined 7090 germplasm accessions and 124 inter-specific derivatives, and selected 75 individual plants from 35 sources. Based on their morphological traits these selections were classified into five groups, some with no pollen or scanty pollen and others differing in style lengths. Of these, the translucent anther type variant was selected for further study because it was totally devoid of pollen grains (Fig 16) and its anther morphology permitted easy identification under field conditions. This trait was found to be under control of a single recessive gene 'ms_1' (Reddy et al. 1978). They also reported that in the male-sterile plants tetrads did not separate

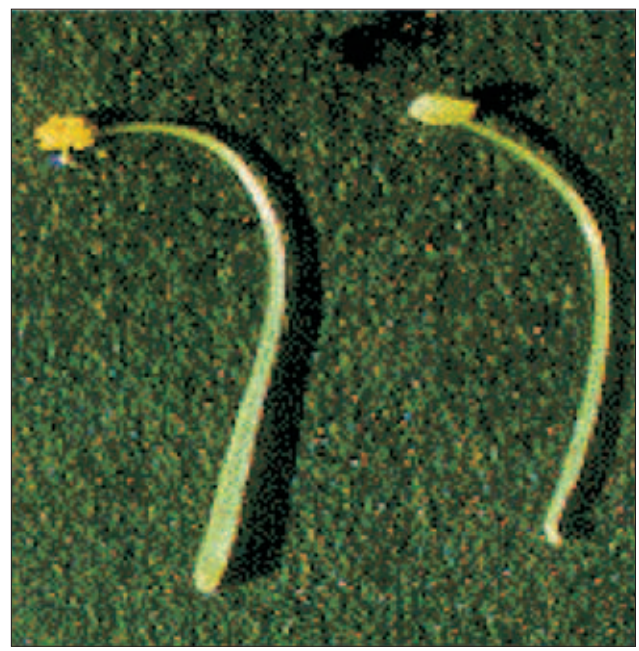

Fig 16. Male-fertile (left) *and male-sterile* (right) *anthers of pigeonpea.*

and gradually disintegrated during microsporogenesis. This was due to the persistence of the tapetum and inter-cellular wall of the two adjacent microspores. Under open-pollination, these male-sterile plants set pods and thus established a potentiality in the hybrid and population breeding programs. In Australia, Saxena et al. (1983) reported a different source of genetic male-sterility, characterized by brown, shriveled arrowhead anther shape. The anthers of this natural mutant were completely devoid of pollen grains and their morphology also allowed easy identification. This new source of male-sterility was also controlled by a single non-allelic recessive gene designated as 'ms_2'. Dundas et al. (1981) studied microsporogenesis and anther wall development of this mutant and found that this male-sterility was caused by the breakdown of normal microsporogenesis at the young tetrad stage. This was accompanied by degeneration of the tapetum by vacuolation during the first division of meiosis. The male-sterile plants also had an enlarged inner middle layer of the anther wall and they lacked the endothecium.

13.2 Cytoplasmic nuclear male-sterility (CMS) system

Cytoplasmic nuclear male-sterility is the most widely accepted means of producing commercial hybrids in the field crops. The expression of CMS, in part, is controlled by the factors carried only through the female parent, which is never lost or diluted in the succeeding generations of reproduction. Nuclear genes generally influence the expression of this trait, and environmental conditions may also alter its expression in many, but not all, gene-cytoplasm combinations. Cytoplasmic nuclear male-sterility is conditioned by an interaction between nuclear and cytoplasmic factors. The cytoplasmic factor is referred to as 'N' for normal fertile cytoplasm, and `S' for the sterile cytoplasm. The CMS lines are maintained by these cytoplasmic factors. The CMS 'A' line must be homozygous (*msms*) for nuclear genes, and the maintainer 'B' line must have a normal (N) cytoplasm and be homozygous (*msms*) for nuclear genes (Fig 17). The F_1 between 'A' and 'B' line is always male-sterile, since the 'N' cytoplasm, which is responsible for fertility in the 'B' line, is not transferred to the F_1. For producing fertile hybrid seed, the 'A' line in 'S' cytoplasm is crossed with a fertile line with fertility restorer nuclear genes, commonly known as 'Fr' genes. To sum up, the three-line system is geared for multiplying 'A' line

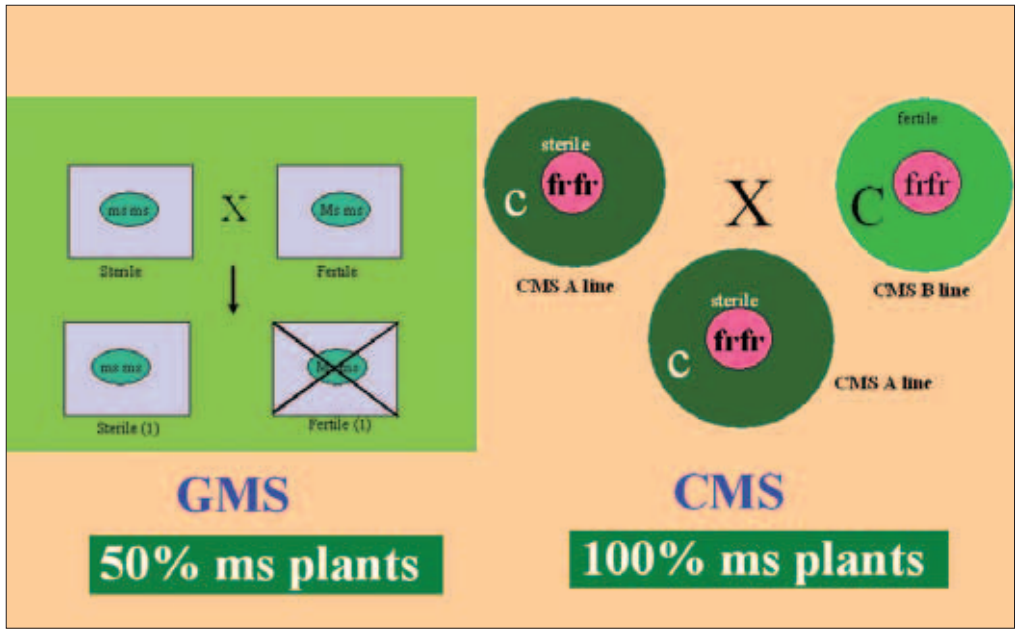

Fig 17. Comparative segregation for male-sterility in the seed maintenance of the male-sterile lines.

with the help of 'B' line and for producing hybrid seed the 'A' line is crossed with 'R' line.

