

Genetics and Breeding of Pigeonpea

Compiled by

Faujdar Singh and D.L. Oswalt



Skill Development Series no. 10



ICRISAT

Human Resource Development Program

**International Crops Research Institute for the Semi-Arid Tropics
Patancheru, Andhra Pradesh 502 324, India**

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Pigeonpea Genetics

Qualitative Inheritance

Growth habit, stem color, plant height, leaf shape, and foliage color, flower color, pistil conditions, pod color, seed-coat color, and disease resistance show qualitative inheritance.

Growth habit. Chaudhari and Thombre (1975) reported a 3:1 ratio for growth habit. Growth habit was reported to be controlled by three genes (*Cgra*, *Cgrb1*, and *Cgrb2*) with a segregation of 45 erect: 9 creeping: 10 prostrate as well as two complementary genes, 9 spreading: 7 erect (Deokar et al. 1971a and 1972b).

The segregation of creeping and erect habit in the F₂ showed 13 creeping: 3 erect, suggesting two factors one of which has inhibitory action (Shinde et al. 1971). The other studies are listed in Table 1.

Table 1. Genetics of growth habit.

Traits	Gene(s) / Description(s)	Reference(s)
Spreading vs erect	Spreading branch (<i>Sbr</i>) habit dominant to erect branching (<i>sbr</i>).	D'Cruz and Deokar 1970; Deokar and D'Cruz 1972.
	Erect monogenic dominant to spreading.	Rekhi 1966; Sheriff et al. 1975.
	3 spreading : 1 erect	Narkhede et al. 1980
	Erect habit partial dominant to spreading.	Shaw 1936
	Crowded habit of inflorescence dominant to open.	Shaw 1936
Determinate vs indeterminate	Determinate monogenic recessive to indeterminate (IDT)	Shaw 1936; Reddy and Rao 1974; Saxena and Sharma 1990.
	IDT (<i>Dt1</i>) and semideterminate (SDT) (<i>Dt2</i>) governed by single dominant genes. IDT results as <i>Dt1/dt1</i> and SDT: controlled by <i>Dt2/dt2</i> . Determinate growth (DT) results with all recessive alleles (<i>dt1dt1 dt2dt2</i>). DT types were obtained by crossing IDT x SDT resulting in a ratio of 12 IDT : 3 SDT : 1 IDT.	Gupta and Kapoor 1991
	Two dominant genes, ' <i>Id</i> ' and ' <i>D</i> ' with inhibitory action control an indeterminate growth habit.	Waldia and Singh 1987

Stem characters. Ganguli and Srivastava (1967) reported incomplete dominance of purplish pigmented stem color to the green stem. Other studies are listed in Table 2.



Table 2. Genetics of stem characters.

Trait (s)	Gene (s) / Description (s)	Reference (s)
Stem color	Purple (Pst) dominant to green (pst) 3 purple : 1 green	D'Cruz and Deokar 1970 D'Cruz et al. 1974; Narkhede et al. 1980.
	Dwarfness controlled by single recessive gene.	Marekar et al. 1978
Height	Tall ($T_1T_1T_2T_2$) x dwarf ($t_1t_1t_2t_2$), segregation ratio in F_2 , 15 tall: 1 dwarf duplicate genes for D_0 of lines.	Waldia and Singh 1987.
	Crosses involving dwarf phenotypes D_0 , PD_1 , and PBNA with tall ICPL 1, BDN 1, ICPL 366, and NP (WR) 15 indicate dwarf phenotypes controlled by a single recessive gene. F_2 ratio's 3:1; test cross ratio's 1:1. Dwarf lines D_0 and PD_1 involve the same dwarfness allele. Cross D_6 x PBNA (both dwarfs) also gives ratio of 3 D_6 type : 1 PBNA type; showing dominance of D_6 type over PBNA. Similar was the case when PBNA was crossed with PD_1 . They designated gene T_3T_3 for tall types, t_3t_3 for PD_1/D_6 dwarfs and gene th_3th_3 for PBNA dwarf phenotypes.	Saxena et al. 1989a

Leaf characters. The pigeonpea leaflets are trifoliate and lanceolate. Segregation of stipule length was observed as a ratio of 9 long : 7 short with two complementary genes 'Lsta' and 'Lstb' (Deokar and D'Cruz 1972). A broad-leaflet base was controlled by two dominant genes (*Bdlba* and *Bdlbb*) which were dominant to a narrow leaf base (Kolhe et al. 1972). Other leaf traits are listed in Table 3.

Table 3. Genetics of leaf characters.

Trait (s)	Gene (s) / Description (s)	Reference (s)
Shape	Lanceolate leaflets (<i>Lit</i>) monogenic dominant to short leaflets (<i>Lst</i>) 3:1.	D'Cruz and Deokar 1970
	Two genes (<i>Bdlba</i> and <i>Bdlbb</i>) control broad leaflet base, which is dominant to narrow. Notchless leaf apex (<i>Lit</i>) dominant to notched.	Kolhe et al. 1972
	Lanceolate leaflets (<i>Llt</i>), Round leaflet shape (<i>Rlt</i> and <i>Llt</i>), Obcordate- oblong leaflet (<i>Rlt</i> and <i>Clt</i>), Obcordate-round leaflet (<i>Rlt</i>), Obcordate-connate leaflet (<i>Clt</i>)	Ghatge and Kolhe 1984
Petiole size	Long petiole (<i>Lpt</i>) dominant to short petiole (<i>lpt</i>).	
Foliate number	Trifoliate leaf (<i>Tf</i>) dominant to multifoliate	Patil et al. 1972
Leaf surface	Gene for normal leaf (<i>Nh</i>) ; Gigas leaf (<i>nh</i>) with crinkled surface	Pokle 1976
Apex	Pointed leaf apex (monogenic) dominant to round apex	Rekhi 1966

Flower characters. Ganguli and Srivastava (1967) reported late flowering dominant to earliness. Genes reported for flower characters are given in Table 4.

Table 4. Genetics of flower characters

Trait (s)	Gene (s) / Description(s)	Reference (s)
Petal color	Monogenic 3 orange:1 yellow	Dave 1934
	Yellow ventral surface of standard petal (<i>Yvs</i>) dominant to pale yellow (<i>yvs</i>).	D'Cruz and Deokar 1970
	Complementary for ventral surface of standard petal, F_2 segregation 9 yellow-purple : 7 yellow veins flowers.	D'Cruz et al. 1973
	Red veins on dorsal surface of standard petal dominant to yellow. Governed by two genes (<i>Rdvds</i> _a and <i>Rdvds</i> _b).	Patil 1970 ; Jain and Joshi 1964.
	Duplicate gene W_1 and W_2 results in white flowers. These in presence of inhibitory gene (<i>Iy</i>) result in yellow flower.	Patil and D'Cruz 1962
	Controlled by four genes, one basic (<i>Rvds</i>), one inhibitory (<i>I-Rvds</i>) and two anti-inhibitory (<i>A-I-Rvds</i> ₁ and <i>A-I-Rvds</i> ₂).	Marekar and Chopde 1985
	Two genes (<i>Pvds</i> ₁ and <i>Pvds</i> ₂) control vein color on the back side of the standard petal.	Deokar et al. 1971a
	Purple standard petal dominant to yellow, and orange wings to yellow.	Ganguli and Srivastava 1967
	Trigenic model for petal color; basic color (<i>y</i>) ; absence of variation (<i>u</i>), and (<i>p</i>) locus interact with <i>y</i> locus.	Jain and Joshi 1964
	Pigmentation of standard petal controlled by genes; yellow (<i>Apcev</i> , or <i>apcev</i>); yellow streaked with red (<i>Apcevs</i>); uniform purple (<i>APCEVs</i>); yellow streaked with purple (<i>ApCevs</i>); purple streaked (<i>APCEVs</i>); and blood red (<i>APCEVS</i>).	Menzes 1956
Keel shape	Boat shaped keel dominant to filiform, united keel dominant to free.	Kolhe et al. 1972
Density	Dense inflorescence dominant to open.	Kolhe et al. 1972
Male sterility	Translucent anthers single gene recessive <i>ms</i> ₁ ; arrow-head shaped anthers recessive gene <i>ms</i> ₂ .	Saxena et al. 1983b

Pod characters. Two genes *Gpstpd* and *Gpshpd* control the pod color in epistatic manner, 9 purple: 3 green with purple streaks: 4 green with purple shades (Deokar et al. 1971a). Four-seeds *pod*⁻¹ monogenically dominant to three-seeds *pod*⁻¹ (Rekhi 1966). Singh et al. (1980) reported reciprocal difference with poor pod setting as a dominant character. Backcrosses showed a cumulative effect. The other genes proposed are listed in Table 5.



Table 5. Genetics of pod characters.

Trait	Gene (s) / Description (s)	Reference (s)
Pod color	Streak pod color dominant to green. Gene ' <i>Blpd</i> ' for ripe pod color. Dihybrid supplementary gene action.	D'Cruz et al. 1970; Patil 1970
	Gene ' <i>Gpstdp</i> ' for green pod with purple streak.	Deokar et al. 1971a
	Gene <i>Gpshpd</i> for supplementary (9 purple : 3 green with purple streak : 4 green with purple shade). Greenish-black pod color dominant to maroon blotched.	Patil and D'Cruz 1965

Seed characters. D'Cruz et al. (1974) reported monogenic inheritance of seed-coat color (3 brown : 1 white). D'Cruz et al. (1973) also reported complementary genes (9 brown : 7 white) for seed-coat color. The purple-splashed seed coat was incompletely dominant over chocolate seed coat and light-brown seed coat (Ganguli and Srivastava 1967). The genes proposed for seed characters are listed in Table 6.

Table 6. Genetics of seed characters.

Trait	Gene (s) / Description (s)	Reference (s)
Seed coat color	Brown seed coat partially dominant to white (monogenic).	Rekhi 1966
	Brown seed coat (<i>Brsd</i>) dominant to white.	Patil 1970
	Purple-splashed seed coat dominant to chocolate and light-brown seed coat.	Ganguli and Srivastava 1967
	Gene for crimson seed-coat (R) color; black seed coat (B); and white seed coat (P).	Singh 1971
	Reddish brown seed color governed by three genes, ' <i>Brsd₁</i> ', ' <i>Brsd₂</i> ' and ' <i>Brsd₃</i> '.	Patil et al. 1972

Linkage Studies

The vein color (*Drv*) of the standard petal was reported as being linked with the seed-coat color (*Plsd*) (Chaudhari and Thombre 1975). The complementary factor of vein color showed a linkage with the basic factor of leaflet shape, with a crossover value of 24% (Chaudhari and Thombre 1977). D'Cruz and Deokar (1970) reported that the spreading branch habit (*Sbr*) forms a linkage group with the purple stem (*Pst*), lanceolate leaflets (*Llt*), and long petiole (*Lpt*); while the maroon-blotched pod (*Gppd*) gene forms a linkage group with the red-brown seed coat (*Brsda*).

D'Cruz et al. (1971) reported that stem color (*Pst*) was linked with leaf thickness (*Tnlt*) and leaflet shape (*Llt*) forming a linkage group *Pst*, *Tnlt*, and *Lit*.

Deokar and D'Cruz (1972) reported two linkage groups. I. branching habit (*Sbbr*), petiole length (*Lsta*), and leaflet shape (*Llt*), and; II. Stem color (*Psta*) linked with dorsal surface (*Oyvsa*) of the standard petal. The other genes were independent.

Brown seed (*Brstd*) was observed linked with (*Gpshpd*) the purple streaked pod, and the gene '*Cgra*' controlling growth habit was found linked with the '*Pvds*' of vein color of the standard petal (Deokar et al. 1971a). The leaflet shape gene '*let*' was found linked with the seed-coat color '*Rsd*', with a crossover value of 21% (Deokar et al. 1972a). Deokar et al. (1971b) reported linkage of genes for red veins of corolla with red testa with a crossover value of 8%.

Patil and D'Cruz (1965) reported linkage between color of the unripe pod (*Blp*) and leaflet shape (*Llt*) with a recombination value of 3%.

Marekar (1982) reported a linkage group involving genes for early-flowering habit (*Efla*), branching habit (*Clbr*), and seed size (*Bsda*). Another linkage group was observed between plant height (*PTht*) and stem condition (*Strstb*).

