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Foreword

ICRISAT organized a grain legume workshop in January 1975, soon after the initiation of the Institute's pulse improvement research program. The object was to bring together grain legume workers of the world and to focus attention on the status of pigeonpea and chickpea research. Several aspects of production agronomy, phenology, and quality factors were discussed and ICRISAT scientists proposed a program for improving the genetic potential for yield. After 3 years of work, ICRISAT planned two international workshops, one on chickpea in February 1979 and the other on pigeonpea in December 1980.

The pigeonpea workshop committee sought to provide a forum to review significant research results in pigeonpea improvement, discuss present utilization of pigeonpeas and their potential for the future, identify priorities for further research and development, and recommend a future course of action.

Because of the strong interest of the Indian Council of Agricultural Research (ICAR) in pigeonpea improvement, the Council joined with ICRISAT to organize and cosponsor the International Workshop on Pigeonpeas. The Workshop was held at ICRISAT Center from 15 to 19 December 1980. In all there were 220 participants from 17 countries. ICRISAT's international role in pigeonpea improvement as well as its current plans of research were endorsed. A few eminent scientists were asked to prepare a critique and synthesize the presentations and discussions. This critique and synthesis, presented in a plenary session at the end, will form the basis of future research on pigeonpea by ICRISAT.

The program committee not only invited papers on specific topics to ensure a broad coverage of the subject matter but also opened the doors to voluntarily contributed papers to further widen that coverage. The response was overwhelming, and it was not possible to put together all the papers in one volume. Therefore, these proceedings are published in two volumes: the first includes all the invited papers and discussions and the second volume includes all the contributed papers. We believe these volumes will be a valuable reference work for pigeonpea research scientists.

All the papers were reviewed for technical content prior to the Workshop. ICRISAT scientists who assisted in reviewing the papers were D. G. Faris, R. W. Willey, W. Reed, J. A. Thompson, L. J. G. van der Maesen, R. Jambunathan, N. P. Saxena, L. J. Reddy, Umaid Singh, and J. B. Smithson. I sincerely appreciate their valuable contribution to the Workshop.

Y. L. Nene
Workshop Coordinator

Genetic Resources and Taxonomy

Session I

Chairman : D.N. De
Rapporteur : P. Remanandan

Taxonomy of the Genus *Cajanus* DC

K.Thothathri and S.K. Jain*

Abstract

The taxonomic history of the genus Cajanus *in general and pigeonpea* (C. cajan [L.] *Millsp.) in particular from the pre-linnean to the post-linnean period is reviewed. The origin, distribution, and phytogeography of the genus are discussed.*

The Genus *Cajanus*

Taxonomic History

Cajanus as a genus was founded in 1813 by A.P. De Candolle, based on two species, *c. flavus* and *c. bicolor.* De Candolle attributed both species to India, with a note stating that *c. fiavus* also occurs cultivated in America. He cited *Cytisus cajan* L. (1753) under *cajanus flavus,* thereby making it clear that the Linnaean plant is the same as his *c. fiavus.* In fact, he should have used the Linnaean epithet *cajan* for *fiavus.* In citing *Cytisus cajan,* De Candolle's reference reads, "Linn. sp. 1041"; this should be "Linn. sp. 739." The type species of the genus is C*ajanus cajan* (L.) Millsp., based on *Cytisus cajan* L.

However, there existed an earlier, validly published generic name *Cajan,* described by Adanson in 1763. He gave a short description and cited *cytisus* of Plum. ic. 114 and of Burman's Thesaurus Zeylanicus (1737), a cross-reference to *cytisus cajan* L.

It is therefore evident that the name *Cajan* was validly published in 1763. But under the rules of the International Code of Botanical Nomenclature (Lanjouw et al. 1978), *cajan cajan* is illegitimate (a combination made by Huth in 1893), being a tautonym. Hence the next available name *Cajanus* A.P. DC. (1813) was conserved against *cajan* Adans. (1763)(vide International Code of Botanical Nomenclature 1952). The third generic name C*ajanum* Rafinesque (Sylva Tellur. 25, 1838), based on *cytisus pseudocajan* Jacq., is also a superfluous name.

Distribution

The genus includes two species: *c. cajan* (L.) Millsp., now distributed pantropically, and *c. kerstingii* Harms, endemic in West Africa.

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* Botanical Survey of India, Howrah, India.

Origin

It is interesting to sum up briefly the views of the native home of the genus, van Rheede (1686), Linnaeus (1737, 1747, 1748), Burman (1737), and Jacquin (1770) mentioned pigeonpea, the plant on which the genus was founded, as native to the (East) Indies (including Ceylon). Rumphius (1750) suggested that it was native to Malaya. A.P. De Candolle (1813), while establishing the genus, mentioned "India Orientalis" as its home and tropical America as another area of cultivation. A. de Candolle (1885) pointed to the absence of pigeonpea occurring wild in India and to several finds of wild pigeonpea in Africa.

Some of the modern workers (Good 1964; Purseglove 1968; Zeven and Zhukovsky 1975) are of the opinion that *cajanus* is probably a native of Africa, from where it spread to India as a secondary center. Ronald Good (I.C.), while grouping the genera found entirely or predominantly in the tropical regions, excluding those occurring pantropically, places *cajanus* under the subgroup Africa, Asia. Sturtevant (1972) mentioned that Schweinfurth during his travels in Africa between 1868-1871 reported the presence of a seed of pigeonpea in Egyptian tombs of the 12th Dynasty (2200-2400 B.C.). It can therefore be tentatively concluded that *cajanus* is a native of Africa, with India as a secondary center of origin.

The generic name *cajan* is derived from "Katjang" or "Catjang", being the vernacular name in the Malay language (Watt 1889; Bailey 1954) and meaning pod or bean.

The Species in *Cajanus*

Cajanus cajan (L.) Miilsp.

In the pre-linnaean period (before 1753) van Rheede (1686) referred to pigeonpea *(Cajanus cajan* [L.] Miilsp.) as *Thora paerou,* with a detailed description and a good illustration. *Thora paerou* is the local name in Malayalam, in India, meaning common dhal. Plukenet (1691, 1696) described the plant as *"Phaseolus erectus incanus, siliquis torosis, Kayan dictus"* and mentioned that it is a *Cajan,* native of India. He cited not only Rheede's reference on Thora paerou but also a number of other names such as Kajan, Katsjan, Kadjang, Pigeonpea, etc. A good figure of the plant with flowers and pod supplemented his description. Sloane (1696) followed Plukenet in referring to the plant as *cajan* and pigeonpea, with description and reference to Rheede's work (1686). He mentioned Jamaica and the Caribbean as areas of occurrence.

Linnaeus in a series of publications (1737, 1747, 1748) referred *the* plant to *cytisus,* with a good description, and suggested its home was Malabaria (India), Zeylonia(Ceylon), and Caribaeis (West Indies). A reference to Rheede's "Thora Paerou" was also made in all the works cited above. Burman (1737) called the plant *cytisus zeyianlcus* and provided a good figure. Rumphius (1750) named the plant *phaseolus balicus,* with an elaborate discription and a good illustration. In addition to his reference to Burman (1737) and Linnaeus (1737), he attributed to it local names such as Katjang Baly (Malay), Undi and Undis (Balinese).

The post-linnaean period (from 1753) started with the binomial *Cytisus cajan* L. (Linnaeus 1753), for pigeonpea. Linnaeus' short description included references to his own earlier works (1737, 1747, 1748), Plukenet (1696) and Burman (1737). Another name *c. pseudocajan* was given by Jacquin in 1770 when he described pigeonpea mentioning that it was a variety of c. *cajan.* A good illustration was provided by him. De Candolle (1813) while founding the genus *cajanus* described two species (c. *bicolor* and c. *fiavus)* and distinguished between them by the color of the vexillum, number of seeds per pod, and length of the stipellae. He treated *cytisus pseudocajan* Jacq., *Thora paerou* Rheede, and Plukenet's *Phaseolus* under *Cajanus bicoior* and placed *Cytisus cajan* L. under *Cajanus fiavus.* In fact, he should have used the earliest epithet *cajan* for his *fiavus.*

Sprengel (1826) proposed another name, cajanus *indicus,* for pigeonpea and mentioned as synonyms *cytisus cajan* L., *c. pseudocajan* Jacq., *cajanus bicoior* DC. and *C. fiavus* DC. *Cajan cajan* Huth (1893), *Cajanus pseudocajan* Schi. & Guill. (1920), and *c. cajan* Druce (1917) are some of the more recent names and authorities proposed for pigeonpea.

All these names are superfluous, as they all cite the type and name of *Cytisus cajan* L. The valid name is *Cajanus cajan* (L.) Millsp. (1900). In the *Flora of British India* (Baker 1876) and all regional floras (Cooke 1902; Prain 1903; Duthie 1903; Haines 1922; Gamble 1918; Kanjilal et al. 1938), the pigeonpea is known by the name *cajanus indicus* Spr. and the above floras should have used at least one of De Candolle's names (c. *fiavus),* if not the linnaean epithet. In the *Flora of Java* (Backer and Bakhuizen van den Brink 1968), the authority for *cajanus cajan* is ascribed to Huth (1893), which is again not correct. In reality, Huth made the combination *cajan cajan* just to discuss tautonyms. The binomial *cajanus cajan* cannot be treated as a tautonym, as the specific epithet *cajan* does not spell entirely identical to the generic name *cajanus.*

The correct nomenclature of pigeonpea is as follows: *Cajanus cajan* (L.) Millsp. in Field Columb. Mus. Bot. 2:53. 1900. *cytisus cajan* L. Sp. PI.2: 739. 1753. *c. pseudocajan* Jacq. Hort. Vind. 2:54. t. 119. 1772. *Cajanus fiavus* DC. Cat. Hort. Monsp. 85. n. 43. 1813. *c. bicoior* DC. I.e. 1813. c. *indicus* Spr. Syst. Veg. 3: 248. 1826. Baker in Hook. f. Fl. Brit. Ind. 2: 248. 1876. *Cajan cajan* Huth in Helios 11: 133. 1893, *nom. niegit.* *cajanus cajan* (L.) Druce in Rep. Bot. Exch. CI. Brit. Isls. 1916. 64.1917, *nom.superfi.* *c.pseudocajan* Schinz & Guill. in Sarasin & Roux, Nov. Caled. 1:159.1920. *Thora Paerou* Rheede, Hort.Ind.Malab. 6:23.t.13. 1686.

Type

According to Westphal(1974), Steam lectotypified the pigeonpea with the I, Fol 14 specimen in Paul Hermann's herbarium at BM. Of four specimens, this is the only one with flowers and developed fruits and it carries Linnaeus' diagnosis in his handwriting for the Hortus Cliffortianus: Ceylon: *"Cytisus racemis axillaribus erectis .... intermedio longius petiolato."* Westphal (1974) followed this choice and pointed out that

Verdcourt (1971) only referred two other specimens (II, Fol. 76 and III, Fol. 30) as being syntypes.

Distribution

Pigeonpea is widely cultivated in the tropics of both the New and the Old World (America, Hawaii Islands, West Indies, India, Africa, and Australia). In India it is mainly cultivated in Uttar Pradesh, Madhya Pradesh, Bihar, Maharashtra, Andhra Pradesh, and Tamil Nadu. It grows well even at elevations up to 3000 m.

Cajanus kerstingii Harms

In 1915, Harms published the description of *c. kerstingii* Harms from Togo. The type (Kersting 570 from Sokode-Basari) at Berlin was burnt,, and isotypes have not been located. The description is very clear, but bears no illustration. The species is quite close to the pigeonpea, but Harms did not see ripe seeds which have a prominent strophiole. The absence of a strophiole is generally considered to be the only character distinguishing *Cajanus* from the related genus *Atylosia* W.& A. (1834). *C. kerstingii* is endemic in the West African savannas, from Senegal to Nigeria, and of rare occurrence. Its possible role in the origin of the pigeonpea as a progenitor was already stressed by Harms; except for Verdcourt (1971), later authors rarely referred to it.

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Taxonomy of *Cajanus*

L.J.G. van der Maesen*

Abstract

The taxonomy of Cajanus *and* Atylosia *has been revised. Based on herbarium and field studies on morphology from 1975 to 1980, strengthened by breeding and cytological and chemotaxonomical evidence,* Atylosia *is judged to be congeneric with* Cajanus. Dunbaria heynei *W. & A. also belongs in* Cajanus, *while some taxa previously described in* Atylosia *are excluded from* Cajanus.

The revision is to be published elsewhere (Communications of the Agricultural University, Wageningen, the Netherlands) with the necessary nomenclatorial changes. Geographical distribution, detailed descriptions, and sectional arrangements, as well as vernacular names and eventual use, are now available. Some results on interspecific hybridization are mentioned. This paper is as preview for the benefit of the users of pigeonpea genetic resourses.

Wild species related to cultivated crop species belong to the germplasm of those crops. To serve present and future breeders, ICRISAT needs to obtain a comprehensive collection of pigeonpea. This need induced a proper stock-taking of locations to search for wild species, of which only four were available at the end of 1974 (van der Maesen 1976). The sources of information were to some extent the published floras, but detailed information had to be obtained from preserved material in herbarium institutes. It soon appeared that several species needed reclassification, nomenclatorial changes, and even description as species new to science. A taxonomical revision of the two genera was therefore undertaken. In *Cajanus* De Condolle (1813), only two validly published species remained, *Cajanus cajan* (L.) Millsp. and *c. kerstingii* Harms. A closely related genus, *Atylosia* Wight & Arnott (1834) harbors most of the species once also described as *cajanus.*

Are *Cajanus* and *Atylosia* Congeneric?

Cajanus and *Atylosia* have always been considered very close. Many authors advocated merging the two, although only von Mueller (1860 and later) actually listed Australian *Atylosia* spp. as *cajanus. cajanus*

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was mostly considered to be monotypic because *c. kerstingii* Harms (described in 1915 from West Africa), was unknown to most agricultural scientists working in the Asian region. Harms would have classified his new species in *Atyiosia* rather than in *cajanus,* but seeds were unavailable to him. *c. kerstingii* seeds have large strophioles, an important character used to distinguish between the genera. Seeds of *Cajanus* are generally described with strophioles absent, *c. kerstingii* is quite rare and so is *Atyiosia cajanifolia* Haines (described in 1920 from the Puri forests in India), which also has large strophioles, but is otherwise so similar to the pigeonpea that casual observers might assume it is pigeonpea escaped from cultivation, *A. cajanifolia* is morphologically the closest relative of pigeonpea.

In reality the strophiole is not altogether absent in pigeonpeas; unripe seeds always have one, and in more than 144 cases pigeonpea accessions at ICRISAT do possess a small strophiole. In many legume genera, species with and without strophiole exist (e.g. *Rhynchosia).* Several *Atyiosia* species are cross-compatible with pigeonpea and produce fertile hybrids, as work at Pune, Kharagpur, ICRISAT, and elsewhere has proven. This is also an important consideration for congenericity, although morphology is the most important one.

Cytological research has proven that homology between pigeonpea and *Atyiosia* spp. is remarkable (Reddy 1973; Pundir, personal communication). Seed protein profiles are also very similar (Ladizinsky in press; Pundir, personal communication; Jambunathan, personal communication), but differ enough between *c. cajan* and *A.cajanifolia* to warrant separate status as species, not as genera. In leguminosae successful generic hybrids are rare, while those reported are subject to doubt (McComb 1975). McComb considered that the generic boundaries assigned to *Cajanus-Atyiosia* were unwarranted. All breeders and cytologists working with the pigeonpea so far have advocated a merger of the two genera, with the biochemists following suit. Lackey (1977) expressed the relation as follows: *"cajanus* is quite possibly nothing more than a cultigen of *Atyiosia."*

I have also come to the conclusion that *Atyiosia* is congeneric with *cajanus* and present my views in more detail (van der Maesen, in press). Descriptions, synonyms, distribution, and sectional classification are treated presenting the diversity in one consolidated publication. In this text the necessary new combinations will not be mentioned, to avoid confusion about the actual merger carried out in the taxonomical revision. *cajanus* DC. (1813) has priority over *Atyiosia* W. & A. (1834). A revision of the Australian species was prepared by Reynolds and Pedley (personal communication) but this has not been published so far.

Other Genera in the Subtribe *Cajaninae*

The subtribe *cajaninae* Benth. is a natural group in the tribe *phaseoieae* Benth. of the *Papilionoideae* subfamily of *Leguminosae.* Two kinds of genera are distinguished on a rather artificial basis: seeds two or less and three or more per pod. Of course border cases exist. Crossability barriers between *Cajanus* and genera other than *Atyiosia* are definitely stronger than between *cajanus* and *Atyiosia,* although few hybridization attempts have been made so far. *Rhynchosia rothii,* a climber with two-seeded pods, has always failed to produce hybrids with the pigeonpea, but many shrubby species exist in *Rhynchosia* and these may have a better chance of crossing with pigeonpea. This, however, does not at all imply the necessity to merge *Rhynchosia* and *cajanus.* The natural entity of the genus *Rhynchosia* (+200 species) is generally well appreciated, while the almost monotypic *cajanus* was kept apart from its relatives, probably out of traditional considerations. The unique status of a monotypic genus, however, is warranted only in cases where no close relatives exist; in the case of *cajanus,* knowledge now accumulated indicates that this status should be changed.

The genus *Dunbaria* (pods flat, seeds three or more per pod) is also \/ery close. On *Dunbaria, D. heynei* W. & A., belongs in *cajanus* since the pods are not really flat but have delineations, an important distinguishing character between *Cajanus sensu largo* and *Dunbaria.*

Eriosema is a genus (+ 100 species) from Africa and the Americas, with shrubby species having two-seeded pods. This genus may also be of interest for studying in relation to *cajanus,* as are *Fiemingia* and other, less known, *cajaninae.* There are no more than 30 species in any of these, and some have only one to three species. Thus a generic revision in *cajaninae* is long overdue (Lackey 1977).

Geography of *Cajanus*

cajanus cajan (L.) Millsp., the pigeonpea, is now spread pantropically, and is most adapted and productive in the semi-arid tropics. Originating from India, still its main area of cultivation, it moved more than 4000 years ago to Africa, where in East Africa a secondary center of diversity developed. From Africa the pigeonpea travelled to the West Indies and spread all over tropical America (van der Maesen 1981a). In the Caribbean area the crop has considerable economic importance; in other areas such as South America, West Africa, and Southeast Asia, the plant is a garden or hedge crop and not grown in large quantities (van der Maesen 1981b). The presence of so many close wild relatives (15) and the diversity of the pigeonpea point to Indian origin; in Africa, only two relatives occur, of which *A. scarabaeoides* (L.) Bth. is probably a recent introduction.

On the other hand, the diversity of wild species in North Australia is also remarkable, but pigeonpea is of recent introduction there. No less than 13 endemic species and some varieties can be distinguished in Northern Australia (van der Maesen, in press). More knowledge about their distribution is needed, as some seem to be restricted to a small area and have been collected only a few times. A common geographic origin of progenitors can be postulated.

After the separation of Asia and Australia in the Pliocene, different species evolved in the two main areas of the genus. The distribution of several species is probably more limited now than in the past, as the habitat was apparently reduced due to climatic changes in a recent geological era and due to human interference in historical times. Certain habitats are under such pressure that a total wipe-out is possible (e.g. *A. elongata* Benth. in Meghalaya, India). Only *A. scarabaeoides* is widespread and can be considered as a beneficial element of many grasslands. Most other species have retreated to sanctuaries such as reserve forests, unapproachable ledges at high altitudes, and uninhabited areas. Many species palatable to cattle cannot stand heavy grazing. Pressure of insects and diseases seems, in general, not to be very harsh, although no species is known even in nature to escape pod borer (*Heiiothis* spp.) or podfly *(Meianagromyza* spp.) attack. Some species definitely avoid or resist drought, judging from the locations where they are found.

Infraspecific Taxonomy of *Cajanus Cajan*

In the previous century it appeared that *c. fiavus* DC. and *c. bicolor* DC. (tur and arhar respectively, with yellow and red-striped yellow flowers) could not be kept separate. With many genotypes available, the range is indeed continuous, and these groups cannot be maintained even as varieties. Based on a few genes, the characters are impractical for infraspecific classification. The classification by Shaw et al (1933) into 86 "types" was an attempt to categorize the germplasm available then. Probably more such "types" could be distinguished now, and these would be termed cultivar groups to conform to modern terminology. Grouping by maturity is a rather artificial but practical approach. However, photoperiodic influence on plant habit and maturity is marked, and this complicates classification. Apart from maturity, habit, flowering pattern, and seed color and size, few characters seem to matter to eventual users of any classification. Based on several years of evaluation, data clustering is feasible, if demand by the users(e.g. breeders) existed.

Conclusion

Van der Maesen (in press) distinguishes 32 species in *cajanus* (including *Atyiosia),* of which five are newly described, one from the Philippines and four from Australia. Sixteen species are distributed over the Indian sub-continent and Burma. In Australia, 13 species are endemic, *A. scarabaeoides(I.)* Bth., being the most widespread, has a variety endemic in Australia. The pigeonpea is a pantropical species.

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Ethnobotanical Aspects of Pigeonpea

D.C.S. Raju

Abstract

Ethnobotanical aspects relating to ancient usage, vernacular names, origin of the crop, and various types of historical and modern classifications are described. Morphology, breeding behavior, and uses by primitive people all are pointers to the course of evolution, and data gathered may further usage of germplasm of pigeonpea and allied taxa.

Origin of Pigeonpea

The pigeonpea, known as red gram in India, is of ancient cultivation and is supposed to have been in use for over 4000 years. All kinds of beans from the Old World, including pigeonpea, are valued in cultivation with banana, eggplant, cucumber, grapes, mulberry, rice, soybean, and tea from times immemorial. Vavilov (1940) considered the Indian region as a primary center of oriain of cultivated pigeonpea, but existence of wild populations of *cajanus cajan* (L.) Millsp. in Angola and the existence of popular names such as Congobean or Congopea lend some support to the view of Zeven and Zhukovsky (1975), and many earlier authors, that the primary center of origin of pigeonpea is Africa.

Names of the Pigeonpea and Some Derivations

In religious ceremonies, including the Hindu marriage, it is customary to sow pigeonpea as one of the nine seedcrops (nava dhanya) for perpetuation of the human race. Though pigeonpea is known as Adhaki in Aryan literature, many call it Tuwar. The religious-medical work Ayurveda mentions it only as a supplementary diet article. The split dhal is the main pulse food of Indians and treated as "meat" for Hindu priests. In Andhra cuisine, pigeonpea goes into a variety of well-spiced curries to improve the appetite.

Ancient cultivation and usage induced names of townships like Kandi in Andhra Pradesh. (It is an interesting coincidence that Kandi, (the local name for pigeonpea) is located within a 25-km distance from the ICRISAT campus, where the International Pigeonpea Workshop is being held.) Two more towns, Kanduru (Chittoor district) and Kandukuru (Ongole district), are also located in the SAT area.

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Surnames have also been taken from the vernacular: for example, Kandukuri Veeresalingam and Kandula Nagabhushanam. Three local Telugu cultivar names of pigeonpea are known: Billa kandi (flat pea) from the Deccan, Mabbu kandi (grey pea) from the Coromandel coast, and Erra konda kandi (red hill pigeonpea) of Visakhapatnam district in the Eastern Ghats of India.

There are numerous vernacular names for pigeonpea in India, Malaysia, Africa, Madagascar, and in the Americas where the pulse crop is widely cultivated (see Table 1). These names, which are associated with different ethnic groups, indicate economic aspects of consumption and communication, which are separate from classification and cultivation. Within India we have not yet recorded the data on uses and vernacular names for pigeonpea from the Nicobar Islands, Arunachal Pradesh, Manipur, Nagaland, Meghalaya, Sikkim, and Kangra Valley, where it is also cultivated.

Table 1. Some vernacular names of pigeonpea.

Asia

Burma: Pe Zingon
China: Shan Tou Ken
India: Red gram (English)
- Andhra Pradesh: Kandi, Kandulu (Telugu)
- Assam: Garmah, Koklaingmah
- Gujarat, Maharashtra: tur, Arhar (Hindi & Marathi)
- Karnataka: Togare (Kannada)
- Kerala: Thuvara (Malayalam)
- Tamil Nadu: Thovary (Tamil)
- Sanskrit : Adhaki

Indonesia: Goode, Katjang goode
- Sunda Isles: Heeris

Japan: Ki mame
Malaysia: Katjang eeris, Kachang dal
Nepal, Bhutan: Arhar
Philippines: Kadios, Gablos, Kaldis, Kidis, Tabios
Sri Lanka: Paripu

Europe

France: Embrevade
Germany: Angolische Erbse, Straucherbse
Great Britain: Pigeonpea, Pigeon pea
Spain: Guisante de paloma

Africa: Angola bean, Angola pea, Pois d'Angole
Angola: Ervilha de Congo
Ethiopia: Yewof-ater

Continued

Table 1. Continued.

Madagascar : Kadjoo
Mauritius: Ambrevade
Niger: Ohle
Nigeria: Waken Kurawa
Sierra: Leone, Guinea: Congo pea
Sudan: Lubia adassi, Ads Sudani
Somalia: Salbocoghed
Tanzania: Mbazi
Uganda: Apenga, Burusau
Zambia: Impose
Zanzibar: Nkol
America: Pigeonpea, Guandu
Costa Rica: Timbolillo
Cuba: Frijol Gandu
Mexico: Chicaro de arbol
Nicaragua: Garbanzo falso
Peru: Puso poroto
San Salvador: Alberga
Venezuela: Chinchoncho

Various Classifications of Pigeonpea

The religious-medical accounts of the Hindus show that pigeonpea is included in many practical classifications. According to Majumdar (1927), in one of the oldest classifications based on dietary food value by Charaka, an ancient surgeon, pigeonpea is listed under "Samidhanya varga" (category of grain crops) of second rank, whereas Susruta, another ancient author, recognized beans under "Simva" (pulses) as the eighth category in his system. Bhavaprakasha synthesizes both old systems and recognizes "Simbi" (pulses) as a subgroup of his seventh "Dhanya varga."

In Europe and the Middle East, ancient and medieval botanists described the crop plants of those days in Greek, Latin, and Arabic. With the advent of scientific botany, botanical classifications developed mainly in Latin, enabling the western scientists to communicate with one another. Greek and Latin polynomials appeared in botanical literature, and Plukenet, for example, classified red gram from India in his bean group as *"Phaseolus erectis incanus, siliquis torosis, kayan dictus."* The Swedish biologist Linnaeus (1753) placed pigeonpea under *Diaiephia decandria* with the binomial *cytisus cajan,* and the diagnosis reads: *"Cytisus racemis axillaribus erectis, foliolis sublanceolatis tomentosis; intermedio longius petioiato,"* based on a collection from Ceylon(Sri Lanka). The Swiss botanist De Candolle reclassified the plants of the world and included many beans in the tribe *Phaseoieae.* Pigeonpea is assigned to this tribe under *cajanus* DC. as *c. flaws* DC. and *c. bicolor*

DC, later considered to be a single species, and finally correctly named *Cajanus cajan* (L.) Millsp.

A simple key is given below to show how various cultivated beans and their wild relatives can be grouped. More details can be found in various floras. It is clear from Table 2 that many of the edible beans are classified in the large tribe *phaseoieae,* a category that can be equated with the Simbi of ethnobotanical lore.

Table 2. A key to some cultivated beans in the tribe *Phaseoleae.*

(Anthers uniform, pod two-valved, not articulate, leaves pinnately trifoliolate)

A. Style bearded (subtribe *phaseolinae* = Euphaseoleae)

Lablab purpureus (L.) Sweet	Lablab Bean, Batao, Shimbi or Indian bean
Macrotyloma uniflorum (Lam.) Verdc. = Dolichos uniflorus Lam.	Horse Gram
Pachyrrhizus erosus (L.) Urban	Sinkamas, or Yam Bean
Phaseolus lunatus L.	Lima Bean
P. vulgaris L.	Common or Wax Bean
Psophocarpus tetragonolobus L.	Winged Bean
Vigna radiata (L.) Wilczek	Mung Bean, Green gram
V. umbellata (Thunb.) Ohwi & Ohashi	Rice Bean, Anipay
v. aconitifolia (Jacq.) Marechal	Moth Bean
V. unguiculata (L.) Walp.	Cowpea
V. unguiculata ssp. *sesquipedalis* (L.) Verdc.	Asparagus Bean, Barbati or Stringless Bean, Sitao

AA. Style glabrous (not bearded)

B. Nodes of raceme swollen (subtribes *Diocleinae* and *Erythrininae* resp.)

Canavalia ensiformis (L.) DC.	Barasem, Jack Bean

Continued.

Table 2. Continued.

AA. Style glabrous (not bearded)		
B. Nodes of raceme swollen (subtribes *Diocleinae* and *Erythrininae* resp.)		
	c. gladiata (Jacq.) DC.	Sword Bean
	Mucuna pruriens (L.) DC. var. *Utilis* (Wall. ex Wt.) Baker ex Burck.	Velvet Bean
BB. Nodes of raceme not swollen		
C. Leaves not gland-dotted (subtribe *Glycininae)*		
	Glycine max (L.) Merr.	Soybean
CC. Leaves copiously gland-dotted (subtribe *Cajaninae)*		
D. Ovules 1-2 (Wild 1 to 2-seeded relatives of pigeonpea)		
DD. Ovules 4 to many (Pigeonpea and close wild relatives)		
E. Seeds with aril *Atylosia, Dunbaria.*		
	e.g. *Atylosia scarabaeoides* (L.)Bth.	Walkollu
EE. Seeds without aril		
	Cajanus cajan (L.) Millsp.	Pigeonpea, Congo Bean

While it is useful to record all analytical characters for evaluation, haphazard interpretation of limited numbers of either quantitative and qualitative data often hinder biological improvement, particularly of *cajanus cajan* cultivars. Baker described gland-dotted species of *Cajaninae* in six genera: *Atylosia, Cajanus, Cylista, Dunbaria, Eriosema* and *Rhynchosia* with some 50 species. The number of ovules and hence seeds is the only major character delineating *Atylosia, Cajanus,* and *Dunbaria* from the other few-seeded taxa. Whereas quantitative characters like depression of the pod valves between seeds are taken to segregate *Dunbaria* from the closely allied *Atylosia* and *cajanus,* the latter has been sorted out by absence of the seed aril, a qualitative character. Several wild relatives of pigeonpea were once described in *cajanus* and later transferred into *Atylosia,* confusing plant breeders searching for genetic resources of pigeonpea. Species like *cajanus cinereus* F.v. Muell., c. *grandifolius* F.v.Muell. from Australia (also transferred to *Atylosia)* and *c. kerstingii* Harms (Hepper 1958) from West Africa have received *very* little attention ever since they were first discovered in their native habitats.

Morphology and Distribution

In searching for pigeonpea germplasm resources, not only the entire range of morphological range of variability or related taxa, but also the habitat range should be studied for biological assessment. Features such as floral biology and morphology indicate the extent of introgression among closely related species, while the distribution pattern gives us the ecological amplitude. These two aspects are of great significance to pigeonpea breeding to select biotypes for extension of cultivation. Considering the morphology and breeding behavior, it has been suggested that several taxa like *Atyiosia voiubilis* (Blanco) gamble, *Dunbaria heynei* W & A , *A. grandiflora* Bath.ex Bak., *A. lineata* W & A , *A. trinervia [DC.)* gamble, *A. sericea* Bth.ex Bak. and *A. villosa* Bth. ex. Bak. should be brought nearer to *c.cajan* to make the classification more useful and natural, *A. cajanifolia* Haines from Bailadilla in Madhya Pradesh, a SAT area, occurs close to the habitat of the pigeonpea cultivar *Yerra konda kandulu* of the Northern Cirears (Visakhapatnam), collected by Cleghorn some 100 years ago. The *Podu* cultivation by tribals of Koraput in Orissa and usage of other wild legumes are suggestive of primitive agriculture and domestication of wild beans. The name *Bilia kandi* of Andhra Pradesh is suggestive of *Dunbaria,* which is allied to pigeonpea.

If the aril late condition of the seed is regarded as primitive, the nonarillate pigeonpea should be a mutant with advantages of selection by man, and hence propagation as a crop. It is worth mentioning here that monkeys, both Rhesus and Langur, eat green pigeonpeas from standing crops in parts of Andhra Pradesh in the same manner as youngsters do.

When habit and seed-bearing capacity are considered, species like *Atyiosia albicans* W & A, *A. lineata* W & A and *A. trinervia* (DC.) gamble can be placed at one end of the range and *c.cajan* with maximization at the other. Indeed two- to three-seeded cultivars of pigeonpea, such as found in the southern Andamans, and the substrophiolate seeds of *Rhynchosia beddomei* Baker, *R.pseudo-cajan* Cambess. (semi-erect plants) and *Dunbaria ferruginea* W. & A. (climber) fill the gaps in the evolutionary network of *cajanus* by intermediate taxonomic characteristics. Pigeonpea scientists could confirm these views by biosystematic research for better interpretation of species re\lationship and benefit of growing populations in the semi-arid tropics.

The patterns of distribution and consumption of pigeonpea in various countries of the world are significant for two reasons: (1) to indicate the climatic conditions and soil types to which the pigeonpea is adapted and the phenotypic expression of genotypes; and (2) to evaluate selection methods and methods of crop cultivation knowledge by ethnic groups in relation to rural economy and local traditions. Data on consumption of pigeonpeas produced locally or obtained through trade channels are important to study the pattern of utilization with relevance to crop production and improvement.

Such studies are better made in herbarium collections to save labor and time. A preliminary survey of pigeonpea accessions in the Calcutta Herbarium confirms that the crop is cultivated both in the tropics and the subtropics. Records of cultivation from the Szemao Mountains of Yunnan (Henry 1899) and Kwantung in China, the mountains of Java and Philippines, Timor(Masters 1883), Rio de Janeiro in Brazil, Vera Cruz in Mexico, and the Latin American countries of Venezuela, Bolivia, and Colombia indicate the adaptation of the species to medium (2U00 m) altitudes and associated soils. Occurrence of the crop at the fringes of the Nubian desert and in Arunachal Pradesh in India indicate the tolerance of the species to variations in precipitation (250 to 2500 mm rainfall).

The pods are broad in Madhya Pradesh (India), large in Yunnan and the Andamans, and many-seeded (5-7) in the Philippines and Sadiya(Assam). Bunches are large in Cadellganj (Assam). The plants are grown near houses in Siang Frontier; in the "Jhoom" cultivation areas of Tripura and the Garo Hills of Megnalaya; in the Tangya system of Burma, in association with cotton on teak plantations; and as a perennial crop on "hoomas" or paddy terraces in the Philippines. Pigeonpea is extensively grown by Indian farmers, including the Santals of Bihar and the Manipuris, but it is limited to some extent in Nagaland.

Some Uses of Pigeonpea

The uses of pigeonpea are manifold. Dhal is the ubiquitous protein-rich dish eaten by most Indians. Ochse and van den Brink (1931) mention various uses of the pigeonpea. Green pigeonpeas are relished both as cooked and smoked pods. In Java young pods are used in preparations called "Sayor" and "Roodjak", large quantities of which are believed to be soporific but harmless. Husks of pods are used as cattle feed; the green foliage as green manure or fodder; dried stalks as fuel or thatch; roots for soft coal; the whole plant as host for the lac insect, and foliage for rearing of silkworms. Pigeonpea wood is even used to strike a light by the Wahiyon.

Much more light is yet to be thrown by scientific study on ethnobotanical aspects of pigeonpea which is a promising crop of the future in the semi-arid tropics.

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Pigeonpea Germplasm of Assam and the Garo Hills

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Abstract

Local germplasm lines of pigeonpea, Cajanus cajan *(L.) Millsp., from different regions of Assam and the Garo Hills of Meghalaya have been grouped based on metroglyph analysis. Fifty-two diverse genotypes, including 47 local perennial and five improved cultivars, have been grouped into broad categories on the basis of yield potential. The high-yielding group with 14 genotypes is characterized by late maturity, large number of pods per plant and of seeds per pod. The medium and low-yielding groups consist of 14 and 24 genotypes, respectively. Material from districts north of the Brahmaputra river produced more on the average than material from south of the Brahmaputra. The prospects of combining the high pod number of the late-maturing perennial types with the early-maturing annual types are discussed.*

A basic prerequisite to continuous and long-term progress of a plant improvement program is the establishment and evaluation of a diverse germplasm collection. Classification analysis by various approaches such as D^2 statistics (Mahalanobis, 1936), multiple range tests (Arunachalam et al. 1965) and other statistical techniques adopted (Murty et al. 1967) involve heavy computations. A simple technique known as metroglyph analysis, suggested by Anderson (1957), serves as a valuable aid for grouping of a large number of germplasm accessions according to their characters. In this paper, grouping of a pigeonpea germplasm collected from three different regions of Assam and Garo Hills (Meghalaya) has been attempted based on metroglyph analysis.

Materials and Methods

Fifty-two diverse genotypes of pigeonpea (47 local perennial ones and 5 improved ones) were collected from districts north of the Brahmaputra, south of the Brahmaputra, and the hill districts of Assam and the Garo Hills of Meghalaya. The material was sown during kharif 1978 at the

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research farm of the Assam Agricultural University, Jorhat (26°47'N, 94°12'E, 86.6 m altitude) in Assam, India.

The experiment was laid out in a randomized block design with two replicates. Seven characters were recorded: plant height (cm), days to 50% flowering, days to maturity, pods per plant, seeds per pod, 100-seed weight (g), and yield per plot (g). For metroglyph depiction, yield per plot and days to maturity were taken as X and Y axes, respectively. With increased duration, the pod number, seed size, and yield generally increase, indicating a positive relation between yield and maturity duration (Reddy et al. 1975). Hence, the number of days to maturity is taken to represent the Y ordinate. The index values for the three classes of each character (Table 1) have been presented by varying lengths of rays, i.e. low (no ray), medium (short ray) and high (long ray).

Results and Discussion

The fifty-two genotypes showed a clustering into three broad groups on the basis of their yielding ability. The first group consisted of genotypes with grain yield ranging from 400 to 1000 g per plot, the second with yields between 1000 and 1600 g per plot, and the third with yield more than 1600 g per plot; these are designated low-, medium-, and high-yielding groups, respectively (Figure 1).

The low-yielding group consisted of 24 lines. Most of the lines were characterized by dwarf to medium plant height and low pods per plant. Seed number per pod varied from low to medium. Hundred-seed weight was described as low, medium and high.

The medium-yielding group was represented by 14 lines characterized by medium to tall plant height, low to medium number of pods per plant and medium to high number of seeds per pod. Hundred-seed weight ranged from low to medium.

The high-yielding group also consisted of 14 lines, mostly of medium to tall plant height. No dwarf line was found in this group. The lines were mostly characterized by medium to high number of pods per plant, number of seeds per pod, and 100-seed weight.

On the basis of days to maturity, the collection was grouped into three categories: early, medium, and late.

Twelve lines represented the early-maturing group. The plant height ranged from dwarf to medium tall. None of the lines in this group was tall. The lines were low yielders because of low number of pods per plant and low to medium number of seeds per pod.

The medium-maturing group consisted of 17 lines covering dwarf, medium-tall, and tall plants with medium to high number of seeds per pod.

The maximum number of lines (23) have been included in the late maturing group. This group was represented by most of the high-yielding lines characterized by medium-tall to tall plant height. No dwarf line was found in this group.

Table 1. Index values of the variables in a pigeonpea collection from Assam and the Garo Hills of Meghalaya.

Character	Index values					
	Low		Medium		High	
	Index value	Symbol	Index value	Symbol	Index value	Symbol
Plant height(cm)	⩽ 150	0	151-220		⩾ 221	
Days to flowering	⩽ 115	0	116-150		⩾ 151	
Days to maturity	⩽ 175		176-225		⩾ 226	
Pods/plant	⩽ 485	0	486-840		⩾ 841	
Seeds/pod	⩽ 3.80	0	3.81-4.37		⩾ 4.38	
100-seed wt (g)	⩽ 7.40	0	7.41-9.05		⩾ 9.06	
Yield/plot (g)	⩽ 1000		1001-1600		⩾ 1601	

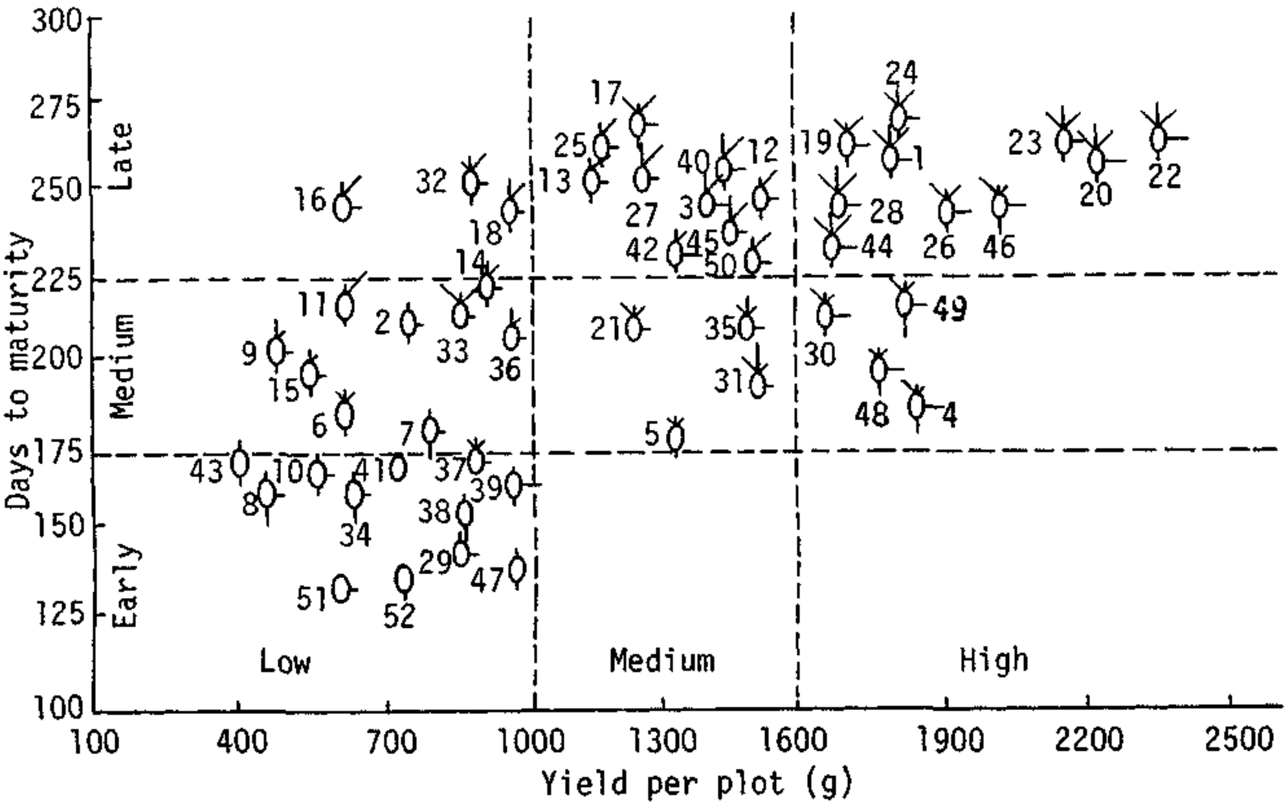

Figure 1. Metroglyph diagram in pigeonpea showing distribution of characters in genotypes grouped into low-, medium- and high-yielding and as early, medium, and late maturity lines.