The first attempt to develop cytoplasmic nuclear male-sterility (CMS) in pigeonpea using the crossable wild relatives of pigeonpea was made by Reddy and Faris (1981). They crossed C*ajanus scarabaeoides*, a wild species with fertile F_1 plants of C. *cajan* × C. *scarabaeoides* cross. The resultant BC_1F_1 plants were fertile but in BC_1F_2 generation some male-sterile segregants were identified. This male-sterility was linked with female-sterility and, therefore, it was not pursued further. Ariyanayagam et al. (1995) crossed C. *sericeus* with pigeonpea, and the F_1 progeny was partially male-sterile and the backcross (BC_1F_1 - BC_3F_1) populations were found segregating for male-sterility. Encouraged with the initial success in developing CMS at ICRISAT, six ICAR centers – Indian Institute of Pulses Research (9 species), Indian Agricultural Research Institute (1 species), Gujarat Agricultural University (2 species), Punjabrao Krishi Vidyapeeth (2 species), Tamil Nadu Agricultural University (1 species), and Punjab Agricultural University (2 species) – also joined the efforts to develop CMS lines through intro-specific crosses. So far four primary

CMS sources have been reported in pigeonpea. These are (1) A_1 cytoplasm, derived from C. *sericeus* (Saxena et al. 1996); (2) A_2 cytoplasm, derived from C. *scarabaeoides* (Tikka et al. 1997; Saxena and Kumar 2003); (3) A_3 cytoplasm, derived from C. *volubilis* (Wanjari et al. 2001), and (4) A_4 cytoplasm from C. *cajanifolius* (Saxena and Kumar 2005).

14. Seed Production of GMS-based Hybrids

The yield levels of pigeonpea over the past few decades have remained low and unchanged at about 600–700 kg ha^{-1}. With the aim of achieving a quantum jump in the yield of pigeonpea, its phenomenon of natural cross-pollination has been used to exploit the hybrid vigor. Initially, a genetic male-sterility (GMS) system was used to breed high yielding hybrids and in 1991, the world's first pigeonpea hybrid ICPH 8 was developed at ICRISAT and released by ICAR (Saxena et al. 1992b). Subsequently, five more GMS-based hybrids were released by ICAR. All these hybrids recorded over 25–40% yield advantage in farmers' fields but due to large-scale seed production difficulties, these hybrids could never cover large area to make any impact on national pigeonpea productivity. The seed production procedures of producing GMS-based hybrids and parents are summarized below:

14.1 Nucleus seed production of parents

Female parent: Since in the GMS sources, a single recessive gene controls the male-sterility, it has to be maintained in a heterozygote (*Msms*) form only. To achieve this, the male-fertile heterozygote plants are crossed, either by hand pollination or through pollinating insects, with the male-sterile (*msms*) segregants appearing in the same population. In the subsequent generation, this testcross seed lot will segregate in a proportion of 1 male: 1 female. This process is repeated generation after generation to maintain the GMS lines.

For large-scale seed multiplication of GMS line, the backcross seeds, harvested from the male-sterile plants, are grown in isolation. At flowering, a young floral bud from each plant is manually opened and its anthers checked for their morphology and the presence (male-fertile) or absence

(male-sterile) of pollen grains. These two types of plants are identified with different colored tags. At maturity, the seeds obtained through cross-pollination of male-sterile plants are harvested. The seed harvested from the fertile segregants is rejected.

Male parent: The male parent in this hybrid breeding system is multiplied in a separate isolation. The population should be intensively rogued for the off-types. Growing single plant progenies and selecting uniform progenies will enhance its genetic purity.

14.2 Certified seed production of hybrids

For producing large quantities of seeds of the selected hybrid combinations, the seeds harvested from the male-sterile segregants in the maintenance block (as described above) are sown along with the required pollen parent. Tests at ICRISAT have indicated that good pod set on the male-sterile plants was obtained when one pollinator (male-parent) row was sown after every six male-sterile (female-parent) rows. Since in the female rows, both male-fertile (*Msms*) and male-sterile (*msms*) plants would appear in equal proportion, the fertile segregants from the female rows are rogued out as soon as possible (Fig 18). This operation is very critical and time-bound. The first bud that appears on each plant needs to be examined manually

Fig 18. Roguing operation in a seed production plot of a GMS-based hybrid at Patancheru.

and male-fertile plants should be removed based on anther color and size (fertile anthers being orange and robust) before their flowers open and insect transfer their pollen to the male-sterile plants. Since this operation is very critical, it should be carried out every day and be continued till all the fertile plants from the female rows are removed. Then a final checking should always be done to ensure the quality. In the large-scale seed production endeavors, timely roguing is generally not feasible, mainly because it is a labor-intensive job and requires precision in the identification of male-fertile and male-sterile plants. Besides this, the roguing needs to be completed in about one week. At maturity, the cross-pollinated hybrid seed is harvested from the male-sterile plants. In the hybrid seed production block, the planting of 1 male: 4 female ratio is not a rule and this proportion may be altered depending on the presence of pollinating vectors at the seed production site, planting time, and the phenology of parents.