Disease Resistance

a) **Wilt.** Inheritance of wilt resistance showed a ratio of 9:7, with resistance being dominant (Shaw 1936), controlled by multiple factors (Pal 1934), the presence of two complementary genes (Pathak 1970), and a single dominant gene (Joshi 1957). Resistance to wilt showed a single gene dominant to susceptibility (Pawar and Mayee 1986). Resistance was dominant over susceptibility (Sharma 1986).

b) **Sterility mosaic disease (SMD).** Sharma et al. (1984) explained the inheritance of sterility mosaic assuming the presence of four alleles at two loci. Two alleles control resistance, one of which was dominant and the other recessive to tolerance. The allele responsible for susceptibility was found dominant over the other three alleles; *alb1* susceptible; *a3b3* tolerant; *a2b2* and *a4b4* resistant. Singh et al. (1983a) reported SMD was governed by four independent nonallelic genes. The presence of at least one dominant and one recessive gene was necessary for resistance. Singh et al. (1983a) also reported four independent nonallelic genes (*Sv₁*, *Sv₂*, *Sv₃* and *Sv₄*) controlling sterility mosaic disease. At least one dominant and one recessive genes were necessary to express resistance. Resistance was controlled by four independent loci, two duplicate dominant genes (*Sv₁* and *Sv₂*), and two duplicate recessive genes (*sv₁* and *sv₄*). For expressing resistance reaction at least one dominant allele at locus 1 or 2 and homozygous recessive at locus 3 or 4 are necessary.

c) **Phytophthora and alternaria blight.** Resistance to phytophthora blight was reported to be governed by a single recessive (*Pdl*) gene (Sharma et al. 1982). Alternaria blight was controlled by a single recessive (*abrl*) gene (Sharma et al. 1987), further Singh et al. (1988) confirmed that it is governed by monogenic recessive gene *al*.

Quantitative Inheritance

Heritability and genetic advance. The heritability and genetic advance studies are summarized in Tables 7a and 7b.

Table 7a. Estimates of heritability broad sense (H), narrow sense (h) and genetic advance (G) for vegetative characters.

Character (s)	Estimates	References
Flower initiation	High H	Sharma et al. 1973a
Days to flowering	High H High h High H	Munoz and Abrams 1971; Singh and Pandey 1974; Chandra et al. 1975
Plant height	High H and high G High H and moderate G High H Moderate H and G Low H	Hiremeth and Talwar 1971; Jag Shoran 1983 Munoz and Abrams 1971; Kumar and Reddy 1982. Kumar and Haque 1973 Joshi 1973
Primary branches plant ⁻¹	High H and low G High H	Hiremeth and Talwar 1971 Govinda Raju and Saratchandra 1972; Chandra et al. 1975.
Secondary branches plant ⁻¹	High H	Kumar and Reddy 1982
Maturity	Moderate H and G High H and Moderate G	Kumar and Haque 1973 Jag Shoran 1983
Total dry matter	High H and G	Khapre and Nerkar 1986
Number of leaves	High H and high G	Kumar and Haque 1973
Plant spread	High H	Govinda Raju and Saratchandra 1972

Table 7b. Estimates of heritability broad sense (H), narrow sense (h) and genetic advance (G) for pod and seed characters.

Character (s)	Estimates ¹	References
Number of pod clusters plant ⁻¹	High H	Kumar and Reddy 1982
Pods plant ⁻¹	High H and high G High H Low h	Hiremeth and Talwar 1971 Kumar and Reddy 1982 Dahiya and Barar 1977
Pod length	High H and low G High H	Hiremeth and Talwar 1971 Singh et al. 1972
Seed pod ⁻¹	High H and low G High H and high G Low H	Hiremeth and Talwar 1971 Kumar and Haque 1973 Joshi 1973; Chandra et al. 1975.
Seed yield plant ⁻¹	High H and high G	Khapre and Nerkar 1986
100-seed mass	High H and low G Low h High H	Hiremeth and Talwar 1971 Dahiya and Barar 1977 Munoz and Abrams 1971
Seed size	High H	Ratnaswamy et al. 1973

1. The high and low values are in relation to characters studied and the material involved in the experiments.

High heritability combined with high genetic advance is indicative of additive genetic variance (Johansen et al. 1955). The heritability estimates are highly influenced by genotype x environment interaction. So it is difficult to quantify the high or low value of heritability. Therefore, it should be interpreted on the basis of comparison of the traits measured in the same experiment. Also, the heritability value based on an experiment conducted at one location may not be as valuable as it is based on experiments conducted over several locations and years.

Gene effects. Fisher (1918) partitioned the genetic variance into additive, dominance and their interactions, additive x additive, additive x dominance, and dominance x dominance. The gene effects other than additive are referred to as nonadditive. Heritability and genetic advance values are indicative of gene effects. Likewise, high general combining ability (GCA) variance indicates a preponderance of an additive gene effect, whereas high specific combining ability (SCA) variance indicates nonadditive gene effects'. Selection is effective when a character is controlled by additive genes. In case of nonadditive gene effects, the utilization of hybrid vigor is considered more appropriate. Selected genetic studies in pigeonpea are summarized in Table 8a and 8b.

Table 8a. Estimates of gene effects in pigeonpea for vegetative characters.

Character(s)	Genetic variance(s)	Reference (s)
Days to flowering	Additive	Dahiya and Barar 1977.
Flower initiation	Additive	Sharma et al. 1973a; Venkateswarlu and Singh 1982.
Plant height	Higher additive than nonadditive High GCA than SCA thus more additive Additive Single recessive (d) gene for dwarf height	Singh and Pandey 1974 Sharma et al. 1973b Singh et al. 1983b Sen et al. 1966
Plant growth	Additive higher than nonadditive	Singh and Pandey 1974
Early maturity	Additive Partial dominance, additive and dominance	Dahiya and Satija 1978 Mohamed et al. 1985
Days to maturity	Additive Nonadditive	Sidhu and Sandhu 1981 Singh et al. 1983b; Patel et al. 1987
Leaf area	Additive	Sharma and Saxena 1983
Leaf mass	Additive	Sharma and Saxena 1983
Petiole length	Additive	Sharma and Saxena 1983
Petiole mass	Additive	Sharma and Saxena 1983
Fruiting branches	Additive	Singh et al. 1983b
Raceme length	Additive	Singh et al. 1983b



Table 8b. Estimates of gene effects in pigeonpea for pod and seed characters.

Character (s)	Genetic variance (s)	Reference (s)
Pods plant ⁻¹	Nonadditive (overdominance) Both additive and nonadditive Additive	Dahiya and Barar 1977. Venkateswarlu and Singh 1982. Singh et al. 1983b
100-seed mass	Nonadditive (overdominance) Additive Both additive and nonadditive Additive x additive Dominance x dominance	Dahiya and Barar 1977 Sidhu and Sandhu 1981; Singh et al. 1983b. Patel et al. 1987; Venkateswarlu and Singh 1982 Mohamed et al. 1985
Seed yield	Nonadditive (overdominance) Predominantly nonadditive Higher GCA variance than SCA thus additive Nonadditive Both additive and nonadditive	Dahiya and Barar 1977; Singh et al. 1983b Singh and Pandey 1974 Sharma et al. 1973b Dahiya and Satija 1978 Venkateswarlu and Singh 1982; Patel et al. 1987
Seed size	Additive with partial dominance of small seed size	Singh and Pandey 1974
Protein content	Nonadditive Both additive and nonadditive	Singh and Pandey 1974 Sharma et al. 1972
Early maturity	Additive Partial dominance, additive and dominance	Dahiya and Satija 1978 Mohamed et al. 1985
Pod width	Additive	Sidhu and Sandhu 1981
Seeds pod ⁻¹	Both additive and nonadditive Dominance, additive x dominance, and dominance x dominance	Venkateswarlu and Singh 1982 Mohamed et al. 1985

The genetic studies on pigeonpea (Table 8) showed that both additive and nonadditive gene effects were involved in the inheritance of quantitative traits. However, pod width, days to maturity, and 100-seed mass had predominantly additive gene effects (Sharma et al. 1972 and 1973b; Dahiya and Barar 1977; Pandey 1972). The nonadditive gene effects were more pronounced for grain yield and protein content (Pandey 1972; Dahiya and Barar 1977; Kapur 1977; Reddy et al. 1979; Sidhu and Sandhu 1981; Dahiya et al. 1977). The additive genetic variance can be exploited by simple progeny selection procedures. However, it becomes difficult to combine all desirable genes in a pure line due to linkage and the quantitative nature of characters. Therefore, population breeding approaches such as recurrent selection, sib-pollinated line selection techniques, and diallele selective-mating systems were advocated in pigeonpea (Sidhu and Sandhu 1981).

Kapur (1977) proposed an ideal plant type in pigeonpea with medium spread, early maturity, and high yield combined with photoperiod insensitivity and high harvest index. The main factor responsible for the lower yields in pigeonpea compared with wheat is poor harvest index. Therefore, to improve the yield of pigeonpea genetic reconstruction for a high harvest index is essential (Jain 1975; Sidhu and Sandhu 1981). It is suggested in pigeonpea

that selection for high harvest index would be practical under high population density (Singh and Shrivastava 1979).

Experiments conducted at ICRISAT Center helped to identify ideal plant types of pigeonpea for different environments. For high growth (7-8 t ha⁻¹) potential environments, where solar radiation, and temperatures are high and soil moisture availability and drainage are good, generally, genotypes of indeterminate growth habit, having high harvest index (>35%) are likely to perform better. For environments with moderate growth (5-6 t ha⁻¹), genotypes of determinate growth habit with a 30-35% harvest index, initial vigor and tolerance to drought, and water logging would be ideal (Y.S. Chauhan, ICRISAT, personal communication 1992) .

Character association. The correlations and path analysis studies in pigeonpea are summarized in Table 9. Ganguli and Srivastava (1972) reported mutual association among length of pod, number of pods, and 100-seed mass that were negatively correlated with grain yield. Total branches plant⁻¹, fruiting branches plant⁻¹, pods plant⁻¹, and leaves plant⁻¹ were significantly correlated with yield and among themselves. These could be used as selection criteria.

Table 9a. Correlation studies in pigeonpea.

Character(s)	Correlation(3)	Reference(s)
Positive correlations with		
Grain yield	Pods plant ⁻¹	Dasappa and Mahadevappa 1970; Ganguli and Srivastava 1972; Dahiya et al. 1978; Gupta et al. 1975; Kumar and Haque 1973; Kumar and Reddy 1982; Gunaseelan and Rao 1976; Malhotra and Sodhi 1977; Balyan and Sudhalcar 1985.
	Clusters plant ⁻¹	Veeraswamy et al. 1975; Malhotra and Sodhi 1977; Ram et al. 1976a.
	Total branches plant ⁻¹	Ganguli and Srivastava 1972; Beohar and Nigam 1972; Gupta et al. 1975; Kumar and Haque 1973; Baniwal et al. 1981; Kumar and Reddy 1982; Malhotra and Sodhi 1977; Ram et al. 1976a.
	Fruiting branches plant ⁻¹	Ganguli and Srivastava 1972
	Secondary branches	Singh et al. 1972; Balyan and Sudhakar 1985.
	Seeds pod ⁻¹	Dahiya et al. 1978; Kumar and Haque 1973
	100-seed mass	Dahiya et al. 1978; Balyan and Sudhakar 1985.
	Pod length	Singh et al. 1972
	Plant height	Kumar and Haque 1973; Singh et al. 1972; Baniwal et al. 1981; Kumar and Reddy 1982.
	Number of leaves'	Kumar and Haque 1973
	Harvest index	Ram et al. 1976a
Pods plant ⁻¹	Branches plant ⁻¹	Beohar and Nigam 1972; Joshi 1973

Table 9b. Path studies in pigeonpea.