Table 2. Mean and range of variability in a pigeonpea collection assembled in three regions of Assam and the Garo Hills of Meghalaya, India.

Character	North bank of Brahmaputra River		South bank of Brahmaputra		Hill Districts	
	Mean	Range	Mean	Range	Mean	Range
Plant height (cm)	204	143 - 254	188	116 - 271	183	141 - 289
Days to flowering	166	113 - 188	149	97 - 193	138	98 - 190
Days to maturity	241	162 - 268	236	164 - 260	229	153 - 273
Pods/plant	1396	198 -3620	533	123 -1781	427	166 -1541
Seeds/pod	4.40	3.90- 4.76	4.30	4.00- 5.55	4.38	3.55- 4.95
100-seed weight (g)	8.20	6.10- 11.70	7.75	6.25 10.85	8.45	5.75- 10.85
Yield/plot (g)	1545	412 - 2372	1406	400 -2093	1369	692 -2002

Thus the results have indicated that maturity duration combined with plant height, pods per plant, seeds per pod, and 100-seed weight give a good indication of the yielding ability of the lines.

Material from districts north of the Brahmaputra river showed a higher mean and range of variability for yield (Table 2), compared with material originating from districts south of the Brahmaputra. The mean value for days to maturity was highest for material from north of the Brahmaputra and lowest for those originating from hill districts. A similar trend was observed for plant height, days to 50% flowering and number of pods per plant. However, the mean value for 100-seed weight was higher in material from the hill districts compared with material from north of the Brahmaputra.

The index scores of the five top-yielding lines—serial numbers 20, 22, 23, 26, and 46, have been presented in Table 3. A perusal of this table indicates that days to maturity, number of pods per plant, and number of seeds per pod are relatively more important than plant height and 100-seed weight. Lateness and pod number are important components of grain yield (Reddy et al. 1975). The role of plant height is significant in altering the plant size and harvest index rather than directly influencing yield.

In Assam, ratooning of pigeonpea is a common practice with the well-adapted late (duration >250 days) and perennial types. These

Table 3. Scores of five top-yielding lines of pigeonpea for different characters.

Character	Line				
	No.22	No. 20	No. 23	No. 46	No. 26
Plant height (cm)	3	3	3	2	2
Days to flowering	3	3	3	2	3
Days to maturity	3	3	3	3	3
Pods/plant	3	3	3	3	3
Seeds/pod	3	3	3	3	3
100-seed wt (g)	3	2	3	3	2
Yield/plot (g)	3	3	3	3	3
Total score	21	20	21	19	19

Score: 1=low, 2=medium and 3=high

cultivars are characterized by high podding ability, resulting in high grain yield per plant, but their profuse vegetative growth habit combined with long duration substantially reduces their yield per hectare per day. In early and medium-maturing cultivars the regrowth after the first grain harvest develops flowers and pods quickly, whereas in late-maturing types new growth is mainly vegetative (Sharma et al. 1978). Hence, breeding possibilities aiming at combining the higher pod number of late-maturing perennial types with early ratooning potential of the early and medium-maturing types need to be investigated. This will constitute an appropriate step towards developing genotypes with increased grain yield per hectare per day under ratooning practices.

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The Wild Gene Pool of *Cajanus* at ICRISAT, Present and Future

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Abstract

This paper summarizes the present status of and future plans for the genetic resources activities on wild pigeonpeas at ICRISAT. The scope of exotic germplasm in generating more variability in pigeonpea, building resistance against pests and diseases, and upgrading nutritional value is discussed with specific examples. The worldwide distribution of the closely related taxa is presented, and the center of origin and diversity of pigeonpea is discussed. With the ever-increasing trend of genetic erosion, several wild species are now under threat of extinction. The need to collect them is stressed, and priority areas are indicated.

Utility of Exotic Germplasm in Pigeonpea Improvement

The genetic potential of wild relatives in crop improvement is now a well-demonstrated fact. Even with a world germplasm collection of the crop species at hand, breeders often reach almost dead ends for lack of some unique characters, for example, annuality or insect resistance in pigeonpea. Wild relatives are not a ready answer, but we now have some lead that indicates that the wild relatives of pigeonpea can make a substantial contribution to overcome these problems. The transfer of annuality from wild relatives such as *Atyiosia piatycarpa, Rhynchosia minima, R. aurea,* etc. to pigeonpea would result in a breakthrough in pigeonpea breeding. ICRISAT entomologists have already found mechanisms of pod-borer resistance and varying degrees of resistance to podfly, *Hymenoptera*, and bruchids in wild relatives of pigeonpea. The antimetabolic nature of protease inhibitors, as reported (Singh and Jambunathan 1980b) in the closely related species *Rhynchosia rothii* (314% increase over *cajanus)* could provide physiological resistance against certain insects. *Atyiosia piatycarpa* and *A. sericea* accessions that are immune to blight are now in the ICRISAT collection.

The variability for protein content in pigeonpea germplasm is limited. Eight wild relatives, including six *Atyiosia* species, were analyzed by ICRISAT biochemists. Strikingly, all of them had higher protein content; 28.3 to 30.5%, compared with 24.2 in pigeonpea (Singh

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and Jambunathan 1980a). No appreciable differences were recorded in the values of protein digestibility for *cajanus* and *Atylosia* (U. Singh, personal communication). The efforts of the breeders at ICRISAT to develop high-protein lines by utilizing *Atylosia* germplasm have resulted in the selection of high-protein derivatives with desirable agronomic traits (Reddy et al. 1978). The attempts of the biochemists to identify pigeonpea cultivars with high sulfur amino acids (which are the limiting essential amino acids in pigeonpea) in. the world dollection have so far not been successful. However, the analysis of eight closely related species resulted in the identification of one species of *Fiemingia* which showed a high percentage of methionine and cystine. At present, 28 more closely related species are available, with 121 accessions, and interesting biochemical results may be expected.

It is recognized that wild species are able to tolerate water stress relatively better than crop plants. The identification, collection, and subsequent transfer of drought tolerance to pigeonpea would be a significant advance in breeding of pigeonpea for the SAT regions. The recently collected Australian species, *Atylosia acutifolia* (still in transit) is very drought tolerant. Apart from these desirable traits, a unique quality like cytoplasmic male sterility, which is not easily available in the pigeonpea germplasm, has been obtained by exploiting the exotic germplasm (L.J. Reddy, personal communication). *Atylosia* germplasm has been successfully introgressed into a number of locally adapted pigeonpea cultivars and the breeders are making extensive use of the hybrids and backcross progenies to reach their targets.

Close Relatives of Pigeonpea, Their Distribution, and Center of Diversity

Pigeonpea belongs to the subtribe *cajaninae* (tribe *Phaseoleae,* family *Leguminosae)*, which is a natural assemblage of about 13 closely related genera distributed mainly in tropical regions (Table 1). The generic distinctions are sometimes not based on sharp and well-defined morphological characters, and biosystematic relationships of these genera are not yet completely understood. The number of species included in each genus varies from flora to flora and author to author. For example, Hooker (1876) classified 20 species in *Atylosia* and 80 in *Rhynchosia,* while Shaw *(in* Willis 1973) included 20 in *Atylosia* and 300 in *Rhynchosia.* However, there is widespread agreement on the close relationship of *cajanus* and *Atylosia.* Von Mueller *[in* Bentham 1864) proposed the merger of the two genera. Supporting this suggestion Lackey (1977) considered *cajanus* to be a cultigen of *Atylosia.* Deodikar and Thakar (1956) suggested the merger of the two genera on the basis of morphological, taxonomic, and cytological evidence and the high degree of fertility of intergeneric hybrids.

Electrophoretic patterns of salt-soluble proteins revealed close similarities between *cajanus* and *Atylosia* species (Singh and Jambunathan 1980a). Further, in *A. cajanifoiia,* the taxon closest to pigeonpea in morphological characters, the protease inhibitor activity of trypsin and

Table 1. Distribution of subtribe *Cajaninae*.

Genus	No. of species	Distribution	Areas ICRISAT collected	Priority areas
Adenodolichos	± 15	Tropical Africa		
Atylosia	± 35	Tropical Asia, Australia, Africa, Madagascar, New Caledonia	India(Western and Eastern Ghats, NW Himalayas), Sri Lanka, Thailand, Australia (Qld.)	Australia, Africa
Baukea	1	Madagascar		
Cajanus	2	India, Africa	India, Nepal, Burma, Sri Lanka, Kenya, Thailand	Africa, SE Asia
Carissoa	1	Angola		
Chrysoscias	6	S. Africa, Australia		
Dunbaria	± 15	Tropical India, Japan Malaya, Australia, New Guinea	India	
Endomallus	2	Indochina		
Eriosema	± 130	Tropical and south Africa and America, Tropical Asia and Australia		Tropical and South Africa, tropical America & Australia
Bolusafra(Fagelia)	1	South Africa		
Flemingia	± 35	Tropical Africa and Asia	India	Tropical Africa
Paracalyx	6	India, Indochina, Suqutra (Arabian Sea), South and northeast Africa	India	
Rhynchosia	± 200	Tropical and subtropical America, Africa, and Asia (China, Japan, India)	India	Tropical and sub-tropical America, Africa, Japan, China

chymotrypsin was strikingly similar to that of *cajanus* (Singh and Jambunathan 1980b). These biochemical results support the merger of the two genera.

The interrelationship of *cajanus* and *Atyiosla* has a close bearing on the origin and center of diversity of *cajanus,* which is now a debated issue. Harms (1916) proposed *cajanus kerstingii* as a precursor of the cultivated form, and Westphal (1974) believes that the pigeonpea originated in Africa. Bentham (1865) and de Candolle (1883) suggested an Asiatic origin, which has been upheld recently by van der Maesen (1980). On the basis of a study of 25 known species of *Atylosia,* De (1976) concluded that an erect *Atyiosia* is the progenitor of pigeonpea and the upper Western Ghats area of India is the possible center of origin of pigeonpea. The intimate involvement of *cajanus* with *Atyiosia,* the great diversity in *cajanus cajan* grown in India, and the abundance of *Atyiosia* spp. in the subcontinent, especially in the Western Ghats, support the view that *cajanus* originated in India.

Building up of a Wild Gene Pool at ICRISAT

Though the genetic resources activities on wild relatives are basically the same as on crop plants, the methods used are not exactly the same. The planning and the collection strategy involves elaborate preparations. Data on geographic distribution, precise location, time of fruiting, etc., are gathered from floras and herbaria, and through correspondence. The priority areas are decided on the basis of the possible utility of the wild relatives and threat of genetic erosion. The location data are often very old and not precise. Genetic erosion is a major problem in the Indian subcontinent, where wild plants are disappearing at an alarming rate. The Western and Eastern Ghats, and the northeastern hills are the most important gene centers of *cajaninae.* Deforestation and overexploitation of land is a major problem in the Western Ghats, where most of the natural vegetation has already been replaced by secondary forests or cash crops. Areas of the Eastern Ghats, and the northeastern hills suffer from shifting cultivation, in which tribals burn the forest, cultivate on virgin soil, and shift to other virgin lands.

Because the wild relatives are rather uncommon plants in natural vegetation, it is not always feasible to follow the recommended sampling strategy for crop plants. However, *every* effort is made to gather seeds from as large a population as possible and from as diverse habitats as possible. Each sample from each location is assigned a separate number and maintained separately. Maintenance is not difficult except in some temperate species. The seeds are kept in cold storage (±4°C) and are available to researchers all over the world.

The evaluation involves multidisciplinary participation. The important data on morphological characters are recorded and the seeds are sent to the ICRISAT Pathology, Entomology, Biochemistry, and Microbiology sections for special screenings and evaluation. Our experience reveals that there is considerable heterogeneity within the species and that it is desirable to obtain a large number of accessions of each species. Accessions with desirable traits are identified and included in introgression attempts.

ICRISAT has made a beginning in building up an exotic gene pool for pigeonpea and its subsequent utilization. The gene bank has now enough seed of 129 accessions belonging to 35 species and six genera (Table 2). The *cajanus-Atylosia* hybrids and backcross progenies that have resulted from introgression efforts are listed in Table 3.

The interspecific crosses between *Atyiosla* species are carried out with the primary objectives of combining desirable traits in the wild species and to understand the biosystematic relationships of these species. Seeds of wild species and introgression materials are available for distribution in limited quantities.

The introgression work is not without problems. Several species like *A. platycarpa*, *A. volubilis*, and *A. grandifolia* so far have not crossed with *cajanus*. *A. txinexvia* crosses easily, but the F_1 is partially sterile. However, efforts continue to involve more and more exotic germplasm in introgression. A one-way crossing barrier was noticed between *Atylosia* species and *cajanus* when *Atyiosia* was used as female parent. This barrier was very strong when *A. sericea* and A. *scarabaeoides* were used as female parents without any success, while with *A. LIneata* and *A. albicans* the percentages of success of the reciprocal crosses were 9 and 30, respectively. The exact nature of this one-way incompatibility is now under investigation.

Future Plans

Out of the 13 genera with about 450 species of the subtribe *cajaninae,* only five genera with 35 species and 129 accessions are available at ICRISAT. Hence we are still at the initial stage. The main future thrust has to be on collection, as genetic erosion, which is now a worldwide phenomenon, is threatening the wild species. The priority areas of collection are indicated in Table 1.

The collected accessions will be evaluated with multidisciplinary participation, and efforts will continue to introgress the wild species into *cajanus* to generate more variability and to transfer desirable traits. The generated materials will be passed on to various disciplines for screening and utilization in breeding work.

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Table 2. Present status of subtribe *Cajaninae* at ICRISAT.

Species	No. of Acces-sions	Origin	Remarks
Atylosia albicans W.& A.	8	Karnataka, Andhra Pradesh, Kerala; Sri Lanka: Kandy district	Sterility mosaic(SM) resistant, blight and podfly susceptible, high seed protein content, high trypsin and chymotrypsin inhibition
A. cajanifolia Haines	3	Madhya Pradesh, E. Ghats	Highly susceptible to SM, blight susceptible, susceptible to lepidopteran borers
A. goensis (Dalz.) Dalz.	1	W. Ghats, southern parts	
A. grandifolia F.v. Muell. ex Benth.	4	Australia: Queensland	Exists in erect and twining forms
A. lineata W.& A.	12	Karnataka; W. Ghats: north and south	SM resistant, blight susceptible, high seed protein content
A. marmorata Benth.	2	Australia: Queensland	
A. mollis Benth.	1	Himachal Pradesh	
A. platycarpa Benth.	11	Andhra Pradesh, Uttar Pradesh, Himachal Pradesh, Madhya Pradesh; Maharashtra; Chandigarh	Blight resistant, SM susceptible, high seed protein content, behaves like annual
A. rugosa W.& A.	3	Tamil Nadu; Sri Lanka: Nuwara, Eliya & Badulla	
A. scarabaeoides (L.) Benth.	31	Maharashtra, Bihar, Karnataka Tamil Nadu, Himachal Pradesh,	Varying degrees of susceptibility to SM and blight, *Hymenoptera*

Continued

Table 2. *Continued.*

Species	No. of Accessions	Origin	Remarks
A. scarabaeoides (L.) Benth.	31	Punjab, Andhra Pradesh, Uttar Pradesh, Orissa, Gujarat, Western & Eastern Ghats, NE Hills; Australia: N.T.; Papua New Guinea; Fiji; Japan	susceptible, Antibiosis to *Heliothis armigera*, high seed protein content
A. sericea Benth. ex Bak.	4	W. Ghats north	Blight and SM resistant, susceptible to Lepidopteran borers, high seed protein content
A. trinervia (DC.) Gamble	7	W. Ghats south; Sri Lanka: Districts Nuwara Eliya, and Badulla	
A. volubilis (Blanco) Gamble	6	Western and Eastern Ghats, Bihar, Punjab; Burma	SM resistant, blight susceptible, high seed protein content, high trypsin and chymotrypsin inhibition
Dunbaria ferruginea W.& A.	2	Western and Eastern Ghats	
D. heynei W.& A.	5	Western Ghats	
Rhynchosia albiflora (Sims.) Alst.	2	W. Ghats south	
R. aurea DC.	1	Uttar Pradesh	Annual
R. bracteata Benth. ex Bak.	2	Andhra Pradesh, Burma	
R. cana DC.	1	Tamil Nadu	

Continued

Table 2. *Continued.*

Species	No. of Acces-sions	Origin	Remarks
R. densiflora DC.	2	W. Ghats	
R. filipes Benth.	1	W. Ghats	
R. heynei W.& A.	1	Andhra Pradesh	
R. minima DC.	2	W. Ghats	Annual
R. rothii Benth. ex Aitch.	2	W. Ghats	High seed protein content, extreme trypsin & chymotrypsin inhibition
R. rufescens DC.	2	W. Ghats	
R. suaveolens DC.	1	Andhra Pradesh	
Rhynchosia sp. EC 130746	1		
Rhynchosia sp. EC 121204	1	Australia: Northern Territory	
Flemingia macrophylla(willd) Prain ex Merrill	2	Madhya Pradesh, W.Ghats south	
F. nilgheriensis (Baker) Wight ex Cooke	1	W.Ghats north	
F. semialata Roxb.	2	NE Hills, Jaintia and Garo Hills, Himachal Pradesh	High seed protein content, rich in methionine and cystine
F. stricta Roxb.	1	Burma	
F. strobilifera (L.) Aiton	1	NE Hills	
F. wightiana Grah.	1	W. Ghats south	
Paracalyx scariosa (Roxb.) Ali	2	W. Ghats north Karnataka	

Table 3. Introgression work on pigeonpea at ICRISAT.

Cajanus x *Atylosia* crosses	Generation	Backcross progenies	Generation	Interspecific crosses	Generation
Pant A-2 x *A.albicans*	F_3	(*A.cajanifolia* x Pant A-2) x Pant A-2	BC F_1	*A.albicans* x *A.scarabaeoides*	F_1
Pant A-2 x *A.scarabaeoides*	F_3	(Pant A-2 x *A.scarabaeoides*) x Pant A-2	BC F_1	*A.albicans* X *A. lineata*	F_1
Pant A-2 x *A.trinervia*	F_3				
UPAS-120 x *A.albicans*[b]		(Pant A-2 x *A.trinervia*) x Pant A-2	BC F_1	*A.lineata* x *A.albicans*[a]	
UPAS-120 x *A.lineata*[b]					
UPAS-120 x *A.sericea*	F_1			*A.lineata* X *A.scarabaeoides*	F_3
UPAS-120 x *A.trinervia*	F_3				
A.cajanifolia x Pant A-2	F_3			*A.sericea* X *A.scarabaeoides*[b]	
A.cajanifolia x UPAS-120	F_3			*A.scarabaeoides* X *A.sericea*	F_3
A.lineata x Pant A-2[b]					
A.lineata x UPAS-120[b]					

a. Plant died after a few days of stunted growth.

b. Raised at Banaras Hindu University, Varanasi, where the hybrid did not flower or seeds are not available.

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Genetics of *Cajanus cajan* (L.) Millsp. x *Atylosia* Spp.

L.J. Reddy, J.M. Green, and D.

Abstract

The genus Atylosia W. & A. is closely related to Cajanus DC '(plgeonpea) . Attempts were made to cross five diverse pigeonpea cultivars with eight species of Atylosia. A. platycarpa and A. volubilis could not be crossed with any of the pigeonpea cultivars tried. Inheritance studies of hairy pods, strophioled seeds and mottled seeds from F_2 *and* F_3 *generations indicated that they are governed by one or two major genes.*

Pigeonpea belongs to a small genus, *Cajanus,* in which at present only two species-- the cultivated *cajanus cajan (L.)* Millsp. and the wild *cajanus kerstingii* Harms. -- are classified. The genus *Atylosia* is closely related to *cajanus* and is separated from the latter on the basis of the presence of arillate seeds (Baker 1876). The close affinity between *Atylosia* and *cajanus* has been substantiated by their successful hybridization (Deodikar and Thakar 1956; Kumar and Thombre 1958; Kumar et al. 1958, 1966; Sikdar and De 1967; Reddy 1973). Some of the *Atylosia* species possess *very* valuable characteristics that are lacking in pigeonpea cultivars. For instance, *A. scarabaeoides* (L.) Bth. possesses both physical and antibiosis type of resistance to the podborer, *Heiiothis armigera,* while *A. sericea* Bth. ex Bak. and *A. albicans* W. & A. are rich in protein (Reddy et al, 1979). *A. grandifolia* (F.V. Muell.) Bth. (misspelled as *A. grandiflora* Bth. ex Bak.) has been reported to be hardy and fire-tolerant (Akinola et al. 1975). In view of the production of normal fertile hybrids between *cajanus* and *Atylosia* the latter can be utilized in breeding superior cultivated pigeonpeas. At ICRISAT a study is being made to assess the usefulness of various *Atylosia* species in upgrading economic characters in the cultivated forms. In this direction, several collections of *Atylosia* species have been made by our Genetic Resources Unit, and attempts made to hybridize these with diverse types of pigeonpea cultivars. The present paper deals with the crossability of eight *Atylosia* species with five pigeonpea cultivars and the genetics of some contrasting characters of taxonomic importance.

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* Pulse Improvement Program, ICRISAT.

Materials and Methods

Five diverse pigeonpea cultivars, Pant A-2, Baigani, ICP-6997, ICP-7035. and ICP-6915 were used in crosses with the *Atylosia* species given in Table 1.

Table 1. *Atylosia* species used in crosses with five pigeonpea cultivars.

Atylosia species	Habitat	Habit
A. lineata W. & A.	Western Ghats, Maharashtra, India	Erect shrub
A. sericea Benth. ex Bak.	Western Ghats, Maharashtra, India	Erect shrub
A. scarabaeoides (L.) Benth.	Kharagpur, West Bengal, India	Herbaceous creeper
A. volubilis (Blanco) Gamble	Hundru Falls, Ranchi, Bihar, India	Perennial climber
A. platycarpa Benth	-	Herbaceous creeper
A. albicans (W.&A.) Benth	Kodaikanal, Bangalore and Tirumalai, India	Perennial climber
A. trinervia (DC.) Gamble	Ootacamund, Tamil Nadu, India	Bushy shrub
A. cajanifolia Haines	Bailadila area, Bastar, Madhya Pradesh, India	Erect shrub

Crosses were made in different years, as and when the new *Atyiosia* species became available. In the first year, the first five *Atyiosia* species were crossed with all the five pigeonpea cultivars, and crosses were made in both directions. Based on the first year's experience that the hybrids are produced more readily only when *Atyiosia* species are used as male parents, the subsequent crosses with other *Atyiosia* species were made only in that direction. In the case of *A. trinervia,* pollen was brought as flower buds from Ootacamund on ice in a thermos flask and the pollinations were effected 48 hours after flower collection.

Pollen viability of the F_1s was determined with 1% acetocarmine stain. For each hybrid plant, five flowers were collected, and for each flower pollen counts were made under three different fields of a light microscope.

The-inheritance pattern of three characters—hairiness of pods, presence of strophiole, and mottles on the seed coat—was studied in the F*2* populations of different crosses, and the ratios were confirmed from the F3 progeny studies for the strophioled seed and mottled seed condition.

Probabilities of goodness of fit with the proposed hypothesis was found from chi-square (Fisher 1941) using the standard formula: $\chi^2 = \Sigma \frac{(O-E)^2}{E}$ where 0 and E stand for the observed and expected frequencies, respectively. The genes were symbolized according to the principles laid down by Tanaka (1957).

Results

Crossability

The percentages of pod-setting in different *Atyiosia* species crosses with five pigeonpea cultivars are given in Table 2. Only a few flowers of *A, lineata* and *A. trinervia* were available, limiting the number of pollinations carried out. *A. lineata* gave the highest percentage of pod-Setting, followed by *A. albicans, A. trinervia, A. cajanifolia, A. sericea,* and *A. scarabaeoides*. However, in the case of *A. albicans* a large percentage of germinated crossed seeds were found to be selfs. It is surprising to note that the success of pod-set in the crosses between various pigeonpea cultivars and *A. cajanifolia,* which is closest to *Cajanus* on the basis of morphological characters, is less than that Obtained with other species Of *Atyiosia, A. lineata, A. trinervia,* and *A. albicans.* Although a small percentage of pod-set was obtained in crosses involving *A. piatycarpa,* all the crossed seeds were found to be selfs after germination. Thus no crosses were obtained with *A. piatycarpa* and *A. volubilis.* Successful Crosses of *A. lineata, A. sericea,* and *A. scarabaeoides* with pigeonpea have been reported earlier (Deodikar and Thakar 1956; Reddy 1973). *A. albicans, A. trinervia,* and *A. cajanifolia* have been successfully hybridized for the first time with different pigeonpea cultivars.

Pollen Sterility

Percentage of pollen sterility in different F_1S of pigeonpea x *Atyiosia* spp. crosses is given in Table 3. The pollen sterility in the normal pigeonpea cultivars (ICP-6997) is around 9.9%, while in the different hybrids it ranged from 12.1 to 67.4%. Of the five *Atyiosia* species hybrids tested for their pollen sterility, hybrids of *A. scarabaeoides* showed the largest variation in sterility across different pigeonpea cultivars.

Inheritance of Qualitative Characters

The inheritance patterns of the following characters have been determined from crosses of different cultivars and *Atyiosia* species.

Strophioled versus Nonstrophioled Seeds

In the Fis of all the crosses involving different *Atyiosia* species and

Table 2. Percentage of pod-setting in *Cajanus cajan* x *Atylosia* spp. crosses.

Atylosia species[a]	Pigeonpea Cultivars									
	Pant A-2		Baigani		ICP-6997		ICP-7035		ICP-6915	
	A[b]	B[b]	A	B	A	B	A	B	A	B
A. lineata	110	32.7 (6.0)[c]	130	26.9 (-)	170	38.5 (13.0)	305	8.7 (4.5)	160	16.0 (Nil)
A. sericea	1260	2.5 (Nil)	670	9.3 (Nil)	1990	1.7 (Nil)	1520	1.8 (6.7)	1700	5.2 (10.0)
A. scarabaeoides	760	4.6 (6.3)	440	5.9 (9.1)	670	2.8 (Nil)	575	0.5 (14.3)	640	5.6 (Nil)
A. platycarpa	3035	0.3 (100)	526	0.4 (100)	1508	0.1 (100)	560	2.0 (100)	503	1.8 (100)
A. volubilis	926	Nil	1627	Nil	1251	Nil	1313	Nil	1167	Nil
A. albicans	1150	23.0 (53.7)	645	20.3 (42.9)	1200	34.0 (36.7)	1200	20.9 (100)	1200	14.5 (69)
A. trinervia[d]	125	35.2 (Nil)	50	4.0 (Nil)	46	10.9 (Nil)	32	31.3 (Nil)	NA[e]	
A. cajanifolia	2460	1.0 (Nil)	1139	8.3 (12.4)	1355	3.4 (1.0)	905	13.8 (2.0)	625	17.6 (7.0)

a. The first five *Atylosia* species were crossed during 1975 and pollinations were made in both directions. The rest of the species were crossed in the next year and the pollinations were made using pigeonpea cultivars as the female parents.
b. A = Number of pollinations; B = Percentage of pod setting.
c. Figures in parentheses refer to percentage of selfs based on the number of seeds germinated.
d. Flowerbuds were brought in a thermos flask from Ootacamund and pollinations were effected 48 hours after flower collection.
e. NA = Not attempted.

Table 3. Pollen sterility in F_1s of *Atylosia* spp. x *Cajanus cajan*.

Male parent	Female parent	No. of plants studied	Percent sterility Mean	Range
A. scarabaeoides X				
	ICP-6997	5	22.5	13.6-26.3
	Pant A-2	15	43.1	19.4-67.4
	Baigani	10	26.4	21.0-36.7
	ICP-6915	6	23.7	21.1-27.3
	ICP-7035	2	24.1	21.8-26.5
A. sericea X				
	ICP-6997	8	37.6	30.8-47.9
	Pant A-2	6	35.4	31.8-39.6
	Baigani	7	36.5	28.4-47.0
	ICP-6915	14	37.3	29.8-49.2
	ICP-7035	9	37.3	33.3-40.5
A. lineata X				
	Pant A-2	1	41.5	
	ICP-6915	4	27.5	24.9-30.9
A. albicans X				
	Pant A-2	12	19.2	12.1-24.9
	Baigani	3	23.3	19.0-25.5
	ICP-6997	5	16.3	14.0-21.0
	ICP-6915	3	25.2	18.3-31.7
A. trinervia X	ICP-7035	3	29.0	21.2-32.6
ICP-6997	(Check)	7	9.9	4.1-16.0

pigeonpea cultivars, the strophioled seed character of Atyiosia was dominant over the nonstrophioled seeded condition of pigeonpea cultivars. In the F_2 generation a good fit was observed for inhibitory gene action with a 13.3 ratio in the crosses of ICP-6997 and 6915 with A.scarabaeoides and A. sericea (Table 4J. However, the crosses of A. albicans showed a good fit for 3:1 and 9:7 ratios with Pant A-2 and ICP-6997 respectively, the other two crosses of A. scarabaeoides with Pant A-2 and ICP-7035 did not show a good fit to any of the ratios tested.

Table 4. Segregation pattern of strophioled vs nonstrophioled seeds in C. cajan x Atylosia spp. crosses.

Cross	Number of F_2 plants with Strophioled seeds	Number of F_2 plants with Nonstrophi-oled seeds	Probable ratio	χ^2 value	Probability
Pant A-2 x A. scarabaeoides	269	125	3:1	9.51	0.01-0.001
ICP-6997 x A. scarabaeoides	178	48	13:3	0.92	0.5-0.3
ICP-6915 x A.scarabaeoides	205	36	13:3	2.30	0.2-0.1
ICP-7035 x A.scarabaeoides	185	90	9:7	13.58	<0.001
ICP-6997 x A.sericea	123	27	13:3	0.06	0.90-0.75
ICP-6915 x A. sericea	94	26	13:3	0.67	0.50-0.25
Pant A-2 x A. albicans	232	68	3:1	0.87	0.5-0.25
ICP-6997 x A. albicans	65	39	9:7	1.65	0.25-0.1

To confirm the F_2 observations on the inheritance of strophioled seeds, 23 F_3 families derived from F_2 plants with strophioled seeds and 19 F_3 families derived from those with nonstrophioled seeds of ICP-6997 x A.scarabaeoides were studied. Of the 23 families of first category,eight bred true, ten families gave a good fit for 3:1 ratio (Hetero χ^2 = 9.54; P = 0.8-0.7) and two families gave a very good fit for 13:3 (Hetero χ^2 = 0.065; P = 0.8-0.7); the remaining three families did not give a satisfactory fit for either of the ratios. However, in the second category of 19 families, five bred true and 14 gave a good fit to 1:3 ratio (Hetero X^2 = 7.88; P = 0.90-0.75), thus confirming the inhibitory gene action governing the strophioled seeds. The discrepancy in the first category could be due to mistakes in classification. The genes proposed are nsSD I for strophioled seeds and NSsd i for nonstrophioled seeds.

Mottled versus Nonmottled Seeds

The mottledness of A.scarabaeoides seeds was dominant over the uniform color of pigeonpea seeds in the F_1s. In two crosses, ICP-6915 x A. scarabaeoides and ICP-7035 X A.scarabaeoides, the F_2 data fit to a 9:7 ratio indicating the involvement of two complementary genes in the expression of mottledness (Table 5). However, the data from ICP-6997 x A. scarabaeoides indicated duplicate factor inheritance with a good fit to a 15:1 ratio.

Table 5. Segregation pattern of mottled vs nonmottled seeds in C. cajan x A. scarabaeoides crosses.

Cross	Number of F_2 plants with		Probable ratio	χ^2 value	Probability
	Mottled seeds	Nonmottled seeds			
Pant A-2 x A. scarabaeoides	290	101	13:3	12.87	<0.001
Baigani x A. scarabaeoides	297	182	9:7	6.44	0.02-0.01
ICP-6997 x A. scarabaeoides	212	16	15:1	0.23	0.7 -0.5
ICP-6915 x A. scarabaeoides	151	97	9:7	2.17	0.2 -0.1
ICP-7035 x A. scarabaeoides	141	129	9:7	1.78	0.2 -0.1

To confirm the F2 behavior, 35 F3 families of ICP-6915 x A. scarabaeoides and 39 F3 families Of ICP-6997 X A. scarabaeoides were studied. Out of the 35 families of the first cross, 24 were derived from the F2 plants with mottled seeds and 11 from those with nonmottled seeds. The latter 11 families bred true. From the former group, 3 bred true, 17 segregated into 3:1 (Hetero χ^2 = 7.65; P = 0.98-0.95), and 4 into 9:7

(Hetero χ^2 = 0.75; P = 0.75-0.50) ratios. These observations confirm that the mottledness of seeds is controlled by two complementary genes. The genes proposed are Msd a Msd for mottling and mSd a msdb for nonmottling of seeds.

In the second cross, ICP-6997 x A. scarabaeoides the F_3 families did not show good fit to any of the expected ratios. Hence the duplicate factor inheritance of mottledness of seeds in this cross could not be confirmed.

Hairy versus Glabrous Pods

The hairiness of Atyiosia pods was dominant over glabrous pods in the F_1s of all the crosses. The F_2 data on ICP-6997 x A. scarabaeoides (Table 6) showed a good fit to a 13:3 ratio, suggesting inhibitory gene action in the nonexpression of glabrous pods. However, the F_2 data from ICP-6915 x A. scarabaeoides showed a good fit to 3:1, indicating that hairy pods are governed by a single dominant gene. These observations need confirmation from the studies on F_3 families. The F_2 data on the A. scarabaeoides crosses with other pigeonpea cultivars did not fit any of the ratios tested.

Joint Segregation Studies

Joint segregation studies on hairy pods and mottled seeds of Atyiosia showed independent segregation in ICP-6997 x A. scarabaeoides and linked inheritance in ICP-6915 x A. scarabaeoides (Table 7). In ICP-6997 XA. scarabaeoides, nonstrophioled and nonmottled seeds of the Cajanus parent were found to be linked, whereas inpendenti segregation was observed in ICP-6997 x A. scarabaeoides (Table 8). The glabrous pods and non-strophioled seeds were observed to be linked in both the crosses, ICP-6997 X A. scarabaeoides and ICP-6915 X A. scarabaeoides (Table 9).

Conclusions

Attempts have been made to cross five diverse pigeonpea cultivars (Cajanus cajan)with eight species Of Atyiosia: A. lineata, A. sericea, A. scara-baeoides, A. albicans, A. trinervia, A. cajanifolia, A. platycarpa, and A. volubilis. The latter two species, A. platycarpa and A. volubilis, could not be crossed with any of the five pigeonpea cultivars. Although the pollen sterility in different crosses ranged from 12 to 67%, highly fertile hybrids could be obtained with most of the species, suggesting that the present relegation of these species into two different genera is not justified. Also, in view of their easy crossability, various Atyiosia species can very well be utilized in breeding superior strains of c. cajan.

F_2 and F_3 data from crosses of pigeonpea x Atyiosia spp. indicated that some characters of Atyiosia were governed by either one or two major genes. Studies on F_2 populations and F_3 progenies showed that the

Table 6. Segregation pattern of hairy vs glabrous pods in *C. cajan* x *A. scarabaeoides* crosses.

Cross	Number of F2 plants with		Probable ratio	χ^2 value	Probability
	Hairy pods	Glabrous pods			
Pant A-2 x *A. scarabaeoides*	441	248	9:7	16.84	< 0.001
Baigani x *A. scarabaeoides*	442	288	9:7	5.48	0.02-0.01
ICP-7035 x *A. scarabaeoides*	226	110	9:7	16.55	< 0.001
ICP-6997 x *A. scarabaeoides*	312	78	13:3	0.4	0.7 -0.5
ICP-6915 x *A. scarabaeoides*	263	76	3:1	1.2	0.3 -0.2

Table 7. Joint segregation for hairy pods and mottled seeds vs glabrous pods and nonmottled seeds in *Cajanus cajan* x *A. scarabaeoides* crosses.

Cross	No. of F2 plants with				Expected ratio	χ^2	Probability	Remarks
	Hairy pods		Glabrous pods					
	Mottled seeds	Nonmottled seeds	Mottled seeds	Nonmottled seeds				
ICP-6997 x *A.scarabaeoides*	153	13	53	4	195:13:45:3	7.52	0.10-0.05	Assorted independently
ICP-6915 x *A.scarabaeoides*	116	78	39	7	27:21:9:7	17.10	< 0.005	Linked

Table 8. Joint segregation for strophioled and mottled seeds vs nonstrophioled and nonmottled seeds in *Cajanus cajan* x *A. scarabaeoides* crosses.

Cross	No. of F_2 plants with				Expected ratio	χ^2	Probability	Remarks
	Strophioled		Non-strophioled					
	Mottled seeds	Nonmottled seeds	Mottled seeds	Nonmottled seeds				
ICP-6997 x *A.scarabaeoides*	169	8	39	7	195:13:45:3	8.80	0.05-0.025	Linked
ICP-6915 x *A.scarabaeoides*	132	79	19	17	117:91:27:21	6.55	0.01-0.05	Assorted independently

Table 9. Joint segregation for hairy pods and strophioled seeds vs glabrous pods and nonstrophioled seeds in *Cajanus cajan* x *A. scarabaeoides* crosses.

Cross	No. of F_2 plants with				Expected ratio	χ^2	Probability	Remarks
	Hairy pods		Glabrous pods					
	Strophioled seeds	Nonstrophioled seeds	Strophioled seeds	Nonstrophioled seeds				
ICP-6997 x *A.scarabaeoides*	139	28	39	19	169:39:39:9	17.96	< 0.005	Linked
ICP-6915 x *A.scarabaeoides*	168	23	14	43	39:9:13:3	166.82	< 0.005	Linked

strophioled and mottled seed characters were governed by inhibitory and complementary gene actions respectively. The hairiness of pods was controlled by a single dominant gene in ICP-6915 x *A. scarabaeoides* However, it was inferred from F_2 data of ICP-6997 x *A. scarabaeoides* that the glabrous pod character (allelic to hairiness) of pigeonpea was inhibited by a gene present in the *Atyiosia* parent. This observation needs confirmation from F_3 studies. From the joint segregation studies it was concluded that the genes governing glabrous pods and nonstrophioled seeds in *Cajanus* parents were linked.

Acknowledgment

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Atylosia in Australia

L. Pedley*

In Australia *Atylosia* is represented by ten species, nine of them endemic; namely:

A. acutifolia (F. Muell. ex Benth.) Reynolds & Pedley ined. *(Rhynchosia acutifolia* F. Muell. ex Benth.)

A. cinerea F. Muell. ex Benth.

A. lanceolata W.V. Fitzg.

A. latisepaia Reynolds & Pedley ined. *(A. grandifoiia* F. Muell. ex. Benth. var. *Calycina* Benth.)

A. mareebensis Renolds & Pedley ined.

A. marmorata Benth.

A. piuriflora F. Muell. ex Benth.

A. pubescens (Ewart & Morrison) Reynolds & Pedley *(Tephrosia pubescens* Ewart & Morrison)

A. reticulata (Dryander) Benth. (*A. grandifoiia* F. Muell. ex Benth.)

A. scarabaeoides (L.) Benth.

The species are widely distributed in northern Australia, only three species extending for a short distance into the subtropics (Fig.1). *A. scarabaeoides* is also widely spread in the tropics of the Old World. They are plants of open woodlands, often on infertile, well drained soils. Theugh widely ranging some species are not at all common. Most are shrubby in habit, but *A. scarabaeoides, A. marmorata,* and *A. mareebensis* have trailing stems.

It is plain that *Atylosia, cajanus,* and *Rhynchosia* are closely related and that, despite recent herbarium studies (Reynolds & Pedley, in press) the taxonomy of *Atylosia* and related genera is far from clear. Some of the species recognized differ from each other only in size of flowers and inflorescences and in type and density of indumentum. Variability within some species is considerable and intergrades between species occur. Some infraspecific taxa have been recognized, but in most cases field studies and more intensive collecting of herbarium material is needed to elucidate patterns of variation.

Most species have a "trans-Australian" distribution but *A. plurifiora* and *A. mareebensis* are found only in northeastern Australia, the latter with an extremely narrow range, and *A. lanceolata* and *A. latisepaia* only

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in the northern part of Western Australia and the adjacent parts of the Northern Territory. From the distribution patterns it appears that *A. pubescens* extends farthest into arid regions, but herbarium specimens may not reflect the true ranqes of all species. Collections towards the end of the wet season are needed, particularly from Western Australia.