14.3 Seed production cost

Seed cost plays an important role in the adoption of hybrids. Both, the technology itself and crop management practices are critical in determining the production costs. The seed production feasibility studies showed that the hybrid pigeonpea seed could be produced at a reasonable price (Saxena et al. 1986). Later, a detailed cost of seed production study was undertaken by the Tamil Nadu Agricultural University, Coimbatore. In this experiment, 813 kg ha^{-1} of hybrid seed was obtained in a single harvest resulting in approximately 1:32 seed-to-seed ratio. The estimated cost of hybrid seed was Rs 6.25 kg^{-1} (Table 9). The roguing was found to be the most critical activity and it accounted for about 45% of the total production cost, and to rogue a seed production area of one hectare, 15 workers for a fortnight need to be employed (Murugarajendran et al. 1990). Studies conducted by the Punjab Agricultural University, Ludhiana, showed a large variation in the production costs of male-sterile and hybrid seeds. In 1990, 275 kg ha^{-1} seed of a male-sterile line MS Prabhat (DT) was produced at a cost of Rs 39.4 kg^{-1}. In the subsequent year, the production cost was drastically reduced (Table 10) and it was directly linked to the quantity of seed harvested. The estimated production cost of hybrid seed in this experiment was Rs 13.8 kg^{-1} (Srivastava and Asthana 1993). Experiments at ICRISAT demonstrated that

adopting multiple harvest system could reduce the production costs. In tropical environments with warm winters, pigeonpea produces several flushes of pods within a year and the perennial nature of this crop can be exploited to produce quality hybrid seed at low cost. In an experiment designed to assess the feasibility of producing cross-pollinated seeds from multiple harvests, it was revealed that multiple harvests substantially reduced the cost of hybrid seed production as there is no need to rogue after the first crop and the same seed production nursery can be used in subsequent years (Saxena et al. 1992b). Plants in such a production system should be ratooned at a manageable height, as they tend to grow tall making insect control and harvesting difficult. The effectiveness of management of the seed production crop, especially with respect to insect and diseases, plays an important role in yield maximization and consequently in determining its cost of production. Studies conducted in Ludhiana clearly suggest that under good management the cost of producing hybrid seed is not as high as feared in the initial stages. The primary cost data collected by Niranjan et al. (1998) directly from seed

Table 9. Cost (Rs.) of one hectare hybrid pigeonpea seed production at Tamil Nadu Agricultural University, India, rainy season, 1988.

Gross expenditure		
Field preparation	=	1142
Inputs (Fertilizer, irrigation, insecticides, etc.)	=	1220
Labor (Sowing, weeding, spraying, harvesting and seed cleaning)	=	1524
Roguing fertile plants	=	3200
Total cost	=	7086
Returns		
Hybrid seed yield (kg)	=	813
Pollen parent		
seed yield (kg)	=	304
value1 of seed	=	1824
value of fuel wood	=	200
Cost of production		
Gross expenditure	=	7086
Cost of producing 813 kg of hybrid seed = (7086) – (1824+200)	=	5062
Cost of one kilogram of hybrid seed	=	6.25

1. For these calculations, it was assumed that the cost of parent seeds was Rs 6.00 kg^{-1}.

Source: Murugarajendran et al. (1990).

Table 10. Cost (Rs) of producing hybrid (PPH 4) and its female parent MS Prabhat seeds at Punjab Agricultural University, Ludhiana.

	Female parent		Hybrid	
Item	1990	1991	1992	1992
Gross expenditure[1]	13194	13194	13194	13194
Hybrid seed yield (kg ha^{-1})	275	630	1040	800
Fertile plants yield (kg ha^{-1})	315	720	1275	257
Value of commercial grains	2205	5040	8924	1799
Value of by-products	375	375	375	375
Value of total seed	10614	7779	3894	11020
Cost of one kg seed	39.4	12.3	3.7	13.8

1. Estimated cost does not include such fixed costs as land rent, land revenue, depreciation, and interest on fixed cost
Sources: Verma et al. (1994)

growers revealed that roguing, spraying and fertilizer application were the main labor demanding operations. Of the total labor requirement (in days), 58% was for roguing, 17% was for insect control, 11% was for fertilizer, and the balance (14%) was for other operations.

15. Seed Production of CMS-based Hybrids

15.1 Seed production of experimental hybrids

For identification of high-yielding hybrid combinations in pigeonpea, each year a large number of experimental hybrids need to be produced and evaluated. Seeds of such experimental hybrids are best produced by hand pollinating the male-sterile plants. Under normal conditions, a trained person can pollinate about 300 floral buds in a day. A pod-set of 30–40% (Table 11) can be expected and the resultant hybrid seed is sufficient for testing in a small-scale replicated station trial.

15.2 Nucleus seed production of parental lines

A-Line: The nucleus seed of the parental lines of the hybrids should be produced with the highest standards of genetic purity. For multiplying nucleus seed, both A- and B-lines should be grown in adjacent plots, preferably inside an insect-proof cage. Each and every plant of A- and B-lines be examined for various genetic purity parameters and off-types be rogued. The pair wise (single plants of A- and B-lines) crossing should be continued until the desired number of pods is produced. The seed from each A- and B-plant be harvested separately and examined for seed purity. The crossed seed of different plants be bulked only after the breeder is satisfied about purity of the plants involved in hybridization. In case, the breeder is assured about the purity and uniformity of A- and B-lines, the

Table 11. Pod-set in the crosses involving different CMS lines and cultivars.