Character (s)	Correlation (s) with	Reference (s)
Direct positive (path analyses) effect on yield		
Grain yield	Pods plant ⁻¹	Kumar and Reddy 1982; Gunaseelan and Rao 1976; Ram et al. 1976b; Reddy et al. 1975; Pokle and Mahalkar 1976; Patil et al. 1988.
	Primary branches	Kumar and Reddy 1982; Veeraswamy et al. 1975; Patil et al. 1988.
	Plant height	Kumar and Reddy 1982; Gunaseelan and Rao 1976; Veeraswamy et al. 1975; Patil et al. 1988
	Pod clusters plant ⁻¹	Ram et al. 1976b; Veeraswamy et al. 1975.
Negative correlations		
Grain yield	Plant height	Dahiya et al. 1978
	Days to flowering	Kumar and Hague 1973; Singh et al. 1972
	Days to maturity	Kumar and Haque 1973
	Protein content	Dahiya et al. 1977

Based on the above discussions selection for high yield could be based on highest number of branches plant⁻¹, pod clusters plant⁻¹ and pods plant⁻¹ (Gupta et al. 1975). Gunaseelan and Rao (1976) indicated that plant height and number of pods plant⁻¹ were the most important yield components. Malhotra and Sodhi (1977) reported that branch number, pod number, and cluster number form effective selection criteria for yield improvement in pigeonpea. Ram et al. (1976b) observed that number of primary branches, clusters plant⁻¹, and harvest index were the major yield components. Wakankar and Yadav (1975) reported that high pod number, secondary branches plant⁻¹ with high seed indices, and limited spreading were reliable selection criteria. Malik et al. (1981) suggested an ideal plant type should be short and bushy with profuse branching and podding, medium seed number and seed mass, more seeds pod⁻¹, and medium to late maturity.

Pod number and seed size were reported to be an important component of yield (Reddy et al. 1975). Significant direct effect of pods plant⁻¹ was observed on yield (Pokle and Mahalkar 1976). Hence Patil et al. (1988) concluded that plant height, pods plant⁻¹, effective branches plant⁻¹, and days to maturity are important attributes for yield improvement in pigeonpea.

Heterosis

Morbad and Solanki (1957) indicated 24% hybrid vigor in pigeonpea, though the best hybrid did not outyield the best parent. Shrivastava et al. (1976) recorded mean heterosis of 67% for yield, 96% for secondary branches, and 80% for number of pods plant⁻¹. The later two characters contributed the most for increased yield. Medium x medium, low x medium GCA crosses, and genetic diversity resulted in high hybrid vigor.

Venkateswarlu et al. (1981) reported a mean heterosis of 39% for yield and 16% for days to flowering, and pods plant⁻¹. In general early x late and medium x late maturity crosses resulted in high heterosis. Sinha et al. (1986) reported that most of the heterotic crosses with high yield involved low yielding parents and suggested that a measurement of heterosis is imperative for selecting lines for hybridization. A high number of branches had more plant spread and more pods cluster⁻¹. Hybrid vigor reported for important characters is given in Table 10.



Table 10. Hybrid vigor recorded for yield and yield components in pigeonpea.

Characters	References
Seed yield	Solomon et al. 1957; Sharma et al. 1973b; Veeraswamy et al. 1973; Shrivastava et al. 1976; Reddy et al. 1979; Marekar 1981; Vankateswarlu et al. 1981; Singh et al. 1983b and 1989; Omanga 1984; Sinha et al. 1986; Saxena et al. 1986a, 1989b; Patel et al. 1987; Cheralu et al. 1989; Jadhav and Nerkar 1983.
Pods plant ⁻¹	Veeraswamy et al. 1973; Shrivastava et al. 1976; Reddy et al. 1979; Venkateswarlu et al. 1981; Omanga 1984; Sinha et al. 1986, Saxena et al. 1986a, 1989b; Patel et al. 1987; Cheralu et al. 1989; Singh et al. 1989.
Seed size	Shrivastava et al. 1976; Reddy et al. 1979; Marekar 1981; Sinha et al. 1986 and 1989; Saxena et al. 1986a; Patel et al. 1987.
Seeds pod ⁻¹	Saxena et al. 1986a, 1989b; Singh et al. 1989.

Jag Shoran (1989) found no relationship between genetic and geographic diversity and suggested that selection of parents for hybridization should be on the basis of genetic diversity.

Natural outcrossing. Pigeonpea flowers being cleistogamous favor self pollination. However, natural outcrossing of 14% was reported (Howard et al. 1919). Since then several studies have reported outcrossing ranging from 0% to 70% (Singh et al. 1990). Factors affecting natural outcrossing at a given site include flowering habit of a genotype, presence of insect population, temperature, humidity, wind velocity, and wind direction (Bhatia et al. 1981). The main insect species responsible for natural outcrossing in pigeonpea are bees (*Megachile lanita*), and *Apis florea* (Pathak 1970), *Apis dorsata* and *Megachile* spp (Williams 1977). Prasad et al. (1972) reported genetic differences in the natural outcrossing among pigeonpea genotypes. Similarly, Byth et al. (1982) observed in the same field, the genotype Prabhat exhibited >40% outcrossing while genotype Royes had <2% outcrossing. They attributed the reduced natural crossing in 'Royes' due to the 'wrapped petals,' a modification in its floral morphology. This is a condition where overlapping of the standard petal delays the opening of the flower. A genotype with cleistogamous flowers that provided a mechanism for almost complete selfing in pigeonpea was reported (ICRISAT 1978). The flower opening in this genotype was delayed and reduced the chances of outcrossing. The development of cleistogamous lines and lines with a high level of natural outcrossing will be helpful in producing pure lines and creating genetic variation in the pigeonpea populations. Further a substantial level of natural outcrossing in pigeonpea provides opportunity for exploitation of hybrid vigor. A heterosis breeding program in pigeonpea, based on natural outcrossing coupled with genetic male sterility have resulted in high-yielding and drought-tolerant hybrids (Saxena et al. 1986b). However, for utilizing natural outcrossing for assumed gains in pigeonpea yield, through population breeding and hybrids, it is necessary to determine the level of outcrossing in the genotypes at a particular location to develop efficient breeding and seed production strategies (Saxena et al. 1990).

Male Sterility

At ICRISAT Center in 1974, 72 male-sterile plants were identified out of 7 000 accessions. Five types of male-sterile variants were reported in pigeonpea (Reddy et al. 1977):

Ordinary male steriles. These have small pale-yellow anthers, apparently empty and scale like. Some plants show partial pollen fertility.

Translucent male steriles. The anthers were white, translucent, small,

and scaly. No pollen was found in the plants.

Long-styled type. These had a longer style than stamen and possessed a groove on the bud that did not occur on the normal type. No fertile pollen was produced.

Short-styled type. The stigma was enclosed inside the staminal column. The style was shorter than normal without affecting the length of stamens. There was partial pollen sterility.

Incomplete-short-styled types. These plants had both normal and short-styled flowers. Pollen sterility ranged from 5-60%.

The translucent and pollen-free types were utilized to develop male-sterile lines. The male-sterile lines MS 3A and MS 4A were found in accessions ICP 1555 and ICP 1596 respectively, both were from field collections in India. This form of male sterility, caused by nonseparation of tetrads associated with a persistent tapetum and is controlled by a single recessive (*msl*) gene (Reddy et al. 1978). The marker (white, translucent anther) provides an efficient way of recognizing male-sterile plants before anthesis.

Male-sterile sources (MS 3A and MS 4A) were transferred to early maturing pigeonpea cultivars, such as Prabhat and T 21 by repeated backcrossing at ICRISAT. Two male-sterile lines MS-Prabhat and MS-T 21 were developed by backcrossing of MS 3A with the parents (Gupta et al. 1983). Later two new male-sterile sources (B 15 B and MS-41) were identified by Saxena et al. (1983b), and Gupta and Faris (1983) respectively.

New sources of genetic-male sterility characterized by brown, arrow-shaped anthers were identified at the University of Queensland, Australia in the line B1 5B. This type of male sterility is conditioned by a single recessive gene that is nonallelic to *msl*. They proposed the gene symbol *ms2* for this new source of male sterility (Saxena et al. 1983a). MS4A was later released as ICPM1 (ICRISAT, Plant Material Description no. 10, 1987).

Genotype by Environment Interaction

In pigeonpea, genotype x environment interaction for seed yield and other quantitative characters were reported. Jag Shoran (1985) reported pods plant⁻¹ and 100-seed mass were quite stable whereas days to 50% flowering was unstable to stabilize the expression of seed yield. Further, stability for pods plant⁻¹, 100 seed mass, and plasticity for days to 50% flowering were the main components of stability for seed yield in pigeonpea.

Highly significant interaction between genotype and location for protein (%) in pigeonpea dhal were observed (Jain et al. 1986). Balakrishnan and Natarajaratnam (1986) could not identify a genotype stable for dry matter accumulation (DMA). However, stable genotypes for photosynthetic rate, leaf area index (LAI), and leaf-stem ratio were identified.

Pigeonpea Breeding

The main objectives of pigeonpea breeding at ICRISAT include developing genetic stocks, broad based populations, lines and cultivars of short, medium, and long duration to provide higher and more stable yields in the Semi-arid tropics (Singh 1986). These objectives could be fulfilled by collection of germplasm and its utilization through selection, hybridization, population improvement, mutation breeding to develop pure lines, hybrids, or populations for commercial cultivation. Development of hybrids requires production of male-sterile lines using genetic-male sterility and its utilization in hybrid combinations. Breeding for resistance to insect pests, diseases, salinity, acidity, and drought are also necessary for the stability of pigeonpea yields.

Germplasm Resources

The world collection of germplasm maintained at ICRISAT Center contains about 12 000 accessions from 52 countries. ICRISAT also maintains 240 accessions of wild species belonging to 6 genera. This collection includes landraces, established cultivars, and breeding stocks with specific characters (Remanandan et al. 1988b).

Pigeonpea being an often cross-pollinated crop, makes maintenance of genetic purity difficult and expensive. Accessions are multiplied under controlled pollination by covering the whole plant or a branch with muslin or nylon bags (MP 3). The selfed seed from 30 plants per accession is bulked to constitute the next generation and to simulate the original population. Another way to control outcrossing is to cover the whole plot with nets using frames that can be dismantled. The harvested pods are sun-dried, threshed, and stored at 6% moisture. Selfed seed lots are rejuvenated from time to time to maintain their viability and germination.

At ICRISAT airtight aluminum or plastic cans are used for medium-term storage at -4°C and 25% relative humidity. In the long-term storage -18°C is maintained to keep seed viable for 30-100 years.

The genetic variability in pigeonpea germplasm at ICRISAT ranges from 55-210 days to 50% flowering; 97-260 days to 75% maturity; 39-85 cm height; 24-66 primary branches; 0-145 secondary branches; 60-915 racemes; 1-8 seeds pod⁻¹; 3-22 g for 100 seed mass; 0.6%-63% harvest index; 6%-87% shelling ratio, and 12%-30% protein (Remanandan et al. 1988a).

Hybridization

The main objective of hybridization in pigeonpea is to improve its yield and stability. This could be achieved by developing genotypes resistant to insect pests, diseases, salinity, drought, and improvement in milling quality and recovery of *dhal* (split dehulled seed). Additional considerations include whether the hybrid or variety is for sole or intercropping, early, medium, or late duration, mechanical, or manual harvest. Therefore, before starting a hybridization program important objectives based on the location and purpose of cultivation should be decided. For instance, when breeding for sole cropping system the variety should be of short duration, it should possess resistance to *Helicoverpa* and have a 100-seed mass of 8-10 g with high yield potential. In the same way genotypes for intercropping system should be of medium to late duration and tolerant to cold, with an ability to tolerate drought stress. Singh et al. (1990) have discussed in detail the pigeonpea breeding objectives and procedures.

Choice of parents. Parents should be selected fulfilling the breeding objectives. Generally one parent can be a desirable variety of the area, and the other parent or parents may be the genotype(s) with complementary traits not present in the first parent. Some desirable genotypes for different traits are listed in Table 11.

01294 ((. -8EF B5 F74 C864BAC41 64ABFHC4E G8F7 34E8D1294 FD18FE.

/SLaLNcPa >PYochpP

.. BYbPNc coWPaLYc WTyp

L. GoO MoaPa
(,4Bi2EM4Gp/
/GCig4G/'
EgcaL PLaWh7 B;GC 52-26 E/
ELaWh 7 B;G 6-6)E0^M8 DPOTdm7 GGE 12)/8
DPOTdm7 GGE 12)/8
CLcP 7 B;G .5..)E)0(B;G .6-0E.(B;G .-133)E0
B;G 03.2)E.(B;G 5F61)/)I/%1(B;G 5.-/2)I.%1(
B;G 2-03)E)/(GGE 04)2
(JoWPaLYc aLcTYRb oQ 1 k -.2'
1) GoO QWh
'-4B/D/gGECNO/
E1ILH/(
DPOTdm7 B;G 4-2-)E.(B;G .-20.)E.(B;G 3644)E.(
B;GC 503/)E:(B;G 5-61)/)I.(B;G 061-)E:
(JoWPaLYc aLcTYR oQ 0 k .'
N. GoO fLbp
(./D/EHIigCE34H
2/A/DiD/4(
ELaWh7 B;G 4/-0)E.(IPSoap).64)2E:
CLcP 7 B;G 5-61)/)I/(g'(B;G 061-)E.
(JoWPaLYc bNoaP oQ 0 k .'