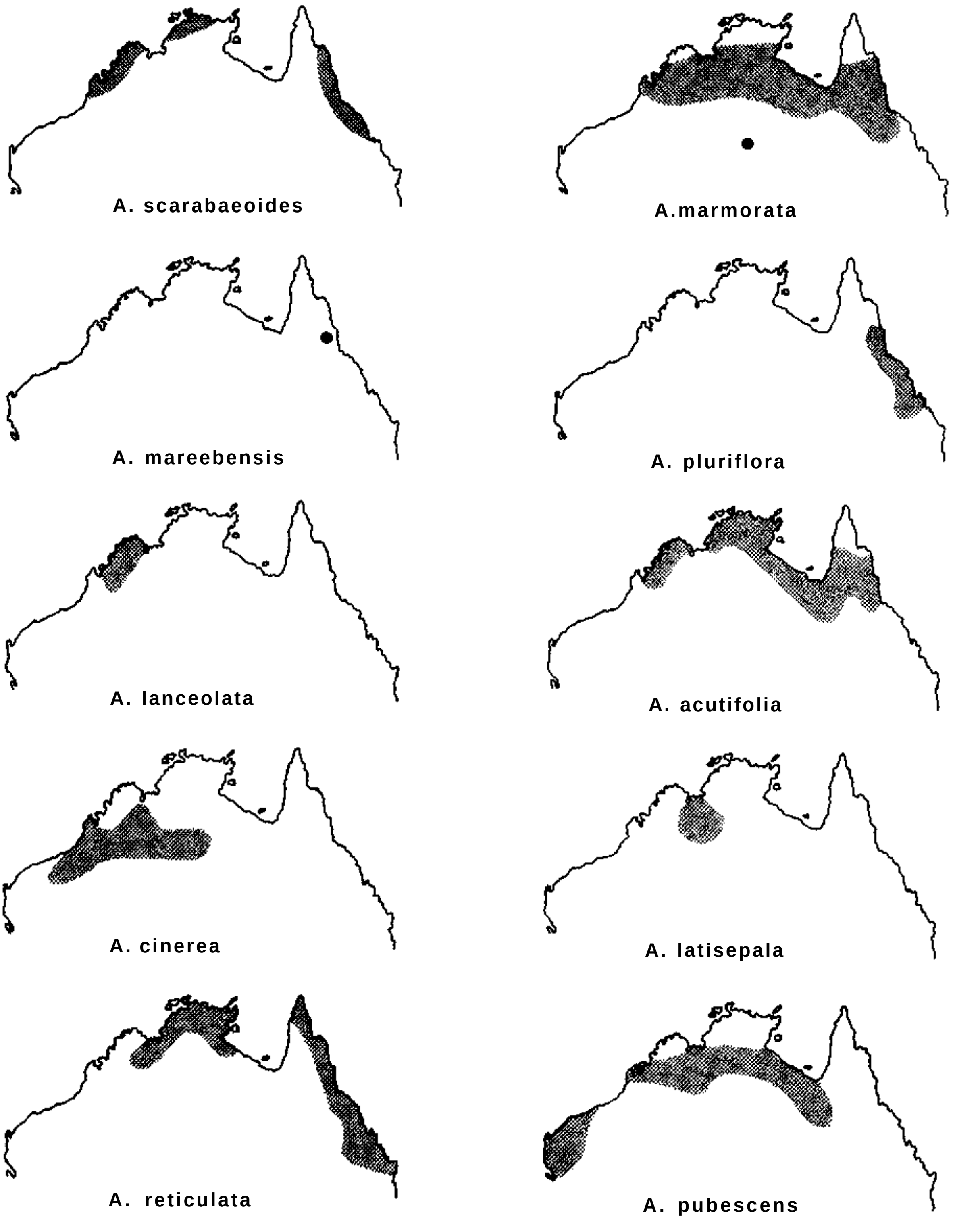

Figure 1. Distribution of *Atylosia* species in Australia.

Genetics and Plant Breeding

Session I	Chairman : S. Ramanujam
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Session II	Chairman : Laxman Singh
	Rapporteur : G.K. Bhatia

Genetic Analysis of Plant Height in Pigeonpea

H.K. Sharma*

Abstract

*Diallel analysis for plant height for nine cultivars of pigeonpea (*Cajans cajan [L.] *Millsp.) having a wide range of variability in different characters was conducted to determine genetic parameters for plant height. The D and H_1 components indicated the importance of both additive and dominance gene effects and that the degree of dominance was in the over-dominance range. Plant height may have complex inheritance with low heritability. The scatter of parental arrays indicated that genes controlling tall stature were dominant over genes controlling short stature.*

Among pulse crops, pigeonpea occupies an important place in Indian agriculture. However, the production of this crop per unit area is still below that of cereals. Genetics of important yield-contributing characters provide a basis for sound breeding programs. In pigeonpea, genetics of seed-size, flowering initiation, and protein content have been reported. Plant height has also shown significant positive correlations with yield. This paper deals with the genetic analysis of plant height.

Materials and Methods

Nine varieties of pigeonpea — S-5, T-21, Baigani, No. 148, C-ll, R-3, NP-69, NP(WR)-15, and Gwalior-3 -- were intercrossed in all possible combinations excluding reciprocals. The 36 crosses (F_1S) and their parents were grown in a randomized block design in two replications. Each entry was grown in a single row 5 m long with 1-m spacing between rows and 30 cm between plants. Observations on plant height were recorded on five representative plants in each entry. The data were analyzed according to Jinks and Hayman (1954).

Results and Discussion

The mean values of plant height for parents and F_1s are shown in Table 1. The mean plant height ranged from 169-5 cm to 291 cm in parents and

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Table 1. Mean values for plant height (cm) for parents and F_1 hybrids in pigeonpea.

Cultivar	S-5	T-21	Bai-gani	No.148	C-11	R-3	NP-69	NP (WR) -15	Gwal-ior-3
S-5	169.5	269.5	254.0	250.5	269.5	293.0	272.0	272.5	271.5
T-21		239.5	258.5	262.5	285.5	294.0	278.0	288.0	287.5
Baigani			239.0	259.5	255.0	290.0	277.5	265.0	272.5
No.148				232.5	257.5	268.0	238.5	252.5	262.5
C-11					254.0	291.5	267.0	272.5	284.0
R-3						291.0	290.0	280.0	274.5
NP-69							225.5	272.0	257.5
NP(WR)-15								260.5	274.0
Gwalior-3									276.5

238.5 cm to 294 cm in F_1s. The hybrids had higher mean values than the parents. Significant differences were shown among parents and F_1s in the analysis of variance of the experiment (Table 2). The block differences were also significant; therefore the Wr and Vr values were calculated separately for each replication and the genetic components were derived from the mean values over the two replications.

Table 2. Analysis of variance for plant height.

Source	df	SS	MS	F
Blocks	1	2867.38	2867.38	15.34**
Parents	8	19400.80	2425.10	12.98**
F_1s	35	13113.28	374.67	2.0004*
Parent $V_s F_1$s	1	11446.92	11446.92	61.25**
Error	44	8223.62	186.90	

* = Significant at *5%* level; ** = Significant at 1% level

The homogeneity of Wr-Vr, which indicates confirmation of the hypothesis postulated for the diallel cross, was tested by the analysis of variance of Wr-Vr. In this analysis the mean squares for arrays were not significant. Also, the regression coefficient for Wr, Vr was significantly different from zero but did not deviate from unity (0.896 + 0.087), showing absence of epistatic interaction.

The parameter estimates are shown in Table 3. D (1144.9 ± 135.9)

Table 3. Estimates of genetic parameters and ratios

Components/ratio	Estimates	Standard Error	
D	1144.961	± 135.99	P .01
F	1293.562	± 317.49	P .01
H_1	1326.763	± 300.23	P .01
H_2	808.714	± 258.16	P .05
r^2	2545.047	± 173.18	P .01
E	188.900	± 42.81	P .01
$(H_1/D)^{1/2}$	1.130		
$H_2/4H_1$	0.152		
$\frac{(4DH_1)^{1/2} + F}{(4DH_1)^{1/2} - F}$	3.208		
h^2/H^2	3.147		

shows the additive component of variation while H_1 (1326.7 + 300.2) shows the component of variation due to dominance effects of the genes. In the present study, both D and H_1 are significant and have almost equal values, the magnitude of H_1 being slightly higher than D. This clearly shows that both additive and dominance effects are involved in the expression of this character. The large and highly significant values of h^2 show that dominance is largely unidirectional. The h^2 indicates the overall dominance effects of the heterozygous loci. The mean degree of dominance given by the ratio$(H_1/D)^{1}/_{2}$was in the overdominance range (1.130). This confirms the importance of dominance effects in the expression of plant height. The estimate of H_2 showing variation due to non-additive effects corrected for gene distribution was less than H_1. Also, the ratio $H_2/4H_1$ deviated from 0.25, suggesting asymmetry in distribution of positive and negative alleles. The ratio $(4DH_1)^{1}/_{2}+F/(4DH_1)^{1}/_{2}-F$, which estimates the proportion of dominant and recessive genes in the parents, was 3.208. Since this ratio differs significantly from unity, it implies inequality between the number of dominant and recessive alleles in the parents, the dominants being more than the recessives. The ratio h^2/H_2, showing the number of gene groups controlling the character and exhibiting dominance to some degree was 3.14. This suggests that at least three of the genes controlling plant height exhibit some degree of dominance.

The Wr, Vr graph shows that the line of unit slope cuts the limiting parabola below the origin, thereby confirming the degree of dominance to be in the overdominance range. The dispersion of parental arrays along the regression line shows that parent 6 viz. R-3 has maximum dominant genes, since it lies on the extreme end towards the origin, whereas the

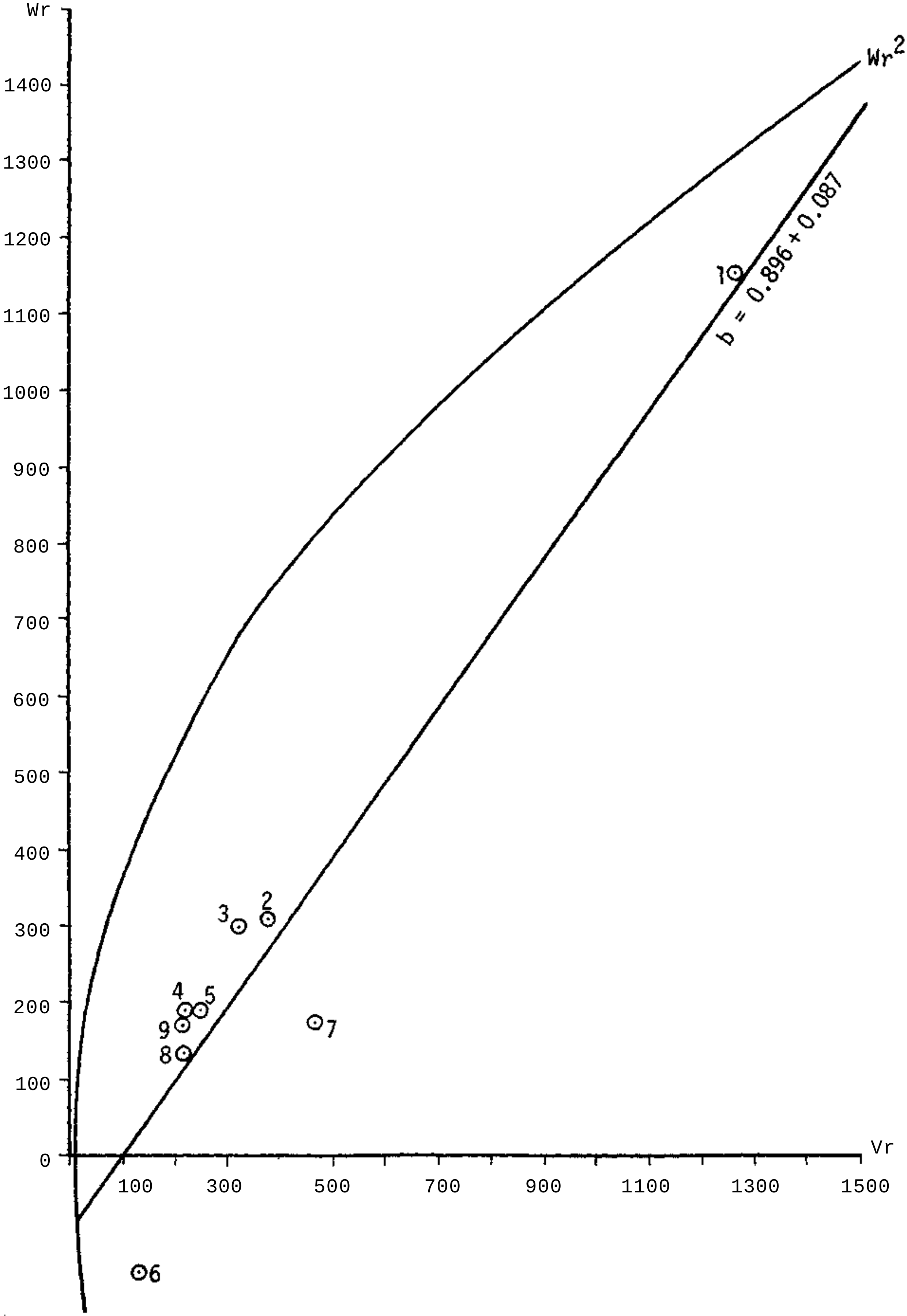

Figure 1. Vr, Wr graph for plant height for 9 varieties of pigeonpea.

parent S-5 has the maximum recessive genes, since it is at the farthest end of the regression line. Since parent 6 was the tallest and parent 1 the shortest of the parents, it is inferred that the genes controlling tallness are dominant over shortness. Parents 4, 5, 8, and 9, i.e. No. 148, C-ll, NP(WR)-15, and Gwalior-3 have more dominant genes and fewer recessives since these parents lie near the origin. Parents 2, 3, and 7, i.e. T-21, Baigani, and NP-69 also have more dominant genes but less than parents 4, 5, 8, and 9, since their position on the regression line is above these parents. Thus the dispersion of parental arrays confirms that these parents have more dominant alleles than recessives.

We observed that parents 6 and 7 are not very near the regression line, and concluded that this probably shows the presence of some nonallelic interactions, although this remains undetected in the analysis of variance of the Wr-Vr and Wr, Vr regression. A long gap on the regression line is seen between parent 1 and the other parents, suggesting that the parents included in the study do not represent the whole range of variability for plant height, and that studies with more diverse parents are needed for a better understanding of the gene action involved in the expression of plant height.

The estimate of heritability in the narrow sense, calculated by the formula $1/4D/1/4D + 1/2H_1 - F + E$ (Crumpacker and Allard 1962) was 35.1%. This low heritability indicates that selection for plant height by simple selection on a single-plant basis may not be *very* effective.

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Inheritance of Days to Flower and of Seed Size in Pigeonpea

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Abstract

Crosses involving a large-seeded parent, ICP-8504, and a small-seeded parent, Prabhat, were made, and the inheritance pattern was studied by growing parents, F_1s, F_2s, and back-crosses. The results are discussed in this paper.

Pigeonpea *(Cajanus cajan* [L.] Millsp.) is an important grain legume of the semi-arid tropics. At present, early-maturing varieties of pigeonpea are receiving considerable attention, as these escape frost and can fit into a multiple-cropping system. Seed size in thiscrop is a characteristic important to increasing yield and market acceptability. However, in general, the early-maturing types have small seeds and relatively low variability for this character. Early-maturing cultivars Prabhat and UPAS-120, recommended for cultivation in rotation with wheat in irrigated areas of northern India, have small seeds (6.3 and 7.9 g/100 seeds, respectively). Our studies on the relationship of seed size and yield indicate that there is no correlation between yield and seed size in the range of 9 to 12 g/100-seed weight. The lines with improved seed size appear to have better yield potential than the early types available so far. However, information on the genetics of days taken to flower and of seed size in pigeonpea is not adequate. This information is essential for organizing a systematic breeding program to develop varieties with desired maturity period and seed size. Therefore, the present study was undertaken to determine the inheritance of seed size and days taken to flower, which is a reliable index of the maturity period.

Materials and Methods

The parents used for this study were ICP-8504 (P_1 = late-flowering and large-seeded) and Prabhat (P_2 = early-flowering and small-seeded). The F_1, F_2, B_1F_1 (F_1 of backcross to P_1), and B_2F_1 (F_1 of backcross to F_2) of the cross Prabhat x ICP-8504, and the selfed parental lines were grown in a randomized block design with three replications during kharif (rainy season) 1978. In each replication 60 rows of F_2S, 20 each of backcrosses, and 10 each of parents and F_1s were grown in rows 3 m long and 75 cm

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apart, accommodating 13 plants 25 cm apart. Two hundred and fifty competitive plants of the F_2, 100 each of the backcrosses, and 30 each of the parents and the F_1 were selected in each replication for recording the data on days taken to flower and 100-seed weight (g).

The biometrical procedures outlined by Mather (1949) and followed by Warner (1952) were used in analyzing the data. The joint scaling test of Cavalli (1952) was applied, using the weighed least square method suggested by Hayman (1960) and Nelder (1960), to test for epistasis and to estimate the parameters of the model, m, d, and h. Generation means were analyzed using the method of Jinks and Jones (1958) to fit a six-parameter model for determining gene action. Standard errors of the estimates were obtained as suggested by Mather and Jinks (1971). Heritabilities were computed using both Burton's (1951) and Warner's (1952) approach. Effective factors were estimated using procedures suggested by Castle (1921), Mather (1949), and Sewell Wright (Burton 1951).

Results and Discussion

The range, mean, variance, and coefficients of variability for different generations of the cross, Prabhat x ICP-8504, are summarized in Table 1 for days to flower and in Table 2 for seed size.

Table 1. Range, mean, and variances for days to flower in pigeonpea.

Population	Number of plants	Range	Mean + SE	Expected mean	Variance	CV(%)
P_1 (ICP-8504)	90	98-114	106.6±0.23	107.1	4.61	2.01
P_2 (Prabhat)	90	80-92	85.5±0.79	81.7	5.59	2.76
F_1	90	83-107	87.0±0.34	87.4	10.63	3.74
F2	750	83-111	90.4±0.23	90.9	40.25	7.01
B_1F_1	300	83-110	96.9±0.39	97.3	46.45	7.03
B_2F_1	300	81-98	84.9±0.13	84.6	5.15	2.67
Mid-Parent	-	—	96.00			

The average number of days taken to flower both for F_1 and F_2 was less than the mid-parental value, indicating that alleles for earliness are partially dominant (Table 1). For seed size, both F_1 and F_2 means were similar to mid-parental value (Table 2), suggesting that gene action for seed size is primarily additive. Both for days to flower and for seed size, F_2 ranges did not give any indication of transgressive segregation, suggesting the possibility that plus and minus factors were isodirectionally distributed in the parents.

The probability values of less than 0.005 in the joint scaling test revealed that the three-parameter model used was not adequate to explain

Table 2. Range, mean, and variances for 100-seed weight (g) in pigeonpea.

Population	Number of plants	Range	Mean ± SE	Expected mean	Variance	CV(%)
P_1 (ICP-8504)	90	8.30-14.00	11.198±0.130	11.54	1.524	11.02
P_2 (Prabhat)	90	4.60-9.00	6.857±0.101	6.46	0.933	14.08
F_1	90	9.00-11.20	9.304±0.068	9.32	0.426	7.01
F_2	750	5.00-13.20	9.069±0.047	9.16	1.648	14.15
B_1F_1	300	6.00-14.00	10.623±0.064	10.43	1.220	10.39
B_2F_1	300	4.60-11.00	7.432±0.068	7.89	1.381	15.81
Mid-Parent	–	–	9.027			

the entire variation. The genetic components of variance and degree of dominance are summarized in Table 3, and estimates of heritability and number of effective factors are presented in Table 4. The additive, dominance, and (additive x dominance) interactions were significant for days to flower. The estimate of the additive component was higher in magnitude than the estimate of the dominance and (additive x dominance) components. This indicates that predominantly additive gene effects govern the inheritance of days to flower. The high heritability estimates of 71.8 and 73.6% for days to flower (Table 4) also show that a considerable amount of genetic variability is due to additive gene effects. The degree of dominance for days to flower was 0.55, suggesting partial dominance for earliness.

The analysis of variance components from all the three models (Table 3) clearly indicates that seed size is primarily governed by significant additive effects of genes. However, additive x dominance and dominance x dominance interaction components were also significant. The heritability estimate for seed size obtained by Warner's procedure was 42%. This low heritability value may be due to the high coefficient of variability. The degree of dominance was zero, indicating the complete absence of dominance for seed size.

The mean days to flower and seed size of F_1, F_2, B_1F_1, and B_2F_1 did not deviate markedly from their expected means. This, in addition to higher and significant estimates of D and d (Table 3), clearly indicates that predominantly additive gene effects govern the inheritance of these characters. Pandey (1972), Sharma et al. (1972, 1973a), and Dahiya and Satija (1978) also found additive genetic variance with partial dominance for earliness. Additive gene effects for seed size have also been reported by Pandey (1972), Sharma et al. (1972, 1973b). Heritability for days to flower have been reported ranging from 31 to 99% (Munoz and Abrams 1971; Pandey 1972; Khan and Rachie 1972; Sharma et al. 1973a; Kumar and Haque 1973; Rubaihayo and Onim 1975; and Singh et al. 1979). Sharma et al. (1972) reported a heritability value of 82% for seed size.

Table 3. Genetic components of variance and degree of dominance for days to flower and 100-seed weight in pigeonpea.

Components	Days to flower	100-seed weight (g)	Gene effects
A. Mather (1949):			
D	57.816	1.390	Additive
H	17.616	-0.028	Dominance
E	6.940	0.960	Environmental
$\sqrt{H/D}$ (Degree of dominance)	0.552	0.000	
B. Cavalli (1952):			
M + SE	94.42±0.218	9.00±0.062	
d	12.74*	2.54*	Additive
h	-6.99*	0.32	Dominance
$\sqrt{h/d}$ (Average dominance)	0.549	0.126	
C. Jinks and Jones (1958):			
m ± SE	94.00±1.31	9.45±0.277	
d	10.50*	2.15*	Additive (A)
h	-7.40*	-1.25	Dominance (D)
i	2.00	-0.40	A x A
J	3.00*	2.10*	A x D
1	0.40	1.10*	D x D

*Significant at *5%* level.

Table 4. Heritability and number of effective factors for days to flower and 100-seed weight in pigeonpea.

Character	Heritability *(%)*		Number of effective factors		
	Warner (1952)	Burton (1951)	Mather (1949)	Castle (1921)	Sewell Wright (1951)
Days to flower	71.82	73.59	4.6	1.9	2.6
100-seed wt. (g)	42.17	74.15	2.7	1.9	1.9

An effective factor has been described by Mather (1949) as the smallest unit of hereditary material that is capable of being recognized by the methods of biometrical genetics. It may be a group of closely linked genes or a single gene. The number of effective factors computed by three different methods varied from 1.9 to 4.6 for days to flower and 1.9 to 2.7 for seed size (Table 4). Simple genetic control of seed size has also been reported in pigeonpea (Sharma et al. 1972), lima beans (Allard 1956), and wheat (Sharma and Knott 1964; Knott and Talukdar 1971).

The high heritability, predominantly additive genetic variance, and comparatively low number of effective factors controlling both days to flower and seed size suggest that effective selection in a segregating population on an individual plant basis is possible for developing early-maturing lines with bigger seeds. These lines with improved seed size may have better yield potential than the existing small-seeded early-maturing cultivars.

Summary

The inheritance of days taken to flower and of seed size (g/100 seeds) was studied in six generations of the cross, Prabhat x ICP-8504. Genetic analysis of the characters was carried out by using means and variances of different generations, following the methodology developed by Mather (1949), Cavalli (1952), and Jinks and Jones (1958). Heritabilities and number of effective factors were also estimated. Partial dominance was observed for earliness. Additive gene effects were found to be most important in the expression of both earliness and seed size. Both of these characters were found to be under comparatively simple genetic control. The study indicated the possibility of improving seed size in early-maturing cultivars by simple selection procedures.

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Induced Mutagenesis in Pigeonpea with Gamma Rays, Ethyl Methane Sulfonate (EMS) and Hydroxylamine (HA)

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Abstract

Pure seeds of R-60 and NP(WR)-15 pigeonpea cultivars were irradiated with 5, 10, 20, 30, and 40 kR $^{60}C_o$ gamma rays; treated with 0.02, 0.04, and 0.06 molar solution of ethyl methane sulfonate (EMS) and 0.1, 0.2 and 0.3 molar solution of Hydroxylamine (HA). Gamma irradiation as well as treatment with chemical mutagens reduced germination, seedling height, pollen fertility, and survival at maturity, which was linear from low to higher doses/concentrations. R-60 was the least, NP(WR)-15 the most, sensitive to both gamma rays and chemical mutagens. The chlorophyll mutation rate was characterized by linearity at low to medium doses and saturation as well as by erratic behavior at high doses. The potential of mutagens in enhancing the frequency of chlorophyll mutation was in the order of gamma rays > EMS > HA. The spectrum in gamma rays was Xantha > viridis > chlorina, whereas in EMS and HA it was viridis > chlorina > Xantha.

Genetic variability has been induced through mutagenesis in a large number of crops, but the information available in pigeonpea *(cajanus cajan* [L.] Millsp.) is meager (Khan et al. 1973, Khan and Veeraswamy 1974; Venkateswarlu et al. 1978). Gamma rays and EMS induced a number of chlorophyll and viable mutations in variety Co-1; EMS was less effective than gamma rays (Khan and Veeraswamy 1974). Cultivar R-60 was the least, NP(WF)-15 the most, radiosensitive (Venkateswarlu et al. 1978). Attempts have also been made to establish the correlation between male sterility in the M_1 and frequency of chlorophyll mutations in the M_2 (Caldecott 1961; Kavi 1965; Sharma and Bansal 1970). The present study aims to investigate (1) the relationship between biological effects in M_1 and the chlorophyll mutation frequency in M_2; (2) the sensitivity of two pigeonpea cultivars to different mutagens; and (3) the efficiency of gamma rays compared with that of Ethyl methane sulfonate (EMS) and Hydroxylamine (HA).

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Materials and Methods

Pure and dry (8-9% moisture content) seeds of R-60 and NP(WR)-15 pigeonpea cultivars *were* irradiated with 5, 10, 20,30, and 40 kR ^{60}C0 gamma rays. Treatment with the chemicals EMS and HA was done separately on seeds pre-soaked in distilled water for 5 hours using 0.02, 0.04, and 0.06 molar solutions of EMS and 0.1, 0.2, and 0.3 molar solutions of HA, for 4 hours at room temperature (30°C) and washed in running tap water for 4 hours. One hundred seeds were treated with each dose or concentration. Half of the seeds were sown in the field in two replications at the Agriculture Research Farm, Banaras Hindu University, during the 1974-75 crop season. Germination (after 10 days), pollen fertility, and survival at maturity of M_1 were scored in the field. The remaining seeds were sown in petri dishes in the laboratory to record observations on seedling height on the seventh day. Ten randomly selected plants were considered for recording the pollen fertility from each variety and each dose/concentration. The M_2 generation was raised from the M_1 seeds and chlorophyll mutations were scored and expressed as a percentage of M_2 plants.

Results and Discussion

Biological Effects

Germination

Germination of the M1 was severely reduced at higher doses (30 and 40 kR) of gamma rays in both the cultivars R-60 and NP (WR)-15 (Table 1). Germination Us a percentage of the control) was observed to be less than 2.0 in NP(WR)-15 as against 18.2 or less in R-60 at the above doses. At the remaining doses, the germination ranged from 42.4 to 57.1% of the control for R-60 and 37.0 to 40.5% for NP(WR)-15. For the chemical mutagens the reduction in germination was apparent and linear with increasing concentration, except 0.06 M EMS in NP(WR)-15.

Seedling Height

Seedling height in general decreased with increasing doses of gamma rays/ chemicals in both the strains but this decrease was more pronounced in NP(WR)-15 than R-60 (Table 1). Seedling height was most affected at 30 and 40 kR of gamma rays and 0.04 M and 0.06 M EMS in NP(WR)-15 and also 0.06 M EMS in R-60. HA was not as effective in reducing seedling height as EMS.

Pollen Fertility

Treated populations showed lower pollen fertility than the respective controls (Table 1). The pollen fertility decreased with the increasing

Table 1. Relative germination, seedling height (laboratory), pollen fertility, and survival to maturity in M_1 populations of pigeonpea strains irradiated with ^{60}Co gamma rays and treated with EMS and HA.

	R-60				NP(WR)-15			
	Germination (%)	Seedling height (cm)	Pollen fertility (%)	Survival to maturity (%)	Germination (%)	Seedling height (cm)	Pollen fertility (%)	Survival to maturity (%)
Gamma rays								
0 kR	100.0 (84.0)[a]	100.0 (9.2)[a]	100.0 (97.7)[a]	100.0 (80.0)[a]	100.0 (80.0)[a]	100.0 (13.7)[a]	100.0 (97.6)[a]	100.0 (79.2)[a]
5 kR	57.1	97.6	86.8	26.3	36.8	48.6	95.6	22.3
10 kR	42.4	96.4	75.6	27.0	40.5	46.1	84.8	25.3
20 kR	43.0	76.5	62.1	20.3	30.3	37.0	37.5	14.8
30 kR	18.2	57.5	72.2	8.3	1.5	21.8	-[b]	-[b]
40 kR	16.7	52.7	45.0	8.0	0.5	11.8	45.4	0.5
Chemicals								
EMS 0.02M	72.4	52.0	53.5	25.0	73.3	27.6	51.5	20.0
0.04M	68.8	50.8	47.7	21.9	66.7	12.8	37.5	7.5
0.06M	44.8	21.8	41.8	9.4	16.7	11.3	31.8	2.5
HA								
0.1 M	100.0	110.0	65.9	81.3	86.7	93.3	83.2	67.5
0.2 M	89.7	89.9	48.0	65.6	83.3	69.9	56.4	62.5
0.3 M	82.8	87.5	34.3	34.9	83.3	53.6	22.8	40.0

a. Actual control values.
b. No plants reached maturity.
Note: Data are expressed as a percentage of the control values.

doses of gamma rays/chemicals except for 30 kR of gamma rays in R-60 and 40 kR of gamma rays and 0.06 M EMS in NP(WR)-15, where a relatively higher fertility was observed than for the next lower dose. This could be due to sampling error, since only a few treated plants were available for study. No plant survival was observed in NP(WR)-15 at 30 kR. A drastic reduction in pollen fertility was obtained with all the treatments of EMS and 0.2 and 0.3 M HA in both cultivars.

Survival at Maturity

The reduction in plant survival at maturity was more pronounced in both the cultivars at all the doses of gamma rays and EMS than the HA (Table 1). Higher doses of gamma rays (30 and 40 kR) and EMS (0.06 M) further reduced the survival, which was *very* poor (0.0-9.4% of the control).

Higher doses of gamma rays as well as chemicals greatly affected the biological parameters studied. The reduction in various parameters was more with the increasing doses of gamma rays/chemicals. Drastic reduction in germination and survival occurred at the higher doses. The reduction was greater in the cultivar NP(WR)-15 than in R-60. It is clear from the data that cultivar NP(WR)-15 showed more sensitivity to the mutagens than R-60 for all characters. Thus it appears that pigeonpea strains differ considerably in their radiosensitivity (Venkateswarlu et al. 1978) as well as their reaction to various chemicals. It may be pointed out that a 54% reduction in seedling height occurred in NP(WR)-15 as against only 2.5% in R-60 at 5 kR, indicating a remarkable differential response between these two strains.

Chlorophyll Mutations

Controls (i.e. untreated plant progeny) did not show any chlorophyll mutations (Table 2). Three types of chlorophyll mutations, chlorina, xantha, and viridis, were recovered in the M2 of the treated populations. Cultivar R-60 produced chlorophyll mutations at 10, 20, and 30 kR doses of gamma rays, whereas NP(WR)-15 produced such mutations only at 5, 20, and 40 kR. The highest frequency of chlorophyll mutations (6.61%) was produced by NP(WR)-15 at 20 kR.

In the case of EMS and HA, the highest mutation frequency, in general, was observed at the middle doses.

The potential of mutagens for enhancing the frequency of chlorophyll mutations was in the sequence of Gamma-rays > EMS > HA. Cultivar NP(WR)-15 produced more chlorophyll mutations than R-60. The data on chlorophyll mutation frequency (Table 2) clearly show that the cultivar NP(WR)-15 that has produced the maximum number of chlorophyll mutations, appears to be more sensitive to the different mutagens when compared with R-60.

Chlorophyll mutations of three types, chlorina, xantha and viridis, were recovered in the treated populations. The spectrum in gamma rays (Table 3) was xantha > viridis > chlorina. In EMS and HA it was viridis > chlorina > xantha.

Table 2. Chlorophyll mutation frequency in the M_2 generation of pigeonpea.

Dose/conc.	Cv R-60			Cv NP(WR)-15		
	Total seedlings	Mutant M2 plants	Percent mutants	Total seedlings	Mutant M2 plants	Percent mutants
Control	2050			1850		
Gamma rays 5 kR	1045			971	2	0.21
10 kR	2139	4	0.19	1450		
20 kR	1408	9	0.64	2193	145	6.61
30 kR	956	8	0.84	1321		
40 kR	978			595	1	0.17
Total	6526	21	0.32	6530	148	2.67
EMS 0.02 M	1565	3	0.19	1662	8	0.48
0.04 M	1172	2	0.16	1793	58	3.23
0.06 M	1485	5	0.33	1456	24	1.65
Total	4222	10	0.24	4911	88	1.79
HA 0.1 M	1675			1478	3	0.20
0.2 M	1742	8	0.46	1382	25	1.81
0.3 M	1360	2	0.14	1655	13	0.78
Total	4777	10	0.21	4515	41	0.91

The spectrum of chlorophyll mutant types varied with the treatment. All three types of mutants for a single treatment was only observed in the chemical mutagens. Each gamma ray treatment produced only one or two types of chlorophyll mutations. In other words, chemical mutagens induced a wider spectrum of chlorophyll mutations than gamma rays at a given dose, which supports the findings of Aradhya and Menon (1979). The optimum dose treatment estimated on the basis of chlorophyll mutation is around 20 kR of gamma rays, 0.04 M for EMS and 0.2 M for HA for the sensitive cultivar NP(WR)-15.

It is significant that xantha mutants formed the major class of chlorophyll mutations with gamma rays; viridis mutants with the chemical mutagens. Xantha are lethal mutations resulting from drastic effects on chromosomes, but viridis and chlorina can survive and reproduce. These observations support the proposal that radiation produces extreme mutations, such as xantha and albino, compared with mutagenic chemicals,

Table 3. Spectrum of chlorophyll mutations in the M_2 generation of pigeonpea cultivars R-60 and NP(WR)-15.

Mutagen	Dose/ Conc.	Spectrum of chlorophyll mutations (% M_2 plants)			
		Xantha	Viridis	Chlorina	Total
Gamma rays			R-60		
	10 kR		0.14	0.06	0.19
	20 kR	0.50	0.14		0.64
	30 kR	0.74	0.10		0.84
			NP(WR)-15		
	5 kR	0.21			0.21
	20 kR	6.39	0.22		6.61
	40 kR	0.17			0.17
Total		8.01	0.60	0.06	8.66
EMS			R-60		
	0.02 M		0.13	0.06	0.19
	0.04 M		0.08	0.08	0.16
	0.06 M	0.07	0.13	0.13	0.33
			NP(WR)-15		
	0.02 M	0.12	0.24	0.12	0.48
	0.04 M	1.00	1.17	1.06	3.23
	0.06 M	0.55	0.69	0.41	1.65
Total		1.74	2.44	1.86	6.04
HA			R-60		
	0.2 M	0.17	0.12	0.17	0.46
	0.3 M	0.07		0.07	0.14
			NP(WR)-15		
	0.1 M		0.13	0.07	0.20
	0.2 M	0.51	0.72	0.58	1.81
	0.3 M	0.18	0.36	0.24	0.78
Total		0.93	1.33	1.13	3.39

which produce the viridis and chlorina mutations (Westergaard 1960).

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Spontaneous Mutations with Pleiotropic Effects in Pigeonpea

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Abstract

Sharma and Green (1975) enumerated the following problems in pigeonpea breeding: (1) Variation in the outcrossing creates difficulty in maintenance of true-to-type seed. (2) Multiplicity of cropping systems pose the problem of relating the environment of the breeding nursery to that of the farmer's field. (3) Long period of growth and maturity limit work to one breeding generation per year.

Pleiotropism and linkage of desirable and undesirable characters adds complexity to the crop breeding program. The present paper reports pleiotropic effects observed in spontaneously occurring pigeonpea mutants.

Materials and Methods

A broad-leaved variant isolated from the F3 of T-21 x EC-107656 in 1976-77 (Wanjari et al. 1978) has been designated as a compact mutant. This compact mutant and a unifoliate mustard-like mutant isolated from improved variety No. 148 formed the material for the present study. Advance F_4 and F_5 selfed single-plant progenies of the F_3 line producing compact mutants were studied for segregation of the mutant genotypes. The unifoliate mutant was used as pollen parent for crossing with several cultivars and study of the F_1 plants is in progress.

Results and Discussion

Compact Mutant

The morphological characters of the compact mutant along with one of the parents (T-21) are given in Table 1. F_3 segregation was found to be in the proportion of 15 normal: 1 compact (Table 2). Single-plant progenies of the compact plant carried from F_3 to F4 showed its true-breeding behavior, confirming it as a spontaneous mutation. However, the progenies of normal plants from the same F_3 line of a cross (T-21 x EC-107656)

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Table 1. Some plant characteristics of a compact mutant in pigeonpea compared with cv T-21.

Plant character	Compact bushy	Compact erect	T-21
Plant height (cm)	62.80±4.72	64.60±6.42	130.00±12.25
No. of primary branches	5.40±2.68	4.80±1.80	7.20 ± 1.67
Leaflet size (cm)			
Left Length	5.72±1.96	5.40±1.71	5.99 ± 0.78
Breadth	3.64±0.86	3.56±0.73	1.92 ± 0.36
Central Length	7.22±0.45	7.14±0.44	7.50 ± 0.99
Breadth	4.29±0.64	4.26±0.56	2.52 ± 0.32
Right Length	5.88±1.54	5.56±1.84	5.95 ± 0.96
Breadth	3.76±0.86	3.68±0.59	1.94 ± 0.45
No. of pods/plant	9.60±4.38	11.60±7.69	30.00±14.59
Pod length (cm)	5.52±2.31	5.40±1.88	5.10 ± 0.24
No. of seeds/pod	4.03±3.50	3.76±0.52	4.20 ± 1.20
10-seed weight (g)	1.23±0.32	1.17±0.86	0.72 ± 0.02
Seed weight/plant (g)	6.61±4.13	7.23±4.79	12.74 ± 4.51
Pollen fertility (%)	88.90	85.60	95.20

Table 2. F_3 progeny showing compact mutant in pigeonpea.

Progeny no.	Segregation		X^2 (15:1)	P
	Normal	Mutant		
16	57	5	0.3484	0.80-0.90

showed both true breeding for normal plants and segregating lines for normal and compact types (Table 3). The segregation confirmed the expectation that the compact type was the expression of double recessive mutation of duplicate gene factors.

The compact plants in segregating F4 lines showed two distinct types: bushy and erect, which were found to be monogenically inherited with dominance of bushy characters (Table 4).

Table 3. F_4 behavior of progenies from F_3 of normal plants arising from the compact pigeonpea mutant.

Nature of segregation	No. of progenies observed	Expected proportion	χ^2 and P
All normal leaf	25	7	χ^2 = 0.3120
15 normal : 1 compact	15	4	P = 0.80-0.90
3 normal : 1 compact	17	4	

Progenies of all F_3 compact type plants bred true.

Table 4. Segregation of erect and bushy pigeonpea types among compact mutant in F_4 and F_5.

Segregation of mutant types for growth habit	Observed no. of progenies	χ^2 (1:2:1)	P
F_4			
All Bushy	11	0.0476	0.95-0.98
3 Bushy : 1 erect	21		
All erect	10		
All Bushy	39		
3 Bushy : 1 erect	84	0.1464	0.90-0.95
All erect	41		

Both the bushy and erect types, however, had all other characters of the compact type, i.e., short stature, short internodes, broad, thick leaves with mucronate apex, short petiole, and irregular floral organs. Thus mutant genes had pleiotropic effects.

The mutants can be accommodated in very limited space with a good amount of biomass production. Pollen fertility, number of pods, and yield were found to increase in later generations (Table 5), showing improvement in its acclimatization.

Table 5. Some characteristics of compact mutants of pigeonpea in different generations.

Character	Generation			
	F_3	F_4	F_5	F_6
Pollen fertility	87.50	88.56	88.20	88.90
No. of pods/plant	4.50	8.90	9.40	9.60
No. of seeds/pod	1.80	3.50	3.80	4.03
Grain weight/plant (g)	1.90	4.10	4.62	4.62

Unifoliate Mustard-like Mutant

The unifoliate mutant occured spontaneously during 1978-79 and 1979-80, with an average frequency of 2.3585 per 100 000 plants (Table 6). It was of dwarf stature, with much less foliage than the normal plant. This foliage consisted of unifoliate leaves on the basal portion of the branches. The upper part of the branches showed reproductive growth. Some of the floral buds were rudimentary. Many flowers grew well but failed to set seed. The plant thus appeared like a mustard plant. Limited vegetative growth and a large amount of reproductive growth in the mutant is a desirable character for breeding pigeonpea. High harvest index is important for crop breeding (Jain 1975). However, the association of other undesirable characters is a constraint in further breeding.

Jeswani and Deshpande (1962) reported a similar variant in CP 32546, which was reported to be monogenic recessive. The mutant reported here had a large number of flowers with the standard covering the whole flower. The pollen from the mutant plant were used for crossing with six local strains, and hybrid seed could be secured. The hybrids are under further observation in the field.

Jeswani and Deshpande (1962) also reported a sepaloid mutant and a cleistogamous mutant. They concluded that in all probability the leaf and floral modifications were the pleiotropic effects of single genes. Joshi and Ramanujam (1963) reported a simple-leaf mutant that showed close association with sepaloidy, pointing to close linkage or pleiotropy. A nonbranching single-stem spontaneous mutant reported by Dahiya and Sidhu (1979) seems to be distinct from the parental stock in some characters such as leaf size, maturity, and plant height. Deshmukh (1959) had also reported similar mutation associated with female sterility.

Pleiotropy causing undesirable characteristics is observed frequently in spontaneously occurring mutants, which restricts their use, although they have some desirable characters that would be useful in a breeding program. Similarly pleiotropy is a major constraint to using mutation breeding in pigeonpea. Hence this phenomenon needs attention from the breeders.

Table 6. Frequency of unifoliate mustard-like mutant in pigeonpea.