Hybrid No.	Number of pollinations	Number of pods	Pod set (%)
Pod-set on (A1) cytoplasm			
ICPH 2899	1570	411	26.2
ICPH 2352	600	126	21.0
ICPH 2913	300	126	42.0
ICPH 2332	350	130	37.1
ICPH 2324	1500	344	22.9
ICPH 2328	250	120	48.0
ICPH 2920	350	90	25.7
ICPH 2904	650	177	27.2
ICPH 2905	970	326	33.6
ICPH 2922	250	98	39.2
Total / Mean	6790/679	1948/195	322.9/32.3
Pod-set on (A2) cytoplasm			
ICPH 2984	435	147	33.8
ICPH 3092	350	150	43.9
ICPH 3133	500	130	26.0
ICPH 3171	260	125	48.0
ICPH 2982	236	77	32.6
ICPH 3172	175	160	91.4
ICPH 3174	149	33	22.0
ICPH 3176	233	51	22.0
ICPH 3178	130	20	15.0
ICPH 3179	140	25	18.0
Total / Mean	2608/261	918/92	352.7/35.3
Pod-set on (A4) cytoplasm			
ICPH 3472	100	65	65.0
ICPH 2740	50	23	46.0
ICPH 2655	150	85	56.6
ICPH 3420	75	36	48.0
ICPH 3396	100	49	49.0
ICPH 3386	100	65	65.0
ICPH 3411	50	26	52.0
ICPH 3446	300	169	56.3
ICPH 3485	300	152	50.6
ICPH 2647	300	173	57.3
Total/Mean	1525/152	843/84	545.8/54.6

pollen from several plants of B-lines can be bulked and used for pollination the number of plants in A-line.

B-line and R-line: The maintainer (B) and restorer (R) lines are male-fertile in nature and thus can produce quality selfed seed provided the plants maintain their genetic purity. For nucleus seed production of B- and R-lines, about 100 plants should be harvested from the central portion of the breeders seed production plot and their progenies should be grown in the subsequent generation. After the assessment of their purity aspects, the selected progenies are bulked to serve as nucleus seed.

15.3 Breeder seed production of parental lines

A-line: For the production of breeder's seed of A-line, a field with appropriate isolation distance is selected and A- and B-lines are grown with recommended agronomic package. At ICRISAT, a ratio of 4 A-lines: 1 B-line has been found effective in producing seed of A-line (Fig 19). In the short-duration CMS line, the mature pods on male-sterile and fertile plants be harvested by pod picking or by cutting the top-bearing portion of the plants. The perennial nature of species will force the plants to re-grow and produce a second fresh of flowers and pods.

B-line and R-line: The source seed for breeder seed production is nucleus seed. These male-fertile lines can be multiplied in separate isolations. It is also important to multiply seed in large quantities so that the foundation seed production is feasible. In addition, the B-line seed can also be harvested from the A-line seed production isolation (see above paragraph).

15.4 Foundation seed production of parental lines

The source seed for the production of foundation seed is breeder seed supplied by the breeder of the respective line. The package of practices followed in producing breeder seed is also followed in producing the foundation seed of the parental lines. Always sufficient care should be taken to rogue the off-types as and when they are identified in any seed production plot.

Seeds of both A- and B-lines are planted at the same time in the ratio of 1 male (B-line) to 4 female (A-line) rows. Soon after flowering the pod