). ,8E41E4 FB94D1AF 98A4

L. KTWc
B;G 553.^{MOP}(B;G 553/^{MOP}(B;G 2-64^{MN}(B;G 5-61^{MN}
B;G 5530^O(B;G 5534^{MO}(B;G 5526^O(B;G ../53^O
B;G ../66^O(B;G 5535^N(B;G .-625^N(B;G ../54^N
B;G ../65^M(B;G 5525(B;G 5526(9C .^M(A43)2.^M(
A43)32^M(B;G. /34^M(<9./^M
M. IcPaTWTch mobLTN
B;G /30-^O(B;G 14/2^O(B;G 4.55^O(B;G 513-^N
B;G ..0-^N B;G ..0-/j
N. GShcopScSoaL
BYOTNLcPO Mh %N% TY cSP LMoeP RPYochpPb.
O. 9WcPaYLaTL MWTRSc
BYOTNLcPO Mh %O% TY cSP LMoeP RPYochpPb.
P. HoocVYoc YPmLcoOP
BYOTNLcPO Mh %P% TY cSP LMoeP RPYochpPb.
0. <aodRSc coWPaLYc WTypB
<E 2(B;GC 501-(B;G 0/00(G:E,920(B;G 1532.
1. ILWTYTch coWPaLYc WTyp
B;GC //4

(IodaNPb7 ITYRS .6538 ITYRS Pc LW. .6528 ILgPYL .6568 LYO B;HBI9J .654(.655'

.1F8A6 34E86A. JSP caLTcb LeLTWLMWP TY cSP bodaNPb NLY MP NomMTYPO TY L
bTYRWP Naobb(OodMWP Naobb oa cSaPP)fLh Naobb Lb pPa cSP MaPPOTYR oMUPNcTePb.
JSP eLWdP oQ pLaPYcb NLY MP OPcPamTYPO fTcS aPbpPNc co NomMTYTYR LMTWTch TY
bTYRWP)Naobb NomMTYLCtoYb(OTLWWPW oa WTyp g cPbcPa mLcTYR bNSPMpb (ILgPYL
.656'. ITYRWP(OodMWP(cSaPP)fLh(LYO caTpWP NaobbPb SLep MPPY LccPmpcPO TY
pTRPoYpPL TYNwdOTYR OTLWWPW LYO WTyp g cPbcPa OPbTRYb (B;HBI9J .645'. Jo
aPcLTY paoOdNcTeTch LYO LoLpcLcToY co L bPpNTQTn PYeTaoYmPYc ALacfTR (.64/'
bdRRPbcPO oYP oa moaP MLNVNaobbPb co cSP LoLpcPO pLaPYc. ISLamL LYO >aPPY
(.65-' SLep OPbNaTMPo cSP ShMatOTiLcToY cPNSYTqdPb TY pTRPoYpPL.

JSP paoNPodaPb oQ bPWQTYR(NaobbTYR(LYO pPOTRaPP aPNoaOTYR TY pTRPoYpPL
LaP OTbNdbbPO TY DG .(DG /(LYO DG 0. BY ShMatOTiLcToY(poO bPc Tb
TYQWdPYNPo Mh pLaPYcb TYeoWePO TY cSP NaobbPb(PQQTNPYNh oQ cSP poWWTYLcToY(
LYO TybPNc OLMLRP. ILgPYL Pc LW. (.643' aPpoacPO .6" LactQTNTLW poWWTYLcToY
bdNNPbb fTcS L aLYRP oQ 2")1-" Lc B;HBI9J. ITYRS Pc LW. (.65-' aPNoaOPO /-"
bdNNPbb TY ShMatOTiLcToY Lc GLYcYLRLa. ILgPYL Pc LW. (.654' aPpoacPO Naobb
TYNompLcTMTWTch TY bomP pTRPoYpPL NaobbPb LYO pobcdWLcPO cSLc Tc fLb
RPYPcTNLWWH NoYcaoWWPO. :LWLVaTbSYLY LYO ELcLaLULaLcYLM (.653' aPpoacPO
bcaoYR YPRlCteP NoaaPWLcToY MPcfPPY poO)bPc LYO mLGtmdm cPmpPaLcdaP(LYO% L
fPLV YPRlCteP NoaaPWLcToY fTcS mTYTmdm cPmpPaLcdaP. AofPePa(OLcP oQ bofTYR
OTO Yoc TYQWdPYNP cSP poO)bPc TY cSP bPWPNCPO NdWcTeLab.



Handling of crosses, F_2 , and advance generations. The hybrid seeds are grown to verify their quality and desirability for further selection. To avoid out-crossing they should be grown in bee-proof cages or in the field with adequate selfing facilities. The undesirable plants and low-yielding crosses could be safely rejected on the basis of the F_1 performance (Saxena and Sharma 1983). Crosses with a high yield in the F_1 are grown in the F_2 for further selection. The F_2 performance was found consistently related to cross performance in succeeding generations. Therefore, multilocal testing of the F_2 plants will be useful in reducing genotype x environment interaction. Green et al. (1981) observed that in single crosses of pigeonpea the variance of individual plant yield was similar in the parents and their F_2 's indicating a high level of environmental influence on the expression of individual plant yield. Singh et al. (1990) suggested the use of shuttle breeding or alternate-selection cycles in diverse systems and seasons to develop widely adapted genotypes.

The efficiency of three breeding methods most commonly used in pigeonpea: pedigree, mass selection with intermating, and backcross breeding were compared for combining large seed with earliness in vegetable pigeonpea at ICRISAT Center (Jain et al. 1981). Two crosses were made involving an early, but small-seeded cultivar (T21) as female parent and two late large-seeded lines (JA 278 and EC 100467) as male parents of the base population. In each case, selection was first practiced for earliness and then for large-seed size among the selected plants for earliness. On the basis of the mean number of days to flowering and seed size for selections in both crosses the pedigree method and mass selection with intermating were found better than the backcross method.

Effectiveness of pedigree selection was illustrated by citing an example of a cross (ICP 7979 x ICP 8503) with the population size of 2746 plants in the F_2 (Jain et al. 1981). In this cross the female parent, ICP-7979 had large seeds (18 g 100^{-1} seed) and large pods (6-9 seeds pod^{-1}). In the F_2 plants with poor branching (less than six seeds pod^{-1}) were discarded (70% plants were rejected). The second stage selection was done on the basis of 100-seed mass by rejecting about 18% of the small-seeded (less than 18 g 100^{-1} seeds) plants. Consequently only 5% of the plants were retained. These selections were grown at ICRISAT Center in 4-row plots with a control every fifth plot. Out of 152 F_3 progenies, 86 progenies (57%) had more than six seeds pod^{-1} and more than 18 g 100^{-1} seed. Jain et al. (1981) concluded that the pedigree method was more practical than mass selection with intermating or backcross breeding. However, its application for the improvement of yield character with low heritability can be questioned.

Procedures for handling material using the pedigree method, mass selection with intermating, and backcrossing are available in plant breeding text books. The procedures for maintenance of breeding stocks, composites, and newly released lines are discussed in MP 4.

Population Breeding

In an often-cross pollinated crop like pigeonpea, attainment of homozygosity is quite slow. The homozygous genotypes are unlikely to be found in early generations. Therefore, population breeding methods were advocated (Khan 1973; Byth et al. 1981) for pigeonpea improvement. However, Onim (1981) reported limited success in pigeonpea while using population improvement procedures.

To increase recombination, a population breeding program based on a dual-population system (Rachie and Gardner 1975) and the use of the male sterility were initiated at ICRISAT Center. In the dual-population method a parent with an easily identified recessive marker was used. The F_2 generation was grown in isolation and plants with the recessive marker were harvested to ensure that only cross-pollinated plants were advanced. The finished product from this method did not show a significant gain in yield (Saxena 1989).

Onim (1981) reported, in a marginal rainfall area of Kenya, a 4% and 6% yield gain per cycle of selection under stratified-mass selection (SMS) and mass-selection with progeny testing (MSPT) using a selection pressure of 10% and 5% respectively for grain yield in pigeonpea. The procedure for the development of populations using male sterility has been discussed in MP 5.

The grided-mass-selection method proposed by Gardner (1961) was used at ICRISAT Center in four segregating populations (two medium and two late duration). The medium-duration population grown in an intercropping system showed no improvement in the yield after two cycles of selection (Green et al. 1979).

The single-seed-descent (SSD) method proposed by Brim (1966) was applied to pigeonpea populations at ICRISAT Center. Several populations were advanced by growing approximately 4000 F_2 plants and harvesting one pod from each plant. The harvested seed was sown and thinned to maintain 4000 plants in the next generation. To reduce plant size and shorten days to flowering, sowing was done in August or September. Three generation bulks (F_2 , F_3 and F_4) of four crosses were evaluated for variability in original and nonselected advanced populations. The results showed no decline in ranges and variances of the populations over generations for days to flowering, pod or seed color, plant type, growth habit, seed pod⁻¹, seed size, or yield. This suggested that the single-seed-descent or single-pod-descent methods can be useful selection procedures in pigeonpea breeding (Green et al. 1979).

The development of pigeonpea populations at ICRISAT Center are confined to the following area (Faris 1985) :

1. **Germplasm composites.** Based on maturity, height, and growth habit, germplasm lines are grown in isolation and advanced by collecting three pods plant⁻¹. In each generation, part of the seed is kept as a remnant and the other is used for advancing the generation.
2. **Bulk populations.** Nonselected bulk populations (F_3 to F_5) developed by the single-seed-descent method are shared with national breeders for utilizing in their breeding programs. These populations are screened for disease resistance (wilt, sterility mosaic, and phytophthora blight) and insect resistance.
3. **Composite population.** These populations are developed using F_2 seed from a large number of crosses and by using male-sterile lines.

Green et al. (1981) concluded that selection among lines derived from advanced hybrid bulks appears to be more efficient than pedigree selection for yield. Pedigree selection is useful for the improvement of highly heritable characters.

Hybrid Breeding

The discovery of genetic-male sterility provided an opportunity for utilization of hybrid vigor in pigeonpea. Saxena et al. (1986b) tested 106 hybrids. Nineteen hybrids showed heterosis of more than 10% and 9 hybrids over 20%. In the year 1977, a cross MS 3A x C 11 gave a 32% yield increase over the control. In 1978 four hybrids outyielded the control by more than 20%. Similarly, in 1979, three hybrids out of 22 gave more than 20% heterosis. Hybrid ICPH 2 (MS 4A x BDN 1) was tested over 7 locations in 1980. This hybrid outyielded the control by a margin of 23%. However, during 1981 and 1982 this hybrid yielded 11% and 6% higher than the control.

Heterosis over the male parent ranged from 4 to 41% for yield in various pigeonpea hybrids. Heterosis for yield was found associated with number of pods.plant⁻¹ and primary branches. Seed pod⁻¹ and 100-seed mass had little influence on seed yield (Saxena et al. 1986b).

Multilocal tests in the All India Coordinated Pulses Improvement Project Trial showed ICPH 8 (MS-Prabhat x ICPL 161) as a promising hybrid. This hybrid out yielded 'UPAS 120' by 35% and 'Manak' by 31% in the north-western plains of India. In the central zone, the hybrid yielded 33% more than 'UPAS 120', and 53% more than 'Manak'. In the southern zone, 'ICPH 8' yielded 24% more than 'UPAS 120' and 27% more than 'Manak' (Saxena 1989). Based on its consistent performance ICPH 8 was released as a hybrid for cultivation in India in 1991.

Saxena and Sharma (1990) concluded that since there is little evidence of inbreeding depression in pigeonpea (low dominance), it may be possible to select pure lines equal in performance to a F₁ hybrid. Nevertheless, a hybrid breeding program will be a complementary program to varietal improvement.