Year	Population raised	No. of mutants observed
1978-79	48 510	1
1979-80	36 289	1
1980-81	84 700	2
Total	100 000	
Average mutants/100 000		2.36

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Genetic Analysis of a Diallel Cross of Early-Flowering Pigeonpea Lines

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Abstract

The full half-diallel cross of seven early-flowering pigeonpea lines was evaluated in the F_1 and F_2 generations at Redland Bay (27°S), Australia. The F_1 trial was space planted (1m x 1m); the F_2 trial was in higher density (0.5 x 0.2 m). There was a clear effect of method of evaluation on the expression of genetic differences among the progenies. The implications of this and of the inclusion of a parent with only moderately different phenology are discussed in relation to the accuracy and meaningfulness of genetic parameters estimated in this and similar studies. Despite these biases, it is shown that GCA variance predominated for all characters considered. SCA variance was significant for some characters, but was small compared with GCA. This paper discusses the implications of these results — and those of other workers— for breeding strategies.

The pigeonpea is a quantitative short-day plant, and its phenology is strongly influenced by photoperiod (Spence and Williams 1972) and by photoperiod temperature interactions (L.V. Turnbull, personal communication). Genotypes ranging from photoperiod-insensitive to strongly short-day in response exist, and a wide range of phenology and extremely diverse production systems are possible. Aspects of breeding strategies based on these production systems were discussed by Byth et al. (these proceedings).

In general, average yields of seed in the traditional cropping systems are relatively low. However, the crop is capable of high seed yield under favorable management, and significant improvements in production can result from both agronomic and breeding research. To date, improvement in yield via breeding has been limited (Singh 1971), perhaps because of the relatively poor understanding of the ecophysiological adaptation of the crop and the consequent difficulty of defining clear quantitative breeding objectives.

Relatively little genetic knowledge of agronomic and economic characters exists, and this complicates the definition of breeding

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objectives and selection strategies appropriate to the crop. Most cultivars are landraces maintained by open-pollination within somewhat restricted germplasm bases, hut both pure-line and hybrid cultivars have been proposed and researched. Quantitative analysis has indicated that both additive and nonadditive genetic variances are important for yield, its components, and most agronomic characters (Sharma et al 1972; Sharma 1973; Dahiya and Brar 1977; Reddy et al. 1977b; Reddy et al. 1979a, 1979b).

Relatively little genetic analysis has been carried out on early-flowering short-season pigeonpeas. In quantitative breeding of any crop in which phenology is sensitive to environmental influences, a basic problem is that interpretation of the results of mating designs is complicated by physiological changes associated with phenological differences. Thus, the inheritance of yield and associated characters is confounded with the pleiotropic effects of genes influencing phenology. Further, since plant size and habit are strongly influenced by phenology, the agronomic system used in evaluation can have a major differential influence on the performance of entries. This effect confounds any genetic interpretation.

The present study was designed to investigage genetic variability, gene action, and breeding value for various agronomic and yield characters in a population of early-flowering, short-season pigeonpeas. Material of this phenology is of interest in the development of short-season and off-season production systems (Byth et al., Wallis et al. these proceedings), particularly where mechanical culture is intended.

Materials and Methods

The seven lines used as parents were all relatively early flowering. QPL-1, QPL-2, QPL-3, and QPL-4 were derived from a photoperiod-insensitive population in Australia. Prabhat, UPAS-120, and 3D-8103 are photoperiod-sensitive but relatively early-flowering cultivars at this latitude.

A full half-diallel of these lines was evaluated in the F_1 and F_2 generations, together with the parents, at Redland Bay, Australia(27°S). Both the trials were randomized complete block designs with three replications, and were sown on 20 December 1979, The F_1 trial was space planted (1 m x 1 m) in two-row plots 5 m long. The F_2 trial was in six-row plots, 3 m long, with 0.5 m x 0.2 m plant spacing. Each plot was bordered by Prabhat, at the same spacing, to provide uniform competition. The site was a humid coastal environment with a deep, high clay Oxisol (Krasnozem) soil. Fertilizers were applied to correct all known deficiencies, and spray irrigation was used as necessary to avoid moisture stress. The plants were protected from weed competition and insect damage throughout the trial.

The following characters were observed in both trials: days to flower, pod number, seed size, seeds per pod, seed weight per plant, and plant height (only in F_1). In the F_1, observations were made on each plant. For the F_2 plots, ten competitive plants per plot were sampled at random. In crosses segregating for plant habit, five plants of each type were included. Number of days to flowering was recorded on a plot basis for the F_2 trial, and a bulk harvest was done for the plot yield. Analysis of the data followed method 4, model I, of Griffing (1956).

Results and Discussion

Analysis of the 7 x 7 Diallel Cross

Significant differences existed among the progenies in the F_1 trial for all characters (Table 1). Substantial genetic variation existed for plant height, yield per plant, and days to flower, but the genetic coefficient of variation (GVC%) values were relatively low for seed size and seeds per pod.

General combining ability (GCA) variance was significant for all of the characters measured. Specific combining ability (SCA) variance was significant for days to flower and plant height only. These two traits also exhibited high precision of determination (3.5% and 4.9% coefficient of variation or CV, respectively). The variance component due to GCA was substantially greater than that due to SCA for all the characters, indicating a preponderance of additive gene action.

In contrast, significant differences existed among the progenies in the F_2 trial only for days to flower, seed size, and yield per plot (Table 1). The extent of genetic variation among the progenies was considerably lower than in the F_1 for yield per plant, but was similar to the F_1 for all other characters. There was substantial genetic variability for yield per plot in the F_2. GCA variance was significant for days to flower, seed size, and yield per plot, while SCA was significant for days to flower and yield per plot. For each of these characters, the GCA variance component was large compared with the SCA variance component. The coefficients of variation for each character were similar for the F_1 and F_2, implying that the characters had similar precision of determination in these trials.

The crosses differed significantly in pod number and yield per plant in the F_1, but not in the F_2. The cause of this is not known. However, we consider that the expression of genetic variability for these characters was influenced by the differences in interplant competition between the trials. In the F_2 trial, the use of higher plant density resulted in greater competition, and this suppressed expression of genetic potential for certain characters. In contrast, in the space-planted F_1 trial, plants were virtually noncompetitive throughout growth and in consequence full expression of growth potential was possible. This resulted in much larger plants of some crosses, particularly those involving the later flowering parents, and thus in the realization of relatively higher variance components (Table 1). Consequently, the expression of genetic differences was confounded with the nature of the test environment in these trials. This automatically limits the inferences that can be drawn from these data. Similar influence of

Table 1. Mean squares and statistics from analysis of combining ability for various characters in the F_1 and F_2 from a 7 x 7 diallel.

Source	Days to flower		Plant Height	Pod Number		Seed Size		Seeds/pod		Yield/plant		Yield/plot
	F_1	F_2	F_1	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_2
Entries	573.9**	348.4**	4072.3**	87122**	2465	.365**	.529**	.126**	.109**	6444**	96.21	432500**
GCA	610.1**	354.8**	4359.9**	59864**	1154	.374**	.490**	.103**	.039	4982**	57.31	336341**
SCA	11.9**	13.8**	70.6**	15831	679	.014	.042	.016	.035	934	21.25	61806*
[1] σ^2GCA	121.64	70.03	869.93	9755.85		.073	.092	.018		883.12		62067
[2] σ^2SCA	10.03	9.18	60.42	4746.14		.003	.013	.004		367.12		35801
[3] GCV(%)	20.36	16.43	32.31	14.11	9.83	4.47	5.25	6.13	4.82	20.37	9.34	26.47
[4] CV(%)	3.50	5.82	4.88	19.20	22.49	3.19	4.06	6.59	8.57	21.22	22.49	21.51
$\overline{X}$	67.6	64.3	113.6	949.6	176.0	7.2	7.3	2.8	2.8	195.2	35.4	1298.7

[1,2] Mean square of GCA and SCA effects respectively.
[3] Genetic coefficient of variation.
[4] Coefficient of variation.

environment on the expression of genes was also found by Yermanos and Allard (1961).

there was a close association between the GCA effects for a parent and actual parental performance in the F_1 trial (Table 2); that is, parental performance per se was good predictor of breeding value for most characters. Thus the earliest flowering parents, QPL-1, QPL-2, QPL-3, and QPL-4, conditioned relatively early-flowering, short plants, low pod number, and low yield per plant, whereas the progeny of the later flowering 3D-8103 tended to be relatively late flowering and taller, with large pod number, small seed size and high yield per plant in the F_1 trial. In contrast, there was close positive association between GCA effect and parental performance only for days to flowering in the F_2 trial. For seed yield, this reflects a marked difference in GCA between yield per plant in the F_1 and yield per plot in the F_2. Cultivars 3D-8103, UPAS-120, and Prabhat conditioned high seed yield per plant in the F_1, but 3D-8103 was inferior in GCA to the other two lines for yield per plot in the F_2.

Further, QPL-1 to QPL-4 had similar negative GCA effects for yield per plant in the F_1, but QPL-3 and QPL-4 had large positive GCA effects for yield per plot in the F_2. These differences reflect the effects of differential interplant competition in these trials, and indicate that cautious interpretation of genetic parameters is necessary for all characters responsive to such competition. Evaluation of mating designs should be in cultural conditions simulating normal practice, at least for plant density. However, since GCA variance predominated in both trials for most characters (Table 1), it can be inferred that substantial additive genetic variance and/or additive x additive epistasis can be exploited in the improvement of early-maturing pigeonpeas.

Most of the SCA effects for most characters in the F_1 and F_2 trials were not significantly different from zero, however, for cross UPAS-120 x 3D-8103, there was a significant negative SCA effect for days to flower (F_1 and F_2) and for plant height (F_1), indicating significant contribution of nonadditive gene action in the expression of these traits in this cross. None of the crosses involving Prabhat or QPL lines had a significant SCA effect for days to flowering. This probably reflects the relatively narrow genetic base for genes influencing flowering in these early-flowering parents, and suggests that the prospects for selecting even earlier material in their progeny are low.

Analysis of the 6 x 6 Diallel Cross

In view of the potential influence of differences among the parents in phenology on quantitative genetic analysis and of parameter estimates from such analysis, the diallel cross was reanalyzed as a 6 x 6 diallel, eliminating the latest flowering parent 3D-8103. The precision of the data was similar for the 7 x 7 and 6 x 6 mating designs (Tables 1,3), and there were only relatively small changes in the overall mean for most characters (Table 3).

Elimination of the 3D-8103 progenies had no influence on the significance of differences among the progenies (Table 1,3), but SCA

Table 2. GCA effects in a seven-parent diallel in F_1 and F_2.

Parent	Days to flower		Plant Height	Pod Number	Seed size		Seeds/ Pod	Yield/ Plant	Yield/ Plot
	F_1	F_2	F_1	F_1	F_1	F_2	F_1	F_1	F_2
Prabhat	0.39	0.04	0.48	71.26	-0.17	-0.02	0.27	28.69	79.70
UPAS-120	9.23	8.64	20.20	61.10	0.56	0.41	0.04	30.20	177.62
3D-8103	20.42	14.64	57.47	187.34	0.08	-0.49	-0.08	40.24	-553.89
QPL-2	-6.05	-4.96	-15.82	-40.71	-0.07	-0.19	-0.11	-17.34	- 13.21
QPL-1	-8.26	-5.96	-21.71	-103.53	-0.18	0.17	-0.03	-26.83	- 29.84
QPL-4	-8.68	-6.23	-22.39	-78.79	0.02	0.29	-0.09	-20.65	179.37
QPL-3	-7.04	-6.16	-17.27	-96.67	-0.24	-0.18	-0.15	-34.31	160.25
$LSD_{G_iG_j}$	1.73	2.76	4.09	134.51	0.13	0.22	0.14	30.41	206.02
$\overline{X}$	67.6	64.3	113.6	949.6	7.2	7.3	2.8	195.2	1298.7
$r_{GCA,\overline{X}_p}$ [a]	0.99**	0.97**	0.99**	0.64	0.94**	-0.45	0.92**	0.81**	0.27

a. Correlation of GCA effect of a parent with its mean performance.

Table 3. Mean squares and statistics from analysis of combining ability for various characters in the F_1 and F_2 from a 6 x 6 diallel.

Source	Days to flower		Plant Height		Pod Number		Seed Size		Seeds/pod		Yield/plant		Yield/plot
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_2
Entries	288.9**	218.8**	1528.1**	1864.1**	63101*	1156.6	.431**	.377**	.166**	.029**	5992.6**	94.59	773946**
GCA	263.0**	192.6**	1359.6**	1680.4**	42776**	347.7	.392**	.301**	.130**	.021	4723.5**	48.45	42392
SCA	3.7	6.1	37.3**	32.9	8954	406.5	.012	.029	.011	.003	482.8	22.13	16579
σ^2GCA	65.29	47.04	338.52	404.06	8479		.094	.069	.030		1051.7		
σ^2SCA	1.86	1.59	31.82	0.00	97.95		.004	.004	.003		0.0		
[3]GCV(%)	15.99	13.89	23.75	19.85	12.44	5.36	5.02	4.28	7.58	0.00	21.16	9.95	32.49
[4]CV(%)	3.86	6.23	4.30	7.20	18.37	17.73	2.78	3.54	6.16	8.75	21.66	20.62	18.73
$\overline{X}$	60.8	59.4	94.5	118.9	887.1	170.0	7.2	7.5	2.8	2.8	181.8	36.2	1483.4

[1,2] Mean square of GCA and SCA effect respectively.

[3] Genetic coefficient of variation

[4] Coefficient of variation.

variance for days to flower and GCA and SCA variances for yield per plot were not significant in the 6 x 6 design. For most characters, there was a substantial reduction in the size of the GCA and SCA components, e.g., in the GCA and SCA for days to flower and plant height, and in SCA for pod number and yield per plant. As in the 7 x 7 design, GCA variance predominated for all characters exhibiting significant differences among the progenies but the ratio of the GCA to the SCA component was even greater in the 6 x 6 design.

Character Associations

Phenotypic and genotypic correlations among the characters in the F_1 and F_2 trials were generally similar in magnitude and direction, and only phenotypic correlations will be considered here (Table 4). In the F_1 trial of the 7 x 7 design, yield per plant and days to flowering were moderately to strongly associated with each other and with all other characters. Seed size (100-seed weight) was statistically independent of seeds per pod and pod number.

For the 7 x 7 F_2 diallel, yield per plot was negatively associated with days to flower and positively associated with seed size and seeds per pod. In contrast, yield per plot and days to flower were strongly positively associated (R = 0.70**) in the 6 x 6 F_2 diallel. This marked change in association resulted from deletion of the progenies of the latest flowering parent, 3D-8103, and occurred because these progenies formed a quite distinct and relatively low-yielding, late-flowering group in the F_2 trial. The low yield of the 3D-8103 progenies in the F_2 trial may be related to two causes: first, these F_2 progenies segregated for plant habit between the tall 3D-8103 type and the short, insensitive parent; second, interplant competition was greater for the tall, vegetative 3D-8103 proaenies at the relatively high plant density used for the F_2 trial. It should be noted that in the F_1 trial, 3D-8103 had the highest GCA effect for yield per plant, indicating that its progenies were, on average, the highest yielding entries.

General Discussion

The study was restricted to a set of piqeonpea lines that were relatively early flowering. Crosses among these parents differed significantly for most of the agronomic characters measured. There was a clear effect of method of evaluation on the expression of genetic differences among the progenies, and the inclusion of a parent with only moderately different phenology resulted in a change in the magnitude of the differences and of the genetic parameters, these results emphasize the importance of conducting evaluation trials under a cultural system similar to that used in commercial production, and the need to restrict parentage of mating design to a relatively narrow range of phenology. Failure to accomplish these restrictions inevitably prejudices the accuracy and meaningfulness of the genetic parameters estimated for such trials.

Despite these biases to estimation inherent in the mating designs

Table 4. Phenotypic correlations among various characters in 7 x 7 and 6 x 6 diallels.

Character	Diallel	2	3	4	5	6	Yield/ plot
Yield/plant	7 x 7	.75**	.69**	.97**	.51**	.86**	*a*
	6 x 6	.74**	.68**	.97**	.43	.92**	
Days to flower	7 x 7		99**	.77**	.55**	.45*	*b* (-.46*)
	6 x 6		.99** (.96**)	.66**	.79**	.48	(.70**)
Plant height	7 x 7			.73**	.50*	.39	
	6 x 6			.66**	.80**	.41	(.68**)
Pod Number	7 x 7				.39	.78**	-
	6 x 6				.31	.93**	
Seed size	7 x 7					.12	(.59**)
	6 x 6					.06	(.34)
Seeds/pod	7 x 7						(.69**)
	6 x 6						-

a. Mean square nonsignificant for one variate.
b. ( ) F_2 generation.

and evaluations reported in this study, it was shown that GCA variance predominated for all characters considered. SCA variance was significant for some characters, but was small compared with GCA. These results are similar to those of Sharma et al.(1972), Sharma et al. (1973), and Dahiya and Brar (1977) for later maturity groups of pigeonpea. They imply that substantial additive genetic variation and additive x additive interactions can be exploited in the improvement of early-flowering pigeonpea. In contrast, Reddy et al. (1977b, 1979a, 1979b) reported predominance of SCA variances for all characters studies, including phenology, plant height, and seed yield and its components. The cause of this marked difference between these studies is not known, but it may be related to the genetic material used or the method of evaluation. However, phenology, plant height, and seed size are known to be relatively highly heritable characters in pigeonpea (Munoz and Abrams 1971; Khan and Rachie 1972; Sharma et al. 1972, 1973), and this is incompatible with estimates indicating a preponderance of SCA variance for such traits (Reddy et al 1977 b, 1979a, 1979b).

Estimates of the form of genetic variation have quite fundamental influence on the definition of breeding strategies and methods, and on the relevance of particular types of cultivars. Thus, further research is urgently required to validate the nature of gene action operating to determine agronomic characters in pigeonpea populations of different maturity classes. Such research should be conducted within relatively narrow phenological groups, and evaluation methods should be considered closely in the design of such trials.

On the basis of their estimates of gene action, Sharma et al.(1973) suggested the development of composite varieties; Dahiya and Brar (1977) preferred the use of bulk population improvement over pedigree methods, and Reddy et al. (1979b) advocated the exploitation of nonadditive gene action via hybrid cultivars.

In view of the conflicting literature on gene action, it is not possible to define breeding strategies directed exclusively at the exploitation of additive versus nonadditive genetic variance. In fact, it is unnecessary to do so. The reproductive biology of pigeonpea permits both options. Varietal hybrids based on genetic male sterility (Reddy et al. 1977a, Wallis et al. vol.2, these proceedings) have exhibited considerable heterosis for seed yield (Green et al. 1979). Conversely, pedigree or bulk-breeding methods can be used successfully in pigeonpea, directed towards pure-line or multiline cultivars. Natural outcrossing can be utilized in the improvement of predominantly self-pollinated plants (Frey 1975; Khan 1973). Byth et al.(these proceedings) reported a modification of floral morphology, which enforces self-pollination in pigeonpea, and proposed its use with genetic male-sterility to allow population improvement of pigeonpea as a self-pollinated crop for the production of pure-line cultivars. They considered that the exploitation of heterosis in hybrid cultivars was not incompatible with this general approach to pigeonpea improvement.

Considerable research into the strategies of breeding appropriate to pigeonpea is required. Objective decisions on this fundamental question cannot be made now, in view of the limited and conflicting literature on genetic variation in this crop.

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Some Combining Ability Analyses in Pigeonpea (*Cajanus cajan* (L.) Millsp.)

L.J. Reddy, K.B. Saxena, D. Sharma, and J.M. Green*

Abstract

General (GCA) and specific combining ability (SCA) variances were determined from a 10 x 10 group diallel, a 28 x 28 variety diallel, and a 7 x 7 variety diallel. All the diallels have indicated predominance of additive gene action for most of the characters studied; however, highly significant, SCA variances were observed for yield in all the diallels. Therefore, breeding programs should aim at exploiting both additive gene action through pedigree, mass selection, and population improvement, and nonadditive gene action through F_1 hybrids and bulk hybrid advance by single-pod descent. In general, a high rank correlation was observed between the mean performance per se and the GCA of the parents, indicating that the parents can be chosen for a crossing program on their per se performance. The GCA variances were affected relatively more than the SCA variances by the phenological diversity of the parents involved in the crosses.

Diallel crosses have been extensively used in both self- and cross-pollinated crops for estimating genetic variances and combining ability of the parents; however, there are *very* few reports on this aspect in pigeonpea. These studies are limited to a very small number of genotypes and to a few characters; often, conflicting reports have been made on the gene action for yield and other agronomic characters (Chaudhari et al. 1980; Reddy et al. 1979a, 1979b; Dahiya and Brar 1977; Sharma et al. 1973a, 1973b). In view of the scanty information available on the genetic potential of cultures in a maturity group or plant type of pigeonpea, it would be desirable, for speedy evaluation, to determine the potential of a particular ecotypic or racial group rather than to evaluate individual cultures. Such an approach becomes all the more important in crops such as pigeonpea, where the number of cultures with unknown background run into several thousands, with a possibility of many duplicates. At ICRISAT Center a 10 x 10 group diallel and two variety diallels, 28 x 28 and 7 x 7, were made and evaluated. Our objectives were to assess general (GCA) and specific combining ability (SCA) for different characters, to discuss the efficiency of parental performance as an indicator of progeny

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performance, and to study the effect of phenological diversity of parents on the GCA and SCA variances.

Materials and Methods

Group Diallel (10 x 10)

The entire germplasm collection (3480 cultures,) available during 1973-74 at ICRISAT was classified into ten broad groups, based on important plant characters such as plant height, plant spread, maturity period, and seed weight. Each group was formed by mixing equal number of seeds for each culture of a similar type. Crosses were effected both between and within the groups, and 45 inter- and 9 intra-group crosses obtained. Care was taken to collect pollen from all the available plants of the male parent and to use all the plants of the female parent for emasculation and pollination to minimize the sampling error. The *F1s* of all the crosses and the parents were grown in an 8 x 8 simple lattice with four replications. Observations were recorded on 30 randomly chosen competitive plants per plot. For diallel analysis only intergroup crosses and parents were considered.

Variety Diallel (28 x 28)

During 1974-75, a diallel set involving 28 diverse parents was planted in parental arrays in two replications. Observations were made on different characters on an individual plant basis.

Variety Diallel (7 x 7)

During 1976-77 a seven-parent diallel was made and all the 21 F_1s along with their parents were planted in two replications. Observations on 20 competitive plants per plot were recorded for all the characters.

For the diallel analysis all the three experiments were treated as Randomized block designs and the error variance obtained was used as the error component in the analyses of combining ability. The analyses of general and specific combining ability was done according to method 2, model 1, of Griffing (1956).

Results and Discussion

Group Diallel (10 x 10)

The analysis of variance for all the characters revealed significant differences among genotypes (Table 1). Both GCA and SCA mean squares were highly significant for all the characters. However, the magnitude of SCA variance estimates was lower than that of GCA estimates for all

Table 1. Analysis of variance for various characters in a 10 x 10 group diallel of pigeonpea.

Source	df	Mean squares for: Days to 50% flowering	Plant height	Primary branches	Secondary branches	Yield/ plot	Harvest index (Transformed)
Replications	3	144.64**	10830.58**	24.25**	287.56**	0.43	36.96**
Genotypes	54	990.66**	1056.86**	2.71**	95.25**	2.44**	20.32**
Error	162	17.06	161.90	1.51	25.04	0.58	9.72
GCA	9	1425.28**	946.73**	1.81**	97.03**	2.63**	16.36**
SCA	45	12.14**	127.71**	0.45**	9.17**	0.21**	2.82**
Error (Me)	162	4.27	40.48	0.38	6.26	0.14	2.43
$\hat{\sigma}^2$gca		118.4	75.5	0.12	7.56	0.21	1.16
$\hat{\sigma}^2$sca		7.87	87.2	0.07	2.91	0.07	0.39
$\hat{\sigma}^2$gca/$\hat{\sigma}^2$sca		15:1	0.87:1	1.71:1	2.60:1	3:1	2.97:1

**Significant at 1% level

the characters except plant height, indicating the preponderance of additive gene action for days to 50% flowering, primary and secondary branches, yield, and harvest index.

The estimates of GCA effects for all the ten parental groups for various characters are given in Table 2. The early-maturity groups 1 and 2 were the best general combiners for earliness. Groups 1, 2, and 7, with dwarf stature, showed significant negative effects for plant height. Also the high-yielding parents, G-8, G-9, and G-10 showed highly significant positive effects for yield. Similarly, groups 1 and 2 with high harvest index were the best general combiners for this character.

Table 2. General combining ability effects of parents for various characters in a 10 x 10 group diallel of pigeonpea.

	Character					
Parent	Days to 50% flowering	Plant height	Primary branches	Secondary branches	Yield/ plot	Harvest index (Transformed)
G-1	-16.58**	-17.59**	-0.41*	-4.25**	-0.35**	1.81**
G-2	-11.76**	-10.57**	-0.58**	-3.02**	-0.40**	1.26**
G-3	- 2.22**	5.85**	-0.31*	-3.06**	-0.17	0.09
G-4	- 4.72**	2.43	0.46**	2.11**	-0.15	-0.20
G-5	- 3.26**	- 2.98	0.09	-0.14	-0.37**	0.23
G-6	10.36**	4.70**	-0.50**	-1.35*	-0.45**	-2.66**
G-7	- 8.20**	- 4.63**	0.25	1.25	-0.08	0.27
G-8	13.28**	11.23**	0.30	1.11	0.59**	-0.31
G-9	11.90**	7.14**	0.38*	4.03**	0.71**	-0.04
G-10	11.20**	4.14*	0.25	3.32**	0.67**	-0.27
SE (gi)	0.5656	1.7423	0.1683	0.6853	0.1042	0.4268
CD (5%) (g_{i-j})	1.6526	5.0907	0.4918	2.0021	0.3046	1.2471

*Significant at 5% level; **Significant at 1% level.

G-1 : Early maturity, dwarf, compact and determinate growth habit
G-2 : Early maturity, spreading and semispreading and indeterminate growth habit
G-3 : Medium maturity, tall and compact growth habit
G-4 : Medium maturity, tall and semispreading
G-5 : Medium maturity, tall and spreading growth habit
G-6 : Large-seeded, medium and late maturity
G-7 : Medium maturity and dwarf plant type
G-8 : Late maturity, tall and compact growth habit
G-9 : Late maturity, dwarf, spreading and semispreading growth habit
G-10 : Late maturity, tall, and spreading and semispreading growth habit

Variety Diallel (28 x 28)

It can be argued that the parentage of a mating design should be restricted to a relatively narrow range of phenology in order to get meaningful estimates of genetic parameters. For this reason the entire diallel set was divided on the basis of parental phenology into early x early, early x medium, medium x medium, medium x late, and late x late cross combinations, and the combining ability analysis was carried out separately for each of these subsets (Table 3). The genotypic differences were not significant for days to flowering and yield per plant in medium x medium crosses. Excepting for these, the GCA mean squares were highly significant for various characters in different subsets. For seeds per pod, the SCA mean squares were not significant both in the main set and in all the subsets. The SCA mean squares were not significant for seed size in medium x medium crosses but were significant in early x early, early x medium, early x late and medium x late and late x late crosses. In all the subsets, except early x medium crosses, SCA mean squares for yield were highly significant. It is interesting to note that the estimate of SCA variance for yield was higher than that of GCA variance in the early x early crosses. In general, the relative increase in the magnitude of GCA variance estimates, as compared with the SCA variance estimates, was greater as the diversity of the parents involved in the crosses increased.

Variety Diallel (7x7)

The analysis of variance for different characters revealed significant differences among the genotypes (Table 4). Both GCA and SCA mean squares were highly significant for plant height, seed weight, and yield per plant. SCA mean squares for days to flowering and GCA mean squares for seeds per pod were not significant. The magnitude of GCA estimates was higher than that of SCA estimates for plant height and seed weight but not for yield per plant. These observations suggest predominance of additive gene action for days to 50% flowering, plant height, and seed weight, and nonadditive gene action for seeds per pod and yield per plant.

Estimates of GCA effects of all the seven parents for various characters are given in Table 5. All the four late-maturity parents—ICP-6982, ICP-1900-11, ICP-3193-12, and JA-3--showed significant positive effects for lateness (days to 50% flowering) and the two early-maturing parents--UPAS-120 and Prabhat--showed significant negative effects. Both the early parents were equally good general combiners for earliness. The lowest yielding parents, UPAS-120 and Prabhat, were found to be poor general combiners and the highest yielding parent, ICP-1900-11 was the best general combiner for yield. Similarly, the larger seeded parents, BDN-1 and JA-3, showed significant GCA effects for seed weight.

Parental Performance vs GCA Effects

In all the three diallels, the parents were ranked for parental mean, GCA

Table 3. Analysis of combining ability variances in a 28 x 28 diallel of pigeonpea and its subsets.

Source of variation	df	Mean squares			
		Days to 50% flowering	Seeds/ pod	100-seed weight	Yield/ plant
28 x 28 diallel (entire set)					
GCA	27	7130.46**	1.38**	65.35**	19877.52**
SCA	378	35.93**	0.03	0.61**	435.60**
$\hat{\sigma}^2 gca/\hat{\sigma}^2 sca$		11.10:1		5.96:1	4.35:1
Subsets					
Early x early crosses					
GCA	6	157.00**	0.103**	5.15**	121.00**
SCA	21	6.00**	0.007	0.14*	52.00**
$\hat{\sigma}^2 gca/\hat{\sigma}^2 sca$		4.17:1		6.73:1	0.31:1
Early x medium crosses					
GCA	13	918.00**	0.28**	12.00**	2706.00**
SCA	91	8.00**	0.01	0.23**	132.00
$\hat{\sigma}^2 gca/\hat{\sigma}^2 sca$		17.61:1		8.67:1	
Early x late crosses					
GCA	20	7749.00**	1.08**	63.00**	18428.00**
SCA	210	31.00**	0.03	0.66**	445.00**
$\hat{\sigma}^2 gca/\hat{\sigma}^2 sca$		18.49:1		6.26:1	4.28:1
Medium x medium crosses					
GCA	6	NS[a]	0.30**	4.00**	NS
SCA	21	NS	0.009	0.38	NS
$\hat{\sigma}^2 gca/\hat{\sigma}^2 sca$					
Medium x late crosses					
GCA	20	3240.00**	1.27**	51.00**	8946.00**
SCA	210	39.00**	0.04	0.66**	490.00**
$\hat{\sigma}^2 gca/\hat{\sigma}^2 sca$		7.76:1		6.28:1	2.39:1
Late x late crosses					
GCA	13	426.00**	0.92**	53.00**	5861.00**
SCA	91	25.00	0.04	0.62**	409.00**
$\hat{\sigma}^2 gca/\hat{\sigma}^2 sca$				21.58:1	1.63:1

a. NS = Genotypic differences were not significant.
*Significant at *5%* level; **Significant at 1% level.

Table 4. Analysis of variance for various characters in a 7 x 7 variety diallel of pigeon pea.

		Mean squares				
Source	df	Days to 50% flowering	Plant height	Seeds/ pod	100-seed weight	Yield/ plant
Replication	1	7.14	301.79*	0.05	0.08	5.17
Genotypes	27	405.10**	1043.60**	0.05*	2.99**	179.61**
Error	27	7.00	54.71	0.02	0.08	30.92
6CA	6	886.98**	2016.50**	0.02	5.98**	235.32**
SCA	21	7.00	94.74**	0.03*	0.22**	48.23**
Error (Me)	27	3.50	27.36	0.01	0.04	15.46
$\hat{\sigma}^2 gca$		98.16	221.0		0.66	24.4
$\hat{\sigma}^2 sca$			67.38	0.02	0.18	32.77
$\hat{\sigma}^2 gca/\hat{\sigma}^2 sca$			3.28:1		3.67:1	0.74:1

*Significant at 5% level; **Significant at 1% level.

Table 5. General combining ability effects of parents for various characters in the 7 x 7 variety diallel.

Parents	Days to 50% flowering	Plant height	100-seed weight	Yield/ plant
UPAS-120	-13.79**	-13.27**	-0.15	-6.84**
Prabhat	-13.79**	-24.60**	-0.85**	-6.86**
3193-12	6.19**	9.12**	-0.10*	1.29
1900-11	6.49**	16.40**	-0.78**	6.03**
6982-6	10.21**	14.06**	-0.43**	4.83**
JA-3	5.16**	1.56	1.06**	1.23
BDN-1	- 0.45	- 3.27	1.15**	0.32
SE (g_i)	0.58	1.61	0.04	1.21
CD (5%) (g_{i-j})	1.81	5.07	0.20	3.80

*Significant at 5% level; **Significant at 1% level.

effect and array mean (mean of a set of crosses involving a particular parent), and rank correlations were calculated to determine the relationship of GCA effect with parental and with array means (Table 6). Rank correlation coefficients were highly significant in both comparisons for all the characters in all the three experiments. In general, slightly higher values of correlations were found between array mean and GCA effects than between parental mean and GCA effects. However, for yield, parental performance appears to be a better indicator of the general combining ability of the parents than the *array* mean performance in both the 10 x 10 group diallel and the 7 x 7 variety diallel.

Specific Combining Ability Effects

In view of the large number of F_1s studied, no SCA effects are presented in this paper. However, mention may be made of an interesting observation on SCA effects for yield in all the three experiments. In the 28 x 28 variety diallel, out of 29 crosses that showed significant positive SCA effects for yield, 18 crosses involved parents with significant negative GCA effects. In the 10 x 10 group diallel, the lowest yielding parent, G-6, produced the highest yielding cross. Similarly in the 7 x 7 diallel UPAS-120 and Prabhat, which were poor general combiners for yield, produced the highest yielding hybrids. These observations suggest that high x low crosses produce the highest yielding hybrids in pigeonpea.

General Discussion

In all the three experiments, the analyses of variance showed significant mean square values for both GCA and SCA for most of the traits studied, indicating the presence of both additive and nonadditive gene action. For days to 50% flowering and 100-seed weight, preponderance of additive gene action was indicated in all the experiments. However, observations for yield and plant height in the different experiments were not in agreement with each other. While additive gene action for yield was more important in the 10 x 10 group diallel and the 28 x 28 variety diallel, nonadditive gene action was of higher magnitude in the 7 x 7 variety diallel and early x early crosses of the 28 x 28 variety diallel.

Similarly for plant height, the 10 x 10 group diallel revealed a predominance of nonadditive gene action. The disagreement among different experiments on the gene action might have resulted from genetic differences of the parents in each diallel and high genotype (G) x environment (E) interactions. Similar conflicting reports have been made by different workers on the gene action for yield and other agronomic characters (Table 7).

For days to 50% flowering and seed size, while most workers have reported additive gene action, Reddy et al. (1979a, 1979b) have reported a *very* high magnitude of nonadditive gene action.

Likewise, conflicting observations have been made on the importance of additive and nonadditive gene action for yield. These differences might have resulted from (1) different methods employed by various authors

Table 6. Rank correlations of general combining ability (GCA) effects with parental mean and array mean for various characters in pigeonpea.

Character	Correlation of GCA effects with Parental mean	Correlation of GCA effects with Array mean
10 x 10 group diallel[a]		
Days to 50% flowering	0.988**	1.000
Plant height	0.967**	0.903**
Secondary branches	0.855**	1.000
Yield/plot	0.903**	0.879**
Harvest index (transformed)	0.794**	0.806**
28 x 28 variety diallel		
Days to 50% flowering	0.962**	0.993**
Seeds/pod	0.860**	0.980**
100-seed weight	0.960**	0.998**
Yield/plant	0.870**	0.997**
7 x 7 variety diallel[a]		
Days to 50% flowering	0.929**	0.964**
Plant height	0.964**	1.000
100-seed weight	0.964**	0.964**
Yield/plant	0.964**	0.857* .

*Significant at *5%* level, **Significant at 1% level.
a. Significant levels of r_s were determined from Kendall's table.

for estimating genetic parameters; (2) genotypic differences among parents (which were often very few in number); and (3) high G x E interactions. For example, Sharma et al. (1973a) inferred the magnitude of additive and nonadditive variances by comparing 6CA and SCA mean squares, which is not a correct procedure (Arunachalam 1976). Similarly, Reddy et al. (1979a) used F_2 data for their diallel analysis, which needs considerable pre-cautions especially because the segregation observed in different crosses is, as a rule, not comparable (Arunachalam 1976). Combining ability analysis based on the F_2 *data is* questionable in view of large sampling errors and differential segregations in the F_2 that confer unknown advan-tages on certain cross combinations. Also, when complete genetic homo-geneity is not certain, an unconscious selection in the F_1 would result in biased estimates. Likewise, Chaudhari et al. (1980) carned out a combin-ing ability analysis, although the genotypic differences for yield in the experiment were not significant.

Table 7. Comparison of reported gene effects for different traits in pigeonpea.

Source	Preponderance of gene action for			
	Days to flower	Plant height	Seed size	Yield
Present study:				
10 x 10 group diallel	Additive	Nonadditive		Additive
28 x 28 variety diallel	Additive		Additive	Additive and nonadditive[a]
7 x 7 variety diallel	Additive	Additive	Additive	Nonadditive
Other reports:				
Pandey 1972	Additive	Nonadditive	Additive	Additive x additive Dominance x dominance
Sharma et al. 1972			Additive	
Sharma et al. 1973a[b]	Additive	Additive	Additive	Additive
Sharma et al. 1973b	Additive			
Laxman Singh and Pandey 1974	Additive	Additive	Additive	Nonadditive
Dahiya and Brar 1977	Dominance		Over dominance	Over dominance
Reddy et al. 1979b (F_1 diallel)	Nonadditive	Nonadditive	Nonadditive	Nonadditive
Reddy et al. 1979a (F_2 diallel)	Nonadditive	Nonadditive	Nonadditive	Nonadditive
Chaudhari et al. 1980	Additive			Additive[c]

a. In the early x early crosses, the nonadditive variance was predominant for yield.
b. Magnitude of additive and nonadditive variance was inferred by comparing GCA and SCA mean squares.
c. Combining ability analysis was carried out although the genotypic differences for yield in the experiment were not significant.

It should be possible to use successfully the pedigree method in breeding for earliness and large seed size in view of the high magnitude of additive gene action reported by most workers. However, because of the importance of both additive and nonadditive genetic variances, breeding procedures for yield in pigeonpea should be aimed at exploiting both these variances. Additive genetic variance for yield can be exploited through pedigree, mass selection, and population improvement schemes. Nonadditive gene action should be exploited through F1 hybrids and through reciprocal recurrent selection procedures. Moreover, because of the occurrence of high heterotic effects for yield in pigeonpea (Sharma et al. 1973a; Shrivastava et al. 1976; Reddy et al. 1979a, 1979b) and the availability of an economically feasible commercial hybrid production system through the use of genetic male sterility (Green et al. 1980), the potential of heterosis breeding should be thoroughly explored. In addition, it seems advisable to delay selection to advanced generations to have a sufficient number of epistatic combinanations fixed to permit detection of superior near-homozygous progenies. The bulk hybrid advance method by single-pod descent might be helpful in achieving this objective.

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A New Source of Genetic Male Sterility in Pigeonpea

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Abstract

The identification of a new source of genetic male sterility in pigeonpea is reported. This source differs from that reported by Reddy et al. (1977), and cytological examination indicates that the abnormal anther development involves degeneration of the pollen mother cells at the young tetrad stage. This form of male sterility has been recovered in phenological classes ranging from 52 to 80 days to flower for December sowings at 27°S. The character is being maintained in ten phenological groups. This new source of genetic male sterility will widen the genetic base for hybrid production in pigeonpea.

Several forms and sources of genetic male sterility in pigeonpea were identified by Reddy et al. (1977). The most interesting of these forms was characterized by translucent anthers caused by nonseparation of tetrads associated with a persistent tapetum (Reddy et al. 1978). Varietal hybrids between this material and elite male parents of various maturities have exhibited up to a 30% increase in yield over the pollen parent (Green et al. 1979). Hybrid seed can be produced by cross-pollination, using bees as the vector. However, crossing blocks would require isolation, and manual identification and removal of fertile plants within sterile rows is necessary. There are prospects for commercial use of hybrid cultivars, but the labor-intensiveness of seed production may restrict this to countries with low labor costs. Procedures for more efficient hybrid seed production were discussed briefly by Byth et al. (these proceedings).

Identification of a New Source of Male Sterility

Cultivar Royes (formerly designated UQ-50) has recently been released in Australia for mechanized production of dry seed in frost free areas of the tropics and subtropics (Wallis et al. 1979). It was derived from a West Indian accession (Q-8189) identified as "*cajanus cajan* O.P. dwarf (4)." It is a botanically determinate cluster type of medium-late maturity, with red flowers, large pods, and large white seed. During prerelease testing

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in 1976, it was grown at Tamworth (31 °S) by J. Holland, New South Wales Department of Agriculture. He identified an off-type plant that was earlier flowering than cv Royes (approximately *80* days) and had yellow flowers, but was otherwise *very* similar to cv Royes in habit. Open-pollinated seed from that plant was designated B15B. The plant was also crossed to a line of photoperiod-insensitive pigeonpea. Single-plant progenies of B15B and the cross were evaluated at Tamworth and Redland Bay for three generations.

At Redland Bay in 1980, it was noted that some plants within the B15B progeny produced *very* few pods and flowered over a prolonged period. Anthers of these plants were brown, shrivelled, nondehiscent and arrow-shaped, and contained no pollen grains (Dundas et al. 1980). In contrast, all other plants in the B15B had normal pod set, and normal anther development and behavior. Subsequently, over 100 male-sterile plants were identified in the progenies of the B15B x photoinsensitive line. This confirmed that this male-sterile character arose initially in cv Royes, and the original off-type plant used for hybridization in 1976 presumably was heterozygous for the gene(s) determining male sterility.

Characteristics of This Source

We have now recovered male-sterile plants in B15B and its progenies at several locations. The abnormalities of the anthers described above were common to all sites, and pod set on such plants was universally low. This indicates that this form of male sterility is stable in expression across a *number of environments* in subtropical Australia and in Fiji.

Cytological examination of microsporogenesis in male-sterile plants from Redland Bay indicates that the abnormal anther development involves degeneration of the pollen mother cells at the young tetrad stage (Dundas et al. 1980). This differs from the translucent anther type of male sterility in pigeonpea described by Reddy et al. (1977, 1978). Anther wall development was also different between these two forms.