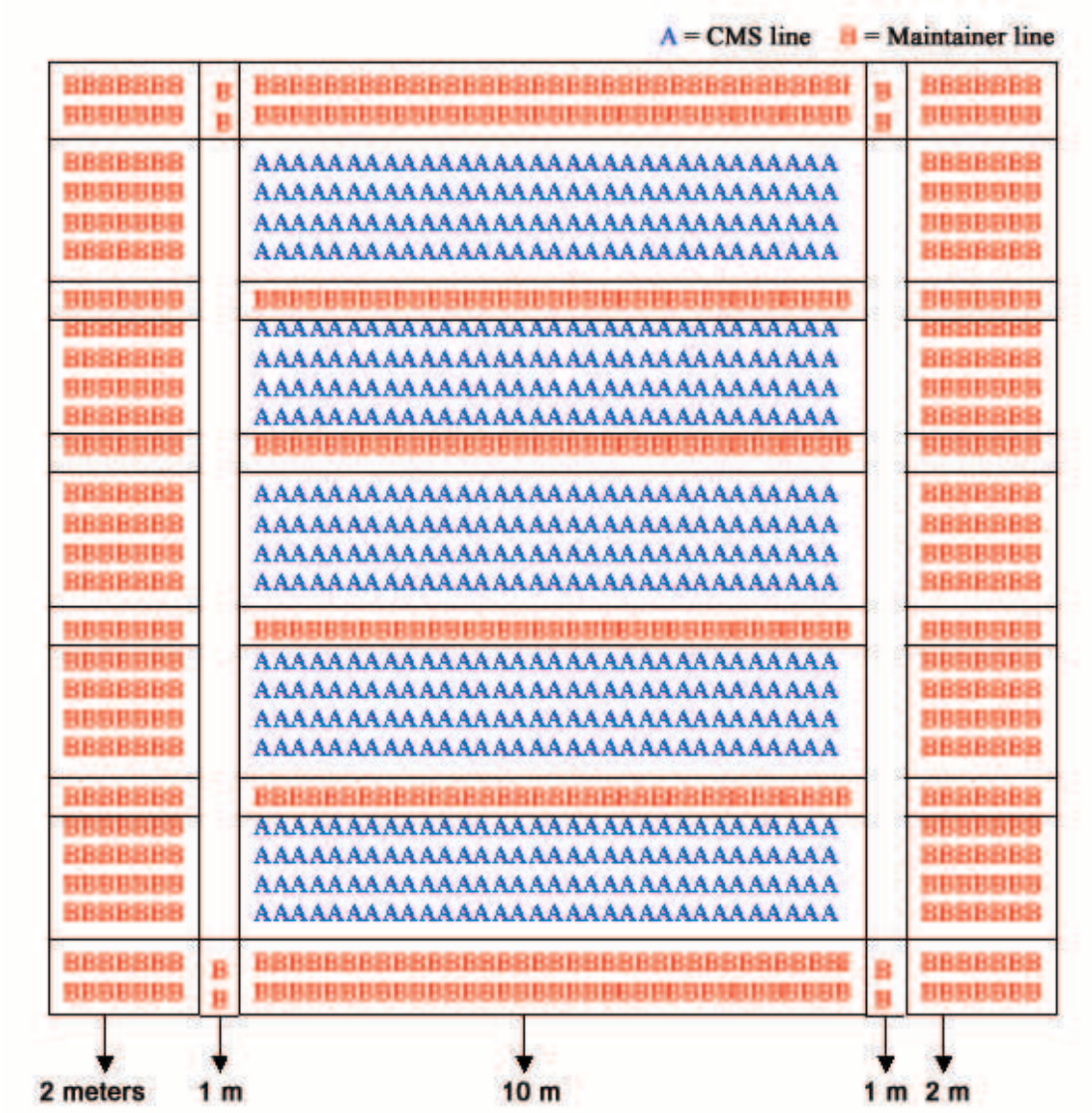

Fig 19. A standard field layout plan for seed production of a CMS line.

set on male-sterile plants will be observed as a consequence of natural out-crossing. Our experience at ICRISAT shows that insect activity at the farm is sufficient for the development of a full pod load. However, if for some reason the pod load on the male-sterile plants is not full and the pollinator plants have also podded, then de-podding of male rows will help in the

emergence of second flush of flowers. In the short-duration group, more than one harvest of the crossed pods is possible. In the seed multiplication of ICPA 2039 sown on 9 June 2005, two harvests were made and 27 kg of crossed seed was harvested from 225 sq m block (Fig 20) with an estimated yield of 1111 kg ha^{-1}. The pods should be harvested when their color turns from green to grey. It is advisable that threshing of pods should commence after three days of sun drying. The seed thus harvested be again dried in sun and packed after treating with Malathion powder @ 1 g kg^{-1} seed. From the same seed production block 'B'-line seed can also be harvested. In case a large quantity of 'B'-line seed is required, it may be grown in isolation. In a similar way, the seed of R-line can be produced in isolation.

15.5 Certified hybrid (A × R) seed production

In a three-line hybrid seed production system, the hybrid seed produced by crossing A-line with R-line, is commonly called certified seed production,

Fig 20. Maintenance of new CMS line, ICPA 2039, at Patancheru.

and is grown in larger scale. In certain cases, the certified seed may also be produced at community level. For the production of certified seed of hybrids, the A-line and its pollen parents (R-line) are grown in 4:1 ratio in an isolated block (Fig 21). Some additional rows of pollen parent can also be sown on each side of the plot. This will enhance pollen availability. The

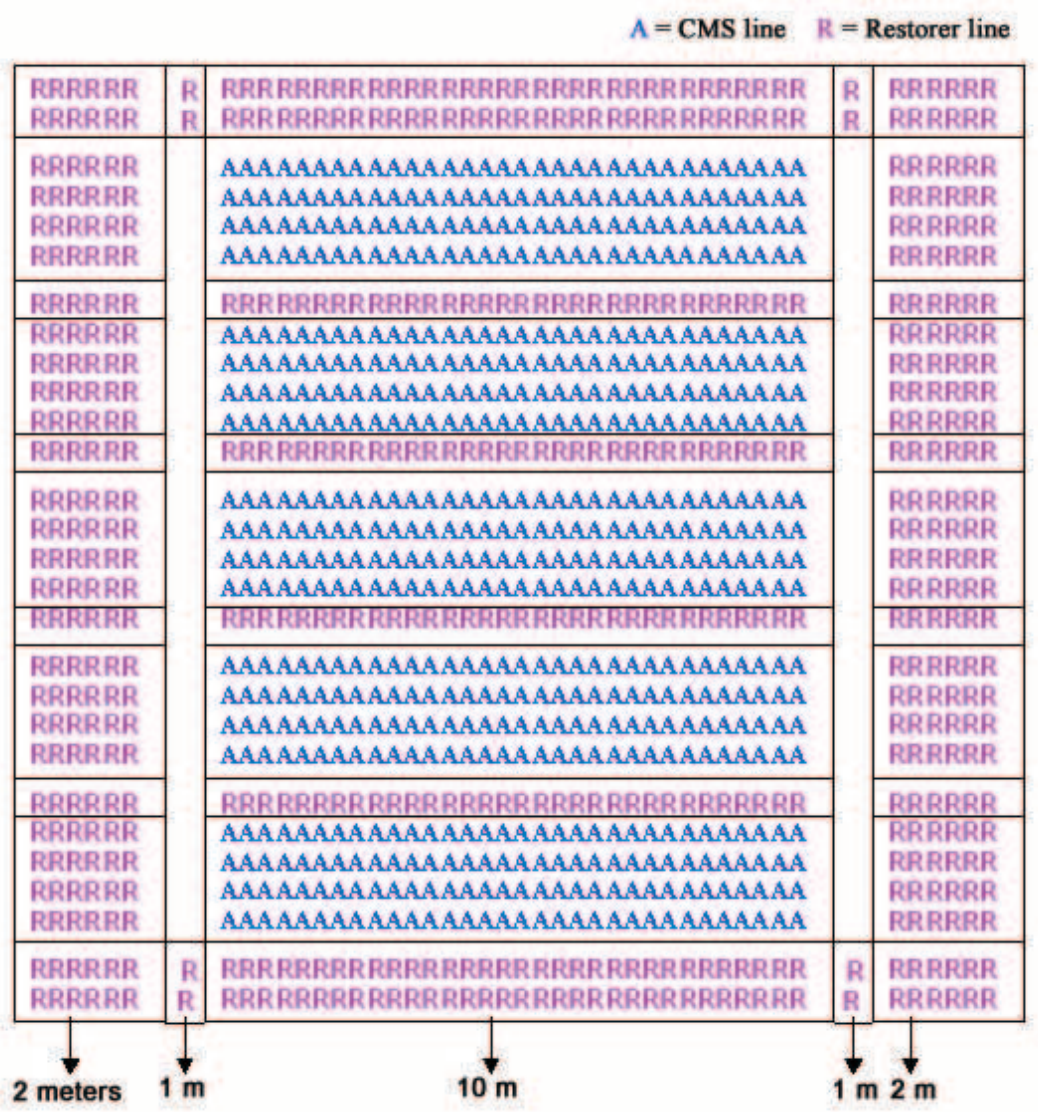

Fig 21. A standard field layout plan of a hybrid seed production plot in isolation.