Saxena et al. (1986a) discussed various aspects of pigeonpea hybrids in the following steps:

- o Development and maintenance of male-sterile lines.
- o Development of pollinator parents.
- o Testing combining ability of parents.
- o Production of hybrid seed (MP 7).

Development and maintenance of male-sterile lines. The procedure for development and maintenance of male-sterile lines using genetic-male sterility is discussed in MP 6.

So far 12 male-sterile lines (Table 12) were stabilized at ICRISAT Center for commercial production of hybrids (Saxena et al. 1986a). It appears that the line MS Prabhat DT holds good promise (K.B. Saxena, ICRISAT, personal communication 1990).

Table 12. Characteristics of promising male-sterile lines (ICRISAT Center).

Line	Days to flower	Height (cm)	Habit ¹	Plant spread	Seeds pod ⁻¹	100 seed mass (g)	Seed color	Remarks
IMS 1	60	85	DT	C	3.5	7.0	B	Photo insensitive
QMS 7	56	125	DT	c	6.0	11.0	W	
QMS 9	52	90	DT	c	4.0	10.0	W	
MS Prabhat	69	87	DT	c	3.6	6.6	B	Good combiner
MS T 21	83	152	NDT	SS	3.9	7.5	B	Good combiner
MS BDN 1	101	143	NDT	SS	3.5	9.0	B	Wilt resistant
MS C 11	124	207	NDT	SS	3.6	10.0	B	Wilt resistant
MS 3A	110	230	NDT	SS	3.5	9.5	B	
MS 4A	110	230	NDT	SS	3.5	9.5	B	Wilt and SMD resistant
MS 7035	136	176	NDT	SS	4.8	19.1	P	
MS 3783	132	235	NDT	SS	4.8	18.1	W	Wilt and SMD resistant
MS NP (WR) 15	147	230	NDT	c	3.5	8.7	W	wilt resistant

1. DT E Determinate, NDT E Nondeterminate, C E Compact, SS E Semispreading, B E Brown, W E White, P E Purple

Development of pollinator parents. Generally well-established varieties or lines are used as pollinator parents for hybrids. The off-types and morphologically variable plants are carefully removed. The selfing could be done in the field by covering individual plants or by covering group of plants in cages. When variability is large, two generations of selfing is required to purify the parent by using individual plant progeny selection (IPP).

However, it may take 3-8 generations to establish purity when crosses are attempted involving diverse parents. Pure lines can be maintained in isolation or by selfing individual plant progenies.

Tasting the combining ability of parents. A line x tester analysis method (Kempthorne 1957) is useful to test the combining ability of parents and the performance of hybrids. This procedure involves crossing male-sterile lines with each inbred line. The hybrids are evaluated with or without the parents for yield, grain size, color, resistance to diseases and insects, and days to maturity. Hybrids performing better than the best controls are recommended for multilocal testing and quality evaluation. The line x tester method is also useful to calculate genetic variances and combining ability effects (GCA and SCA) of the parents. Omanga (1984) reported that an array mean and per se performance are good indicators of parental combining ability in pigeonpea.

Mutation Breeding

Both physical and chemical mutageneses have been reported in the improvement of pigeonpea.

Physical Mutagenesis. Abrams and Velez-Fortuno (1961) reported induced variability in the m_2 generation due to gamma irradiations for plant height and days to flowering. It was possible to fix some genetic characteristics in the m_3 and m_4 generations by single-plant selection (Abrams and Velez-Fortuno 1962). Singh (1973) reported an increase in the number of branches, 1000-grain mass, and grain yield plant⁻¹ in pigeonpea when treated with 10 kr gamma irradiation.

Khan et al. (1973) found a considerable amount of variability in x-ray irradiated, and ethyl methanesulfonate (EMS) treated populations of CO1. The maximum frequency of viable mutants was noted with 16 kr of x-rays and 60 nm of EMS.

Rao (1974) induced variability in pigeonpea for raceme length, pod number raceme⁻¹, seeds pod⁻¹, seed yield, and earliness when gamma rays were used on presoaked seed at 2.5 kr, 5 kr, and 7.5 kr. Jain (1976) reported induced mutations for pod number, pod size, seed size, and number of fruiting branches in pigeonpea due to ionizing irradiations. Sharma and Shrivastava (1974) reported irradiation induced mutant from variety T-21 and designated as No. 9. This genotype had more primary branches, more pods and larger flowers, pod size, and seed number pod⁻¹. Irradiating pigeonpea with gamma rays beyond 30 kr resulted in more than 50% reduction in germination and survival percentage (Mehetre et al. 1983). Natarajan et al. (1983) reported induced mutation in the M2 with gamma irradiation and diethylsulfate (DES). The maximum variability was recorded for number of pods plant⁻¹ followed by plant height. Natarajan et al. (1985) reported the effect of gamma rays and DES on germination, survival of seedlings, plant height, pollen fertility, and seed number in the M1 generation. The germination of seeds and survival of seedlings were gradually reduced by an increase in dose of mutagens, but the reduction was more with gamma rays than DES. Rao and Reddy (1983 and 1986) reported induced polygenic variability due to gamma rays, diethyl sulphate, ethyl methane sulphate, and hydrazide hydrate in two varieties of pigeonpea (ICP 7439 and ICP 2836). The genotypic variance, heritability, and genetic advance showed marked increase in the mutation induced population.

A high yielding and large-seeded line (T 6) was developed by irradiating a small-seeded (T 21) variety (Pawar et al. 1984). The genotype, TAT 5, was identified in India by fast neutron irradiation of variety T 21. TAT 5 has large seeds (a 100-seed mass of 10.0-11.7 g) and early maturity of 140 days (Anonymous 1986). Another high yielding pigeonpea variety (CO 2) suitable for both rainfed as well as irrigated conditions was also developed through mutation breeding (Veeraswamy et al. 1975). Rangaswamy (1986) reported that pigeonpea variety CO 5 was derived from CO 1 by gamma irradiations and is characterized by early maturity, day-length insensitivity, and drought tolerance.



At ICRISAT, wilt resistant mutants have been isolated from the irradiated population of a highly wilt susceptible cultivar, LRG 30 (Saxena 1989).

Chemical mutagenesis. Khan et al. (1973) induced mutation in pigeonpea on presoaked seeds for 6 h using 60, 70, and 80 nm concentrations of EMS for 4 h and found viable mutations at 70 nm. Chaturvedi and Sharma (1978) isolated six male-sterile mutants of tall and dwarf habit in M₂ progenies of Pusa Ageti following treatment of presoaked seed with 0.1-0.3% ethylmethane sulphate for 6 h. These mutants were late in flowering, had reduced inflorescence length, poor fruiting, and high pollen sterility.

The results with mutation breeding indicate that physical as well as chemical mutageneses were useful in improvement of pigeonpea. Therefore, mutation breeding offers an opportunity to improve the yield contributing characters in pigeonpea as a supplement to conventional breeding procedures. Some of the varieties developed by mutation breeding are listed in Table 13.

Table 13. Pigeonpea varieties developed from induced mutations in India.

Name of variety	Year of release or approval	Mutagenic treatment pparent varietyq; or mutant crossed	Improvement attributed
Trombay Vishakha-1	1976	Fast neutrons; pT 21q	35% increase in seed size, with other characters (yield, maturity time, disease reaction) equal to original variety.
Co 3	1977	Seeds; 0.6% EMS; pCo 1q	High yield; 'bold' seeded; higher degree of shelling; field dormancy for 15-20 days.
Co 5	1984	Seeds; 16 kr gamma rays; pCo 1q	Early maturity; insensitive to day length; drought tolerant.
TAT 5	1984	Seeds; 1.5 kr fast neutrons; pT21q	Larger seed size 17 g (100 seed) ⁻¹ ; early maturity (140 days).
TAT10	1985	Cross of mutants TT 2 (large seeds, compact) x TT g (early); both induced by 2.5 kr fast neutrons; pT 21q.	Medium-large grains; extra-early maturity (115-120 days).

(Source: Anonymous 1986 and Mick 1988)

Utilization of Wild Relatives

The subtribe *Cajaninae* is a natural assemblage of about 13 closely related genera mainly distributed in tropical regions (Remanandan 1981). The inter-generic hybridization of *Cajanus cajan* has been successful only with some *Atylosia* species.

Some valuable characteristics in the *Atylosia* species are resistance to pod borer in *A. scarabaeoides* (L.); high protein contents in *A. sericea* Bth. ex. Bak and *A. albicans* W(A. Akinola et al. (1975) reported hardiness and fire-tolerance quality of *A. grandifolia*.

Reddy et al. (1981) used eight *Atylosia* spp in interspecific crosses of pigeonpea of which *A. lineata* gave the highest percentage of pod setting followed by *A. albicans*, *A. trinervia*, *A. cajanifolia*, *A. sericea*, and *A. scarabaeoides*. The pollen sterility in these hybrids range from 12%-67%. Hybrids of *A. scarabaeoides* showed the largest variation in sterility across different pigeonpea cultivars.

A high protein line (HPL 40-5) derived from a cross of pigeonpea with *Atylosia albican* yielded over 20% more protein ha⁻¹ than the control. The mean percentage of *dhal* protein in ICRISAT high protein selections (1982-85) ranged from 28%-31%, compared with 22%-23% for the cultivated variety BDN 1. The sulfur containing amino acids of the high protein lines were similar to those of the control cultivars (ICRISAT 1986).

Four species of *Atylosia* *A. platycarpa*, *A. albicans*, *A. cajanifolia*, and *D. ferruginea* were reported more tolerant to salinity than the cultivated pigeonpea control (ICRISAT 1987). *A. platycarpa* had the maximum tolerance to salt.

Studies indicated that a salt tolerance trait was attributable to salt exclusion from shoots and was inherited as a dominant trait. This should facilitate incorporation of these traits into cultivated pigeonpea (ICRISAT 1988).

The *A. platycarpa* species possess many desirable characteristics like early flowering and maturity, photo-insensitivity, high growth rate, annuality, high harvest index, and resistance to wilt and *Phytophthora* blight. However, the crossing between *A. platycarpa* and cultivated pigeonpea was not successful (Pundir and Singh 1983; Saxena 1989).

Breeding for Special Traits

Pigeonpea breeding for special traits includes the following areas (Saxena et al. 1987):

- a. **Vegetable purposes.** Vegetable pigeonpea has scope for the expansion of this crop in the nonpigeonpea-growing areas. The desirable traits for a vegetable include green pods, sweetness, many seeded, large seed size, and pea-shaped seed. The lines identified for vegetable purposes at ICRISAT are ICPL 24, ICPL 211, and ICPL 87.
- b. **Dwarf types.** These genotypes are easy to mechanically harvest, accommodate more plants unit⁻¹ area, and are easy to spray for insects control.
- c. **High protein lines.** There is scope to improve the protein content of *dhal* and vegetable pigeonpea by utilizing the *Atylosia* species.

MP 1. Selfing in Pigeonpea

Selfing is done by covering an individual inflorescence, a branch of a plant, or a whole plot. When a large amount of seed is required, groups of plants are covered with bee-proof cages.

Bagging

Three types of selfing bags are used for pigeonpea (Gupta et al. 1981b).

1. Glassine bag (13 cm x 8 cm) to cover an individual inflorescence.
2. A small-muslin-cloth bag (60 cm x 20 cm) to cover a flowering branch.
3. A large-muslin-cloth bag (135 cm x 90 cm) to cover an entire plant.

A comparison of the number of pods set plant⁻¹ on the selfed plant with nonselfed plant (open pollinated) led to the conclusion that selfing done by a large muslin bag gave 225 pods plant⁻¹, against, 35 pods plant⁻¹ with a small muslin bag, and 9 pods plant⁻¹ with a glassine bag. The nonselfed plants produced 240 pods plant⁻¹ (Gupta et al. 1981b). Therefore, depending on seed requirements, a large- or small-muslin bag is useful for selfing an individual plant.

Bee-proof Cages

To produce a large quantity of seed, bee-proof cages are used for handling the segregating generations. These cages are formed with nylon net on a movable angle-iron frame that covers the plot. The objective of a cage is to control the insects. A comparative cost of material indicated that the cost of a cage was four times greater than cloth bags. However, due to reduced labor costs and reusability of the cages, bee-proof cages are preferred over cloth bags for large scale selfing (Gupta et al. 1981b).