Preliminary evidence suggests that the new form of male sterility is controlled by a single recessive. Detailed study of the inheritance is continuing.

It is significant that this male sterility arose in cv Royes. This cultivar has a modified floral structure involving overlap of the lobes of the standard petal. Byth et al. (these Proceedings) considered that this "wrapped flower" character effectively enforces self-pollination, probably by mechanical exclusion of bees until after anthesis. The presence of wrapped flowers in cv Royes and B15B allowed easy recognition of male sterility, owing to extremely low pod set on sterile plants. Since the insensitive parent used in crosses to B15B has simple flowers, progenies of this cross segregated for both wrapped/simple flowers and male fertility/sterility. Pod set on sterile/wrapped plants was invariably poor, but was virtually normal on sterile/simple plants. This confirms the effectiveness of wrapped flowers in enforcing selfing (Byth et al. these Proceedings). They also suggested the use of wrapped flowers to establish self-pollinated breeding methods, and of wrapped/simple flowers and fertility/sterility to allow recurrent selection in pigeonpeas.

Significance of this Source

This form of male sterility has been recovered in a range of phenological classes and is being maintained in ten genetic backgrounds ranging from 52 to 80 days to flower for December sowings at 27°S in Australia (Table 1). Plants flowering in less than 60 days from sowing are regarded as photoinsensitive (Wallis et al. 1980). This range of backgrounds will allow the production of hybrids ranging from insensitive to medium-late flowering types.

All of the steriles being maintained are botanically determinate cluster types. In fertile sibs, seed size ranges from 7 to 11 g/100 seeds, and both white and brown seeds have been identified in these backgrounds (Table 1). The potential for seeds per pod is moderate to high in all cases. These seed and pod characteristics are important with respect to the use of these male steriles in breeding. Single-cross hybrids that are large podded, with large white seed, can be produced by the appropriate choice of the male parent.

This new form of male sterility is a useful addition to that of MS3A/4A in that it avoids canalization of breeding on one genetic source of sterility. Further, the genetic backgrounds of the B15B and MS3A/4A sources differ significantly in origin, growth habit, phenology, and seed and pod characteristics. This allows establishment of a broader genetic base for hybrid cultivars.

Table 1. Some characteristics of new genetic male-sterile lines of pigeonpea being maintained at the University of Queensland, Australia.

Identification	Source	Days to flower	Height (cm)	Seed color	Maximum seed/pod
QMS[a]-1	B15B	80	140	White	6
QMS-2	B15B	70	150	Brown	5
QMS-3	Q7701[b]	62	125	White	4
QMS-4	Q7701	62	120	Brown	5
QMS-5	Q7701	66	105	White	5
QMS-6	Q7701	60	100	White	5
QMS-7	Q7701	56	125	White	6
QMS-8	Q7701	59	155	White	5
QMS-9	Q7701	52	90	White	4
QMS-10	Q7701	52	100	White/Brown	5
Standards					
Insensitive		55	75	Brown	4
Royes		110	160	White	6
B15B		80	140	White	5

a. QMS = Queensland Male Sterile
b. Q7701 = B15B x Photoinsensitive line

We are maintaining this character in the nominated backgrounds, and will distribute them on request as soon as possible. Detailed study of the genetic relationship between the B15B and MS3A sources is in progress. We are also evaluating the relative combining abilities of these sources.

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Partial Correlations and Path Coefficient Analysis of Seed Yield Characters in Pigeonpea

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Abstract

Thirty promising genotypes of pigeonpea (Cajanus cajan *L.), evaluated in a randomized block design with four replications for 3 years, were used to compute correlations, first order partial correlations, and a path coefficient analysis. Invariably, similar trends were observed for correlation coefficients in the 3 years and between genotypic and phenotypic correlations in each year. Genotypic correlations were invariably higher than the corresponding phenotypic correlations. Correlation studies showed that all the eight characters under study were components of yield, whereas partial correlations and path coefficient analysis revealed that spreading plants with more branches contributed more to plant yield. Reduced plant height appeared to be desirable. Fruiting branch length appeared to be influenced more by environment. Results showed that for improvement of grain yield in pigeonpea, the ideal plant should be short and bushy, with profuse branching and podding, medium seed number and seed weight, more seeds per pod, and medium to late maturity. Selection of such plants in pigeonpea breeding material is therefore suggested.*

Several approaches are being used by plant breeders to identify suitable plant ideotypes. These are: (1) the statistical approach of factor analysis (Cattell 1965); (2) the use of isogenic lines (Atkins and Mangelsdorf 1942); varieties (Tsunoda 1959), or hybrids (Ramanujam 1975); and (3) the identification of a morphological framework through correlation or association analysis (Donald 1968), regression technique (Smith 1936), partial and multiple correlations, and path coefficient analysis (Dewey and Lu 1959). In the present paper, an attempt has been made to study the plant ideotype using genotypic correlations, first-order partial correlations, and path-coefficient analysis in pigeonpea (*Cajanus cajan* L.).

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Materials and Methods

Thirty promising genotypes of pigeonpea *(Cajanus cajan* L.), selected from All India Coordinated and Advanced Breeding Trials were grown in a randomized block design with four replications at the Research Farm of Haryana Agricultural University during 1977, 1978, and 1979. Normal cultural practices were used. Data were recorded on ten representative plants in each replication for days to maturity, plant height, plant spread, fruiting branch length, branches per plant, pods per plant, seeds per pod, 100-seed weight, and seed yield per plant. Mean data were analyzed to compute the genotypic and phenotypic correlation coefficients following Al-jibouri et al. (1959), direct and -indirect effects following path-coefficient analysis of Wright (1921), and first-order partial correlations using formulae given by Goulden (1962).

Results and Discussion

Genotypic correlation coefficients were found to be higher than the corresponding phenotypic correlation coefficients for all the characters in 3 years of testing as has also been reported by Veeraswamy et al. (1973). Also, the genotypic and phenotypic correlations depicted a similar trend and hence only the estimates of genotypic correlations are given in Table 1. The significance level of the phenotypic correlation coefficients is marked on the estimates of genotypic correlations. Seed yield was found to be positively and significantly correlated with all the characters under investigation. Similar results have been reported earlier by Beohar and Nigam (1972), Ganguli and Srivastava (1972), Singh et al. (1972), Joshi (1973), Kumar and Haque (1973), Singh and Malhotra (1973), Mukewar and Muley (1974). Gupta et al. (1975), and Ram et al. (1976). Seed size was negatively associated with all the characters except seed yield. Secondly, seed size showed positive or negative associations, depending on year, with plant spread, branches per plant and seeds per pod indicating that these associations are more under the influence of environment and hence cannot be used in an indirect selection program.

Partitioning of genotypic correlations into direct and indirect effects revealed a more interesting picture regarding character associations (Table 2). More or less similar trends were evident in the 3 years of testing for most of characters. However, for fruiting branch length and seed weight, there were slight deviations with season in direct and indirect effects. Plant spread and branches per plant were the cardinal components of yield, having highest positive direct as well as indirect effects. The remaining characters, i.e., days to maturity, plant height, and pods per plant depicted negative direct and indirect effects. Veeraswamy et al. (1973) also reported similar results. However, seed size had negative direct effect and positive indirect effect in our material.

The indirect effect of plant spread and branches per plant on yield via other characters and the indirect effects of all the remaining characters through plant spread and branches per plant differed from each other not only in magnitude, but also in direction. Such unequal reciprocal

Table 1. Genotypic correlations (above the diagonal) and first order partial correlations (below the diagonal) in pigeonpea.

Characters	Year	Days to maturity	Plant height	Plant spread	Fruiting branch length	Branches/plant	Pods/plant	Seed/pod	100-seed wt	Seed yield
Days to maturity	1977	1.000	0.865*	0.850*	0.696*	0.878*	0.808*	0.687*	-0.458	0.708*
	1978	1.000	0.884*	0.834*	0.715*	0.831*	0.806*	0.332	-0.301	0.729*
	1979	1.000	0.876*	0.794*	0.705*	0.868*	0.834*	0.440	-0.375	0.723*
Plant height	1977	0.710	1.000	0.913*	0.874*	0.902*	0.799*	0.736*	-0.566*	0.580*
	1978	0.551	1.000	0.938*	0.849*	0.877*	0.973*	0.411	-0.239	0.780*
	1979	0.464	1.000	0.906*	0.853*	0.882*	0.870*	0.503*	-0.293	0.761*
Plant spread	1977	-0.183	0.403	1.000	0.892*	0.969*	0.887*	0.845*	-0.286	0.737*
	1978	-0.125	0.472	1.000	0.829*	0.832*	0.924*	0.456	0.037	0.838*
	1979	-0.247	0.368	1.000	0.833*	0.862*	0.933*	0.513*	-0.066	0.833*
Fruiting branch length	1977	0.660	0.609	0.006	1.000	0.890*	0.861*	0.694*	-0.725*	0.639*
	1978	-0.588	0.656	-0.055	1.000	0.669*	0.779*	0.426	-0.225	0.769*
	1979	-0.559	0.507	0.025	1.000	0.714*	0.825*	0.439	-0.467	0.721*
Branches/plant	1977	0.442	0.260	0.643	-0.648	1.000	0.886*	0.889*	-0.229	0.711*
	1978	0.269	-0.293	0.493	-0.619	1.000	0.857*	0.632*	0.232	0.733*
	1979	0.584	-0.105	0.607	-0.452	1.000	0.821*	0.651*	0.180	0.735*
Pods/plant	1977	0.816	-0.519	0.182	0.021	-0.501	1.000	0.754*	-0.707*	0.828*
	1978	0.506	-0.474	0.078	-0.122	-0.625	1.000	0.570*	-0.315	0.921*
	1979	0.779	-0.420	0.281	0.343	-0.720	1.000	0.555*	-0.473*	0.878*
Seeds/pod	1977	-0.354	0.223	0.169	-0.386	0.720	0.367	1.000	-0.104	0.657*
	1978	-0.315	0.265	0.021	0.255	0.731	0.641	1.000	0.046	0.454*
	1979	-0.451	0.052	0.211	0.002	0.631	0.568	1.000	0.056	0.513*
100-seed wt.	1977	-0.292	0.483	-0.221	-0.129	-0.360	-0.477	-0.330	1.000	0.449
	1978	-0.185	0.213	-0.375	-0.138	0.493	-0.549	-0.010	1.000	0.614*
	1979	-0.113	0.126	-0.201	-0.077	0.309	-0.788	-0.096*	1.000	0.589*

Continued

Table 1 continued

Characters	Year	Days to maturity	Plant height	Plant spread	Fruiting branch length	Branches/plant	Pods/plant	Seed/pod	100-seed wt	Seed yield
Seed yield	1977	-0.184	-0.287	0.665	-0.641	0.459	-0.008	-0.055	0.602	1.000
	1978	-0.246	-0.358	0.742	0.464	0.671	-0.036	-0.048	0.647	1.000
	1979	-0.219	-0.320	0.511	-0.347	0.584	-0.323	-0.085	0.571	1.000

* Phenotypic correlations significant at 5%

Table 2. Results of path-coefficient analysis showing direct and indirect effects of yield characters on yield in pigeonpea.

Characters	Year	Days to maturity	Plant height	Plant spread	Fruiting branch length	Branches/plant	Pods/plant	Seeds/pod	100-seed wt.	Genotypic correlation with yield
Days to maturity	1977	-0.5028	-0.8489	1.3461	-1.0233	1.5633	-0.0162	-0.0667	0.2555	0.708
	1978	-0.3595	-0.0043	1.3147	0.5070	1.4007	-0.0394	-0.1791	0.0889	0.729
	1979	-0.6179	-0.9313	1.5367	-0.2116	1.5377	-0.8128	-0.0559	0.2783	0.723
Plant height (cm)	1977	-0.4349	-0.9802	1.4459	-1.2850	1.6061	-0.0160	-0.0715	0.3157	0.580
	1978	-0.3178	-2.2673	1.4787	0.6020	1.4782	-0.0427	-0.2217	0.0706	0.780
	1979	-0.5413	-1.0631	1.7535	-0.2561	1.5626	-0.8479	-0.0639	0.2173	0.761
Plant spread (cm)	1977	-0.4274	-0.8949	1.5837	-1.3115	1.7254	-0.0177	-0.0811	0.1606	0.737
	1978	-0.2998	-2.1267	1.5764	0.5878	1.4023	-0.0452	-0.2460	-0.0109	0.838
	1979	-0.4906	-0.9632	1.9354	-0.2501	1.5270	-0.9093	-0.0652	0.0490	0.833
Fruiting branch length	1977	-0.3399	-0.8567	1.4127	-1.3903	1.5847	-0.0172	-0.0674	0.4033	0.639
	1978	-0.2570	-1.9249	1.3068	0.7091	1.1276	-0.0381	-0.2298	0.0753	0.769
	1979	-0.4356	-0.9068	1.6122	-0.3002	1.2649	-0.8040	-0.558	0.3465	0.721
Branches/plant	1977	-0.4435	-0.8841	1.5346	-1.3086	1.7806	-0.0177	-0.0805	0.1283	0.711
	1978	-0.2987	-1.9884	1.3116	0.4744	1.6855	-0.0419	-0.3410	-0.0685	0.733
	1979	-0.5364	-0.9377	1.6683	-0.2143	0.7715	-0.8001	-0.0827	-0.1336	0.734
Pods/plant	1977	-0.4063	-0.7832	1.4047	-1.2659	1.5776	-0.0200	-0.0732	0.3944	0.828
	1978	-0.2898	-1.9794	1.4566	0.5524	1.4445	-0.0489	-0.3075	0.0390	0.921
	1979	-0.5153	-0.9249	1.8059	-0.2477	1.4544	-0.9746	-0.0705	0.3510	0.878
Seeds/pod	1977	-0.3457	-0.7214	1.3224	-1.0204	-1.4561	-0.0151	-0.0971	0.0580	0.657
	1978	-0.1194	-0.9389	0.7188	0.3021	1.0652	-0.0279	-0.5395	-0.0136	0.454
	1979	-0.2719	-0.5347	0.9929	-0.1318	1.1532	-0.5409	-0.1270	-0.0267	0.515
100-seed wt.	1977	0.2303	0.5548	-0.4561	1.0630	-0.4095	0.0141	0.0101	-0.5578	0.449
	1978	0.1082	0.5419	0.0583	-0.1908	0.3910	-0.0154	-0.0248	-0.2952	0.614
	1979	0.2317	0.3115	-0.1277	0.1402	0.3189	0.4610	-0.0046	-0.7420	0.589

effects indicate that the extent of the impact of these traits on each other is not the same. Discussing such reciprocal effects, the slightly higher residual effects, particularly in 1977 and 1979, indicate that some variability has been left unaccounted.

First-order partial genotypic correlations were computed (Table 1 below diagonal) to estimate the contribution of various character combinations after eliminating the remaining characters. Invariably, a similar trend was observed in the three seasons except with fruiting branch length. For direct and indirect effects, fruiting branch length and seed size depicted dissimilar behavior, whereas, for partial correlations, seed size showed a similar pattern over all the 3 years.

Considering yield associations, it was observed that plant spread, branches per plant, and seed size contributed positively. Thus, although when tested with simple genotypic correlations all the characters showed positive associations with seed yield, the picture became clear after path coefficient and partial correlations were used. Plant spread and branches per plant were the most important components of seed yield in pigeonpea. Next in order was seed weight. In the present material, most of the varieties represent highly evolved types. While they have an appreciable variation for various morphological characters, the seed weight shows much less variability. In the literature also, seed weight has been observed to show an inconsistent association with seed yield. A positive association has been reported by Wakankar and Yadav (1975) and Dahiya et al. (1978) and negative by Beohar and Nigam (1972), Ganguli and Srivastava (1972), Kumar and Haque (1973),and others, between seed weight and seed yield. Perhaps use of a larger number of genotypes for such studies would help in arriving at some definite conclusion regarding the role of seed weight in determining seed yield in pigeonpea.

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The Role of Genetical Studies in Developing New Cultivars of Pigeonpea for Nontraditional Areas of North India

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Abstract

Pigeonpea (Cajanus cajan [L.] Millsp.) has long been grown as a border crop around cotton and sugarcane fields in the Punjab. With the release of variety cv T-21 some pigeonpea began to be grown as a pure-crop. Pigeonpea is now becoming popular with the farmers because of its high yield potential, stable performance, low input requirements, and remunerative market price. The area of this crop in the state has increased from 1900 ha in 1972 to 7700 ha in 1979.

The low grain yield of pigeonpea is because of its poor harvest index, although its biological yield is comparable with that of cereals. Until recently, improvement has been largely made through single plant selections from locally adapted cultivars and pedigree selections among single intervarietal crosses. Very few genetical investigations have been made. The overall result has been marginal gains.

The main emphasis now is on developing early-maturing varieties with an improved plant type that will not only fit well into rotation with wheat but will also play an important role in raising the yield plateau in pigeonpea.

This paper reviews the current status of knowledge on genetic parameters of economic characters such as grain yield and various developmental and biochemical traits, with the ultimate aim of developing knowledge for improving the efficiency of breeding precedures. The role of early-maturing cultivars with less susceptibility to the pod-borer complex and other insect-pests for extending the cultivation of pigeonpea to nontraditional, irrigated areas of the Punjab for use in rotation with wheat is dicussed.

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India is a leading grower of pigeonpea and commands about 90 to 92% of the world's pigeonpea area and production. Pigeonpea, or arhar, accounts for 10 to 12% of the area and 15-16% of the production of all pulse crops in India. However, the contribution of Punjab, which is not traditionally a pigeonpea-growing state,to the total production of this crop is negligible.

Status of Pigeonpea in Punjab

In the Punjab, arhar has long been grown as a border crop around sugarcane and cotton fields. Until the last decade it remained a neglected crop because the local varieties took 8 to 9 months to mature, thus exposing the crop to winter frost, common in December-January. The late maturity of arhar also interfered with the timely sowing of wheat.

Systematic developmental work on arhar at Punjab Agricultural University started with the introduction of the All India Co-ordinated Project on pulse crops during 1969. Since then, a number of early varieties have been made available and tested in the state. The results indicated a distinct possibility of introducing arhar on a large scale using early maturing varieties. For example, cv T-21, which was tested against cv Pusa Ageti at different locations (Table 1), was released for general cultivation in the state starting a new trend of sole-crop pigeonpea cultivation. The pigeonpea crop is becoming popular with the farmers because of its high yield potential, low input requirements, remunerative market price, and its ability to survive under drought and other stress conditions. As a result of these advantages, the area of this crop has increased from 1900 ha in 1972 to 7700 ha in 1979 in the Punjab.

Table 1. Yield performance of T-21 compared with Pusa Ageti at different experimental stations in Punjab 1969-1972.

Year	Station	Yield (kg/ha)	
		T-21	Pusa Ageti
1969	Ludhiana	2628	1880
1970	Ludhiana	2951	2332
	Gurdaspur	2833	2321
	Average (1970)	2892	2327
1971	Ludhiana	1326	892
1972	Ludhiana	1185	963
	General Mean	2000	1616

Percent increase of T-21 over Pusa Ageti = 32.45

Role of Genetical Studies in Developing New Cultivars

There is a general belief that pulses give lower yield than cereals, and that pulses may have a lower genetic potential for yield than cereals. However, there is no factual evidence at present to suggest that this is so. On the contrary, the available evidence indicates that the pulse crops have as high or a higher genetic potential for yield than the cereals (Jain 1975;. The recent studies on pigeonpea (Swaminathan 1973; Jain 1975; Sharma and Green 1975) have shown that although the biological yield of pigeonpea is comparable with that of cereals, the low grain yield is because of poor harvest index. Basically, the low harvest index is attributable to the fact that pigeonpea has been subjected to little human selection and consequently, natural selection has driven it towards greater adaptability to adverse conditions and has led to poor economic yields. Jain(1975) observed that the per day productivity of some pulse crops compares well with that of wheat. Although at present per day yields in pigeonpea appear low, per day yields comparable to more "efficient" crops may be realized by developing short-duration varieties with higher grain yield.

Improvement in pigeonpea yields has been achieved mostly through single-plant selections from locally adapted cultivars and through pedigree selections among single intervarietal crosses. Very few genetical investigations have been conducted to support these procedures (Singh 1978). The margin of yield improvement has ranged from 10 to 20%.

What is needed for pigeonpea varietal improvement is to reorientate the growth behavior of this crop, reducing its duration to increase grain yield efficiency and making this crop suitable for multiple cropping systems. For this, basic information on genetic parameters of economic characters such as grain yield, and various developmental and biochemical traits is required to determine the most appropriate and efficient breeding methodology for each trait. Such information however, is scanty in pigeonpea, and research on these aspects has only recently received attention (Pandey 1972; Sharma et al. 1972, 1973; Singh et al. 1973; Dahiya and Brar 1977). Findings from these studies have shown that important traits are primarily controlled by quantitative genes.

Several workers have reported genetical studies in pigeonpea (Table 2). In the next section, special attention will be focused on a study by Sidhu and Sandhu (1980). This study involved a diallel cross analysis using eight parents differing in maturity, grain yield, and other morphological characters. In this analysis, the authors observed the importance of both additive and nonadditive gene effects for characters like days to 50% flowering, days to maturity, and plant height (Table 2). Nonadditive gene action was important for affecting grain yield and number of pods per plant, whereas inheritance of grain size (100-seed weight) was controlled by additive gene effects only. Low heritability estimates were observed for all characters except days to 50% flowering and maturity.

The combining ability analysis that the authors (Sidhu and Sandhu 1980) also conducted showed that variation due to general combining ability (GCA) effects was highly significant for all the characters under study except number of seeds per pod. The variance due to specific combining ability (SCA) effects was significant for days to 50% flowering,

Table 2. Summary of results of genetlcal studies in pigeonpea.

Character	Herit-ability	Gene action	Reference
Plant height	36-74	—	Munoz and Abrams (1971)
	48-85	-	Khan and Rachie (1972)
	61	nonadditive	Pandey(1972), Reddy et al (1979)
	88	-	Joshi (1973)
	-	additive	Sharma et al.(1973)
	82	-	Rubaihayo and Onim (1975)
	92-97	-	Sheriff and Veeraswamy(1977)
	-	additive and nonadditive	Kapur (1977)
	27	additive and non additive	Sidhu and Sandhu (1980)
Plant width	13-47	—	Munoz and Abrams (1971)
	29	-	Pandey (1972)
	-	additive	Sharma et al.(1973)
	-	additive and nonadditive	Kapur (1977)
Days to maturity	60-86	-	Munoz and Abrams (1971)
	78-90	-	Khan and Rachie (1972)
	79	additive	Sharma et al. (1973)
	-	nonadditive	Reddy et al. (1974)
	95	-	Pandey (1972)
	72	-	Rubaihayo and Onim (1975)
	66	additive	Dahiya and Brar (1977)
	53	additive and nonadditive	Sidhu and Sandhu (1980)
Pods/plant	76	-	Joshi (1973)
	12	-	Rubaihayo and Onim (1975)
	36	-	Dahiya and Brar (1977)
	78-82	-	Sheriff and Veeraswamy(1977)
	-	additive and nonadditive	Kapur (1977)
	7	nonadditive	Sidhu and Sandhu (1980)
Seeds/pod	82	additive	Pandey (1972)
	16		Joshi (1973)
		additive and nonadditive	Kapur (1977)
	16	-	Sidhu and Sandhu (1980)
Days to maturity	-	additive	Pandey (1972)
	—	additive	Sharma et al. (1972)

Continued

Table 2. *Continued*

Character	Heritability (%)	Gene action	Reference
Days to maturity		additive and nonadditive	Kapur (1977)
	49	additive and nonadditive	Sidhu and Sandhu (1980)
100-seed weight	-	additive	Pandey (1972)
	82	additive	Sharma et al. (1972)
		additive	Sharma et al. (1973)
	28	additive and nonadditive	Dahiya and Brar (1977)
	-	-	Kapur (1977)
	91-99	-	Sheriff and Veeraswamy (1977)
	-	nonadditive	Reddy et al. (1979)
	23	additive	Sidhu and Sandhu (1980)
Grain yield/plant	36-75	-	Munoz and Abrams (1971)
	43-87	-	Khan and Rachie (1972)
	76	additive x additive dominance and dominance	Pandey (1972)
	28	-	Joshi (1973)
	12	-	Rubaihayo and Onim (1975)
	82-89	-	Sheriff and Veeraswamy (1977)
	61	-	Malhotra and Sodhi (1977)
	-	nonadditive	Dahiya and Brar (1977), Kapur (1977), Reddy et.(1979)
	15	nonadditive	Sidhu and Sandhu (1980)
Protein content	59	additive x additive dominance and dominance	Pandey
	23-34	nonadditive	Sharma et al. (1973)
	23 (F_1)	nonadditive	Sharma et al .(1974)
	34 (F_2)	additive and nonadditive	Sharma et al. (1974)
	17	-	Rubaihayo and Onim (1975)
	34-62	-	Dahiya et al. (1977)
	-	nonadditive	Kapur (1977)

highly significant for days to maturity, plant height, number of pods per plant, and grain yield, and nonsignificant for number of seeds per pod and grain size.

The genetical studies so far conducted at Punjab Agricultural University have revealed that parents Prabhat, Pant A-3, UPAS-120, P 8-9 (AL-15) and AL-31 are very good combiners for earliness, whereas parents P 8-8, PS-39, T-21, and S-8 are good combiners for lateness. Where dwarfness is required, parents like P 8-9 (AL-15), Prabhat, AL-31, Pant A-3, P 1-3, were better and for tallness PS-39, P 8-8, S-8, and T-21 are desirable parents. For higher number of seeds per pod P 8-9 (AL-15), P 1-3, S-8, and BS-1 are better parents. P 1-3 and Pant A-3 can be considered desirable for high 100-grain seed weight, whereas H-39, T-21, and S-8 are better for high grain yield per plant. For protein content, T-21, S-8, and BS-1 are good combiners.

Breeding Strategy

Pigeonpea is one of the exceptions among grain legumes of having a tendency towards outcrossing (5-48%) and could be classified as an often cross-pollinated crop. For improvement purposes, the breeders have handled this crop as self-pollinated. Thus, the conventional breeding procedures such as single-plant selections and pedigree selections have found the main basis for improvement. The limitations of such procedures for making further advancements have been discussed by Gill (1980). Singh (1978) also reported narrow genetic base, limited efforts to generate wide genetic variability, and lack of planned handling of segregating populations as being largely responsible for lower grain yields in pigeonpea. Recently, some new concepts in breeding methodology have been advocated, largely based on the genetic parameters estimated in various studies.

Table 2 shows similarities between different genetical studies in pigeonpeas. The slight variation may be due to different materials used in the experiments. The inheritance of different characters revealed the importance of both additive and nonadditive gene effects. Additive genetic variance can be exploited by simple progeny selection. However, for quantitatively inherited characters, it becomes more difficult to combine all desirable genes in a pure line due to linkages and other limitations. Various authors have therefore recommended population improvement to deal with the problems when working with quantitatively inherited characters. Various techniques that can be used to increase the frequency of genetic recombination and maximize the exploitation of genetic variability are discussed below.

Recurrent Selection

Hanson et al. (1967) in soybean and many other workers in different crops have demonstrated that recurrent selection helps in breaking undesirable linkage blocks and results in shifts in the genetic correlation. Different approaches of recurrent selection have been suggested by different workers in self-pollinated crops.

Sib-pollinated Line Selection Technique

Andrus (1963) suggested this technique, which ensures full utilization of both additive and nonadditive gene effects and may lead to the fixation of the character at a desirable level.

Biparental Cross Technique

This approach, suggested by Joshi and Dhawan (1966), offers similar gains; in addition it may help in breaking undesirable linkages. Gill et al. (1974) observed in wheat that the biparental cross approach is efficient in breaking undesirable linkages and exploiting a portion of the additive x additive type epistasis. For exploiting additive genetic variance, Saini and Paroda (1975) suggested the biparental cross approach or the inter se mating among desirable lines. They suqqested that this method, be used with one of the North Carolina designs or with the population-building approach suggested by Doggett (1972) and Eberhart (1972) for sorghum.

Diallel Selective Mating System

Jensen (1970) proposed a diallel selective mating technique for breeding self-fertilized crops. The diallel selective mating system is being currently used by some breeders in pigeonpea at ICRISAT and in some other national programs. Kapoor (1977) suggested that of all the approaches of recurrent selection discussed above, Jensen's diallel selective mating technique would be the best for population improvement in pigeonpea.

Hybrid Varieties

A hybrid program can be based on the presence of dominance genetic effects. Utilization of hybrid vigor as a method of breeding in self-pollinated crop species became possible after the discovery of the cytoplasmic male-sterility and fertility-restoring genes or with genetic male-sterile lines. With the discovery of genetic male-sterile lines MS-3A and MS-4A in pigeonpea, ICRISAT scientists have suggested that these lines be utilized to explore the possibility of increased yields in F_1 hybrids. They have reported a 30% yield increase over the best parent in one F_1 hybrid (All India Kharif Pulse Workshop Baroda, April, 1978).

Formation and Maintenance of Composites

A new approach to the breeding of pigeonpea through the formation and maintenance of composities has been suggested by Khan (1973). These composites can be improved further through natural selection, mass selection, and recurrent selection. Stratified mass selection as suggested by Gardner (1961) may be more useful.

Mutation Breeding

In addition to the conventional methods, another method of creating variation is by induced mutations. Induced mutagenesis has become an important plant-breeding tool, and improvement in various characters in pigeonpea through mutagenesis has been observed by Chopde (1969), Sharma and Shrivastava (1974), Polke (1976); Jain (1977) and Bhagwat et al. (1980).

Wide Hybridization

Though some remarkable achievements have been made with certain crops, intergeneric hybridization in most crops is still in its infancy. Easy crossing of *cajanus* with genus *Atyiosla* has led some workers to consider grouping the two genera together, *Cajanus* is photoperiod sensitive and susceptible to pod borer. The successful incorporation into *Cajanus* of genes from *Atylosia* for earliness, photoinsensitivity and pod-borer resistance has been reported by Ariyanayagam and Spence (1978).

All these breeding techniques will contribute to crop improvement; however, in the *future,* improvement will have to be based not only on changes in morphological architecture, but also on improvements in metabolic capacity.

Improvement in Harvest Index and Plant Type

The importance of a favorable harvest index for high yields has been recognized (Swaminathan 1972; Jain 1975). The concept of developing improved plant types in pulse crops is another factor that could considerably improve the harvest efficiency (Jain 1971, 1977). The incorporation of semi-dwarfing genes and of characteristics such as thermo- and photo-intensitivity in wheat and rice has been rewarding.

Based on earlier as well as his own findings, Kapoor (1977) reported that the ideal plant in pigeonpea would be *one* with medium spread, early maturity, and high yield. This ideal type combined with photoperiod insensitivity and high harvest index would give the desired results in improving yields. Jain (1971, 1974) also suggested that pigeonpea varieties having this constitution should possess determinate and compact growth habit. According to Jain (1975), when selecting for a high harvest index in pulses, the important requirement is to increase the relative proportion of effective pods per plant. This may or may not be associated with photoinsensitivity. However, photo-insensitivity has the merit of enabling varieties to fit into a multiple-cropping pattern. The main factor responsible for the lower grain yields in pigeonpea—compared with wheat--is the poor harvest index of pigeonpea. For major advances in improvement of pigeonpea, therefore a genetic reconstruction of plants in the direction of high harvest index is essential.

Pigeonpea Improvement Work at Punjab Agricultural University

As pigeonpea is a new crop in the Punjab, there has been little opportu- nity to try new breeding techniques for developing new cultivars for this area. Any progress in the development of new lines for the area has been made through conventional breeding methods. Cultivar T-21 was released in 1973 for general cultivation in the Punjab. It matures in mid-November, which delays the sowing of wheat in the state. Therefore all the breeding work on pigeonpea so far carried out has been aimed at evolving varieties with very early maturity and high yield with stable performance. Also being sought is resistance to the pod-borer complex and the podfly. After the release of cv T-21, improved lines so far developed have been developed through single-plant and pedigree selections.

The comparative performance of some of the lines developed at our center is given in Tables 3 and 4.

Table 3. Performance of pigeonpea strains developed through single-plant selection at Punjab Agricultural University.

	Yield (kg/ha)					Days to maturity
	1976	1977	1978	1979		
	Ludhiana	Faridkot	Ludhiana	Ludhiana	Faridkot	
T-21	540	419	833	906	2937	165
P 8-9 (AL-15)	611	586	1063	1093	3667	136
P 1-3	668	518	837	887		139
p 4-4(AL-16)	704	685	948	1077	3742	150
LSD (5%)	7	18	111	196	691	
CV *(%)*	10.73	36.17	15.67	15.01	13.02	

Table 4. Performance of pigeonpea lines developed through pedigree selection at Punjab Agricultural University.

Variety	Cross	Yield (kg/ha)					Days to maturity
		1976	1977	1978	1979		
		Ludhiana	Ludhiana	Ludhiana	Ludhiana	Faridkot	
AL-25	Pant A-3 x Prabhat	676	569	993	746	3509	142
AL-26	UPAS-120 x KH-2			890	947	2979	151
AL-29	Pant A-3 x No.148			1393	833	3694	152
AL-28	T-21 x P 4-4			1327	1069		147
AL-30	T-21 x L-1			1247	780		172
AL-27	T-21 x P 14-7			1240	1284		169
AL-1	Prabhat x P 19-8				628	4060	130
T-21		509	419	1267	906	2937	160
	LSD (5%)	7	18	223	196	691	
	CV (35)	11.40	36.17	12.35	15.01	13.02	

All the lines developed by single-plant selection were earlier and showed better performance than T-21 (Table 3). Line AL-15 appears particularly promising. Similarly, almost all the lines developed through pedigree selection performed better than T-21 (Table 4); all the strains except AL-27 and AL-30 were earlier in maturity than T-21.

Very few genetical studies have been conducted at this institution, and the information obtained from such studies has not been properly utilized. However, recent emphasis on research work has shifted in this direction. Different approaches, such as diallel cross mating, line x tester analysis, and biparental progeny analysis are being used. In addition, the generation mean analysis and the triple testcross design, both of which have been used to estimate the genetic parameters for quantitative characters, are being added to our program. For developing superior lines, information regarding the genetics of different traits would be of considerable help to pigeonpea breeders. In addition, the new breeding approaches for pigeonpea population improvement can lead to the introduction of new cropping systems, such as sole-crop pigeonpea and sequential plantings of wheat and pigeonpea. These differ from the traditional ones that were developed under subsistence farming. In the competitive agriculture of today, particularly in the nontraditional irrigated areas of the Punjab where pigeonpea can be introduced on a large scale, new cropping systems must be considered. To fit these, a major reconstruction of the conventional pigeonpea plant would be required, to give a new improved type with a higher harvest index.

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Estimates of Natural Cross-Pollination in *Cajanus cajan* (L.) Millsp.: Several Experimental Approaches

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Abstract

Although pigeonpea floral biology favors self-pollination, some hybrid seed is usually produced, as a result of bee visits. Several experimental approaches have been utilized to determine the extent of outcrossing through the use of characters which help in' the identification of natural hybrids among the plants of a recessive strain. The extent of outcrossing on plants in different arrangements and the effect of plot size on the amount of outcrossing between lines have been discussed.

Breeding procedures are determined by the reproductive system of a crop. The floral biology of the pigeonpea, *cajanus cajan* (L.) Millsp., favors 100% self-pollination, but in fact there is usually some hybrid seed produced on unprotected plants as a result of bee visits to the flower. Williams (1977) observed insects of many orders on the flowers of pigeonpea and found that *Megachile* spp. were probably responsible for most of the cross-pollination. Various studies (Howard et al. 1919; Mahta and Dave 1931; Deshmukh and Rekhi 1962; Abrams 1965; Khan and Rachie 1972) have shown different outcrossing rates under field conditions. Ariyanayagam (1976) measured the degree of outcrossing in a pigeonpea population by using marker plants and reported a probability of 3% outcrossing beyond 43 feet. He recommended 27 feet of guard rows in adjoining plots as an adequate barrier.

The outcrossing mechanism helps in the production of hybrid seed and in population improvement breeding schemes, but poses problems in developing pure lines and in maintaining purity of released cultivars. No estimates are available of crossing percentage of individual plants with those surrounding them and the extent of outcrossing in successive rows in adjacent blocks. The present study was conducted to obtain such information.

Materials and Methods

The extent of natural crossing may be determined by the selection of such

*Pulse Improvement Program, ICRISAT.

characters (e.g., leaf shape, stem color, etc.) that the natural hybrids can be readily distinguished among plants of the recessive strain. The green stem marker used in this study was distinctive, readily detected, and simply inherited. It had undergone three generations of selfing and was assumed to be homozygous. There were no obvious variations in floral biology of green and purple-stemmed lines that might exert an influence on natural cross-pollination. Scoring the frequency of dominants in the progeny from the recessive plants gave the estimate of natural outcrossing.

A rectangular field layout was planned during *kharif* (rainy season) 1978 at 12 locations in India for estimating the extent of outcrossing within a population. Row-to-row and plant-to-plant distance was kept at 1 meter and within each third row every sixth plant was green stemmed and the remainder were purple stemmed. Data, however, were available only from Varanasi, Badnapur, Coimbatore, and ICRISAT Center. The green-stem plant progenies were planted in the off-season of the next year and were scored 6 to 7 weeks after planting for green and purple stem. The average frequency of purple-stem plants for the individual green-stem plant progenies gave an estimate of the minimum percentage of natural outcrossing. To confirm the observations, the trial was repeated at ICRISAT Center, Hyderabad, during kharif 1979 in two different layouts--a rectangular arrangement (Fig. la) and a hexagonal arrangement (Fig. lb). In the hexagonal arrangement all the plants were spaced equidistant (1 m).

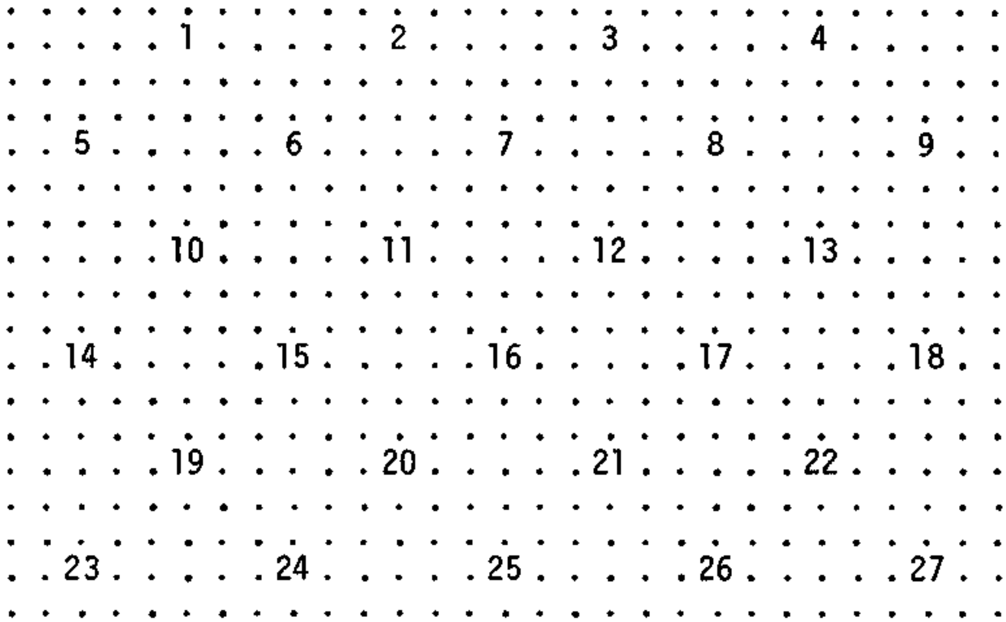
In 1979 kharif, another experiment was planted to determine the effect of plot size on the amount of outcrossing between lines. Plots were planted with green- and purple-stem plants alternately in four-, six-, and eight-row plot blocks of 10-m row length, with a distance of 75 cm from row to row and 25 cm from plant to plant. Distance between adjacent pigeonpea blocks was 10 m. Each row in the green-stem plots was harvested separately, and bulk seed from each row was planted in the field in the off-season. The average frequency of purple-stem plants was estimated for each green-stem plot and each row within a plot to determine the percentage of natural outcrossing in different arrangements.

Experimental Observations and Discussion

Data on percent outcrossing in individual green-stem plant progenies at different locations in India are presented in Table 1. At ICRISAT Center, Hyderabad, the cross-pollination ranged from 0 to 42.1%, with an average of 11.6% for the first harvest, and 13.2 to 41.7%,with an average of 28.2%, for the second harvest. The average outcrossing was considerably higher in the second harvest, suggesting that the pollinators were more active during that period. The pooled data gave a range of 7.8 to 35.1%, with a mean of 20.4%. Kadam et al. (1945) also reported similar results. At the Varanasi location the percentages ranged from 10.0 to 41.4 with a mean of 27%. These observations generally agree with those made at ICRISAT Center. Contrasting results were obtained from Badnapur and Coimbatore. At Badnapur the percentage of outcrossing ranged from 0 to 8.0, with a mean of 2.9, and at Coimbatore from 10.0 to 70.0 with a mean of 40.2. Data obtained from the present study gave conclusive evidence that crossing by bees on normal fertile flowers is neither constant from plant to plant nor from location to location, thus illustrating the randomness of bee activity.

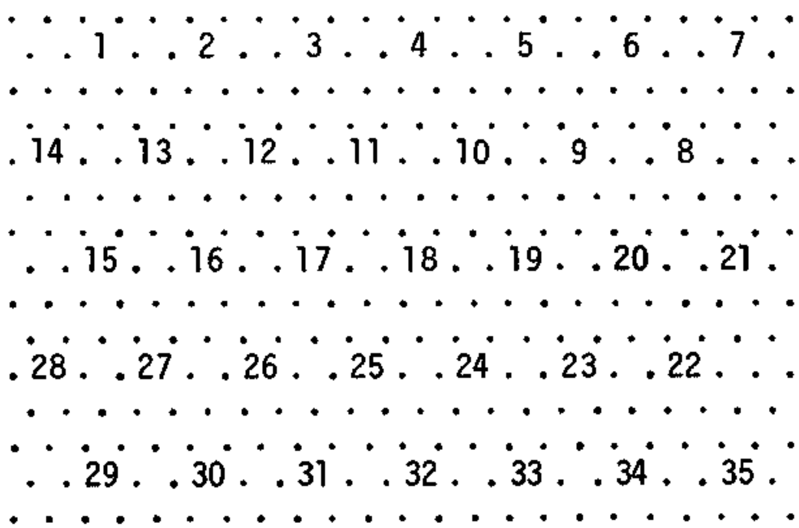
Figure 1. Field layouts to determine extent of outcrossing on individual plants in a pigeonpea population: (a) rectangular layout; (b) hexagonal layout.

a.