pollinating insects actively visit the male and female flowers in a random way and in the process collect pollen and carry out hybridization. The ratio of 4 A-lines: 1 R-line cannot be recommended for all the environments and depending on the insect activity, this ratio could be increased or decreased. If the hybrid parents are of short maturity group, then multiple harvests in the hybrid production block are possible. The seed from the pollinator rows can be used in subsequent generations also. In case the demand for R-line seed is high, then it should be multiplied in an isolation block.

16. Seed Storage

The postharvest seed management is essential to ensure high quality of germination and productivity. This problem is acute in early maturing types because the time between harvest and next season's sowing is about 7–8 months. A number of external factors such as seed moisture, relative humidity, temperature, and infestation by stored grain pests affect the viability of seed during storage. The seeds damaged by bruchids do not germinate well and it results in poor plant stand. Therefore, the seed should be well cleaned and dried to 9.0% moisture. Fumigation of store by Aluminum phosphide (celphhos) and disinfection of gunny bags with 0.1% Malathion 50 EC is recommended. For long-term storage the seed should be mixed with 5% Malathion dust @ 300 g 100 kg^{-1} seed and kept under air tight containers. Pigeonpea seed can also be treated with 7.5 ml rapeseed or groundnut oil per kg of seed. By this way, the seed can be kept safely for 8–9 months. For storing seed in vapor proof containers the maximum moisture should be 8.0%.

The seed can also be solarized for a couple of days before storing them in shade (Chauhan and Ghaffar 1999). High temperatures (about 65°C) in polythene bags due to sunrays will kill any living insect pest. Such bags can be stored for longer period without any chemical treatment and thus the seed would remain safe for both sowing as well as consumption.

The following general practices may also help in reducing the incidence of insect damage during storage:

- Clean the seed store and remove the old seed lots. Do not store new seed with old seed,
- Disinfect the floor and walls of the store well in advance by spraying with 1% Malathion (50 EC),

- Plug all the cracks in floor or walls of the store room to prevent entry of vermin,
- Use new gunny bags lined with polythene for storing seed,
- In case of old bags, disinfect them with 0.1% Malathion 50 EC or with Fenvelrate 20 EC. Dip the old gunny bags in this solution for 10–15 minutes and dry properly in shade before storing the seed.

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Annexures

Annexure I. Pigeonpea Varieties and Hybrids Released in India

S. No.	Variety	S. No.	Variety	S. No.	Variety
1	PUSA AGETI	41	MARUTI (ICP 8863)	81	PUSA 85
2	TYPE-21 (T 21)	42	PUSA-33	82	AKT 8811
3	PRABHAT	43	TTB-7	83	PUSA 992
4	UPAS 120	44	T-7	84	ICPL 332 (ABHAYA)
5	HY-1	45	JAGRITI (ICPL-151)	85	BIRSA ARHAR 1
6	HY-2	46	ICPH-8	86	MA-6
7	HY-4	47	JA-4	87	GWALIOR-3
8	TYPE 17	48	GUJARAT TUR-100	88	DA-11 (SHARED)
9	BDN-1	49	GUJARAT VEGETABLE TUVER-1	89	MAL 13
10	BDN-2	50	ICPL-87119 (ASHA)		
11	HY-5	51	PUSA-855		
12	HY-3A	52	VAMBAN-1		
13	HY-3C	53	PUSA-9		
14	PALNADU (LRG-30)	54	CO-6		
15	JA-3	55	KONKAN TUR-1		
16	CHUNI (B-517)	56	BSMR-175		
17	SWETA (B-7)	57	MADHIRA-66		
18	GS-1	58	AL-201		
19	PT-221	59	PPH-4		
20	PUSA-74	60	BSMR-736		
21	AL-15	61	JAWAHAR KM-7		
22	NO. 290-21	62	COPH-1		
23	NO. 148	63	NARENDRA ARHAR-1 (NDA-88-2)		
24	NO. 84	64	COPH-2		
25	PT-301	65	AMAR (KA-32-1)		
26	C-11	66	SARITA		
27	HYDERABAD-185	67	PARAS (H-82-1)		
28	VISHAKA-1	68	AZAD K 91-25 (M)		
29	20 (105) (RABI)	69	DURGA (ICPL 84031)		
30	CO-4	70	MALVIYA VIKALP (MA-3)		
31	T-15-15	71	APK-1 (ARG-102)		
32	TAT-10	72	VAMBAN-2 (VRG-4)		
33	SA-1	73	LAXMI (ICPL-85063)		
34	CO-2	74	TS-3		
35	CO-3	75	BSMR-853 (VAISHALI)		
36	CO-5	76	SELECTION-31		
37	PUSA-84	77	PA-3		
38	MANAK (H-77-216)	78	LRG-36		
39	BAHAR	79	SAGAR (H77-208)		
40	ICPL-87 (PRAGATI)	80	TT-5		

Source for S. No 1-76: Shanmughan and Gunasekeran (2003).
Source for S. No 77-89: Singh et al. (2005).