MP 2. Emasculation and Crossing Techniques

Emasculation

Emasculation is required for artificial hybridization in pigeonpea. The buds most likely to shed pollen the next day are selected for emasculation (Fig. 1a). These buds are approximately 66% the size of a mature bud and are tightly closed. The corolla of such a bud is bright yellow without any greenish hue. It is best to select two buds on one inflorescence for emasculation and two to ten buds can be emasculated on a branch. All other buds are removed (Sharma and Green 1980).

Emasculation Steps

- a. Hold the bud firmly between the thumb and middle finger with the support of the index finger so that the keel of the standard is facing towards the emasculator.
- b. Remove or push down the sepal covering the keel (Fig. 1b).
- c. Open the corolla by inserting one tip of the forceps at the base of the keel. Now move the forceps upward to the tip of the standard (Fig. 10).
- d. Press the bud with a slight pressure until it opens. This makes the anthers visible (Fig. 1d).
- e. With the forceps remove the anthers from the staminal column (Fig. 1e). Count the anthers or examine the bud with a magnifying glass to ensure that all the anthers or their broken parts are completely removed (Fig. 1f).

Pollination

The pigeonpea stigma is receptive before anthesis, therefore, pollination can be done immediately after emasculation. The day's supply of pollen-source buds are collected between 0800 and 1000. These buds are kept in covered petridishes or on moist filter papers.

While in the bud, pollen remains viable for 42 h at 25-28°C with relative humidity of 50%. Such buds when kept in a refrigerator (10°C and 37% relative humidity) can contain viable pollen for 11 days (Prasad et al. 1977).

Remove the corolla of the pollen-source bud so that the staminal columns and anthers are uncovered. To transfer pollen hold the flower in one hand and touch the anthers to the stigma of an emasculated bud. A single flower can be used to pollinate two or three emasculated flowers (Sharma and Green 1980).



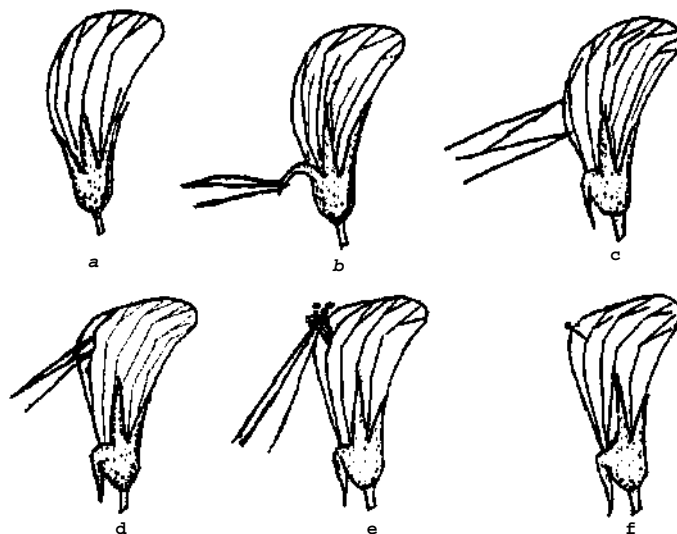


Figure 1. Steps of emasculation procedure.

Pod development

A week after pollination the pods become visible and complete their development in 15-20 days. The seed attains physiological maturity within 30-35 days and are ready for harvest in 40 days (Rao and Rao 1974).

Labelling

Individual female-genotype rows are sown for each cross, therefore labelling of individual buds is not necessary. An identification label for the male parent is written on each plot. To identify the artificially pollinated buds a small, bright-colored, thin nylon thread is tied to the peduncle of the bud. Seeds are harvested only from such pods.

Maintenance of records

Daily notes are recorded on separate sheets for:

- o Female parent
- o Male parent
- o Date of emasculation and pollination
- o Number of buds emasculated and pollinated
- o Number of buds with pod formation (after a week)
- o Number of pods matured and harvested.

Pollination success

Flowers fertilized (%) E $\frac{\text{Number of pods harvested} \times 100}{\text{Number of buds pollinated}}$

Harvesting of pods

Seed is harvested at physiological maturity 30-35 days after pollination. It should be dried to a low moisture content (about 6%) and stored in fully labelled containers indicating parentage ($\text{♀} \times \text{♂}$), season, and year of crossing.

MP 3. Pedigrees Recording of Breeding-material

Recording pedigrees of pigeonpea breeding material includes the following:

- o **Year.**
Example: 77 for the year 1977.
- o **Crosses.**
Example: ICPm 1, if it is 1977 then 770001.
- o **Symbol to designate how cross was advanced.**
-1 for pedigree without selfing;
1~~0~~ plant advance of the pedigree with selfing;
B advance of pedigree by bulk.

Example: ICPm-770001 -1 for without selfing or ICPm-770001 1~~0~~ for with selfing.
- o **Symbol to designate location.**
H for Hisar;
G for Gwalior; and
no symbol for Patancheru.

Example: ICPm-770001-H2-HB. H2 indicates 2nd plant selected at Hisar and bulked (HB).
- o **Symbols for selections made in specific nursery.**
S for sterility mosaic screening nursery;
W for wilt screening nursery;
P for phytophthora screening nursery; and
E for insect screening nursery.

Example: ICPm-770001-W3-S4-E1-P5. In this W3 indicates 3rd plant in wilt nursery, 4th plant in sterility mosaic nursery, 1st plant in insect nursery, and 5th plant in phytophthora nursery.
- o **Selection methods and generation advance.**
M for mass selection indicates one generation advance;
SMP designates selective mating population;
BC for backcross;
BC1 for backcross to female parent;
BC2 for backcross to male parent; and
BC2² second backcross to male parent.

Example: ICPm-77001-B-B-B or ICPm-770001-F₃B. This shows that cross was advanced to F₃ as a bulk.
- o **Flowering habit.**
DT for determinate;
NDT for nondeterminate; and
SDT for semideterminate.

Example: ICPm-770001-DT1-NDT3. This shows that the determinate plant 1 (DT1) was selected in the F₂ and the 3rd plant in F₃ was nondeterminate (NDT).
- o **Source of line.**
ICP for germplasm accessions;
ICPL for advance lines for preliminary testing;
ICPV for advanced lines released for multilocal testing;
ICPH for hybrid released for multilocal testing;
comp. for composite population; and
MS for male sterility.



Summary example of pedigree recording

Pedigree designation ¹	Description
ICPm - 770001. ICP 6997 x NPWR 15-14	A cross involving parents ICP 6997 x NPWR 15-14 was made during 1977.
ICPm-770001-B-B - 770001-F ₄ B or	The above cross was advanced in bulk without selection up to F ₄ . or
ICPm-770001-M-M E 770001-F ₄ M	The cross was advanced in mass selection in the years 1979 and 1980.
ICPm-770001-F ₃ M-W1 ♂	Mass selection advanced then tested in wilt (W1) nursery and selfed in the year 1981.
ICPm-770001-F ₃ M-W1 ♂ - S ₁ ♂ - P ₁ ♂	The above selection tested for sterility mosaic (S ₁) and phytophthora (P ₁) and selfed one generation each in the years 1982 and 1983.
ICPm-770001-F ₃ M-W1 ♂ - S ₁ ♂ - P ₁ ♂ - WB	The selection was retested in wilt nursery and bulked now in F ₇ in the year 1984.
ICPL 84001 E ICPm-770001-F ₃ M-W1 ♂ - S ₁ ♂ - P ₁ ♂ - WB	From the above material one-plant progeny was advanced to replicated trial and given ICPL number in the year 1984.

1. ♂ indicates cross was selfed.

o Other pedigrees

- a. Three-way cross
(ICP 6997 x NPWR-15-14) x ICP 4729 E ICPm-770097
- b. Double-cross pedigree
p(ICP 6997 x NPWR-15-14) x (ICP 4729 x T-21)q - ICPm-770098
- c. Pedigree indicating plant type
ICPm-770002-DT6-2-4-5. ♂

(New designations are given when subsequently different plant types are selected.)

Forexample ICPm-770002-DT6-3-DT4 ♂ - S₅ ♂

For the cross, six-digit numbers (770001) are used to accommodate large amounts of material. For line (ICPL) only five digits numbers are used (84001) to avoid confusion.

(Sources: S.C. Gupta, 1990, and A. Nageswar Rao, 1992, ICRISAT, personal communication; and a note circulated in ICRISAT Pigeonpea Breeding Program by D. Sharma, 1977)

MP 4. Maintenance of Breeding Stocks, Composites, and Cultivars

Maintenance of breeding stocks

Promising germplasm collections, lines, or selections of the pigeonpea are maintained as per Figure 2.

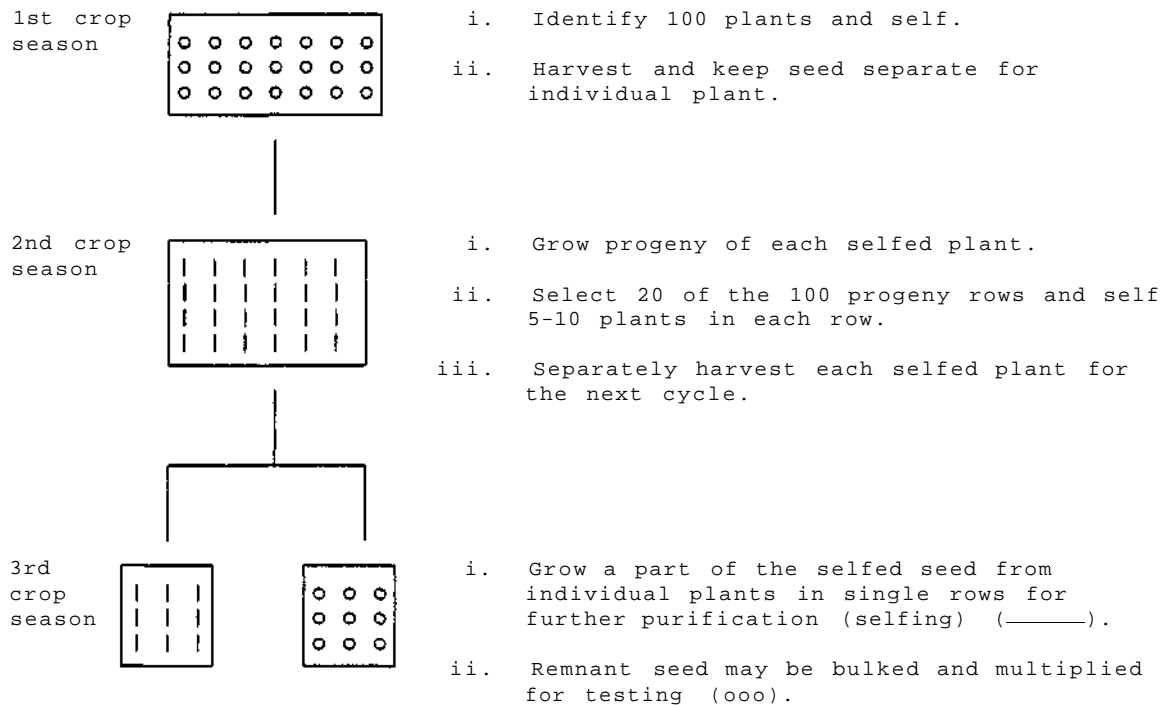


Figure 2. Procedure for maintenance of pigeonpea varieties.

A particular strain from a germplasm collection can be purified initially by taking a handful of seed from the individual plant progenies (Gupta et al. 1981b).

Maintenance of Composite Populations

The composite populations are maintained by growing each population in isolation (100 m from other pigeonpea plants). Where an isolation of 100 m is not possible, a composite population could be maintained by harvesting seed only inside a 14 m barrier strip on each side of each different plot (Gupta et al. 1981a).

Maintenance of Newly Released Cultivars

To maintain varieties and newly released cultivars it was suggested in the All India Kharif Pulses Workshop 1975 at New Delhi that breeders should grow a population of 10 000 plants with an isolation distance of 100 m. Select 1000 single-plant progenies and bulk these progenies on the basis of progeny performance.

At the initial stage of seed multiplication, use of pedigree seed is desirable. Each year 100-200 single-plant progeny rows should be grown from selfed seed of single-plant selections made in the previous year. From within the uniform progeny rows, 5-10 plants are selected and selfed. This results in selections among progeny rows and also among plants within progeny rows. The procedure needs to be repeated every year. Part of the selfed seed from uniform and true-to-type lines (based on progeny performance) are bulked for the multiplication of breeders' seed.