Dot = Purple-stem plants; 1 to 27 = Green-stem plants.

b.



Dot = Purple-stem plants; 1 to 35 = Green-stem plants

Table 1. Percent outcrossing in individual green-stem plant progenies at four locations in India, kharif 1978.

Green-stem plant no.	Hyderabad[a] First harvest	Hyderabad[a] Second harvest	Hyderabad[a] Overall	Varanasi[b]	Badnapur	Coimbatore[b]
1	D	D	D	31.5	8.0	51.6
2	42.1	33.9	34.4	25.5	5.0	30.8
3	10.0	28.9	23.6	25.0	2.0	29.2
4	14.9	20.5	17.6	28.1	7.0	50.6
5	14.1		14.1	30.1	2.0	48.5
6	13.4	22.6	16.4	36.4	4.0	70.0
7	16.7	22.3	22.1	34.0	0.5	34.8
8	14.5	41.5	29.3	35.8	1.0	60.0
9	7.2	30.6	12.9	17.5	2.0	51.6
10	L	24.7	24.7	33.3	0.0	33.3
11	L	29.6	29.6	19.5	1.0	40.0
12	D	D	D	10.0	6.0	43.5
13	4.2	35.0	26.2	26.6	2.0	25.0
14	7.8		7.8	24.4	3.0	10.0
15	13.5	28.8	15.9	27.5	1.0	20.0
16	8.1	23.6	12.0	10.3	3.0	43.8
17	L	35.1	35.1	19.3	2.0	
18	5.6	29.1	23.3	23.6	1.0	
19	0.0	13.2	7.8	41.4	3.0	
20	D	D	D		6.1	
21	13.1	41.7	15.3		8.0	
22	5.3	32.7	28.2		2.5	
23	17.8	28.3	22.3		2.1	
24	7.0	26.3	12.9		1.1	
25	9.6	26.8	19.5		1.5	
26	L	26.0	26.0		1.1	
27	7.6	20.5	12.8		1.5	
Mean	11.6	28.2	20.4	27.0	2.9	40.2
Range	0.0-42.1	13.2-41.7	7.8-35.1	10.0-41.4	0.0-8.0	10.0-70.0

a. At ICRISAT Center pod picking was done twice, with an interval of 15 days.

b. Green-stem plant numbers are not in accordance with the prescribed layout.

L = Late in flowering; D = Dead.

At ICRISAT Center during the 1979 kharif season, the extent of outcrossing in the rectangular layout ranged from 0 to 7.0%, with an average of 2.0% for the first harvest and 0 to 21.4%, with an average of 7.3%, for the second harvest (Table 2). The mean of outcrossing was comparatively high in the second harvest, thus confirming the 1978 results showing that bees were more active during that period. In the hexagonal layout the percent of outcrossing ranged from 9.1 to 54.9, with an average of 24.0 (Table 2). Although the proportion of purple-stem plants in the rectangular layout was more than double that in the hexagonal one, the extent of outcrossing was much more in the latter. This was associated with a marked difference in days to flowering of green-stem and purple-stem plants in the two layouts. In the rectangular layout the green-stem plants flowered a few days earlier than the purple-stem plants, whereas in the hexagonal layout the purple-stem plants flowered earlier. This was because different purple-stem marker lines were used in the two layouts. The higher crossing in the hexagonal layout *very* probably resulted from the presence of an abundance of flowers on the purple-stemmed plants at the time flowering started in the green lines. No comparison of planting arrangement was possible because of the confounding effect of different purple stocks in the two layouts.

This group of tests has served to emphasize the wide differences in the amount of natural crossing. The results showed differences among locations as well as substantial differences among years within locations. Sidheswar Prasad et al. (1972) have also reported a range of 25.7% outcrossing in seven varieties of pigeonpea, depending on variety and site.

In the test to determine the effect of plot size on the amount of outcrossing between lines, the percentage of purple-stemmed seedlings recovered from each row within the green-stemmed plots was practically the same in four-,six-, and eight-row plots (Table 3). The average of the central two rows in the four-row plot, the central two and four rows in the six-row plot, and the central two, four, and six rows in the eight-row plot was similar to their respective overall means. The percent outcrossing from adjacent plots ranged from 36.3 to 40.4, with a mean of 38.5, in the four-row plots; 17.0 to 28.4, with a mean of 20.8, in the six-row plots, and 34.3 to 43.3,with a mean of 38.2, in the eight-row plots. The level of outcrossing was similar in the four- and eight-row plots, while six-row plots showed just over half as much outcrossing. This may be related to the greater insect activity in the 4- and 8-row plot areas, although this was not obvious at the time; or it may be related to the fact that sparse flowering due to a poorer plant stand in the six-row plot area attracted fewer pollinators. The fact that crossing was not reduced in the outer rows of the blocks was both surprising and disappointing. Further work is needed on effective isolation with the pollinators present.

This procedure did not permit recovery of any hybrids that would have resulted from natural crossing among the recessive green-stem plants. If it is assumed that an equal amount of outcrossing was undetected, then the total amount of outcrossing would be considerably greater. A large number of factors determine the amount of outcrossing in pigeonpea. Intercrossing may be affected by the number of insect pollinators present in relation to number of flowers; the flowering habit of the varieties grown; the location of the field in relation to insect habitats; the distance between unlike varieties; barrier crops, and other environmental factors.

Table 2. Percent outcrossing in individual green-stem plant progenies in two layouts at ICRISAT Center, kharif 1979.

Green-stem plant no.	Rectangular layout[a] First harvest	Second harvest	Overall	Hexagonal layout
1	7.0		7.0	10.5
2	4.2	13.0	4.9	D
3	2.6	11.1	3.3	D
4	D	D	D	25.0
5	D	D	D	9.1
6	D	D	D	18.8
7	3.3	0.0	3.2	D
8	0.0	11.6	4.7	D
9	2.3		2.3	21.9
10	D	D	D	16.4
11	1.0	6.7	1.3	19.6
12	1.7	3.6	1.9	17.3
13	1.9	0.0	1.9	26.6
14	0.0	0.0	0.0	18.5
15	0.0	5.6	1.1	28.2
16	0.0		0.0	22.2
17	0.0	21.4	9.4	32.0
18	0.0	9.4	7.7	23.5
19	2.8	5.2	3.1	33.0
20	1.5	11.5	2.6	D
21	2.9	0.0	2.8	30.9
22	1.7		1.7	D
23	3.6		3.6	19.0
24	2.0	2.9	2.4	18.0
25	0.0	12.5	1.5	26.4
26	4.0	3.2	3.7	16.5
27	3.5	13.3	4.7	29.0
28				29.3
29				22.1
30				D
31				D
32				D
33				54.9
34				27.6
35				26.2
Mean	2.0	7.3	3.3	24.0
Range	0.0-7.0	0.0-21.4	0.0-9.3	9.1-54.9

a. Pod picking was done twice with an interval of 15 days.

D = Dead.

Table 3. Average of purple-stemmed plants within each green-stem plot and within each row.

Plot size	Row no.	Total plants	Purple-stem plants (no.)	Purple-stem plants *(%)*
Four-row				
	1	6 196	2 504	40.4
	2	6 275	2 412	38.4
	3	5 627	2 184	38.8
	4	6 724	2 443	36.3
Row 2 and 3		11 902	4 596	38.6
Total		24 822	9 543	38.5
Six-row				
	1	1 340	380	28.4
	2	1 479	344	23.3
	3	1 767	368	20.8
	4	2 047	348	17.0
	5	1 906	331	17.4
	6	1 828	387	21.2
Row 3 and 4		3 814	716	18.8
Row 2,3,4 and 5		7 199	1 391	19.3
Total		10 367	2 158	20.8
Eight-row				
	1	5 625	2 022	36.0
	2	4 822	1 667	34.6
	3	3 898	1 336	34.3
	4	5 233	1 882	36.0
	5	5 314	1 942	36.5
	6	5 088	2 126	41.8
	7	5 265	2 278	43.3
	8	5 728	2 387	41.7
Row 4 and 5		10 547	3 824	36.3
Row 3,4,5 and 6		19 533	7 286	37.3
Row 2,3,4,5,6 and 7		29 620	11 231	37.9
Total		40 973	15 640	38.2

These data indicate that enough natural crossing occurs that must be considered in maintaining genetic purity of various lines in a breeding nursery and in maintaining varietal purity during seed multiplication. Genetic purity of small stocks can be readily maintained by different methods of artificial self-pollination. In field-size plantings the use of barrier crops and of adequate isolation are at present the only practical methods.

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Variation in Harvest Index and its Utilization in Breeding of *Cajanus cajan*

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Abstract

One hundred and ninety-six genotypes from local germplasm collections of Cajanus cajan were grown in a randomized block design with three replications. Harvest index revealed significant variation in the population; also, the heritability estimates in the broad sense were very high for harvest index. A further experiment consisting of three genotypes selected on the basis of plant geometry, harvest index, and maturity was conducted under five planting systems. Results indicated that these genotypes did manifest marked variation in harvest index and growth characteristics under different planting systems. High harvest index observed under lower population density did not exhibit high yield per unit area. It was therefore suggested that selection for high harvest index be practiced under high population density to isolate high-yielding genotypes of pigeonpea.

Besides several physiological and genetic barriers, the low productivity of pulses can also be ascribed to their lower harvest index as compared with soybean and cereals. The crops with a higher harvest index, more than 30% (bread wheats), are well known to exhibit high yield potential. As for improvement of narvest index in pulses, it has been emphasized that selection for higner harvest index is possible on a phenotypic basis. However, it may be argued that breeding for higher harvest index amounts to breeding for higher yield (Jain 1975).

In the present study, 196 genotypes locally collected from Madhya Pradesh were screened for their harvest index. Further, three cultivars showing variation in narvest index and maturity group were evaluated under five different population densities for yield. The results obtained are presented and discussed in this report.

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Materials and Methods

Pigeonpea collected from different regions of Madhya Pradesh - 196 genotypes, including variety NP(WR)-15 -- were grown in a randomized block design with three replications during the rainy season 1975-76 at the Experimental farm of JNKvV, Jabalpur. Eacn plot consisted of single rows of 6-m length, spaced at 1 m between rows and 30 cm between plants. Data on harvest index were recorded from five randomly selected plants in eacn row. Mean, range of variation, and ANOVAwere computed to assess tne variation in narvest index.

Three genotypes were selected; on the basis of their maturity and harvest index. These were Khargone-2 (early), JA-3 (medium;, and NP(WR)-15 (late), which exhibited narvest index around 20.0, 25.0 and 30.0% respectively. The material, comprised of three varieties under five planting systems, was grown in a complete randomized block design, witn four replications in 5 m x 3 m plots. Five planting systems were followed:

1. One plant per hill; hills spaced at 1 m apart;
2. Five plants per hill; hills spaced 1 m apart;
3. Ten plants per hill; nilis spaced 1 m apart;
4. One plant per hill; hills spaced 20 cm apart; and
5. Continuous planting, 30 plants per m.

The expected plant populations under the five planting systems would be 10000, 50000, 100000, 50000, and 300000/ha, respectively.

Observations were recorded on plant height (cm), plant widtn (cm), number of primary and secondary branches, pod number per plant, 100-seed weight (g), grain yield per plant (g), grain yield per plot (g), and harvest index. Character means were calculated and analysis of variance carried out to determine the effect of harvest index on yield under different planting systems.

Results and Discussion

Data on harvest index of 196 genotypes indicated a *very* wide variation ranging from 8.97 (vidisha collection) to 57.75% (Bilaspur collection). The analysis of variance (Table 1) revealed highly significant differences due to genotypes. However, variation due to environmental factors was non-significant, probably because only three replications were used in the experiment. A high heritability estimate in the broad sense was obtained for harvest index — 99%. These results suggest that selection for high harvest index is possible in pigeonpea and that this trait could be a highly heritable character.

Further, results of the test using three genotypes indicated a significant effect of planting systems on plant height, yield per plot (except within JA-3), and seed yield per plant (except within Khargone-2). There was a nonsignificant effect of planting systems on plant width, primary branches, 100-seed weight, pod number per plant (except within NP[WR]-15). These genotypes, however, differed significantly from each other for all the traits (Table 2).

Table 1. ANOVA for pigeonpea harvest index.

Source of variation	df	ms	Heritability (%)
Replications	2	0.54	99.54
Genotypes	195	208.52**	
Error	390	0.95	

** P < 0.01

Data on mean harvest index, growth characteristics, and yield are presented in Table 3. The harvest index calculated under five planting systems varied, ranging from 25% to 36% in Khargone-2, from 24.0% to 40.0% in JA-3, and from 20.0 to 23.0% in NP(WR)-15. It can be observed that higher harvest index exhibited by planting system 4 did not result in higher yield per ha as compared with planting system 5 (i.e., high population density;. Further, there was considerable reduction in number of primary and secondary branches, pod number per plant and yield per plant under high population density (planting system 5), whereas height of plant and 100-seed weight remained more or less unaffected under all planting systems.

These findings suggest that density of plant population plays an important role in production of yield per unit area. High harvest index simply observed for a genotype may not be regarded a sole criterion for selection for high yield. It was therefore suggested that selection for high harvest index under a high population pressure should be practiced to isolate high-yielding genotypes of pigeonpeas.

Conclusions

A wide range of variation exists for harvest index in the local collection of pigeonpea (8.90 to 57.75%). Selection for higher harvest index is possible, since there were high heritability estimates for this trait.

Harvest index can be modified to some extent by different planting systems, resulting in different population densities (10000 to 300000 plants/ha). There is marked reduction in harvest index and growth characteristics, such as width of plant and number of primary and secondary branches, under higher population density.

Grain yield per ha was observed to be many times more under high (300000 plants/ha)than under low (10000 plants/ha) population density.

It is suggested that selection for high harvest index be practiced under high population density in order to exploit high-yielding genotypes of pigeonpeas.

Table 2. Mean sum of squares of different characters in three genotypes of pigeonpea grown under five different planting systems.

Sources	df	Plant height	Plant width	Primary branches (number)	Secondary branches (number)	Pod number	100-seed weight	Seed yield/ plot	Seed yield/ plant
Replications	3	677.5	207.8	4.9	46.4	3108 3	0.6	0.2	146.5
Treatments	14	4693.1**	126.5*	8.5	78.3**	16499.6*	6.3	1.7	270.1**
Within JA-3	4	8.8	86.1	5.7	147.8**	2767.2	1.8	1.0	102.6**
Within Khargone-2	4	185.9**	49.7	7.0	50.1*	831.1	1.2	1.1**	30.7
Within NP(WR)-15	4	793.6**	24.7	5.8	28.4	10293.5**	1.1	2.5**	219.0**
Between varieties	2	30874.7*	564.8*	22.3*	95.4**	87713.4**	35.7*	2.8**	1185.9**
Error	42	33.5	33.7	4.1	17.5	653.5	0.8	0.1	35.5

* $P < 0.05$

** $P < 0.01$

Table 3. Mean seed yield, mean harvest index, and growth characters of three pigeonpea genotypes under different planting systems.

Variety	Planting system	Yield per plant (g)	Yield kg/ha[a]	Harvest index (%)	Plant height (cm)	Plant width (cm)	Primary branches/ plant	Secondary branches/ plant	No. of pods/ plant	100-seed weight (g)
Khargone-2	1	13.3	110.6	25.0	83.0	31.9	7.6	9.7	77.2	9.1
	2	11.6	388.6	32.0	98.6	26.0	8.0	4.0	69.2	10.0
	3	11.6	645.9	32.0	94.3	24.1	7.6	1.5	59.4	10.5
	4	14.4	486.6	36.0	87.3	28.3	8.2	3.2	74.3	10.1
	5	7.1	1039.0	28.0	97.8	23.2	4.9	0.7	41.6	9.4
JA-3	1	17.8	161.9	25.0	92.3	31.8	9.4	76.1	109.9	9.7
	2	16.7	641.9	25.0	90.5	33.0	8.7	9.1	83.7	10.9
	3	11.7	321.9	24.0	90.8	22.9	7.5	3.5	65.9	9.6
	4	12.7	647.3	36.0	91.7	32.8	10.0	10.5	99.9	10.5
	5	7.3	1113.9	24.0	94.2	25.8	7.2	0.5	44.4	9.4
NP(WR)-15	1	24.4	172.6	22.0	135.9	21.9	9.2	7.8	208.6	8.3
	2	32.6	1016.6	23.0	171.6	16.7	10.2	4.3	215.9	7.8
	3	24.8	1207.8	20.0	165.4	17.8	9.2	4.5	173.7	7.2
	4	33.8	998.6	21.0	160.3	21.5	10.6	6.5	230.1	7.8
	5	15.5	1625.8	20.0	167.3	17.4	7.5	0.8	103.6	7.1

a. Calculated on the basis of plot yield.

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Flowering Responses of Thirty-Seven Early-Maturing Lines of Pigeonpea

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Abstract

Early-maturing pigeonpea (Cajanus cajan [L.] Millsp.) *has shown promise in several production systems, including broad-scale mechanized agriculture. Insensitivity to daylength may provide a means for obtaining uniform canopies with constant phenological development across latitudes and sowing dates. Thirty-seven relatively early-flowering lines introduced from India or selected in Australia were grown in natural daylength for December sowings at 27°S and under a 16-hour daylength in which natural daylength was extended using incandescent bulbs. The flowering responses of the lines showed that selection for earliness at any particular site does not necessarily provide a correlated selection for daylength insensitivity. Field extension with incandescent bulbs may be a useful technique in selection of daylength-insensitive lines. Further studies are required to determine the importance of spectral balance of the artificial lighting used.*

Pigeonpea is generally grown as a relatively long-season crop, with or without intercropping. The ecophysiological adaptation of pigeonpea and the potential roles it can play in cropping systems have been reevaluated in recent years. Much of this has involved the concept of the use of short-season crops. Some of the options in production systems were described by Byth et al. (these Proceedings). Short-season crops can be generated either by culture in short days (off-season sowings) or by the use of genetically early-maturing cultivars. Material insensitive to photoperiod (or nearly so) is likely to be the optimal solution of this objective, since it would condition short-season crops regardless of sowing date or latitude, and will allow rapid ratoon cropping whenever the conditions are favorable. Thus earliness and insensitivity to photoperiod are of basic importance in broadening the adaptation and flexibility of use of this crop. The objective of this study was to investigate the extent to which earliness in flowering is associated with insensitivity to photoperiod.

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Materials and Methods

Thirty-seven lines of *cajanus cajan* were used in this study. They were introduced from ICRISAT and Haryana Agricultural University (HAU), India, or were selected at the University of Queensland. Each of the lines was selected because it was classified as early flowering at its site of origin. A maturity group classification of pigeonpea was described by Green et al. (1979) and is used in this study. Two sites of classification were used, and were at a similar latitude: Hissar (India) 29°N; Redland Bay (Australia) 27°S

The lines were sown in the field at Redland Bay, Australia (27°S) on 17 December 1979. Two different photoperiods were imposed at sowing and maintained throughout the trial period: the natural photoperiod, (Wallis et al. 1980) which was a maximum of 14.8 hours including civil twilight, and natural photoperiod extended to 16 hours using incandescent lighting. The lights were spaced at 3 m x 3 m, and were suspended 50 cm above the canopy.

In 16-hour days, single-row plots 3 m long and 75 cm apart were used, with plants 25 cm apart in the row. Multiple plots were grown wherever seed was available. In the natural daylength area, three-row plots were grown using the same plant spacing. The two areas were separated by approximately 50 m and no shading was necessary between the areas. Previous experimentation at this site indicates that micro-environmental differences between fields exert no identifiable influence on the occurrence of flowering.

Irrigation, nutrients, and insecticides were applied as necessary throughout the trial period.

Flowering was recorded on a plot basis when 50% of plants were flowering. Where multiple plots of a line existed, the standard error was calculated on a line mean basis.

Results

In view of the latitude of the test site (27°S) and since sowing occurred just prior to the longest day, this material was exposed to natural daylengths equal to or longer than those which exist in most areas of pigeonpea culture internationally. Thus in terms of photoperiod responsiveness alone, we would expect flowering to occur at least as rapidly in shorter daylengths at lower latitudes or at other sowing dates; that is, this test should provide a reasonable discrimination of the lines for sensitivity to long days. Temperature and photoperiod x temperature interactions can influence flowering, but cannot be considered here since the test sampled only one temperature regime (Table 1).

For the purposes of this trial, we defined lines as "early flowering" if 50% flowering was attained within 65 days from sowing under the natural photoperiod. Further, we regarded lines as "early/insensitive" to daylengths up to 16-hour days if flowering was not delayed more than 10 days as a result of extension of daylength, or if flowering occurred in less than 65 days under 16-hour days.

Table 1. Mean weekly maximum and minimum temperatures (°C) at Redland Bay, Queensland, Australia (27°S), December 1979 to March 1980.

Week Ending	Maximum (°C)	Minimum (°c)
22 Dec 1979	29.8	22.8
29 Dec 1979	28.8	21.6
5 Jan 1980	28.3	20.2
12 Jan 1980	28.1	20.6
19 Jan 1980	29.6	20.3
26 Jan 1980	29.6	23.0
2 Feb 1980	29.7	23.1
9 Feb 1980	28.5	22.6
16 Feb 1980	25.6	20.0
23 Feb 1980	27.6	20.9
1 Mar 1980	27.0	19.2
8 Mar 1980	27.5	19.3
15 Mar 1980	25.1	18.4

A classification of the 37 lines into early flowering, early/insensitive, and relatively late groups is presented in Table 2. The pedigrees (if available) of the lines are in Table 3.

As expected from their origin, all of the lines were relatively early flowering under natural daylengths, and most flowered in less than 65 days (Table 1). However, earliness under natural daylengths does not imply insensitivity to 16-hour days, and flowering of some early-flowering lines was delayed by up to 25 days by exposure to the extended daylength. Equally, some of the lines which were later flowering under natural daylengths showed little response in flowering when daylength was extended.

In general, genetic origin or parentage was not associated closely with the classification of lines on flowering response in this study; for example, lines derived from UPAS-120 x Baigani and Prabhat x Baigani occurred in two of the three groups (Table 1). However, all lines derived from the 0DT composite from ICRISAT were insensitive. The origin of this material is of interest. The composite was formed by bulking equal

Table 2. Classification based on days to flower of thirty-seven *Cajanus cajan* lines grown under natural and extended (16 hours) day length at Redland Bay (27°S).

Code	Cross	ICRISAT[a] Maturity Group	Source	Days to flower: Natural day length	Days to flower: 16 Hour photoperiod	Difference
(1)	Early/Insensitive					
QP-68	UPAS-120 x Baigani	ODT	ICRISAT	50± 3.9	60	10
QP-108				52	56	4
QP-109				49	56	7
QP-111				56	60	4
QP-112	ODT composite	ODT	ICRISAT	56	62	6
QP-113	selections			49	59	10
QP-114				56	56	0
QP-115				56	64	8
QP-116				50	63	13
QP-117				48	56	8
QP-134	UPAS-120 x Baigani	ODT	ICRISAT	62.5 ± 0.5	67.5±2.5	5
QP-135	Baigani x Pant A2	ODT	ICRISAT	60.2 ± 0.4	66	6
QP-138				57.3 ± 1.8	64	7
QP-139	ICP-6997 x Prabhat	ODT	ICRISAT	52	59	7
QP-140				56± 2.3	59	3
QP-141				56	56	0
Insensitive Bulk from ICP-7179			UQ	55.3 ± 0.5	66.3±6	11
(2)	Early[c]					
QP-61	Prabhat x Baigani	ODT	ICRISAT	53.2 ± 2.3	78	25
QP-64	Prabhat x Baigani	ODT	ICRISAT	58.6 ± 0.9	80	21
QP-67	UPAS-120 x Baigani	ODT	ICRISAT	63.5 ± 1.5	76	13
QP-69	UPAS-120 x Baigani	ODT	ICRISAT	56.2 ± 5.2	79	23
QP-70	UPAS-120 x Baigani	ODT	ICRISAT	61.5 ± 0.4	76	15
QP-124			HAU	62	81	19
QP-125			HAU	65	84	19
QP-126			HAU	61	73	12
QP-127	Prabhat x UPAS-120		HAU	64	84	20
QP-132	UPAS-120 x Baigani	ODT	ICRISAT	62.5 ± 4.5	86	24
Prabhat		IDT	ICRISAT	62.9 ± 0.3	80.8±4.6	18
QP-65	Prabhat x Baigani	ODT	ICRISAT	66.2 ± 3.3	78	12
(3)	Relatively Late (> 65 days to flower, *natural* photoperiod)					
QP-66	Prabhat x Baigani	ODT	ICRISAT	78	79	1
QP-119	T-21 x Prabhat		HAU	82	83	1
QP-120			HAU	84	89	5
QP-122	T-21 x UPAS-120		HAU	72	90	18

Continued

Table 2. continued

Code	Cross	ICRISAT Maturity Group	Source	Days to flower: Natural day length	Days to flower: 16 Hour photoperiod	Difference
QP-123			HAU	70	90	20
QP-L5	UQ50-6		UQ	84.7 ± 1.2	88.5+0.7	4
QP-45	UQ50-5		UQ	79.1 ± 3.2	81.4±3.1	2
QP-44	UQ50-4		UQ	82.3 ± 2.9	88.6+1.7	6

a. Field classification by ICRISAT at Hissar.
b. Early/Insensitive = flowers in less than 65 days in natural light or extended light or with less than a ten day delay under extended light.
c. Early = flowers in less than 65 days in natural light.
HAU = Haryana Agricultural University, India; UQ = University of Queensland; QP = University of Queensland accession number

Table 3. Pedigrees of some lines planted in two photoperiods at Redland Bay (27°S).

Identification	Pedigree
QP-61	74068-11-B-B-HODT$_1$-B-QB[a]-B
QP-64	74068-IDT-B-11-1-HODT$_1$-B-QB-B
QP-65	74068-IDT-B-11-2-HODT$_1$-B-QB-B
QP-66	74068-IDT-B-11-2-HODT$_2$-B-QB-B
QP-67	74075-5-B-3-1-HODT$_1$-B-QB-B
QP-68	74075-5-B-3-1-HODT$_2$-B-QB-B
QP-69	74075-5-B-3-1-HODT$_3$-B-QB-B
QP-70	74075-5-B-3-1-HODT$_4$-B-QB-B
QP-119	H74-44[b]
QP-120	H73-20
QP-122	H76-23
QP-123	H76-27
QP-124	H76-48

Continued

Table 3. continued.

Identification	Pedigree
QP-125	H76-11
QP-126	H76-51
QP-127	H76-42
QP-132	74075-5-B-3-2-H0DT$_1$-B-QB-B
QP-134	74075-8-B-6-1-HODT$_1$-B-QB-B
QP-135	74078-20-B-4-2-HODT$_1$-B-QB-B
QP-138	74065 (DTM-95) 76-3-HODT$_1$-B-QB-B
QP-139	74065 (DTM-95) 76-3-HODT$_2$-B-QB-B
QP-140	74065 (DTM-105) 76-3-H0DT$_1$-B-QB-B
QP-141	74065 (DTM-105) 76-3-HODT$_2$-B-QB-B
QPL-5	UQ-50-6[c]
QP-44	UQ50-4
QP-45	UQ50-5

a. QB = Bulked at Queensland University.
b. HAU accession number.
c. Selections from UQ-50, now released as cv. Royes.

quantities of seed of each of 27 crosses of Prabhat and Pant A-2 with a wide range of other parents (Saxena 1977). The composite was cycled for three generations under open pollination at Hissar, India (29°N), after being truncated into maturity groups I, II, and III. The group I composite was split into group 0 and I maturity material in the third cycle. The lines tested here were derived by self-pollination of individual early plants from the fourth cycle. The long history of controlled breeding and the self-pollinated origin of the lines is significant. All other lines entered in this trial were derived as bulk seed from early-flowering plots, mainly by open-pollination. In consequence, such lines could be genetically heterogeneous and/or heterozygous for genes conditioning flowering. This could have influenced the estimation of flowering in this study, both by delaying attainment of 50% flowering and by inflating the difference between natural and extended daylengths.

None of the HAU lines was insensitive, although some were early flowering under natural daylengths. This was surprising in view of their origin from rigorous selection under field conditions at Hissar. The reason for this is unknown, but it may be related to the maintenance of breeding material by open-pollination.

All selections from ICP-6997 x Prabhat (QP138-141) were classed as early/insensitive (Table 1). The cause of this is unknown. Prabhat is group I and ICP-6997 group VI in maturity, and each would normally be expected to flower later than 60 days, particularly in extended daylengths. Clearly, transgressive segregation for flowering response occurred in this cross, and the tested lines are a select group. This suggests that both Prabhat and ICP-6997 contained genes conditioning earliness and insensitivity, and that they were complementary when combined in the progeny. This suggests that several genes are involved in determination of insensitivity.

Discussion

The classification of lines into three groups (early/insensitive, early, and relatively late) in this study must be regarded as somewhat arbitrary. No firm physiological arguments can be advanced for using a cutoff of 65 days to flowering as a separation of early from relatively late, nor for the use of a difference of 10 days between natural and extended daylengths for separating sensitive and insensitive responses. The 65 days to flowering limit is justified solely on the basis that experience with early-flowering pigeonpea suggests this as a natural truncation point. Some interval is required to judge response to extended daylength. We have used 10 days for two pragmatic reasons: first, it is a realistic interval that can be identified statistically on the basis of known standard errors (Table 2); secondly, differences of less than 10 days have little meaning agronomically, regardless of the underlying physiological mechanisms involved.

The response to extended daylength must be interpreted cautiously and in relation to the method of extension. Incandescent bulbs were used and the response of lines may be, in part, a function of the source as well as the daylength. Photomorphogenic responses were induced, with plants under the extended daylength invariably being taller than in natural daylengths. In this study, we cannot separate any possible light source (spectrum) effect on flowering from that of daylength per se.

It is significant and surprising that most of the relatively late-flowering lines showed little response in flowering to extended daylength. This could be used to infer that such lines are insensitive to photoperiod, but this is unlikely to be so. Similarly, cv Royes showed relatively little response (97 days vs 112 days to flower under natural and extended daylengths), despite the fact that it is known to exhibit marked changes in days to flowering for different sowing dates (Wallis et al. these Proceedings). Further, the response of Prabhat (Table 2) does not conform with other evidence (Turnbull, personal communication), which indicated that it was early flowering and insensitive. The cause of the limited responses in flowering of the later flowering material and the unexpected responses of Royes (under the same conditions in adjacent plots) and Prabhat in this trial is unknown and requires further study. Temperature is known to influence floral development (Turnbull, personal communication), and the test year involved relatively high night temperatures throughout growth (Table 1). The possible effect of an imbalanced light spectrum due to the incandescent source requires investigation.

Conclusions

1. Selection for earliness of flowering in the field at 27 to 29° latitude does not necessarily identify material insensitive to daylength; for example, no lines derived from HAU and only some ODT lines from ICRISAT were insenstitive in this trial. Repeated truncation on earliness and controlled pollination has apparently increased the probability of earliness being associated with insensitivity.

2. Most of the lines classified as early/insensitive were derived from crosses of relatively early parents (except ODT composite), which probably have only low degrees of sensitivity to daylength. However, the recovery of insensitive lines from ICP-6997 x Prabhat probably involves transgressive segregation. This suggests that several genes are involved in insensitivity, and that lines sensitive to daylength may contain some of those genes.

3. Since earliness does not necessarily imply insensitivity, classification into maturity groups under natural daylengths is of limited value. The ODT classification in the field is pragmatic but subject to influence by sowing date, latitude, temperature, etc. The maturity classification proposed by Green et al. (1979) could be extended on the basis of this study to include an additional group of lines insensitive to photoperiod. The definition of this group would require controlled testing under extended daylengths. We propose a daylength of sixteen hours for testing which would identify germplasm insensitive to photoperiods to the extent of current pigeonpea production areas. Temperature interactions will confound this definition under field conditions.

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Evaluation of a Population of Early-Maturing Pigeonpea Lines Derived from a Triple Cross Introduced from ICRISAT

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Abstract

From a triple cross (ICP-8504 x Prabhat) x ICPL-10 made by ICRISAT, 26 early, determinate, large-podded F_1 *plants were selected at Hissar in 1978. This population is now in the* F_3 *generation (after quarantine in Australia) and this paper reports the variability and interrelationships in phenology and yield components within and among progenies of various subsets based on maturity within this population.*

Until very recently, early-maturing pigeonpea *{cajanus cajan* [L.] Millsp.) received little attention in production or plant improvement internationally. Most pigeonpea scientists appear to have considered early material to have relatively low yield potential, and to be genetically inferior in seed size, physical quality of the seed, and pod size. However, the low seed yield of early lines compared with later material (for example, Green et al. 1979] is due, in part, to evaluation at plant density that is nonoptimal for the early maturity groups. Highyield potential of a small-seeded early-flowering population was demonstrated by Wailis et al. (1981 a) using high plant density in favorable conditions. Most early-maturing Indian cultivars havesmall seed, but no published evidence of a close genetic association between small seed and early maturity has been seen by us.

Production systems have been identified recently that require the use of early-maturing and/or insensitive cultivars (Byth et al. 1981). Incorporation of larger seed, improved physical quality of seed, and greater numbers of seeds per pod in early-maturing cultivars would increase the commercial potential of such systems.

This paper is a preliminary report on the performance of selected F_3 pigeonpea lines derived from a triplecross. The cross was made at ICRISAT in an attempt to generate a wide range of segregation for phenology, seed size, and seeds per pod.

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Materials and Methods

The triple cross used in this experiment involved the following parentage: (ICP 8504 x Prabhat) x ICPL-10. Prabhat is early flowering (Group I) and small seeded (7 g/100 seed); ICP-8504 is medium flowering (Group VI), with large pods and seed (13.3 g/100 seed); ICPL-10 is an early-flowering (Group III) line derived from JA-275 x Pusa Ageti, with large pods and relatively large seed (11.7 g/100 seed).

A population of the triple cross F_1 was grown at Hissar (29°N) in 1978. Twenty-six determinate plants flowered in less than 75 days and produced pods containing six or more seeds. Open-pollinated seed of these 26 plants was introduced to Australia in 1979, and F_2 plants were grown in isolation in quarantine. Four hundred and seventy F_3 progenies derived by self-pollination from individual F_2 plants of the 26 families were sown at Redland Bay, Australia (27°S) on 20 December 1979. Each F_3 line was evaluated in an unreplicated single row 3 m long sown at 0.5 x 0.2 m spacing.

For this study, five F_3 lines within each of 15 families were sampled at random. Days to flower (up to day 65 after sowing), plant height, pod number, seeds per pod, seed size, and seed yield were recorded for each plant. Estimates of experimental error were derived from replicated plots of three lines of photoinsensitive material (QPL-1, QPL-2, QPL-4) grown in the same field in the same cultural conditions.

Irrigation, nutrients, and insecticides were applied as necessary during this trial.

Results

Agronomic Performance of the Triple-Cross Families

The means over the F2 derived lines in the F_3 within each of the 15 families for some phenological and agronomic characters are presented in Table 1. Seven of the 15 families attained 50% flowering in 65 days or less, and this suggests that some of them may be insensitive to daylength at 27°S (Wallis et al. 1981). Individual plants within the other lines also flowered in 65 days or less, but it is not possible to present days to flowering for these lines because collection of flowering data was terminated for practical reasons at 65 days from sowing. The implication is that virtually all of this population was relatively early flowering, and further advances in earliness could be made by selection among and within the F_3 lines.

The F_3 families were, on average, considerably taller and vegetatively more vigorous than the photoinsensitive lines used as checks. The families ranged from 10.1 to 13.2 g/100 seeds in comparison with the checks at 6.9 to 7.6 g/100 seeds and Prabhat at 7 g/100 seeds. The triple-cross material had considerably greater numbers of locuies per pod than did the insensitive checks. However, actual number of seeds per pod was only marginally superior to the checks in most families (2.4-4.8 vs 2.6-2.8

seeds per pod in the triple cross and checks, respectively). There was a wide range in seed yield and pods per plant among the families, and some families were equal in yield to the insensitive checks. Pod number per plant of the triple-cross families was considerably lower than for the insensitive checks with equivalent seed yield, reflecting the larger pod and seed size of the F_3 lines.

Partition of Variance within the Triple-Cross F_3 Population

Mean squares among families and among lines within families are presented in Table 2 for six characters. For these analyses, the seven families attaining 50% flowering within 65 days from sowing (Table 1) were regarded as early, and the other eight families as late flowering.

No significant differences existed among the early and late families for any character. The early and late groups of families differed in plant height and seeds per pod only, with the late families being slightly taller, with greater numbers of seeds per pod. Significant differences also existed among the combined families for pod number but this reflected increased precision of the test, not a difference between the early and late families.

There were significant differences among the lines within the combined families for all characters except seed size, but the lines were significantly different only for plant height and pod number in the late families.

Considerable variation was documented among plants within the lines for most characters; for example, many plants had seed size in excess of 15 g/100 seeds. This clearly implies transgressive segregation for seed size. However, plant-to-plant variation will not be considered here.

Discussion

The triple-cross material introduced to Australia from ICRISAT is a highly select group in that it represented only the earliest flowering and large-podded fraction of the F_1 population grown at Hissar. Thus any inferences drawn from this study must be restricted to that triple cross and to this particular segment of it.

The initial visual impression of the population of F_3 lines evaluated at Redland Bay was one of relative uniformity among and within lines for all phenological and agronomic characters. This impression was confirmed by subsequent analyses of data; that is, although significant differences did exist both among families and among lines within families, the size of these differences was, in most cases, relatively small. This may be surprising in view of the diversity of parentage in the triple cross and the open-pollinated origin of the triple-cross F_2 seed introduced to Australia. However, we consider that the relative uniformity of the population can be explained on two bases. First, the material evaluated was rigorously selected by us in the F_1 for earliness and pod size. The relative lack of subsequent segregation implies that the F_1s

Table 1. Attributes of 15 triple-cross F_3 families and four photoinsensitive lines of pigeonpea at Redland Bay (27°S).

Source		Height at 50% flowering		Days to 50% flowering		Pods/Plant		Seed Yield (g/plant)[a]		Seed Size (g/100 seeds)		Seeds/Pod	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Triple-cross family	1	125.2	6.4	65.2	2.4	104.6	10.4	38.7	3.7	13.2	0.8	2.4	0.3
	2	140.1	6.7	-[b]		99.4	8.5	35.8	3.5	11.2	0.7	3.2	0.2
	3	119.2	6.7			76.4	9.8	29.3	3.6	10.7	0.8	3.5	0.3
	4	130.7	6.5	64.2	2.4	68.3	8.1	21.4	3.4	10.3	0.7	3.0	0.2
	5	131.0	6.4	64.5	2.7	86.8	9.0	28.0	3.3	10.2	0.7	3.1	0.2
	6	122.0	6.3	61.2	2.6	55.8	8.0	19.9	3.3	11.0	0.7	3.3	0.2
	7	142.1	6.5	67.9	2.7	84.0	9.2	28.7	3.4	10.2	0.7	3.2	0.2
	8	153.5	6.8	-		108.3	8.8	35.1	3.6	10.5	0.8	3.1	0.2
	9	123.4	6.3	57.2	2.9	67.4	8.1	22.9	3.4	11.2	0.7	3.0	0.2
	10	139.3	7.4	66.7	2.8	67.6	9.3	25.1	3.6	11.0	0.8	3.3	0.3
	11	176.4	6.6	-		73.4	10.6	24.2	4.4	11.2	0.9	3.2	0.3
	12	136.3	6.7	-		53.3	10.3	17.2	4.2	9.3	0.9	3.6	0.3

contd.

Table 1. contd.

Source		Height at 50% flowering		Days to 50% flowering		Pods/Plant		Seed Yield (g/plant)[a]		Seed Size (g/100 seeds)		Seeds/Pod	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Triple-cross family	13	136.3	6.7	-		56.7	8.5	19.4	3.5	10.1	0.8	3.4	0.2
	14	139.6	6.7	-		59.4	8.6	22.1	3.5	11.2	0.8	3.4	0.2
	15	154.4	6.7	-		39.5	9.3	18.2	3.9	10.2	0.8	4.8	0.3
Mean over families		138.0				73.4		25.7		10.8		3.3	
QPL[c] - 2		90.3		49.7		150.4		30.5		7.4		2.8	
QPL - 1		99.2		50.7		194.6		35.7		6.9		2.6	
QPL - 4		106.5		53.3		173.1		33.4		7.2		2.7	
QPL - 3		94.0		49.7		168.6		32.6		7.6		2.6	
Mean of QPLs		97.5				171.7		33.1		7.3		2.7	

a. - At this density, 30 g seed/plant ≡3000 kg/ha

b. - Data not recorded > 65 days to flower

c. QPL - Queensland Pure Line

Table 2. Mean squares among and within 15 F_3 triple-cross families grown at Redland Bay (27°S).

Source		Height		Days to flower		Pod Number		Seed Yield		Seed Size		Seeds/Pod	
		df	MS	df	MS	df	MS	df	MS	df	MS	df	MS
Total	Family	14	10934[a]	7	874	14	16304[a]	14	1991	14	33	14	9.0[a]
	Lines/Family	59	2123[a]	25	301[a]	50	3378[a]	55	590[a]	55	26	50	2.4[a]
Early	Family	6	2952	6	503	6	10459	6	1840	6	52	6	3.0
	Lines/Family	27	1498[a]	23	322[a]	23	3931	27	691	27	37	23	1.0
Late	Family	7	13829			7	23514	7	2400	7	18	7	10.9
	Lines/Family	32	2605[a]			27	2907[a]	28	493	28	16	27	3.6
Early vs Late[b]		1	38573[a]			1	902	1	30	1	23	1	31.2[a]

a. Due to the unbalanced data set, an F-test was not imposed. Significance was determined by comparing appropriate components with twice their standard error. This is a very conservative test.

b. Significance tested by F-test using lines/family mean squares.

selected by us were homozygous (or nearly so) for genes influencing phenology and pod size; that is, that earliness and large pod size are determined by recessive genes and our selections were homozygous recessive for most of the genes influencing these characters. Secondly, we have discovered subsequently that most of the plants within the F_3 lines tested exhibit the "wrapped flower" character described by Byth et al. (1981), which acts to enforce self-pollination. Thus the "open-pollinated" seed introduced to Australia probably was derived by self-pollination. It is significant that Byth et al. (1980) noted that, in the Australian collection, the wrapped character is invariably associated with large pods and large seed. ICP-8504 has wrapped flowers; it is probable that selection in the triple cross F1 for large pods resulted in correlated selection of wrapped-flower genotypes.