Annexure II. Pigeonpea Plant and Seed Descriptors

A. Vegetative Traits

Growth habit

1. Erect and compact
2. Semi-spreading
3. Spreading
4. Trailing

Plant height (cm)

At maturity

Plant Stand

Number of plants at harvest

Number of branches

1. Primary
2. Secondary
3. Tertiary branches born on secondary branches

Stem Color

Royal Horticultural Society (RHS) colour codes are given in parentheses beside descriptor states

1. Green (yellow-green group 144B)
2. Sun red (greyed-red group 178B)
3. Purple (greyed-purple group 183A)
4. Dark purple (greyed-purple group 187A)

Stem thickness (mm)

1. Thin (<5 mm)
2. Intermediate (5-13 mm)
3. Thick (>13 mm)

Leaf size (cm^2)

Area of middle leaflet on a secondary branch

Leaflet shape

1. Lanceolate
2. Narrow-elliptic
3. Broad-elliptic
4. Obcordate

Leaf hairiness (lower surface of the leaves)

1. Glabrous
2. Pubescent

B. Inflorescence and Fruit

Days to flower

From sowing or first irrigation/rainfall to when 50% of plants flower

Duration of flowering

From 50% flowering to end of flowering

Vigour at 50% flowering

1. Low
2. Intermediate
3. High

Days to 75% maturity

From sowing or first irrigation/rainfall to 75% maturity

Base flower color

Main color of the petals. Royal Horticultural Society (RHS) color codes are given in parentheses beside descriptor states.

1. Ivory (green-yellow group 1)
2. Light yellow (yellow group 6D)
3. Yellow (yellow-orange group 14A)
4. Orange-yellow (orange-red group 31A)

Second flower color

Color of streaks on dorsal side of the vexillum (flag) and second color of the wings and keel. Horticultural Society (RHS) color codes are given in parentheses beside descriptor states.

1. Red (red group 45A)
2. Purple (greyed-purple group 186A)

Pattern of streaks

Pattern of second color on the dorsal side of a flag (standard petal).

1. Sparse streaks
2. Medium amount of streaks
3. Dense streaks
4. Uniform coverage of second color

Flower pattern

1. Determinate
2. Semi-determinate
3. Indeterminate

Raceme number

Average number of racemes from 3 randomly selected plants in a row

Seeds per pod

Average of 10 randomly selected pods from 3 randomly selected plants in a row

Pod color

Main color of the pod. Royal Horticultural Society (RHS) color codes are given in parentheses besides descriptor states.

1. Green (yellow-green group)
2. Purple (greyed-purple group)
3. Mixed, green and purple
4. Dark purple (greyed-purple group)

Pod form

1. Flat
2. Cylindrical

Pod hairiness

1. Glabrous
2. Pubescent

Pod bearing length (cm)

Distance between lowest and topmost pod on the plant

C. Seed Traits

Seed color pattern

1. Plain
2. Mottled
3. Speckled
4. Mottled and speckled
5. Ringed

Base seed color

1. White (yellow-white group)
2. Cream (greyed-white group)
3. Orange (greyed-orange group)
4. Light-brown (yellow-orange group)
5. Reddish-brown (reddish-brown group)
6. Light grey (grey-brown group)
7. Grey (greyed-green group)
8. Purple (greyed-purple group)
9. Dark purple (black group)
10. Dark grey (black group)

Seed second color

Second color of seed coat coded as in for base color above

Seed eye color

Color around hilum, coded as in for base color

Seed eye width

1. Narrow
2. Medium
3. Wide

Seed shape

1. Oval (egg shaped)
2. Globular (pea shaped)
3. Square (angular)
4. Elongate

Hilum

Presence of seed strophiole
0 Absence
+ Present

100-seed weight (g)

Estimated from a random sample taken from total row yield

D. Seed Yield

Expressed on a 1-9 scale, where

1. Low
2. Average
3. High

Harvest index

Ratio of total grain yield and total biological yield taken from 3 randomly selected plants in a row

Shelling percentage (%)

Calculated from seed-pod ratio of 3 randomly selected plants in a row.

E. Quality Traits

Protein content (%)

Whole seed crude protein percentage based on dry weight using the dye-binding method or automatic protein analyzer.

Dhal milling (%)

After milling (dehusked split peas)

Cookability of dhal

Increase in volume (v/v) after soaking for 24 h and boiling for 25 min

Cookability of dry seeds

Increase in volume (v/v) after soaking for 24 h and boiling for 25 min. If possible, run a regular test and determine the actual cooking time for dry seed without soaking.

F. Abiotic Stress Susceptibility

Scored under artificial and/or natural conditions, which should be clearly specified. These are coded on a susceptibility scale from 1 to 9 viz.:

1. Very low or no visible sign of susceptibility
2. Low
3. Intermediate
4. High
5. Very high

Annexure III. Quality Seed Standards in Pulses

	Isolation distance (meter)		Plants affected by seed-borne diseases		Off types %		Other crop seed (per kg)		Crops of other distinguishable variety (per kg)		Germination (including hard seed) (%)	
Crop	F	C	F	C	F	C	F	C	F	C	F	C
Urdbean	10	5	-	-	0.1	0.2	5	10	10	20	75	75
Mungbean	10	5	0.1	0.2	0.1	0.2	5	10	10	20	75	75
Chickpea	10	5	0.1	0.2	0.1	0.2	None	5	5	10	85	85
Horsegram	10	5	0.1	0.2	0.1	0.2	None	10	5	10	75	75
Indian bean	10	5	-	-	0.1	0.2	None	10	5	10	80	80
Lathyrus	10	5	0.1	0.2	0.1	0.2	None	None	5	10	75	75
Lentil	10	5	-	-	0.1	0.2	5	10	10	20	75	75
Mothbean	10	5	-	-	0.1	0.2	5	10	10	20	75	75
Fieldbean	10	5	-	-	0.1	0.2	5	10	10	20	75	75
Fieldpea	10	5	-	-	0.1	0.2	None	5	5	10	75	75
Pigeonpea	200	100	-	-	0.1	0.2	5	10	10	20	75	75
Rajmash	10	5	5	0.2	0.1	0.2	None	None	5	10	75	75

F: Foundation seed
C: Certified seed

Annexure IV. Package of Cultural Practices for Short-Duration Pigeonpea

Broad guidelines for short-duration cultivars

Fertilizer requirements: In general not recommended. If soils are deficient in phosphorus, a basal application of 100 kg Di-Ammonium Phosphate (DAP) is suggested.