MP 5. Development of Populations Using Genetic Male-sterile Lines

Brim and Stuber (1973) advocated the use of genetic male sterility for population improvement in soybean. In this procedure, a set of breeding lines is emasculated as female parents and hand pollinated with a heterozygous male-fertile line (Msms). The F_1 's are backcrossed with their respective female parent. The selfed seed of these backcrosses is composited to form the base (Co) population. Several cycles of intermating are recommended before the initiation of selection. The procedure involves:

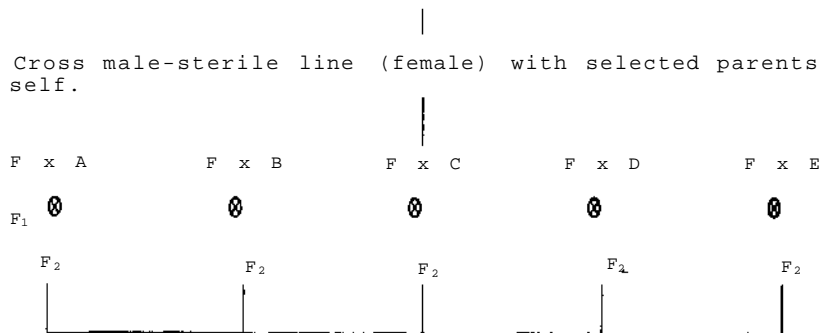
1. Transfer of the ms gene to suitable agronomic backgrounds.
2. Annual increase of the ms and maintainer stocks.
3. Plant by plant examination at the time of anthesis for sterility.
4. The elimination of the ms gene from the population.

At ICRISAT pigeonpea populations have been developed using genetic-male sterility for pod borer, pod fly, and salt tolerance (Mareck 1982). A general scheme for a simple recurrent selection procedure is discussed here.

1. Make crosses involving elite-male parents to sources of genetic-male sterility (Fig. 3). Seeds of these crosses are grown to the F_2 generation. Identify male-sterile plants in F_2 .
2. Composite the seed of a row of sterile plants from each F_2 in equal amount to grow a base population (Co) in an isolation for intermating. Allow three generations of intermating before starting any selection. A minimum population of about 2000 plants is grown in each generation and desirable open pollinated plants are harvested from male-sterile plants after each recombination.
3. Bulks (co) are grown in isolation for two or three generations to allow random mating. At maturity seeds are harvested only from male-sterile plants and bulked.
4. Select the fertile and desirable plants for seed increase and evaluation in a replicated trial and disease nursery. Some seeds are kept as remnant for further use. The male-sterile-plant seeds can also be preserved for further use. Use the remnant seed of each progeny to generate a new bulk for the next cycle of selection. Depending upon the progress made, the second cycle of random mating can be initiated.

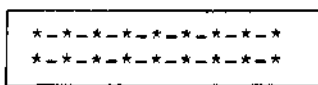
I. Select agronomically superior adapted varieties/genotypes based on heterotic performance and combining ability, eg., A, B, C, D, and E; and male-sterile (msms) F lines.

II. Cross male-sterile line (female) with selected parents and grow F_1 , and self.

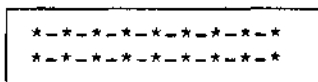


Composite the selfed seed from each F_2 in equal amount and grow (Co)

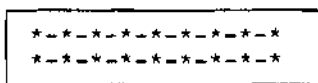
III. Base population (Co)



G1 allow natural crossing and harvest seed from only male-sterile plants and bulk (-).

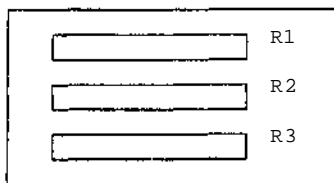


G2 repeat as above.



G3 repeat as above. Select desirable plants for evaluation.

Preserve separately remnant seed of each progeny for a new cycle of selection



Evaluate progenies using half of the seed, and select the best progenies

Figure 3. Simple recurrent selection scheme using genetic male-sterile lines.

MP 6. Development and Maintenance of Male-sterile Lines

The development of a new genetic male-sterile line requires crossing of male-sterile stock (MS) with adapted cultivar (A) and subsequently backcrossing by the adapted parent. Followed by identification of male-sterile plants in the selfed generation and repeated backcrossing. This could be achieved by a conventional backcross method as well as backcross and progeny testing methods.

- Initial step. Male-sterile stock (msms) is crossed with adapted parent, eg., A (MsMs); F_1 which is expected to be Msms is back crossed to the adapted fertile parent (MsMs).
- Step 1. Grow BC_1F_1 individual plant with the adapted parent. Cross BC_1F_1 with adapted parent to produce BC_2F_1 and self the plants of BC_1F_1 to get BC_1F_2 plants.
- Step 2. Grow BC_2F_1 's and their corresponding BC_1F_2 's individual plant progenies. Identify the progenies segregating in BC_1F_2 's (1MsMs : 2Msms : 1msms). Backcross these progenies.

The other steps are given in Figure 4.

Saxena (1986) reported that genetic male-sterility in pigeonpea is controlled by a single recessive gene *msl*. It is maintained by harvesting the seed from the male-sterile (*msl msl*) plants that are pollinated by fertile heterozygote plants (*Msl msl*). The resulting progeny will segregate into a ratio of 1 fertile : 1 male sterile. This seed is grown in isolation and at 50% flowering the male sterile plants are identified and tagged. The seed is only harvested from the tagged plants. If necessary, remove the immature pods from the fertile-male parent to extend the availability of pollen.



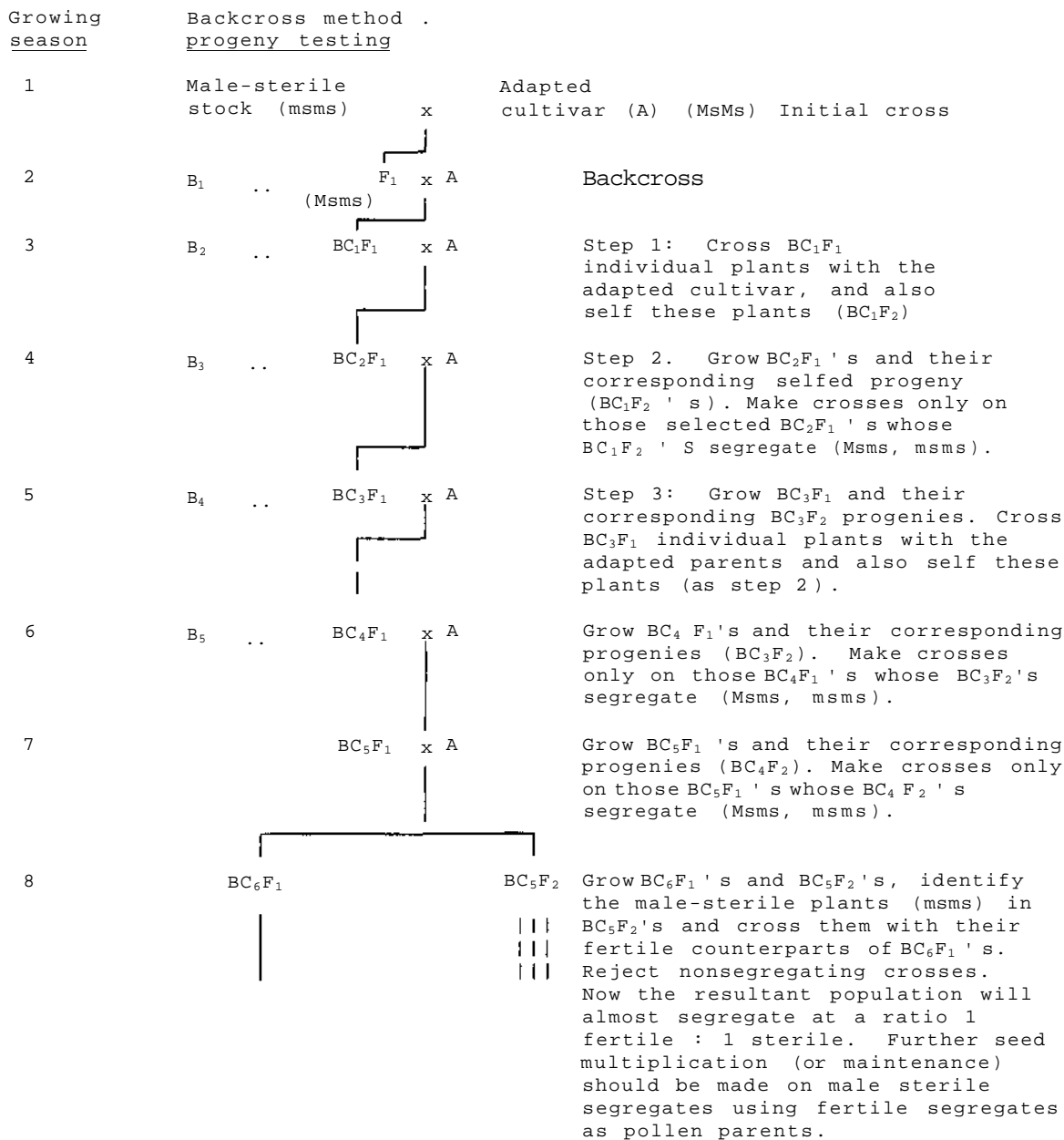


Figure 4. Backcross method for transferring genetic-male sterility in pigeonpea.

(Source: Reddy, L.J., ICRISAT, Pigeonpea Breeding Report of Work June 1978-May 1979, and personal discussion with K.B. Saxena, ICRISAT Center)

MP 7. Production of Hybrid Seed

Hybrid seed using male-sterile lines for initial testing can be produced by hand pollination. One trained person can pollinate about 400 buds a day with the efficiency of 30-40% pods setting seed (Saxena 1986).

The production of a large quantity of hybrid seed requires the use of isolation blocks. Four to six rows of the male-sterile parent sown alternately with one row of the pollinator parent (male) gives good seed-set (Fig. 5). The first bud on each plant in the male-sterile rows is examined. All plants with fertile anthers (normally yellow) in the male-sterile rows are rouged out before anthesis to prevent pollination of the sterile plants. Plants with translucent anthers (male sterile) are tagged. The seed is harvested from the male-sterile (tagged) plants. Periodic removal of pods formed on the pollinator (fertile) parent can prolong the availability of pollen. By synchronizing the flowering of the parents several hybrids can be produced in the same isolation block where the male parent is used with different male-sterile (female) parents. An isolation of 150-200 m is sufficient for hybrid seed production (Saxena 1986). The isolation block may be ratooned to increase hybrid seed production if both parents are suitable to ratoon and if their flowering nicks.

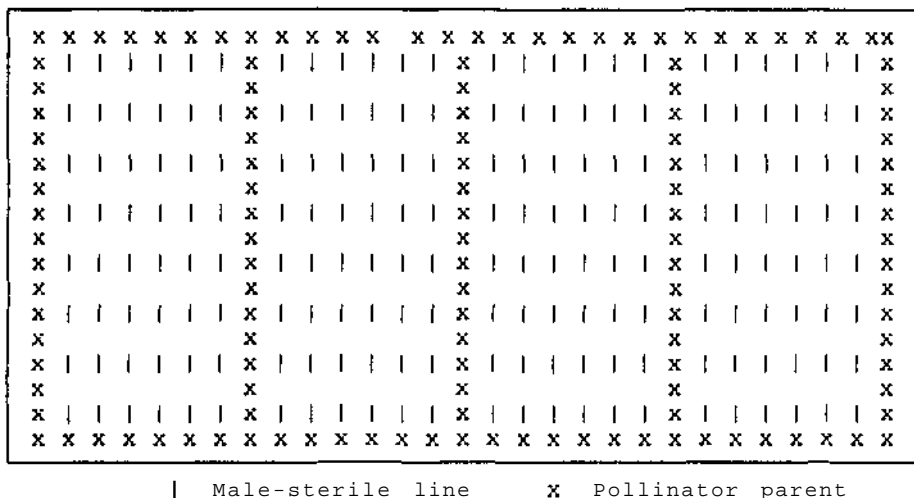


Figure 5 Field plot for hybrid seed production in pigeonpea.

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Evaluation

Select the most appropriate answer and check the correct answer at the end of the booklet.