The form of evaluation used (0.5 m x 0.2 m) clearly was suboptimal for pigeonpea material of this habit and maturity (Wallis et al. 1980). Despite this, mean seed yield was relatively high (2600 kg/ha) and this suggests that the test environment was relatively nonlimiting. In this context, the low average number of seeds per pod (3.3, Table 1) relative to the average number of locules per pod (more than five) in the F_3 population is of considerable concern; that is, numbers of seeds actually filled per pod was considerably lower than the potential initially available. The cause of this high rate of ovule abortion in the triple-cross material is unknown. It may reflect environmental limitations that were not observed by us, and if so may be corrected by management. However, it may be related to inherent limitations of this genetic material; that is, it may reflect a source limitation to yield in this material.

The latter prospect is rather disturbing and requires further study. Earlier studies have suggested that yield in pigeonpea is sink-limited, not source-limited (Narayanan and Sheldrake 1976). Moderate positive association was reported (Anonymous 1978) between seed size and seeds per pod in each of 2 years, but there was no association between seed abortion and number of ovules, locules, or seeds per pod. However, that research was done using quite different genetic material and under less favorable and lower yielding conditions. The present research is the first known to be conducted on early pigeonpea material with a high genetic potential for sink size (large numbers of seed per pod and relatively large seed size). The fact that high ovule abortion occurred under conditions of high seed yield could be indicative of source limitation. Studies will be initiated in 1980-81 to examine this question, which is of basic importance to improvement of early pigeonpea culture in high-input environments.

Despite the reservations expressed above about this breeding material, it does represent the most promising early-maturing pigeonpea material in Australia. It has demonstrated high actual yields and the potential for even greater yields, and seed size and physical quality are substantially superior to that of the early cultivars currently available. The fact that most plants have wrapped flowers is an additional bonus. We intend to conduct further testing of these lines at higher density in 1980-81, with the intention of prerelease of elite cultivars in the near future.

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Performance of Early Generation Lines Under Different Cropping Systems and its Bearing on the Selection Procedure in Pigeonpea Breeding

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Abstract

In the arid and semi-arid regions of Maharashtra State, pigeonpea is normally grown as a companion crop with sorghum. However, in the pigeonpea breeding program, selections are made under sole-crop conditions, on the assumption that the genotypes that do well under solecropping will also do well under intercropping. Where this assumption does not hold true, the breeding program will be handicapped.

An alternative selection procedure was therefore developed, consisting of: (1) raising the F_2 *population as a sole crop and making single-plant selections, (2) growing the* F_3 *progeny rows as an intercrop with sorghum and selecting superior plants in superior families on the basis of yield, maturity, etc., (3) growing the subsequent generations as intercrops, and selecting on the basis of family performance, (4) evaluating selected lines under intercropping conditions. A total of 79 families was tested in the early generations under both inter- and sole-crop conditions. This paper discusses the results in relation to the procedure outlined.*

In the arid and semi-arid regions of Maharashtra State pigeonpea (*Cajanus cajan* [L.] Millsp.) is normally grown as an intercrop with sorghum. In some pockets, intercropping of pigeonpea with cotton or groundnut is also practiced. Pigeonpea is rarely grown as a sole crop; however, in the pigeonpea breeding program, selection and evaluation are made under sole-crop conditions, on the assumption that genotypes that do well under sole cropping will also give superior performance under intercropping. The breeding program may thus be handicapped in cases where this assumption does not hold true. Some pigeonpea cultivars released for commercial cultivation after selection and evaluation under solecropping have not become popular because under the intercropping system practiced by the farmer, these cultivars have not proved their superiority over the local cultivars. Preliminary studies by Singh et al. (1978) indicated that for

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the intercropping system, the yield of pigeonpea cultivars will depend not only on their genetic yield potential but also on their ability to compete with millet. To test this hypothesis and to develop an alternative selection procedure, we conducted an experiment under both sole-crop and intercrop systems.

Materials and Methods

The experimental material was comprised of 79 single-plant selections made in the F_2 generation, raised as a solecrop, and four released cultivars, C-ll, No.148, BDN-1, and BDN-2. The single-plant selections were made on the basis of agronomic traits in the field among the F_2 populations originating from single crosses involving 23 diverse parents. Final selection was done on the basis of grain yield per plant.

These 83 entries were tested in adjacent replicated trials with two replications under two cropping systems — solecropping and intercropping with sorghum cv CSH-6. For each entry, the experimental plot consisted of a single row, 4.5 m long. Under solecropping, between-row spacing was 75 cm; and between plant spacing, 30 cm. Under intercropping, pigeonpea was sown in between paired rows of sorghum. The sorghum paired rows were 60 cm apart; the pigeonpea row spacing was 90 cm, with plant-to-plant spacing of 30 cm. The sole crop of pigeonpea was given a basally applied fertilizer dose of 20 kg N and 50 kg P_2O_5/ha.

The intercrop sorghum was supplied with 80 kg N and 40 kg P_2O_5/ha. This was the recommended fertilizer dose for sorghum. For the intercrop all of the the P_2O_5 and half of the N were applied as a basal dose and the remaining N was applied 1 month after sowing. Interculture and plant protection operations were done uniformly in both systems. Statistical analysis of pigeonpea grain yield was done by a simple factorial design analysis.

Results and Discussion

The grain yield of pigeonpea under both cropping systems and the pooled analysis of variance are presented in Table 1 and Table 2, respectively. The analysis revealed that differences due to entries, cropping systems, and interactions were highly significant (Table 2). The highly significant interaction effects indicate that these early-generation selections expressed differential response to the two cropping systems.

In general, the medium- and late-maturing pigeonpea breeding lines matured about 30 days earlier with intercropping than with solecropping. It was observed that medium-duration pigeonpea lines that mature 30 to 40 days after the sorghum is harvested are better suited for intercropping in the Parbhani region (e.g. Lines No.27, 113, 114, 130, 56-30, 56-45, 56-50). Entries that appeared to be better suited for intercropping were the ones whose canopy covered the land after the sorghum was harvested.

Some breeding lines that gave high yield under solecropping also gave high yield under intercropping (e.g. Lines No.113, 114, 127, 131, 56-13). However, many lines giving high yield under intercropping did not

Table 1. Average grain yield of pigeonpea breeding lines under sole and intercropping systems.

Line No.	brain yield (kg/ha) Sole crop	Intercrop
Good under both systems		
1	1367(+10)[a]	809(+15)
27	1563(+26)	1041(+47)
72	1791(+44)	788(+12)
97	1501(+21)	824(4-17)
101	2804(+125)	770(+9)
109	1319(+6)	880(+25)
113	1764(+42)	916(+30)
114	1754(+41)	998(+41)
116	1627(+31)	716(+1)
127	2280(+83)	816(+15)
131	1797(+45)	907(+28)
149	1393(4-12)	748(+6)
161	1321(+6)	942(+33)
184	2003(+61)	766(+8)
207	1393(+12)	800(+13)
56-9	1559(+26)	787(+11)
56-13	1806(+45)	876(+24)
56-17	1262(+2)	739(+5)
56-19	1382(+11)	781(+11)
56-22	1443(+16)	884(+25)
56-25	1253(+1)	874(+24)
56-33	1985(+60)	782(+11)
56-51	1367(+10)	876(+24)
Good under sole cropping		
39	1767(+42)	539(-24)
43	1538(+24)	505(-28)
85	1310(+6)	684(-3)
94	2121(+71)	594(-16)
96	1570(+26)	641(-9)
98	1221(+2)	708(0)
125	1753(+41)	582(-18)
155	1375(+11)	496(-30)
166	1292(+4)	582(-18)
168	1399(+13)	558(-7)
170	1319(+6)	643(-9)
204	1256(+1)	708(0)
210	2021(+63)	621(-12)
213	1321(+6)	558(-21)
56-7	1399(+13)	701(-1)
56-47	1361(+10)	550(-22)
56-56	1357(+9)	332(-53)

Line No.	Grain yield (kg/ha) Sole crop	Intercrop
Good under intercropping		
9(C-11)	1209(-3)	887(+26)
21	816(-34)	816(+15)
24	1184(-5)	720(+2)
31	991(-20)	816(+15)
33	1206(-3)	827(+17)
36	633(-49)	844(+19)
41	1178(-5)	776(+10)
118	721(-42)	810(+15)
130	1127(-9)	993(+40)
137	1055(-15)	732(+4)
153(BDN-2)	865(-30)	880(425)
157(BDN-1)	1093(-12)	729(+3)
160	988(-20)	824(417)
172	996(-20)	745(45)
205	1036(-16)	809(+15)
220	684(-45)	775(+10)
56-23	933(-25)	830(+17)
56-30	1119(-10)	1110(+57)
56-41	1000(-19)	833(+18)
56-45	1089(-12)	1212(+71)
56-49	633(-49)	744(+5)
56-50	776(-37)	911(+29)
Poor under both systems		
18	840(-32)	452(-36)
30	594(-52)	213(-70)
38	1163(-6)	699(-l)
45	793(-36)	671(-5)
73	1058(-15)	644-9)
78	674(-46)	381(-46)
80	844(-32)	513(-27)
86	1102(-11)	393(-44)
105	916(-26)	474(-33)
145	1160(-7)	440(-38)
174	1067(-14)	533(-24)
180	991(-20)	492(-30)
189	957(-23)	628(-11)
194(No. 148)	1078(-13)	677(-4)
209	927(-25)	524(-26)
219	662(-46)	440(-38)
229	677(-45)	501(-29)

contd.

Table 1. contd.

Line No.	Grain yield (kg/ha) Sole crop	Intercrop	Line No.	Grain yield (kg/ha) Sole crop	Intercrop
Poor under both systems					
231	843(-32)	410(-42)			
56-3	1043(-16)	428(-39)			
56-31	876(-29)	641(-9)			
56-44	687(-46)	636(-10)			
General mean	1246	709			

CD: for line means = 459 kg/ha
for system means = 71 kg/ha
for interaction = 649 kg/ha
CV: 24%
a. Figures in parentheses indicate % increase or decrease over general mean

Table 2. Pooled analysis of variance of pigeonpea yield/(g/plot) under sole- and inter-cropping systems.

Source of variation	D.F.	SS	MS	F
Blocks	2	7092	3546	0.283
Entries (E)	82	2209377	26944	2.151**
Systems (S)	1	2722603	2722603	217.339**
Interaction (ES)	82	1691659	20630	1.647**
Error	164	2054356	12527	
Total	331	8685085		

necessarily do so under solecropping. Entries that gave the highest yield under intercropping were average yielders under solecropping (e.g. Lines No. 27, 130, 56-30, 56-45). These findings indicate that the early generation breeding lines of pigeonpeas differ in their companionship ability when intercropped with sorghum. Thus for use as an intercrop, pigeonpea lines selected in the early generations under intercropping conditions are more likely to give better performance than selections made under solecropping. This implies modification in the present selection and evaluation procedure followed in pigeonpea breeding.

An alternative selection procedure for pigeonpea breeding would involve selecting single plants for yield potential in the F_2 population raised as a solecrop and selecting for companionship in the F_3 progeny rows grown as an intercrop. Subsequent family selection and evaluation should also be done under intercropping; however, there is need to accumulate more data in this regard.

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Breeding for Vegetable-Type Pigeonpeas

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Abstract

Pigeonpeas are normally eaten as fresh green peas in the Caribbean and the Latin American countries. Because of the importance of vegetable-type pigeonpeas internationally, a separate project was initiated at ICRISAT for the development of superior breeding lines and cultivars for vegetable purposes. We have made a large number of crosses between late vegetable types and very early grain types to generate more variability in the material for range of maturity and seed size and to incorporate resistance to sterility mosaic disease and wilt. A large number of lines with a range of 120 to 209 days' maturity and 10 to 20 g/100 seed-weight have been selected. These lines are being evaluated in vegetable-type pigeonpea trials of early (VPPIT-1) and medium maturity (VPPIT-2) in different countries. The market value and consumer preference of vegetable-type pigeonpeas depend on the appearance, size, stage of maturity, and nutritional qualities of the peas. Fresh peas were analyzed for protein, crude fiber, sugar, and starch content, and results are discussed in this paper.

Pigeonpeas are consumed as fresh green peas in many Caribbean and Latin American countries and to some extent in India, Kenya, Tanzania and Zambia. In India there is a great demand for pigeonpeas as vegetables in certain areas, particularly in Gujarat State. Vegetable-type pigeonpeas are, in general, late-maturity types, and their cultivation has been limited to kitchen backyards. In recent years there has been a demand for early and medium-maturity types, so that with a range of maturities, a continuous supply of fresh green pods for the market and the canneries can be assured over a longer period of time.

The main objectives of breeding vegetable-type pigeonpeas at ICRISAT have been to: (1) generate breeding populations and develop high-yielding pigeonpea cultivars suitable for vegetable purposes, and (2) contribute superior breeding lines and populations to breeders throughout the semi-arid tropics.

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Priority of Vegetable-Type Pigeonpeas in the ICRISAT Program

Efforts to conduct research on pigeonpeas for use as vegetables were started during 1976-77, when an unreplicated international vegetable-type pigeonpea nursery consisting of 38 advanced lines was sent to 11 countries. Considering the encouraging response from many countries and the importance of vegetable types internationally, a separate project was initiated in 1978 *Kharif* (rainy season) for the development of breeding populations and cultivars for vegetable purposes. During the same year, two sets of vegetable-type pigeonpea international trials, VPPIT-1 (early) and VPPIT-2 (medium), based on maturity groups, were constituted and sent to 15 locations in eight countries.

Progress at ICRISAT

Germplasm Collection and Crossing Program

The success of any plant-breeding program depends on extensive collection and utilization of germplasm. ICRISAT has assembled 8775 lines from various pigeonpea-growing countries of the world. For the breeding program, 23 large-seeded lines were crossed with lines selected on the basis of their yield potential and other special traits. During 1978-79, most of the crosses were made using a line x tester design. Four good parents were used as testers, so that the value of each parent could be determined on the basis of its mean performance across testers. Largely single crosses were attempted but three-way crosses were also made.

Selection Among Crosses

Resources can be utilized effectively if poor crosses are eliminated in early generations. However, F_1 testing cannot be considered final, because of nonadditive genetic effects; yield testing is not practical at that stage due to the difficulty of getting enough seed. Moll and Stuber (1974) reviewed studies on components of variance in different crops and concluded that because the major portion of genetic variance was additive in nature, performance of parents and F_1s should be related to performance of later generations. Observations reported by Green et al. (1979) on early-generation testing in pigeonpea indicated that differences among generations for days to flower, seeds per pod, and seed size were nonsignificant, except for one cross. Cregan and Busch (1977) also suggested that F_1 performance could be a good indicator of the potential of a cross, but that high-yielding F_1s should be tested in the F_2 generation, since F_2 performance is a better indicator of performance in succeeding generations.

Breeding Methods

Investigations at ICRISAT were made to compare the efficiency of three methods--pedigree, mass selection with intermating, and backcrossing -- for combining large seed size with earliness, because the existing early types have small seed. Two crosses involving an early, but small-seeded, cultivar (T-21), as female parent and two late large-seeded lines (JA-278 and EC-100467) as male parents were taken as the base populations to compare the three methods. In each case, selection was first practiced for earliness and then for large seed size among the plants selected for earliness. On the basis of mean number of days to flower and seed size of final selections, it appeared that in both crosses the pedigree method and mass selection with intermating were better than the backcross method for combining earliness and large seed size.

The effectiveness of the pedigree method can be further illustrated by citing an example of a specific cross (ICP-8503 x ICP-7979). Population size in the F2 generation of this cross was 2746 plants. Our objective in this population was to exercise selection pressure towards larger seed size than the large-seeded .female parent (ICP-7979) which has 18 g/100 seeds and larger pod size than the large-podded male parent (ICP-8503), which is characterized by 6 to 9 seeds per pod. First by discarding plants with poor branching and those having fewer than six seeds per pod, 70% of the plants were rejected. The second-stage selection was done after harvest on the basis of 100-seed weight. At this stage another 18% of the plants were rejected as having small seed (less than 18 g/100 seeds). Only 5% of the plants were retained as being desirable for vegetable purposes. These selections were planted at Hyberabad in four row plots with a check *every* fifth plot. From 152 F3 progenies, 86 (57%) having more than six seeds per pod and weighing more than 18 g/100 seeds were selected. All single-plant selections made in the F3 generation have been planted in 1980 in four row plots with frequent checks for yield evaluation. Based on these observations on breeding methods for early maturity and large seed size, and the greater effort required for mass selection with intermating, the pedigree method was found to be the most practicable of the three methods. Although, the pedigree method was effective for days to flower and seed size, its effectiveness can be questioned for characters with low heritability, such as yield.

Performance of Advanced Lines in Different Maturity Groups

Observation Nursery

Over the years 1973 to 1977, observation nurseries were requested from ICRISAT by several countries. A few of the vegetable-type cultivars in these nurseries showed promise. In 1977 we sent a uniform vegetable pigeonpea international observation nursery consisting of advanced lines developed at ICRISAT to 11 countries. Results from some countries were encouraging. For example, some of the entries, in spite of early maturity, outyielded the late-maturing local check entries in Panama and were at par in Puerto Rico (Table 1).

Table 1. Performance of selected entries in the vegetable-type pigeonpea international nursery (VPPIN 1977) in Panama and Puerto Rico.

Location/Entry	Days to flower	100-seed weight(g)	Yield (kg/ha)
Panama			
39-77(local check)	120	13.0	4702[a]
40-77(local check)	240	11.5	5122[a]
73060-12-1-B III-1-B(W)	100	12.5	5265[a]
73060-12-1-B III-l-B(B)	88	12.5	5214[a]
73073-10-1-1-2-B(B)	114	14.0	4740[a]
Puerto Rico			
2 B-Bushy (local check)	103	16.0	1017
Kaki (local check)	132	21.0	1124
73047-19-7-12-B(W)	79	12.3	1065
73043-37-8-3-B(B)	79	16.6	1044
73043-l-17-2-B(B)	77	13.8	1045

a. Yield of green peas.

International Trials

Based on the encouraging results obtained in the observation nursery sent in 1977, two sets of international trials (VPPIT-1 and VPPIT-2) were constituted in 1978 and distributed to 15 locations in eight countries. Of these 15 locations, results have been obtained from six. Yield data from some of the locations are reported in Table 2.

In kenya, several entries of VPPIT-1 were superior to one of the local checks in yield, and superior to both local checks in seed size. The entries in VPPIT-2 were at par with the best local check in yield, and also had the advantage of large seed size. Many of these lines in both trials were found suitable for release in Kenya, because of earliness and increased pod and seed size. During 1979 two more sets of trials (early and medium) were sent to 13 locations in nine countries. Since planting time in different countries extends from July to May, it is

Table 2. Performance of vegetable-type pigeonpeas in different countries during 1978.

Country	Entry	Days to 50% flowering	g/100 seeds	Yield (kg/ha)
VPPIT-1				
Kenya	NPA 203/1[a]	62	8.2	2316
	NPP 199/10[a]	63	9.8	743
	ICPL-21	64	10.8	1407
	ICPL-26	60	10.4	1095
Puerto Rico	2BB[a]	91	nd	190
	ICPL-10	89	nd	375
	ICPL-27	84	nd	314
India (Coimbatore)	Local check	78	7.1	978
	ICPL-25	72	11.0	813
	ICPL-16	65	13.5	770
India (Junagarh)	UPAS-120[a]	94	nd	500
	ICPL-30	93	nd	761
	ICPL-28	96	nd	676
VPPIT-2				
Kenya	12-NPP-203/1[a]	66	8.3	1331
	ICP-6997	65	13.9	1393
	ICP-7035	61	18.5	1231
Puerto Rico	69-68[a]	113	nd	581
	ICP-6997	107	nd	593
	ICPL-36	110	nd	468
Zambia	ICP-7035	111	41.3[b]	5322[c]
	HY-3C	106	42.6[b]	4961[c]
India (Coimbatore)	Local check	80	7.5	433
	ICPL-35	89	14.4	592
	ICPL-37	68	14.2	491
India (Hyderabad)	ICP-7035	137	20.1	2198
	ICP-6997[a]	125	11.4	1957
	ICPL-41	139	15.9	1923
	ICPL-39	101	11.1	1836

nd = No data reported.

a. Local check.

b. Seed weight of green peas.

c. Yield of green peas.

difficult to get the results from all the locations at one time. So far, results have been obtained from four locations only. Some of the entries in all the four locations were either earlier or larger in seed size and/ or higher yielding than the local check(s). At Junagarh, India, all the entries in trial VPPIT-1 were large in seed size, and four entries were superior to the local check in yield. Similarly, at Coimbatore, India, all the entries except two were larger in seed size than both the local checks in trial VPPIT-2. During 1980, similar trials have been sent to 18 locations in eight countries.

Quality Characters of Vegetable-Type Pigeonpeas

The seed quality of a crop is a function of several physical, chemical, and biochemical factors. Of the physical factors, size, shape, and appearance of the seed receive considerable attention. The nutritional contribution of a crop can be raised by improving the protein quality and by lowering the levels of antinutritional factors such as protease inhibitors, oligosaccharides, and polyphenolic compounds. In this paper, the preliminary results on protein, soluble sugars, crude fiber, and starch contents of vegetable types are reported. Seed samples were collected from the field and oven-dried overnight at 60°C. The dried samples were ground in a Udy cyclone mill using 0.4 mm screen and used for analyses.

Protein content and crude fiber were determined according to the official analytical procedures of the AOAC (AOAC 1970). Soluble sugars and starch content were determined as described by Singh et al. (1980), except that the soluble sugars were extracted using hot distilled water.

The protein content ranged between 17.5 and 22.3%, with a mean value of 19.7% (Table 3). The protein content of vegetable types was similar to that of grain types. Singh et al. (1977) had reported that protein content of green developing seeds of vegetable types ranged between 19.6 and 22.9%.

Although there is considerable interest in breeding vegetable types for higher sugar content than the existing levels, the progress in this area has been very slow. Earlier workers analyzed a few vegetable types for sugar content and found a range of 6.9 to 8.6% (Singh et al. 1977).

The results of sugar analysis of lines of VPPIT-1 and VPPIT-2 trials showed differences between early and medium-maturity vegetable types. In early types, sugar content varied from 10.7 to 14.8%, while in medium-maturity types it ranged from 7.3 to 12.9% (Table 3). The starch content ranged between 36.4 and 47.5% in early types and 48.6 to 53.7% for medium types (Table 3). The crude fiber content ranged between 11.4 and 15.1% in early types, whereas it varied from 7.9 to 10.0% for medium-maturity lines (Table 3). The levels of principal constituents like protein, and carbohydrates change according to the stage of seed development (Singh et al. 1980). The acceptance of pigeonpeas as a vegetable depends on harvesting the pods at an early enough stage of maturity to provide good quality. The present preliminary results indicate that there are also inherent quality differences among maturity classes and among lines within these classes, which should be exploited in a breeding program. Further studies

Table 3. Some chemical characters of vegetable-type pigeonpeas developed at ICRISAT.

Trial	Character (%)	Mean	Range	CV (%)
VPPIT-1	Moisture	65.3	62.8 - 67.9	2.0
	Protein	19.7 (26.3)[a]	17.5 - 22.3 (24.7 - 28.2)	4.7 (2.5)
	Sugar	13.0 (21.1)	10.7 - 14.8 (19.1 - 22.6)	11.5 (6.0)
	Crude fiber	13.2 (21.3)	11.4 - 15.1 (19.7 - 22.9)	8.5 (4.4)
	Starch	41.4	36.4 - 47.5	7.9
VPPIT-2	Moisture	67.7	64.7 - 72.8	3.2
	Protein	20.9 (27.2)	18.7 - 22.7 (25.6 - 28.4)	4.6 (2.5)
	Sugar	10.3 (18.7)	7.3 - 12.9 (15.7 - 21.0)	8.5 (4.4)
	Crude fiber	8.7 (17.1)	7.9 - 10.0 (16.6 - 18.4)	6.6 (3.4)
	Starch	50.1	48.6 - 53.7	4.0

a. Values in parentheses are reported after arc sine transformation.

are required in this direction. It is also important to investigate the levels of some antinutritional factors present in these vegetable types.

Future Approaches

As discussed earlier, the pedigree method utilizing visual selection has been effective for highly heritable characters such as seed size and number of seeds per pod. Selection for individual plants in the F_2 for yield has not been effective in pigeonpea (Green et al. 1979). This may be due to the plasticity of plant growth. The plasticity of plant growth in pigeonpea is such that individual plant selection for yield has little value. Therefore, we may need to depend on F3 or F4 bulk yield performance, which may be related to the performance of selected lines in later generations. We plan to restrict our selection for yield to progeny testing of derived lines. All the advanced lines developed for vegetable purposes will be screened for Fusarium wilt, Phytophthora blight, and sterility mosaic disease.

Characters such as large pod size, more seeds per pod, and large seed size have received our attention in the past. Recently we have screened 20 early and 28 medium-maturity lines for protein, sugar, crude fiber, and starch contents. We will put more emphasis in our breeding program on these as well as other quality characters. Genotype-environment interactions play a *very* significant role during the field-testing phase of a plant breeding program, especially in a breeding program that has a global responsibility to improve the productivity of a particular crop. Due to the inadequate information obtained from trials in the past, it has not been possible for us to make extensive analyses of the data. With the cooperation of national programs, we expect to be able to collect and analyze data that will provide basic information regarding the adaptation of different lines.

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Review of Pigeonpea Breeding in Maharashtra State

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Abstract

The pigeonpea breeding program in Maharashtra State focuses on identifying and developing early types for multiple cropping, and medium to late types suitable for particular intercropping systems in different parts of the state. High yields, and resistance to pests and diseases are also aimed at, since the broad objective of the program is to increase stability and yield levels under rainfed conditions. This paper outlines breeding strategy followed and lists cultivars found especially promising in Maharashtra.

Cajanus cajan L. (Millsp.) (common names pigeonpea, tur or arhar) is one of the major pulse crops of Maharashtra State. The total area under this crop in Maharashtra State is about 614000 ha, with an annual production of 301000 tonnes. In Maharashtra State this pigeonpea generally grown as a rainfed crop (rainfall 400-1000 mm), without any application of fertilizer or suitable plant protection measures. Hence, yields are very low, about 400 to 500 kg/ha. On deep, water-retentive soil, pigeonpea is grown as a companion crop with sorghum, cotton, pearl millet, and groundnut, medium to late cultivars generally being used with tall companion crops.

The most serious disease is *Fusarium* wilt, which is observed in pockets in almost all pigeonpea-growing districts of the state. Pod-boring insects pose a serious threat to pigeonpea production with spraying required for control in many areas. Thrips have been shown to be a factor causing flower drop.

This pulse is consumed as dhal. Bold-seeded, white grained varieties of pigeonpea are preferred to small-seeded, red-grained ones. The broad objective of the pigeonpea breeding program is to increase the stability and level of yield under rainfed conditions; to this end, the program aims at:

- Identification of early types suitable for multiple cropping.
- Identification of high-yielding medium to late-maturing, drought resistant types suitable for intercropping.

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- Development of disease-resistant, particularly wilt-resistant, varieties.
- Development of insect-resistant varieties or of pest-management systems.
- Development of cultivars with acceptable or superior nutritional and cooking quality.

Earlier Work on Pigeonpea Improvement

In Maharashtra State, work on pigeonpea improvement at Niphad resulted in the release of medium-late strain No. 84, suitable in the Nasik district; subsequently No. 290-21 was released for other districts of western Maharashtra (Table 1). A medium-late prolific type KA-132, introduced from Uttar Pradesh, was found suitable in the Deccan Canal area. As a result of breeding work carried out in the Vidarbha region, high-yielding varieties such as No. 148 and Hyderabad-185 were evolved. In the Marathwada region breeding work was initiated at Parbhani. Varieties C-ll and PT-301 have been recommended for general cultivation.

At Badnapur, work was started under the All India Coordinated Pulse Improvement Project in 1970 in agronomy, breeding, entomology, microbiology and pathology; now with the establishment of four agricultural universities in Maharashtra State, research on pigeonpea breeding work is also done at (1) Mahatma Phule Krishi Vidyapeeth, Rahuri; (2) Punjabrao Krishi Vidyapeeth, Akola; (3) Marathwada Agricultural University, Parbhani; and (4) Konkan Krishi Vidyapeeth, Dapoli, under separate schemes to meet particularl the regional requirements.

As a result of concerted efforts made at Badnapur two improved varieties of pigeonpea viz. BDN-1 and BDN-2 have been evolved: BDN-1 (red seeded' and BDN-2 (white seeded). These are medium-late in maturity (150-165 days) and high yielding compared with the traditional late variety C-ll, their productivity per day per hectare being 7.4 kg as against 4.7 kg for C-ll. BDN-1 has shown stable yield performance in the All India Coordinated Trials in the peninsular region for the past 4 years, and at the Kharif Pulses Workshop in 1978, BDN-1 was identified as a superior genotype for the peninsular region. In addition to high and stable yield performance, BDN-1 has been highly resrstant to *Fusarium* wilt and tolerant to pod borer when compared with other cultivars. Similarly, the early strain T-21 has been found to be *very* promising in most of the pigeonpea-growing districts of Maharashtra State. These strains (BDN-1, BDN-2, and T-21) have been recommended for the Marathwada region.

As a result of selection practiced in segregating populations of elite crosses, selections from the cross combination BDN-20 (PT-301 x GW-3), BDN-3 (T-21 x S-5), BDN-46 (Kaki x Prabhat), BDN-46-1 (Kaki x Prabhat), BDN-68 (C-ll x Pant A-3), BDN-71 (C-ll x ICP-6997) and BDN-73 (C-ll x Hy-3A) have shown superior performance over C-ll, No. 148, and T-21. This material has been included in the advanced yield trials for further testing

With a view to evolving high-yielding types with other attributes like white and bold grain, compact growth habit, resistance to the pod-borer

Table 1. Characteristics of improved varieties of pigeonpea for Maharashtra state.

Variety	Days to 50% flowering	Days to maturity	Growth habit	Stem	Leaf	Flower	Pod	Seed	1000-seed wt. (g)	Seeds/pod	Yield (kg/ha)	Remarks
No. 84	95	160-165	Semi-spreading	Reddish	Small dark green	Yellow with red veins	Brown	Brown	85-87	3-4	600-700	
No. 290-21	95	165-170	Semi-spreading	Green	Dark green	Yellow	Constricted pod	Light red	90-95	3-4	700-800	Recommended for western Maharashtra
Kanpur-132	88	160-170	Semi-spreading	Reddish green	Dark green	Yellow	Black with brownish tinge	Dark red	74-76	3-4	800-900	Recommended for western Maharashtra
No. 148	105	165-170	Semi-spreading	Green with pigment	Light green	Yellow with red veins	Brown with red stripes	Red	91-95	3-4	900-1000	Recommended for Vidarbha region
Hyderabad-185	110	180-185	Erect and compact	Dark green	Dark green	Yellow with red veins	Dark brown with red spots	White	90-92	4-5	900-1000	White seeded

Continued

Table 1. continued.

Variety	Days to 50% flowering	Days to maturity	Growth habit	Stem	Leaf	Flower	Pod	Seed	1000-seed wt. (g)	Seeds/pod	Yield (kg/ha)	Remarks
C-11	120	195-200	Semi-spreading	Green	Light green	Yellow	Straight, greenish with brown stripes	Red	85-88	3-4	800-900	Late, wilt-resistant
PT-301	101	175-180	Erect	Reddish green	Medium green	Yellow with red veins	Dark brown with red spots	Brown	75-77	3-4	800-900	
BDN-1	92	150-160	Semi-spreading	Green	Green	Yellow reddish tinged	Brown with red stripes	Light brown	93-96	3-4	1100-1200	High-yielding, resistant to wilt and iron chlorosis
BDN-2	95	150-165	Semi-spreading	Green with pigment	Green	Yellow	Brown with red stripes	White, reddish tinge at micropyle	89-92	3-4	1000-1100	White seeded, resistant to wilt and iron chlorosis
T-21	70	120-125	Erect	Green	Green	Yellow	Brown with stripes	Brownish elongated	62-65	3-4	1000-1100	Early, recommended for Maharashtra state

complex and to wilt, a diallel crossing program using ten diverse parents was attempted during 1976. The F4 population is under study. Parents included in this diallel set were C-ll, No. 148, BDN-2, Hyderabad-185, BS-1, Prabhat, Kaki, Perennial, 15-3-3, and Pant A-3.

Future Program of Work

In view of the limited genetic potential in pulse crops, efforts are under way in all four Maharashtra agricultural universities to generate sufficient variability for isolating high-yielding lines. Elite material from ICRISAT has been obtained for evaluation. Similarly, breeding material is being generated through backcrossing, diallel crossing, and multiple crossing for incorporating desirable yield and yield-contributing characters. A mutation breeding program has also been initiated, using 5, 10, and 15 kr/gamma ray doses.

Recently, sterility mosaic disease, transmitted through mites, has achieved importance in the pigeonpea crop in Maharashtra. Therefore a crossing program for the incorporation of multiple resistance to wilt, sterility mosaic, and Phytophthora blight has been undertaken in adapted strains. The following crosses have been attempted during kharif 1979-80:

- BDN-1 x ICP-7035
- BDN-1 x ICP-8858
- BDN-1 x ICP-1336
- BDN-1 x ICP-8861
- BDN-1 x ICP-7336
- BDN-1 x ICP-5133-2-2
- BDN-1 x ICP-7249-1-1
- BDN-2 x ICP-7035
- BDN-2 x ICP-8861

Promising Material at Hand

The following entries and some crosses selected from segregating material have shown superior performance in regional trials:

ICP-193	ICP-1535	46-1
ICP-730	ICP-2956	20-9-4
ICP-1631	ICP-1458	20-6-11
ICP-3867	ICP-3318	20-9-9
ICP-2881	31-1-1	20-20-10
ICP-7936	43-2	20-10-8
24-1		

These entries are included in large-scale replicated trials.

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Imbibition by and Effects of Temperature on Germination of Mature Seed of Pigeonpea

P.L.M. de Jabrun, D.E. Byth, and E.S. Wallis*

Abstract

This study was conducted to determine the optimum conditions for germination of mature pigeonpea seed of three genotypes. The effects of technique of germination on imbibition and of temperature on germination behavior were studied.

The three genotypes ranged in seed size (7-24 g/100 seeds) and maturity group (55-130 days to flower in December sowings at 27° S).

Germinability of all genotypes was at an optimum over a wide range of temperatures (19-43° C) although growth of the germinating seedling was greatest between 29° and 36° C.

Evidence of differences- between genotypes for germination at high and low temperatures were identified and the implications of this response discussed.

The effect of temperature on the germination behavior of pigeonpea (*Cajanus cajan* [L.] Millsp.) has implications for commercial cropping systems. Pigeonpea is grown traditionally as a summer-sown crop, but recent development of off-season cropping has occurred in India. This involves sowings in November-December at cooler temperatures. The development of short-season production systems based on photoperiod-insensitive genotypes (Wallis et al., these Proceedings; Byth et al., these Proceedings) allows sowings to be made at any time of the year, provided soil temperatures are suitable for germination.

Observations in Australia indicate that although active plant growth will occur at relatively low ambient temperatures, germination and emergence may be inhibited by those temperatures.

We have found no published information on the response of pigeonpea to germination at low soil temperature. However, other warm-season grain legumes have been shown to germinate at relatively low temperatures; for example, soybean attained 95% germination at 10°C (Wilson 1928; Edwards

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1934; Bharati 1976) and mung bean and chickpea showed 90% germination by the fifth day at 13°C (Slater unpublished).

The International Seed Testing Association (ISTA) recommended the use of the between-paper (BP) methods with paper either as rolls, pleated, or in trays at 25°C for testing pigeonpea, with the test lasting 10 days (Anonymous 1976).

This study was conducted to determine the optimum conditions for germination of mature pigeonpea seed of three genotypes. The effects of technique of germination on imbibition and of temperature on germination behavior were studied.

Materials and Methods

Two separate studies were conducted, on the effects of germination technique on imbibition, and of temperature on germination behavior. Three pigeonpea genotypes were used in each study:

1. Photoperiod-insensitive (INS) bulk population derived by self-pollination of an off-type plant in an accession from India (ICP-7179; Wallis et al., these Proceedings); early-flowering short-season type (55 days from sowing to flowering); 100-seed weight approximately 7 g;

2. C-322, a mid-season accession from Jamaica, flowering in 100-days for December sowing at 27°S; 100-seed weight approximately 14 g;

3. UWI-35, a medium-late flowering accession from the University of the West Indies (130 days for December sowing at 27°S); 100-seed weight approximately 24 g.

The seed used in these studies was produced at Redland Bay University farm (27°S) during the 1978 growing season. After threshing, the seed was dried in a forced draft oven at 40°C ± 2°C for 3 days, graded to remove the extreme sizes and damaged seeds, and stored 9°C ± 2°C and 35% ± 5% relative humidity until use. Seed lots were removed from storage 24 hours prior to use and equilibrated to ambient temperatures in the laboratory. The moisture content of each seed lot was determined before use, using the standard method (Anonymous 1976): oven drying at 105°C ± 1°C for 16 hours ± 1 hour and expressed on a wet-weight basis.

Seed was prepared for germination tests as follows. All seed was treated with Captan (50% w/w N-Trichloromethylthiotetrahydrophthalimide) dust at the rate of 1.5 g/200 g of seed to reduce the incidence of fungal contamination (Bharati 1976; Ellis and Paschal 1979). Four replications, each of 50 seeds, were used in each study. Seed was placed between paper towels (Kleenex deluxe roll towels code 4400), either in plastic trays lined with germination paper (1.5 mm thick Ebwip UT0 germination paper) or spaced down the center of cotton towels which were subsequently rolled longitudinally. Before use, the trays were thoroughly washed, dried, and rinsed in absolute alcohol, and the towels were washed and autoclaved at 120°C for 20 minutes. Deionized water equilibrated to the designated temperature was used throughout the trials. Initially, 85 ml water was added to each tray and 200 ml to each roll, and additional water was added as necessary during the trial.

Imbibition Study

Imbibition was studied in the three genotypes at 25°C + 1°C, using the BP tray and towel methods. Seed was sampled at eight time intervals after sowing (0, 1, 2, 4, 8, 12, 18, and 24 hours). At each sampling time, the amount of water imbibed was determined by the standard method described previously.

Two cabinets were used, each with two replications. The design was a split/split/split plot with cabinets as whole plots, genotypes and methods as subplots, and sampling time as sub-subplots. No significant effects due to cabinets existed, and cabinets are ignored in discussion.

Effect of Temperature on Germination Behavior

A multirange temperature incubator with five compartments was used. Three separate runs were used to obtain 15 "mean temperature conditions between 12.7° and 46.5°C. The highest temperature compartment of one run was adjusted to approach the temperature of the lowest temperature compartment of the next run. Two low-temperature treatments (7.1°C and 9.3°C) were studied in separate germination cabinets, giving a total of 17 temperature conditions.

Germination tests were done with the three genotypes, using the BP rolled-towel method only. Germination was defined as the visible emergence of the radicle (Heydecker 1972; Lang 1965) and was recorded daily for 10 days. All germinated seed was removed except for 15 seeds, which were retained for 48 hours after the commencement of germination to observe radicle-hypocotyl elongation. The following germination characters were calculated for each temperature:

1. Germinability (cumulative germination): average of the daily percentage germination over 10 days (Timson 1965; Bharati 1976).
2. Mean days to germination (MDG): calculated from the coefficient rate of germination (CRG) (Heydecker 1972; Harrington 1963), where

$$MDG = 100/CRG,$$

$$CRG = \frac{\Sigma n}{\Sigma Dn} \times 100,$$

and n is number of seeds germinated on day D after sowing.

3. Radicle-hypocotyl elongation (RHE): measured (in mm) 2 days after germination using 15 seedlings per treatment.

Results and Discussion

Imbibition Study

Highly significant differences existed among genotypes and methods, and for genotype x method interaction (Table 1). As expected, the amount of water imbibed increased with sampling time, but there was significant interaction between sampling time and genotype, method, and genotype x method.

Table 1. **Mean squares for imbibition rate for three genotypes evaluated in two methods over a 24-hour interval.**

Source	df	MS
Genotypes (G)	2	0.261**
Methods (M)	1	2.607**
G x M	2	0.157**
Error 1	18	0.003
Sampling time (S)	7	4.750**
G x S	14	0.041**
M x S	7	0.174**
G x S x M	14	0.032**
Error 2	126	0.004

*, ** $P < 0.05$ and 0.01, respectively.

For all three genotypes, imbibition per gram of dry seed weight was greater for the BP roll method than for the BP tray method throughout the duration of the trial. However, the genotypes differed greatly in their rate of imbibition. In both methods, the insensitive genotype (INS) imbibed water at a faster rate during the first 12 hours than did the other genotypes. In contrast, the large-seeded UWI-35 imbibed water relatively. slowly and at a consistent rate over 24 hours in the BP tray method, but was similar in rate of water uptake to the insensitive small-seeded genotype in the BP roll method. C-322 had the lowest imbibition rate in the roll method and responded erratically in trays.

The marked differences between genotypes in rate of imbibition may be related to seed size. Small seed has a larger surface area per gram of seed, and this would influence the relative area of surface contact between seed coat and water. This may facilitate water movement to the micropyle. The large imbibition rate differences between genotypes in the BP tray method were not observed in the BP roll method in which all genotypes had absorbed a similar amount of water per gram of dry seed after 18 hours. It.is probable that this occurred because the roll method provided a more intimate contact between the seed and the water. As such, the BP roll method may simulate more closely the seed-soil contact.