Seed and sowing: Pure seed of good quality should be used. Pigeonpea is often cross-pollinated, hence off-type plants should be rogued out before flowering. When growing for seed a distance of at least 200 m should separate one variety from the other.

Sow at proper time when moisture is adequate for germination on well-prepared field with good drainage. Pigeonpea is susceptible to waterlogging.

Keep row to row distance of 45 to 60 cm (depending on the crop growth) and within the row spacing should be 10 cm to 20 cm. Sow 4–5 cm deep and cover firmly.

Weed control: The slow initial growth of pigeonpea seedlings makes the crop particularly prone to weed competition in the first 6 weeks of growth. During this period keep the crop free from weed competition by hand hoeing. Pre-emergence herbicides such as mixture of Basalin® (@ 0.75 kg a.i/ha), Gessagard® (@ 1.25 kg ai/ha) with an additional light hand weeding 3-4 weeks after sowing can effectively control weeds.

Pest Control: Pod and seed boring/sucking insects like pod borer *Helicoverpa*, pod sucking bug (*Clavigralla*), podfly (*Melanoromyza obtusa*) and blister beetles (*Mylabris pustalata*) are the major pests which may cause reduction in yields and grain quality and sometimes total crop loss may occur. Timely and effective

insecticidal spray is recommended. The following insecticides have been found effective. But use what is available in your location such as Ambush, Karate, Rogor, Sherpa, Decis, etc.

Spray knapsack sprays (500 L of spray liquid/ha).

Ultra low volume (ULV) sprayers are now available and these may also be used since they require much less water (6-7 L/ha).

Give first spray at flowering and a second spray 10-15 days after the spray. If you still observe damage, a third spray 10–15 days after the second may be given.

Blister beetles (*Mylabris pustulata*) can not be controlled by insecticides effectively but reduce their population by capturing using gloves and destroying.

Harvest:

For dry grain, harvest when the pods are fully mature and have turned brown in colour (straw colour). Either pick the pods or cut the branches. Dry in sun and thresh. Clean the grain and store in clean containers free of weevils.

Weevils are a major storage pest. Control by use of Actelic or any fumigant.

For green pods, harvest when pods are fully filled but still green. Harvesting intervals of 4–7 days are recommended.

Annexure V. Package of Cultural Practices for Medium and Long-Duration Pigeonpea

Broad guidelines for medium and long-duration cultivars

Land Preparation: The field should be ploughed and harrowed to obtain fine tilth. The field should have good slope to ensure proper drainage.

Fertilizer requirements: As a general recommendation, 18 kg N ha^{-1} and 20 kg P ha^{-1} is recommended. This requirement can be met by basal application of 100 kg DAP (Di-Ammonium Phosphate).

Seed and sowing : Good seed (pure with high germination percentage) should be sown. Seeds should be drilled in rows to maintain row to row and plant to plant spacing of 75 and 20 cm respectively. This would give approximately 66,600 plants ha^{-1}. A seed rate of 10–12 kg ha^{-1} is sufficient to obtain normal plant population. The sowing should be done between 15 to 30 June to obtain high yield. However delayed sowing up to 15 July has not adversely affected the yield at ICRISAT Center.

Weed control: The slow initial growth of pigeonpea seedlings makes the crop particularly prone to weed competition in the first six weeks of growth. During this period two hand weedings (first 25–30 days after sowing and second about 45–50 days after sowing) are sufficient to manage weeds. Alternatively spraying of a mixture of pre-emergence herbicides such as Basalin and Prometryn (each 1.5 L ha^{-1}) followed by one hand weeding at 25–30 days after sowing has effectively controlled weeds at ICRISAT Center.

Irrigation: Irrigation is generally not recommended if the crop is grown on deep Vertisols. However, if the crop is grown on light Vertisols or Alfisols, one irrigation at early podding stage will be beneficial.

Pest Control: The pod borer (*Helicoverpa armigera*) is the most damaging pest in medium-duration pigeonpea. Monocrotophos (36% EC, one liter ha^{-1}) or Thiodan (35% EC, two liters ha^{-1}) or Quinalphos (25% EC, two liters ha^{-1}) in 500 L of water is recommended.

The first spraying with Monocrotophos or Thiodan should be done at 50% flowering. Quinalphos is recommended at 10-15 days after the first spray. Two sprays should be sufficient to control this pest. However, a third spray of Monocrotophos or Thiodan can be done after 10 days of second spray if pest incidence is high.

Harvesting and Threshing: The crop can be harvested by cutting the plants at the base when the crop reaches 75% maturity (when 75% pods of a plant are mature). The threshing can be done as per the local practices.


Seed production plot


Harvesting by machine


Un-loading of seed


Seed drying


Seed treatment


Seed cleaning


Filling bag with seed


Seed weighing


Seed loading

About ICRISAT®

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is a nonprofit, non-political organization that does innovative agricultural research and capacity building for sustainable development with a wide array of partners across the globe. ICRISAT's mission is to help empower 600 million poor people to overcome hunger, poverty and a degraded environment in the dry tropics through better agriculture. ICRISAT belongs to the Alliance of Future Harvest Centers of the Consultative Group on International Agricultural Research (CGIAR).

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