1. Some qualitative traits in pigeonpea are
 - a) plant height and yield.
 - b) 100-seed mass and yield.
 - c) growth habit and stem color.
 - d) days to flowering and maturity.
2. When creeping types are crossed with erect habit, the F_2 show a ratio of
 - a) 9:3:3:1.
 - b) 9:6:1.
 - c) 13:3.
 - d) 9:7.
3. The determinate character in relation to indeterminate is
 - a) dominant.
 - b) monogenic recessive.
 - c) partially dominant.
 - d) over dominant.
4. Purplish-pigmented stem is dominant over
 - a) red.
 - b) cream.
 - c) pink.
 - d) green.
5. A cross of tall x dwarf pigeonpea segregates in F_2 as
 - a) 1:2:1.
 - b) 9:7.
 - c) 9:6:1.
 - d) 15:1.
6. Segregation for long-stipule length with short-stipule parents is
 - a) 9:7.
 - b) 15:1.
 - c) 9:6:1.
 - d) 3:1.
7. The broad leaflet base is
 - a) dominant over narrow.
 - b) recessive to narrow..
 - c) a quantitative trait.
 - d) complementary.
8. Lanceolate leaflet is
 - a) recessive to short leaflet.
 - b) dominant to short leaflet.
 - c) a quantitative trait.
 - d) complementary.
9. Long petiole is
 - a) dominant to short.
 - b) recessive to short.
 - c) a quantitative trait.
 - d) additive.
10. The trifoliate leaf trait is
 - a) recessive to multifoliation.
 - b) dominant to multifoliation.
 - c) quantitative.
 - d) governed by duplicate genes.
11. The pointed leaf apex is
 - a) dominant to conical.
 - b) dominant to round.
 - c) additive.
 - d) complementary.
12. Late flowering is
 - a) recessive to early.
 - b) dominant to early.
 - c) quantitative.
 - d) partial dominant.
13. Red veins on the dorsal surface of the standard petal is
 - a) recessive to yellow.
 - b) dominant to yellow.
 - c) complementary (9 yellow-purple : 7 yellow).
 - d) partially dominant.
14. White flowers in pigeonpea are governed by
 - a) complementary genes.
 - b) duplicate genes.
 - c) inhibitory genes.
 - d) supplementary genes.
15. A boat-shaped keel is
 - a) recessive to filiform.
 - b) dominant to united keel.
 - c) dominant to filiform.
 - d) dominant to free.



16. Dense inflorescence is
 - a) recessive to open.
 - b) dominant to open.
 - c) a complementary trait.
 - d) supplementary.
17. Male sterility, with translucent anthers is governed by the gene
 - a) MS_1 .
 - b) ms_1 .
 - c) MS_2 .
 - d) ms_2 .
18. Pod color is governed by two
 - a) additive genes.
 - b) complementary genes.
 - c) supplementary genes.
 - d) epistatic genes.
19. The four-seeded pod character is monogenic dominant to
 - a) three-seeded pods.
 - b) two-seeded pods.
 - c) eight-seeded pods.
 - d) six-seeded pods.
20. Streak-pod color is dominant to
 - a) purple.
 - b) green.
 - c) white.
 - d) pink.
21. Brown-seedcoat is monogenic dominant to
 - a) purple.
 - b) pink.
 - c) yellow.
 - d) white.
22. Purple-splashed seedcoat is dominant to
 - a) yellow.
 - b) white.
 - c) brown.
 - d) chocolate and light brown.
23. Reddish-brown seedcoat is governed by
 - a) one gene.
 - b) two gene.
 - c) three genes.
 - d) four genes.
24. The indeterminate growth (IDT) habit in pigeonpea is governed by two epistatic genes
 - a) Dt_1/Dt_2 .
 - b) Dt_1/dt_2 .
 - c) dt_1/dt_2 .
 - d) Dt_1/Dt_1 .
25. Wilt resistance is governed by
 - a) a single dominant gene.
 - b) two genes.
 - c) two complementary genes.
 - d) all the above.
26. The characters predominantly governed by additive gene effects are
 - a) days to flowering, plant height, leaf area, leaf mass, and fruiting branches.
 - b) seeds pod^{-1} , protein content, and seed yield.
 - c) pods plant^{-1} , 100-seeds mass, and seed yield.
 - d) all the above.
27. Characters reported to be governed by additive and nonadditive gene effects are
 - a) days to flowering and petiole mass.
 - b) fruiting branches and raceme length.
 - c) leaf area and leaf mass.
 - d) seed yield, 100-seed mass, and early maturity.
28. Grain yield in pigeonpea showed positive correlations with
 - a) plant height, branches plant^{-1} , and number of leaves.
 - b) pods plant^{-1} , seeds pod^{-1} , total branches plant^{-1} , and clusters plant^{-1} .
 - c) root-shoot ratio, and harvest index.
 - d) primary and secondary branches.
29. The characters with maximum-direct effect on seed yield are
 - a) plant height and days to flowering.
 - b) days to maturity and harvest index.
 - c) pod numbers plant^{-1} , primary branches, and pod clusters plant^{-1} .
 - d) all the above.

30. One of the selection criteria for high yield in pigeonpea is to select for high
 - a) harvest index, plant height, and leaf numbers.
 - b) primary branches, clusters plant⁻¹, and pods cluster⁻¹.
 - c) protein content and sugar content.
 - d) all the above.
31. In general, heterosis for yield in pigeonpea ranges from
 - a) 5-10%. b) 10-15%. c) 20-30%. d) -4-42%.
32. In pigeonpea male sterility is due to a
 - a) cytoplasmic factor. b) cytoplasmic-genetic factor.
 - c) genetic factor. d) spontaneous.
33. The parentage of first release hybrid ICPH 8 is
 - a) MS-Prabhat x UPAS 120. b) MS-Prabhat x ICPL 161.
 - c) MS-Prabhat x ICP 8833. d) none of the above.
34. The main objectives of pigeonpea improvement at ICRISAT are
 - a) collection and maintenance of germplasm.
 - b) developing genetic stocks and broad base populations.
 - c) developing high-yielding varieties, and hybrids resistant to pest and diseases for early, medium, and long duration.
 - d) all the above.
35. ICRISAT is maintaining pigeonpea accessions of over
 - a) 10 000. b) 12 000. c) 15 000. d) 20 000.
36. The medium-term storage requires temperature and relative humidity of _____, respectively.
 - a) -10°C and 10% b) -4°C and 25%
 - c) -2°C and 15% d) -20°C and 30%
37. Genetic variability for days to 50% flowering in pigeonpea germplasm at ICRISAT Center ranges from
 - a) 40-200 days. b) 55-210 days.
 - c) 70-150 days. d) 97-260 days.
38. Seeds pod⁻¹ in pigeonpea ranges from
 - a) 1-8. b) 2-10. c) 3-5. d) 6-8.
39. In pigeonpea accessions at ICRISAT, 100-seed mass ranges from
 - a) 2-50 g. b) 3-22 g. c) 5-25 g. d) 8-12 g.
40. In pigeonpea accessions at ICRISAT, protein content ranges from
 - a) 15-20%. b) 10-25%. c) 12-30%. d) 25-30%.
41. The main objective of pigeonpea breeding is to improve
 - a) disease resistance.
 - b) insect resistance.
 - c) milling quality and recovery of *dhal*.
 - d) yield and stability.
42. For mono-cultivation _____ pigeonpea varieties are best.
 - a) extra-early b) early c) medium d) late
43. Varieties suitable for intercropping purposes are
 - a) extra early and pest resistant.
 - b) medium maturity and wilt resistant.
 - c) medium to late maturity and cold tolerant.
 - d) all the above.
44. To determine the value of a parent in crossing programs, it is necessary to estimate
 - a) heritability. b) genetic advance.
 - c) yield. d) combining ability.

45. The average success in pigeonpea pod-set in the hybridization program is about
a) 10%. b) 20%. c) 30%. d) 40%.
46. The most common breeding procedures used in pigeonpea are
a) line breeding and recurrent selection.
b) mass selection and pure-line selection.
c) pedigree, mass selection, and backcross breeding.
d) none of the above.
47. The translucent type of male steriles possess
a) longer style than stamen and a groove on the buds.
b) stigma enclosed inside the staminal column and a short style.
c) white anthers that are small and scaly in appearance.
d) pale yellow, empty, and scale-like anthers.
48. The male-sterile lines of pigeonpea were developed using
a) ordinary male steriles.
b) long-styled male steriles.
c) short-styled types.
d) translucent male-sterile types.
49. Male-sterile sources (lines) MS3A and MS4A were found in accessions
a) ICPL 87 and ICPL 161. b) ICPL 151 and UPAS 120.
c) ICP 1555 and ICP 1596. d) Prabhat and ICP 8863.
50. The varieties developed through mutation breeding are
a) ICPL 161 and ICPL 151. b) ICPL 87 and UPAS 120.
c) TAT 5, Co 3, and Co 5. d) Prabhat and Bahar.
51. The desirable characteristics in *Atylosia* species are
a) high yield and large seed.
b) plant height and wilt resistance.
c) resistance to pod borer and salinity, and high protein.
d) high nodulation and grain quality.
52. The desirable traits for vegetable pigeonpeas are
a) dwarf type and high protein.
b) white seeded, multipoded, and bold seeded.
c) green pods, sweetness, pea shaped, large seeds, and many seeded.
d) none of the above.
53. The bags used for selfing a single raceme in pigeonpea are of
a) glassine paper. b) craft paper.
c) parchment paper. d) muslin cloth.
54. The cloth bags used for selfing the whole plant of pigeonpea are made of
a) silk. b) muslin.
c) rayon. d) terry cot.
55. The size of a small muslin bag used for selfing is
a) 20 cm x 30 cm. b) 60 cm x 20 cm.
c) 30 cm x 80 cm. d) 10 cm x 20 cm.
56. For the production of large amounts of pure seed it is better to grow pigeonpea
a) in isolation. b) in bee-proof cages.
c) and self each plant. d) and self each raceme.
57. The maximum anthesis in pigeonpea takes place from
a) 0600-1200. b) 0600-1600.
c) 0800-1000. d) 0900-1800.
58. After pollination, pod development in pigeonpea starts in
a) a week. b) a month.
c) 15 days. d) 20 days.

59. A breeder has supplied material to you with the pedigree (ICP 6997 x NPWR-15-14) x ICP 472 E 770097. The material is a
 a) single cross. b) double cross.
 c) three-way cross. d) triple cross.
60. In the number 77097 assigned to the above cross, 97 indicates the
 a) year. b) cross number,
 c) pedigree number. d) none of the above.
61. The minimum isolation distance for composite-pigeonpea variety seed multiplication should be
 a) 50 m. b) 100 m. c) 150 m. d) 200 m.
62. To multiply the seed and maintain a newly released variety it is recommended to grow a minimum of _____ plants in isolation.
 a) 500 b) 1000 c) 5000 d) 10 000
63. For an efficient multiplication of hybrid seed in an isolation it is necessary to grow the male-sterile line and pollinator parent in a ratio of
 a) 4:2. b) 6:2. c) 8:2. d) 6:1.
64. In the hybrid seed-production plot it is necessary to rogue out the male-sterile plants from MS lines
 a) after anthesis.
 b) before anthesis, at first bud formation.
 c) at 50% flowering.
 d) at 75% flowering.
65. The male-sterile plants are identified with
 a) yellow anthers. b) pure anthers.
 c) white anthers. d) translucent anthers.
66. For hybrid seed-production and maintenance of a male-sterile line the required isolation is
 a) 100-120 m. b) 150-200 m.
 c) 200-250 m. d) 300-400 m.

Correct responses to the questions.

1. c); 2. c); 3. b); 4. d); 5. d); 6. a); 7. a); 8. b); 9. a);
 10. b); 11. b); 12. b); 13. b); 14. b); 15. c); 16. b); 17. b);
 18. d); 19. a); 20. b); 21. d); 22. d); 23. c); 24. d); 25. c);
 26. a); 27. d); 28. b); 29. c); 30. b); 31. c); 32. c); 33. b);
 34. d); 35. b); 36. b); 37. b); 38. a); 39. b); 40. c); 41. d);
 42. a); 43. d); 44. d); 45. b); 46. c); 47. c); 48. d); 49. c);
 50. c); 51. c); 52. c); 53. a); 54. b); 55. b); 56. a); 57. c);
 58. a); 59. c); 60. b); 61. b); 62. d); 63. d); 64. b); 65. d);
 66.. b).