Regardless of the cause, it is clear that the use of BP trays for germination studies in pigeonpea can result in substantial confounding of germination behavior due to a seed size x imbibition rate interaction. This effect is essentially eliminated in the BP roll method.

Effects of Temperature on Germination Behavior

No germination occurred at 7.1°C and 46.5°C, and these treatments were excluded from analysis. Temperature had significant influence on germinability, mean days to germination (MDG) and radicle-hypocotyl elongation (RHE) (Table 2). Differences existed between the genotypes and for genotype x temperature interaction for germinability and RHE, but not for MDG.

In all three genotypes, germinability revealed a clear optimum response with an extended plateau of approximately 85 to 95% germination between 19°C and 43°C. Germinability declined abruptly at higher and lower temperatures. These results are similar to those of Bharati (1976) in soybean and Slater (unpublished) in mung bean and chickpea. C-322 had higher germinability at both the high and low temperatures than the other genotypes. UWI-35 was inferior in germination to INS at temperatures less than 19°C but was superior to it at 44.5°C. Considerable interaction of genotype and temperature occurred in the 19°C to 43°C temperature range, with UWI-35 generally showing slightly lower germinability than the other genotypes. However, these changes were small and of little consequence.

MDG declined rapidly with increase in temperature from 7.1°C to 19°C, and was at a minimum and generally similar within the temperature range 26° to 43°C. There was a small increase in MDG at the higher temperatures, particularly for the INS genotype. However, no genotype or genotype x temperature effects were significant.

RHE revealed an optimum response in all three genotypes, with maximum elongation occurring at the temperature range of 29° to 36°C. There was a progressive reduction in RHE at temperatures less than 29°C and a rapid reduction at temperatures greater than 36°C. Averaged over temperatures, the small-seeded INS genotype revealed greater elongation of the plant axis than did C-322 or UWI-35, and this was most marked at the moderate to high temperatures (27°-43°C). The largest seeded genotype, UWI-35, had the lowest RHE in this temperature range.

Table 2. Mean squares from analysis of three germination characters measured for three genotypes at fifteen temperatures.

Source	df	Germinability	MDG (days)	RHE (mm/2 days)
Temperature (T)	14	6792.01**	67.94**	3175.09**
Error A	45	18.35	0.61	25.41
Genotypes (G)	2	1172.50**	1.04	427.25**
G x T	28	260.39**	0.52	34.74*
Error B	90	30.15	0.62	18.78
CV *(%)*		6.9	31.7	20.1

*,** $P < 0.05$ and 0.01, respectively.

Mean over temperatures	Genotype INS	Genotype UWI-35	Genotype C-322
Germinability	79.2	75.7	84.5
MDG	2.6	2.4	2.5
RHE	24.3	19.0	21.4

These data indicated that for all three genotypes, germination did not occur at temperatures of 7.1°C and 46.5°C. As temperature was increased from 7.1°C, there was progressively more rapid germination, increased germinability and more rapid RHE. Germinability and MDG both revealed wide temperature plateaus at temperatures equal to or greater than about 19°C. In contrast, optimal RHE was not attained with about 28°C, and there was a narrow temperature plateau.

In general, the differences among the genotypes were relatively small. However, the seed of genotype C-322 (medium-sized) had superior germinability at both suboptimum and superoptimum temperatures, and was inferior in RHE at optimal and superoptimal temperatures. In contrast, the INS genotype had superior RHE at optimal and superoptimal temperatures. Except for RHE at temperatures greater than 27°C, there was no clear evidence of association between the response of a genotype for any character and the seed size of that genotype. However, seed size and background genotype are totally confounded in this study, and no general conclusions on the effects of seed size are possible.

Conclusions

1. Germination tests should be conducted using the BP rolled towel method. The technique was superior to the BP tray method in that it resulted in similar imbibition rates per gram of dry seed for genotypes of different seed size.
2. In all genotypes, germinability was at an optimum over a wide range of temperatures (19-43°C). Germination was at its most rapid between 26-43°C, but still occurred rapidly down to 19°C approximately. Growth of the germinating seedling was greatest in the relatively narrow temperature range of 29-36°C.
3. The differences between genotypes were small relative to temperature. However, evidence exists of genetic superiority to germinate at both low and high soil temperatures, and for rate of growth of the germinating seedling at temperatures in excess of about 27°C. The small-seeded genotype grew most rapidly, and the large-seeded genotype slowest, but a general conclusion on the effect of seed size per se is not possible from this study.
4. On these data, we conclude that:
   a. Sowings should not be made at soil temperatures less than 19°C.
   b. Rapid, even germination and emergence is fostered by soil temperatures of 26-43°C, and particularly at 29-36°C.
   c. Selection for germinability at low and high soil temperatures, and for RHE at moderate to high soil temperatures, should be effective.

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Association of Maturity, Duration and Seed Size with Seedling Attributes in Pigeonpea

A.S. Tiwari and B.R. Singh*[4]

Abstract

Thirteen pigeonpea genotypes, including four standard checks of extra-early (Pant A-3), early (T-21), medium (No.148), and late (Gwalior-3) maturity groups were studied for their root and shoot characteristics in the seedling stage. These genotypes also differed in seed size and origin. The study was designed to assess seedling vigor in relation to seed size and duration of maturity. Highly significant differences were found among genotypes for root length, seedling height at which cotyledonary leaves and normal leaves occur, leaf length and width, and oven-dry weight of root and shoot. Genotypes belonging to the late-maturity group exhibited significantly higher rates of root and shoot growth under pot conditions. The implications of these findings are discussed in relation to the role of pigeonpea genotypes of varying maturity under mixed farming and rainfed conditions.

Pigeonpea (*Cajanus cajan* [L.] Millsp.) is predominantly a rainfed crop in India. Generally it is grown as a mixed crop with one or more crop species. Pigeonpea has a tremendous variation for maturity period (120 to 256 days) and seed size (4.6 to 15.1 g/100 seeds). Associations among yield components are well known in this pulse crop; however, associations of maturity period and seed size with seedling characters are not known. The present paper deals with such a study under rainfed conditions.

Materials and Methods

Thirteen pigeonpea cultivars, including four standard check varieties of extra-early (120 days), early (145 days), medium (185 days), and late (above 200 days) maturity were studied for ten seedling characters in pots and for three adult plant characters in field trials. Experiments in pots and field were planted on 4 July 1977 at Jabalpur. The observations in pots

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* Pulse and Oilseeds Project, Agricultural Research Institute, Gwalior, and Department of Plant Breeding and Genetics, JNKVV, Jabalpur, India, respectively.

were recorded on three randomly selected plants. In the field trial, there were four replications in a randomized block design. The plot consisted of two rows, 5 m long and 90 cm apart; intrarow spacing was 20 cm.

Results and Discussion

Germination and Cotyledonary Leaf Characters

Data on mean, range, and LSD of germination and cotyledon characters are presented in Table 1. Germination varied from 75.0 to 95.0% (mean 83.3%). Gwalior-3 (100-seed weight 7.0 g) showed highest germination. There was a fair positive association between heights at which cotyledonary leaves appeared and that at which true leaves appeared. The first true leaf appeared at the lowest height in JNAL-516, a cultivar with 100-seed weight 7.2 g and maturity duration of 242 days, and at the highest in Sehore-11, with 100-seed weight of 15.1 g but maturity duration similar to JNAL-516. However, no definite trend of relationship of this character emerged with either seed size or maturity duration.

Seedling Characteristics

The mean, range, and LSD of six seedling characters are given in Table 2. Cultivars differed significantly for these traits. Considerable variation was recorded for all the seedling characteristics and also for rate of growth of root and shoot during the first and second 10-day-periods. Tallest seedlings were produced by Sehore-11, the cultivar with boldest seed. Dry weight of shoot was maximum in Sehore-11 and Gadarwara local cultivars respectively on the tenth and 20th days after sowing, respectively. Root length was also maximum in Sehore-11. However, dry weight of root was maximum in the Gadarwara local (100-seed wt 13.4 g, 252 days' maturity). Fastest rate of root growth, in terms of length, between the tenth and 20th days after sowing was recorded by JNAL-445, a cultivar conventionally grown on paddy bunds, and shoot growth was fastest in Sehore-11. Early and medium-duration cvs Pant A-3, T-21, and No.148 showed a fairly high rate of shoot growth. Rate of root growth, however, was slower in these cultivars, particularly in T-21.

Correlation coefficients were also computed among the above seven characteristics and are presented in Table 3. Seed size was positively and highly significantly associated with five seedling characteristics, particularly with length and width of true leaf and dry weight of root and shoot. Maturity period also had appreciable positive association with root length, dry weight of root and shoot, and leaf length. Maturity duration had a weak and nonsignificant positive association with seed size. Seedling characters were closely associated with each other.

The present study indicates that late-maturing and bold-seeded cultivars are faster in root and shoot growth in the first 20-day period and consequently produce more dry matter. Germinability was best in

Table 1. Germination, development, and yield characteristics of 13 pigeonpea cultivars.

Cultivar	Origin	Germination (%) after 96 hrs.	Height at which cotyledonary leaves appear (cm)	Cotyledonary leaf at 10 days		Height (cm) at which normal leaf appears (20 days)	Maturity (days)	Yield (kg/ha)	100-seed wt (g)
				Length (cm)	Width (cm)				
JNAL-543	Narsinghpur	85.0	6.2	5.9	1.6	8.9	251	600	5.4
Gadarwara Local		82.2	7.6	7.3	2.2	12.7	252	498	13.4
JNAL-538	Satna	85.0	7.1	5.8	1.6	10.3	242	662	4.6
JNAL-320	Sehore	77.5	6.7	6.0	1.6	9.5	240	603	4.9
JNAL-326		67.5	6.6	7.5	2.2	10.4	242	138	13.8
JNAL-156	Hosangabad	76.0	6.6	6.6	2.1	10.5	256	689	15.1
JNAL-516		83.5	6.4	6.5	1.5	8.8	242	724	7.2
JNAL-445	Balaghat	92.5	7.7	6.5	2.0	12.6	200	361	7.9
Sehore-11	Sehore	87.5	7.7	7.6	2.4	14.8	242	656	15.1
Gwalior-3	Madhya Pradesh	95.0	8.6	6.8	2.1	14.2	243	647	7.0
No.148	Maharashtra	87.5	7.3	7.2	1.9	12.5	185	322	10.1
T-21	Uttar Pradesh	80.0	7.5	6.2	1.5	12.0	145	238	7.2
Pant A-3	Pantnagar	85.0	7.2	6.1	1.8	11.6	120	200	7.9
Mean		83.3	7.2	6.6	1.9	11.4	220	448	9.2
Range		75.0-95.0	6.2-8.6	5.8-7.6	1.5-2.4	8.8-14.8	120-256	138-724	4.6-15.1
SE ±			0.2	0.1	0.1	0.3	3.8	43	2.4

Table 2. Seedling characteristics of 13 pigeonpea cultivars.

Cultivar	Height(cm)		Root length(cm)		Normal leaf at 20 days		Dry wt of shoot (mg)		Dry wt of root(mg)	
	10 days	20 days	10 days	20 days	Length (cm)	Width (cm)	10 days	20 days	10 days	20 days
JNAL-543	7.6	12.6	12.6	14.2	4.2	1.3	145.8	350.5	28.8	101.5
Gadarwara Local	11.3	19.5	13.7	15.8	6.0	2.1	227.8	912.3	87.3	307.3
JNAL-538	8.8	14.1	13.4	14.7	4.6	1.4	97.3	358.0	30.0	101.5
JNAL-320	9.2	13.2	13.3	14.7	4.5	1.4	114.5	361.5	30.3	122.5
JNAL-326	10.2	15.5	14.0	17.5	6.2	2.3	293.0	702.8	70.0	268.3
JNAL-156	10.7	16.3	12.8	15.2	5.8	2.0	131.5	740.5	63.0	212.8
JNAL-516	7.8	11.5	13.2	13.2	4.4	1.6	109.3	415.5	32.8	167.0
JNAL-445	9.8	11.4	9.4	16.4	5.3	2.0	197.5	612.8	67.3	204.8
Sehore-11	13.2	22.1	16.6	22.2	6.1	2.2	305.8	815.3	55.5	243.0
Gwalior-3	11.8	19.0	15.3	15.8	4.9	1.7	293.3	479.3	54.0	144.8
No.148	10.4	18.8	11.9	15.0	5.5	1.8	222.8	702.0	56.0	206.3
T-21	10.1	18.2	13.3	13.7	5.0	1.8	187.8	452.3	34.8	111.0
Pant A-3	9.7	15.6	7.1	10.4	4.2	1.4	167.3	312.0	24.5	94.5
Mean	10.1	16.4	12.8	15.3	5.1	1.8	183.8	555.0	48.8	175.8
Range	7.6-13.1	12.6-22.1	7.1-16.6	10.4-22.2	4.2-6.2	1.3-2.3	97.3-305.8	312.0-912.3	24.5-87.3	94.5-307.3
SE ±	0.2	0.2	0.4	0.1	0.1	0.05	9.7	24.5	3.0	9.4
LSD(5%)	0.7	0.5	1.1	1.3	0.4	0.14	28.0	70.7	8.5	27.2

Table 3. Correlation coefficients between maturity, seed size, and some seedling traits at 20 days in pigeonpea.

Seedling trait	Root Length	Normal leaf length	Normal leaf width	Dry weight of shoot	Dry weight of root	100 seed weight	Maturity
Seedling height	0.595	0.681**	0.653**	0.695**	0.515**	0.580**	-0.146
Root length		0.733**	0.698**	0.669**	0.623**	0.582**	0.502**
Normal leaf length			0.956**	0.947**	0.903**	0.894**	0.280*
Normal leaf width				0.893**	0.890**	0.864**	0.189
Shoot dry wt					0.947**	0.891**	0.312**
Root dry wt						0.845**	0.389*
100-seed wt							0.221

* Significant at 5% level; ** Significant at 1% level.

Gwalior-3 (late-maturing, medium seed size) and fastest rate of root growth was shown by JNAL-445 (late-maturity, medium seed size). Cultivars maturing in more than 200 days in general gave significantly higher grain yields. For intercropping and mixed cropping under rainfed conditions, it appears that late-maturing cultivars are preferable since these produce longer roots and therefore may not compete with companion crop species for underground water and nutrients during the early growth period.

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Asymmetry and Yield in Pigeonpea
Cajanus cajan (L.) Milisp.

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Abstract

Asymmetry in plants, wherein a plant or its organs are described as left- or right-handed, based on the direction of the spiraling or overlapping of plant parts, has been recognized for over 70 years. Davis(1972), studying this phenomenon in COCOS nucifera and several malvaceous species, found a correlation between asymmetry and yield; a right-spiraled palm gave 20% more copra than left-spiraled ones. Bible (1976) also found similar results in tomato and pepper. In the present investigation on 15 cultivars of pigeonpea, plants developed from right-handed seedlings were found to be metabolically superior, with higher fruit/seed yield, nodule index, and harvest index. Since the inheritance pattern of asymmetry in plants is found to be non-Mendelian, different workers on this subject have expressed different views regarding the causal aspects of handedness.

The present investigations have been carried out to explore the relationship between handedness and yield in light of morphological and physiological differences in plants developing from left- and right-handed seedlings.

Asymmetry, or left- and right-handedness, in plants and plant organs has been investigated by a number of workers. Compton (1910) first reported seedling handedness in cereals and millets. However, similar handedness in pigeonpea (*Cajanus cajan*) was discovered only recently by Rao and Bahadur(1980). In continuation of our work, we report the effect of handedness on yield in pigeonpea, a common pulse crop of the semi-arid tropics.

Materials and Methods

Seed material of 15 cultivars of *c.cajan* obtained from ICRISAT was used in the present study.

Left and right-handed seedlings were scored following the procedure of Rao and Bahadur (1980). If the overlapping of the seedling leaves

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faces towards the left, it is left-handed and conversly if it faces towards the right it is right-handed. The former is the clock-wise direction and the latter is counter-clockwise. Mature plants developing from left- and right-handed seedlings were used for further investigations of morphological, physiological, and yield parameters.

Primary root length and nodule number were recorded at the appropriate time, and nodule index was calculated following Rangaswami and Chakraborty (1966).

Chlorophyll contents of seedlings and mature leaves of left- and right-handed plants of the same age and position were estimated by spectrocalorimetric and spectrophotometric methods, following Witham et al. (1971) and Mackinney (1941), respectively. Stomatal index and size in seedling and mature leaves of left- and right-handed plants of the same age and position were studied, following Cutter (1969).

The usual yield attributes have also been recorded and analyzed for different cultivars.

Results and Discussion

Seedlings of 15 cultivars of *c.cajan* (total 5057 seedlings) were examined; 2645 (52.34%) of these were right-handed and 2380 (47.06%) left-handed; the rest were neutral seedlings (0.6%). In some cultivars, there was appreciable difference in the number of left- and right-handed seedlings while in others the numbers were similar. This observation is in conformity with the law of occurrence of bioenantiomorphs (Dubrov 1978). Rao(1980) reported an excess of right-handed seedlings in a number of species of *phaseoius* and *vigna.* An examination of the root system showed a profusely branched and longer root system in the..right-handed plants than in the left-handed ones,which had a shorter and less branched root system. Data on nodule indices (NI=Number of nodules/root length) of two cultivars (Table 1) show higher nodule index in right-handed plants but the excess is not significant unlike the one noted by Rao (1980) in left-handed plants of *Vigna radiata, V.mungo,* and *Phaseoius vulgaris.* It was observed that the root nodules of right-handed plants occur in clusters; such clustering was of lower order in left-handed plants.

As Table 2 shows, right-handed plants had more chlorophyll (a, b, and total) than left-handed plants. Chlorophyll quantity of both seedlings and mature plants was also studied under a spectrophotometer and it was found that the chlorophyll of both types of seedlings showed peaks at 640 nm in the visible light spectrum. The transmittance percentage was higher in the right-handed seedlings than in the left-handed ones, indicating thus a significant excess of chlorophyll in the former. In mature leaves also higher peaks were observed in right- than in left-handed plants. Bahadur et al. (1978) in coconut *(cocos nucifera)* noted that the higher yield in right-handed plants of the species obtained by Davis (1972) may be explained as due to the greater amount of chlorophyll in these plants besides other morphological and physiological attributes. They substantiated their findings by studying the absorption spectra of

Table 1. Comparison of nodule indices in left- and right-handed pigeonpea cultivars.[a]

Cultivar	Left-handed	Right-handed
HY-2	8.48	9.01
7406	8.49	9.09

a. Mean of 25 readings.

Table 2. Comparison of chlorophyll content in left- and right-handed pigeonpea cultivars (mg/g tissue).

Cultivar	Left-handed			Right-handed		
	Chlorophyll a	Chlorophyll b	Total Chlorophyll	Chlorophyll a	Chloro phyll b	Total Chlorophyll
HY-2	0.189	0.134	0.320	0.192	0.152	0.352
7406	0.172	0.139	0.310	0.189	0.140	0.326
6972	0.171	0.128	0.297	0.201	0.138	0.336
6930	0.162	0.125	0.286	0.182	0.132	0.313
7220	0.159	0.139	0.289	0.192	0.134	0.324

chlorophylls, and concluded that the right-handed coconut plants are indeed physiologically superior and hence contribute to the higher photosynthetic activity and better utilization of solar energy (unpublished). Rao (1980), however, working with different *Phaseolus* and *vigna* species, showed higher yields from left-handed plants, due to greater quantity and perhaps better quality of chlorophyll. This may also hold true for the cultivars of *c.cajan* we studied. NMR (Nuclear Magnetic Resonance) data on chlorophylls of left- and right-handed seedlings and plants may provide a clue.

Data on stomatal indices (No. of stomata/no. of stomata + no. of epidermal cells), stomatal and pore size of seedling and mature leaves of left- and right-handed plants of *c.cajan* cultivars is given in Table 3. In cv 7406, the left-handed seedling leaves show a higher stomatal index than the right-handed seedling leaves. In the mature leaves developing from such seedlings the reverse holds true. Further, in right-handed seedling and mature leaves, the pore size was comparatively bigger than

Table 3. Comparison of stomatal index, stomatal size, and pore size (m) in left- and right-handed pigeonpea cv 7406.

	Seedling leaves		Mature leaves	
	Left-handed	Right-handed	Left-handed	Right-handed
Stomatal index	29.24	27.08	29.94	32.75
Stomatal size	27.2 x 17.6	33.6 x 24.0	22.4 x 16.0	28.0 x 18.4
Pore size	18.4 x 6.8	24.8 x 6.8	14.4 x 4.0	18.4 x 4.0

in left-handed ones. In addition, differences in the size of epidermal cells are also obvious. Hence it may be said that right-handed seedlings and mature leaves in general show characters superior to those of left-handed ones.

Rao(1980) reported that the left-handed plants showed higher stomatal indexes and bigger stomatal size in different species of *vigna* and *phaseolus* and concluded that the higher yield in left-handed plants is perhaps dependent on these characters.

Yield Attributes

Total Pod Yield

Data in Table 4 show that mean number of pods per plant varies from 37.8 to 266.9 in the left-handed plants, while in the right-handed ones this varies from 48.3 to 314.7. The mean number of pods per plant in each cultivar was compared between the left- and right-handed plants by applying the 't' test. Cultivars 7118, 7086, and 7220 showed significantly higher number of pods per plant in the right-handed than in the left-handed plants ($P<0.05$). In a few cultivars (e.g. 6972), however, left-handed plants showed a higher number of pods per plant than the right-handed ones but the differences are statistically not significant.

Pod Weight

Table 5 shows the mean weight of pods produced; this varies from 22.1 g to 60.9 g in the left-handed ones; from 41.7 g to 79.6 g in the right-handed ones. In each of the cultivars, the mean pod weight per plant was compared among the left- and right-handed plants. Cultivars 7117, and 7086 showed highly significant excess of pod weight in right-handed

Table 4. Comparison of mean number of pods per plant in left- and right-handed pigeonpea cultivars.

Cultivar	Left-handed			Right-handed			't' value	P value
	Mean	SD	CV (%)	Mean	SD	CV (%)		
HY-2	266.9	112.7	42.2	314.7	136.3	43.3	1.4555	>0.05
7406	227.3	115.9	51.0	259.2	155.0	59.8	0.8911	>0.05
6915	37.8	21.1	55.9	48.3	27.9	57.9	1.6121	>0.05
6972	137.0	60.3	51.6	126.2	53.1	42.1	0.6161	>0.05
7118	109.5	44.9	41.0	262.3	148.5	56.6	5.3003	**<0.01
6930	104.4	83.3	79.7	126.7	75.9	59.9	1.0657	>0.05
7220	115.0	93.3	81.1	167.3	83.3	49.8	2.2504	*<0.05
7086	111.0	62.4	56.2	166.8	81.3	48.7	2.4300	**<0.01

* Significant at 5% level; ** Significant at 1% level.

Table 5. Comparison of mean weight (g) of pods in left- and right-handed pigeonpea cultivars.

Cultivar	Left-handed			Riqht-handed			't' value	P value
	Mean	SD	CV	Mean	SD	CV		
7406	54.0	29.6	54.8	64.3	38.1	59.2	1.1442	>0.05
7182	60.9	36.5	59.8	66.6	36.7	55.2	0.3989	>0.05
7086	22.1	19.2	86.8	41.7	29.9	71.7	2.9685	**<0.01
7117	36.9	26.9	73.0	52.4	34.5	65.9	1.8890	>0.05
2628	48.3	44.6	92.2	79.6	48.6	61.0	2.5561	*<0.05
7118	25.9	17.2	44.8	57.6	37.1	64.5	5.9345	**<0.01

* Significant at 5% level; ** Significant at 1% level.

plants compared with left-handed ones. While in cv 2628, the right-handed plants had only a significant higher pod weight. The remaining cultivars did not show any statistically significant differences. Although the number of pods showed statistically significant differences in the left- and right-handed plants, the pod weight did not show similar significant differences in the same cultivars.

Seed Weight

The mean seed weight varies from 9.1 to 29.8 g in left-handed plants and 9.8 to 39.8 g in right-handed plants in different cultivars (Table 6.) In each cultivar the mean seed weight was compared; cvs 7118, 7220, and 7086

Table 6. Comparison of mean weight(g) of seeds of left- and right-handed pigeonpea cultivars

Cultivar	Left-handed			Right-handed			't' value	P value
	Mean	SD	CV	Mean	SD	CV		
7118	9.6	4.9	50.5	39.8	25.9	65.2	6.1572	**0.01
7220	9.1	6.8	75.4	17.6	9.3	52.7	3.9713	**0.01
7086	21.1	12.4	58.9	34.3	16.8	52.0	3.2738	**0.01
7065	18.2	13.3	72.8	9.8	9.2	93.7	2.8249	**0.01
7117	26.1	20.9	80.1	20.5	16.6	80.8	1.1169	0.05
6930	29.8	27.9	93.8	34.1	20.8	61.0	0.1632	0.05

* Significant at 5% level; ** Significant at 1% level.

showed highly significant differences in seed weight between left- and right-handed plants, the right-handed being higher than the left-handed. In cv 7065, however, left-handed plants showed a highly significant greater seed weight than the right-handed plants. Even though in cv 7117 the mean number of pods per plant was found to be significantly higher in left-handed than in the right-handed plants, the pod weight and seed weight did not show any difference. Similarly in cv 6930, the number of pods and pod weight per plant was significantly higher in right-handed ones but the seed weight did not show any significant difference. Rao (1980), however, noted that in the majority of the cultivars of *phaseoius* and *vigna,* the left-handed plants gave higher fruit number associated with seed weight.

Davis (1972) earlier showed that right-handed plants of *cocos nucifera* on an average produced more Copra than the left-handed plants. Bible(1976) found that right-handed plants of tomato and pepper gave nearly 20% more fruits than left-handed plants. Similarly, right-handed plants of the cultivars of *c.cajan* give higher yield and this may be due to combination of many morphological and physiological characters.

Conclusions

Our study indicates that left- and right-handed seedlings and the plants developing from them show differences in a number of morphological, physiological, and yield attributes.

It is interesting that although seedling handedness does not obey Mendelian inheritance (Compton 1910; Davis 1972; Rao 1980) such an important attribute as yield appears to depend, astonishingly, on handedness.

Kundu (1968) reported the dependence of fruit yield on the foliar arrangement, right-handed plants giving higher yields. She noted higher yield of fruits and seeds in normally right-handed *vigna sinensis* and *Dioscorea escuienta* by forcing the vines to grow vertically or by twisting them in the reverse direction. According to Vol'kenshetein (1970) the asymmetry of the biological molecules gives rise to more specific reactions, namely an asymmetric molecule interacts differently with left and right objects. Further, Lehmann (1978) states that the D-forms of thyroxine display considerable activity but less than the L-forms. Dubrov (1978) states that the rates of germination and growth were greatest when the seeds were oriented in the direction of the earth's south magnetic pole. Furthermore, geomagnetic orientation of disymmetric objects affects not only the growth but also very diverse functional and biochemical characteristics, which ultimately is reflected quantitatively in crop yield. Kihara (1972, p.136) opines that the use of R/L characters will enable us to achieve clear theoretical and practical results and consequently fuller understanding of the vital processes, stating, "As there is possible relationship between foliar arrangement and yield of crop plants, it is necessary to examine the differences between R and L strains in their utilization of solar energy." In the light of present findings on differences in chlorophyll content, stomatal index, and size of L and R plants in *c.cajan* and in *Cocos nucifera,* Kihara's(1972) prediction that the L and R strains differ in their utilization of solar energy is confirmed. Kundu and Sarma (1965) first tried to establish the superiority of right-handed plants in jute but failed to establish this character. Similarly, seedling handedness in *c.cajan* could not be established although experiments were conducted for a period of 3 years. It is relevant to remark that the inherent superiority of right-handed plants of *c.cajan* cannot be exploited until this character in the species gets fixed. If this can be done, it may supplement mutation breeding in making an agricultural advance.

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Growth, Development and Yield Physiology of Pigeonpea

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Abstract

Field experiments to study the physiological aspects of growth, development, and seed yield of pigeonpea showed that peak crop growth occurred between the onset of flowering and early pod formation, when canopy was fully developed and captured solar radiation efficiently. Total dry-matter production in early genotypes ranged from 7.7 to 12.1 tonnes/ha; 47 to 77% of this was produced after onset of flowering. Removal of 33 or 66% of leaf area linearly decreased seed yield, and shading of plants also decreased yield. The regulatory control of flower and pod drop was studied through manipulation of source and sink size. Removal of flowers up to 80% enhanced flower production but did not affect seed yield. Removal of leaves decreased the total flower production and flower drop. The retention and transformation of flowers into pods is predominantly determined by availability of assimilates. The implications of these findings for crop evolution and varietal development are discussed.

Pigeonpea is the second most important grain legume of India, which accounts for 90% of world production of this crop. It is mostly grown in intercropping systems in the semi-arid tropics and forms an important component of the vegetarian diet. Physiological studies on pigeonpea have been started only recently at several places and the information available on this crop is therefore limited. The purpose of this paper is to report the physiological research on growth processes, flower and pod set, partitioning of assimilate, and physiology of yield carried out at the G.B. Pant University of Agriculture and Technology, Pantnagar.

Growth Analysis and Seed Yield

Four genotypes of the early-maturing group were grown in a randomized block design with four replications. The crop was planted in 10-row plots, 6 m long, with row spacing of 50 cm and plant spacing of 20 cm.

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Five plants were sampled from randomly allotted sections of inner rows at different intervals for growth analysis. The weight of the fallen materials was included in the total plant components.

Root Growth, Leaf Area Index and Dry Matter Production

The first 30 cm of pigeonpea roots were dug out and were accounted for in total dry matter production. Since pigeonpea roots may go as deep as 130 cm under Pantnagar conditions, the recovered roots represented only a part of the total root system and calculations may involve some error. The root dry weight increased up to harvest. Most of the nodules were found to be confined to the first 30 cm depth. Sheldrake and Narayanan (1979) reported that under Hyderabad conditions, roots extended beyond 150 cm and that root growth continued during the reproductive phase.

The leaf area development in pigeonpea remains slow during the early vegetative growth stage (upto 60 days after sowing) and increases sharply with advancement of crop age. The maximum LAI, ranging between 4 and 6, was attained just after flowering. Leaf senescence is enhanced with progressive delay after flowering. The total leaf fall may be as high as 1.8 to 2.1 tonne/ha and may contain 24 to 30 kg N/ha. During the reproductive phase, the rate of leaf fall exceeds the rate at which new leaves are produced, and the LAI declines sharply.

Development of leaf area and addition of dry matter continued even after flowering in all the cultivars. The total dry-matter production among genotypes ranged from 7.7 to 12.1 tonne/ha. A large portion of dry matter (46-77%) was produced after the onset of flowering in all genotypes. The stems increased in weight substantially during the first half of the reproductive phase. At maturity, there was a decline in the stem weight due to remobilization of a part of stored assimilate.

The crop growth rate (CGR) in all genotypes was low during the first 2 months or so and increased with advancement of crop age, reaching a maximum value (15-20g $m^{-2}day^{-1}$) at pod-filling stage in all genotypes. The crop growth rate declined during late pod-filling stage. The initial low crop growth rate is a disadvantage in sole-crop systems, as the crop may not be able to compete with fast-growing weeds. In mixed cropping, when pigeonpea is grown in association with early-maturing mung *(vigna radiatalt* urd (*vigna mungo)*, or cereals, slow growth may not be a disadvantage, as the pigeonpea is able to grow rapidly after the companion crop is harvested. In appropriate combinations, seed yield may be almost as high as pure-crop yield, resulting in extra economic gain.

These results suggest that for sole cropping, the pigeonpea breeder should select lines with high CGR in the early period, and for mixed cropping, lines with high CGR in later growth periods.

Partitioning of Dry Matter into Seed Yield

The analysis of dry-matter partitioning into plant components at maturity revealed that stems accumulated the largest amount of dry matter produced, followed by pods and leaves. The degree of partitioning into pods ranged from 20 to 25%. It is interesting to note that after flowering, stems accumulated almost the same amount as or more dry matter than pods. The dominance of stem growth led to reduced supply of photoassinrilate to pod setting and ultimately to seed production. Although such indeterminate characteristics are common in many grain legumes, degree of assimilate diversion towards stem growth in pigeonpea is much larger and results in greater competition with pod setting. This appears to be due to the perennial nature of pigeonpea.

14 CO_2 Assimilation and Distribution

Plants of cv Pant A-1 were grown in pots in a glasshouse. Plants were watered well before 14_C assimilation at each stage. The whole plant was supplied $^{14}CO_2$ liberated from 300 uci $Na_2\backslash^{14}CO_3$ (sp. act. μCi/m mole) by addition of 1N lactic acid from 1100 to 1130 firs, in bright sunshine. $^{14}CO_2$ was circulated uniformly in the assimilation chamber by an electric fan placed inside the chamber. The fallen leaves, flowers, and pods were collected and added to individual plant component weight. Four plants were harvested at different intervals and separated into plant parts and oven-dried at 70°C for 48 hrs. The dry weight was recorded, and samples were ground through 40 mesh screen in an electric grinder. A sample of 20 mg of each plant part in replicates was macerated in 0.5 ml methyl alcohol, dried and counted by proportional counter (Ong and Marshall 1975). The percent distribution of total recovered 14_C was computed.

When plants were allowed to assimilate $^{14}CO_2$ at 40 days after sowing, only 8% of total recovered ^{14}C at maturity was found to be in pods and the rest was utilized in the vegetative structure (stem, leaves, and roots). Similarly, plants allowed to assimilate $^{14}CO_2$ at flowering stage, could transfer only 20.5% of total recovered carbon at maturity towards pod growth and the remainder was utilized in the stem, leaf, and root growth. At initial pod formation, the highest amount of recovered ^{14}C at maturity was in pods, followed by stem, leaves, and roots. Similarly at mid-pod-filling stage, pods showed the highest recovery of assimilate. Cheema and Pandey (1980) observed an increased demand for ^{14}C in stem growth during the early reproductive phase. The loss of ^{14}C through respiration ranged from 30 to 40% at different stages of assimilation. The se values are similar to those reported by Hume and Criswell (1973) in soybean. These results show that as crop age advanced after flowering, pods accumulated a larger portion of assimilate, followed by stem, leaves, and roots; it is interesting to note, however, that stems accumulated a larger portion during the early reproductive phase. This pattern is similar to that observed in growth analysis.

Sources of Photosynthate to Developing Pods

The relationship of different leaf positions seed yield was investigated by defoliation at 50% flowering stage: (1) basal leaves (all leaves below the first flowering node on main stem and branches) were removed;

(2) floral leaves (all leaves at flowering nodes) were removed; (3) all leaves on the plant were removed. Treatments were repeated at 7-day intervals when new leaves appeared.

Table 1. Influence of sources of photosynthate on seed yield as shown by defoliation.

Treatment	Pods/ plant	Seeds/ pod	100-seed wt (g)	Seed yield (g/plant)
Control	128	3.2	7.6	23.9
Basal leaves removed	118	3.1	7.7	22.6
Floral leaves removed	48	2.9	6.1	6.3
All leaves removed	7	2.0	6.4	1.2
S.Em ±	8.7	0.04	0.28	0.70
C.D. 5%	26.4	0.12	0.83	2.15

It is evident from Table 1 that removal of floral leaves significantly reduced seed yield. Basal leaves on branches and main stem do not contribute substantially towards pod development, except by maintaining growth of root, nodules, and stem. In the absence of floral leaves, lower leaves may divert some assimilate towards pod growth and in such a situation, developing seeds may also largely depend on pod-wall or stem photosynthesis or on stem reserves. This is the reason why some yield is obtained when floral leaves are removed from plant. Complete defoliation proved *very* detrimental to seed yield. These data suggest that axillary leaves are the primary source of assimilate for pod growth; therefore, the size and efficiency of these leaves deserves consideration in crop improvement.

Effect of Source and Sink Size on Flower Production, Flower Drop, and Seed Yield

The effect of leaf and flower removal on flower production, flower drop, and seed yield was investigated under field conditions. One-third and two-thirds of the leaves were removed when 50% plants had a flower, and the treatment repeated at weekly intervals when new leaves appeared. Flower removal was done at 3-day intervals from anthesis till maturity; 40 and 80% of total newly opened flowers on an inflorescence was removed in such a manner that sink load was uniformly distributed. Flowers and pods were collected on a cloth sheet surrounding the plants and supported on wooden legs. The plants in the vicnity were removed to avoid contamination. The total flowers (dropped on cloth and manually removed) were counted, and the percent flower drop computed against total flowers and pods.

The reduction of photosynthetic area by one-third or two-thirds severely reduced flower production, but the percent flower drop remained unaffected. The seed yield and pods per plant were reduced considerably. The removal of flowers enhanced flower production and reduced percent flower drop, but did not affect seed yield. Shekdrake and Narayanan(1979) have also reported increased flower production with flower removal. It appears that flower production is regulated by the capacity of the plant to supply photosynthate and by the intrinsic characteristics of the plant. The increased production of flowers acts as an insurance against adverse climatic and biotic factors.

Table 2. Effect of source and sink size on pigeonpea flower drop under field conditions.

Treatment	Total flower produc-tion/ plant	Flower drop (%)	Pod drop	Total drop (%)	Pods/ plant	Seeds/ pod	100-seed wt	Seed wt/ plant (g)
Control	633	81.1	4.3	85.4	97	3.3	7.4	22.5
1/3 leaf removal	472	83.5	5.3	88.8	59	3.2	7.6	16.7
2/3 leaf removal	360	85.0	5.4	90.4	35	3.2	7.4	10.1
40% flower removal	750	75.8*	4.4	80.2	99	3.3	7.3	20.3
80% flower removal	881	64.1*	2.5	66.6	98	3.2	6.7	19.8
SE ±	50	-	-	3.9	4.1	0.1	0.4	1.7
LSD (5%)	91	-	-	10.9	12.6	-	-	5.3

* Flowers removed by hand were not taken into account in computation of flower drop.

Effect of Shading

Shading studies were carried out to determine the effect on seed yield of varying degrees of shade during the reproductive period. Shading was provided by using cloth of differing guages which permitted light transmission of 65 and 40%.

The seed yield declined significantly with both the shading treatments, Thus even a 35% reduction in photosynthetic active radiation resulted in decrease in photosynthetic rate, reducing the assimilate supply to pods

Table 3. Effect of shading at reproductive stage on pigeonpea seed yield.

Solar radiation (%)	Pods/plant		Seeds/pod		100-grain wt(g)		Grain yield	
	1976	1977	1976	1977	1976	1977	1976	1977
	Pant A-1	UPAS-120	Pant A-1	UPAS-120	Pant A-1	UPAS-120	Pant A-l	UPAS-120
Full sunlight(100%)	114	132	2.8	3.4	5.1	7.5	17.3	39.4
65% of solar radiation	67	94	2.5	3.4	6.0	6.7	10.3	27.1
40% of solar radiation	47	52	2.4	3.4	5.9	5.9	6.7	13.3
SE ±	4.5	14	0.13	0.16	0.3	0.66	1.17	3.6
LSD (5%)	13.2	43	-		-	2.29	3.47	11.4

and leading to a drastic reduction in pods per plant and in total seed yield. However, shading did not significantly affect number of seeds per pod, and 100-seed weight was reduced only in 1977. Light thus could be a limiting factor in pigeonpea yields when skies are cloudy or overcast and the leaf area index of the crop is high.

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Performance of Pigeonpea in the Post-rainy Season

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Abstract

The major food crops of Andhra Pradesh are rice, sorghum, pearl millet, maize, and pulses. Rice is grown in the rainy season and in the postrainy season where irrigation is available. Where it is not, pigeonpea can be grown without irrigation and with a minimum of fertilizer and cultural operations. Of 13 crops planted following cereals to grow on residual moisture, pigeonpea yielded the highest (2500 kg/ha) in experiments. Medium or long-duration types fared better in Hyderabad than early ones.

Pigeonpea was also tested as a postrainy crop after kharif fallow and gave an average yield of 1000 kg/ha. Fodder yields from the ratooned crop ranged from 7800 to 12 800 kg/ha; however, all three cultivars tested were severely infected by sterility mosaic disease and gave no second grain harvest. SM-resistant cultivars are needed for this cropping system.

Pigeonpea (*Cajanus cajan* [L.] Millsp.) is generally grown during the kharif (rainy) season in India, either as a sole crop or as an intercrop with cereals like sorghum (Mahta and Dave 1931; Pathak 1970). The possibility of growing pigeonpea as a postrainy winter (rabi) crop in peninsular India has been stressed by Narayanan and Sheldrake (1979) and Narayanan and Murthy (1980). The optimum plant population for the rabi crop is three to four times higher than that normally used in kharif, because of the influence of low temperature and short photoperiod. However, the temperatures during the rabi season in peninsular India are relatively high, favoring the growth and development of pigeonpea. The influence of daylength varies with the genotype; thus it is possible to select genotypes for a better performance.

There are three possible ways in which pigeonpea can be fitted into the existing cropping system.

1. Sorghum, pearl millet, and maize planted in Vertisols during the rainy period (in June or July) are harvested in the beginning of

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October in many parts of Andhra Pradesh. Pigeonpea can be one of the alternate crops grown in the rabi (post-rainy) season to utilize the residual soil moisture and nutrients.

2. Rice is one of the major food crops of Andhra Pradesh and is grown both in the rainy and postrainy seasons. But if the irrigation is limited during the postrainy period, it is not possible to grow rice. Under such conditions, pigeonpea can be grown without irrigation and with minimum fertilizer and cultural operations.

3. In some of the Vertisol areas of Andhra Pradesh, only postrainy cropping is done, keeping the land fallow during the rainy season. It is possible to introduce pigeonpea as a postrainy crop either at the end of September or beginning of October, depending on the rainfall. When the grain is harvested in March, the crop can be ratooned at a proper height so as to leave the maximum number of branches. Thus the established crop continues to grow during the summer months because of its deep root system which enables moisture to be extracted from the deep soil layers for the maintenance of crop growth. Premonsoon showers generally received in June induce profuse vegetative growth. The foliage may be harvested as fodder and the crop allowed to reproduce so that a harvest of grain is possible in November or December. Under favorable conditions it is possible to take a further ratoon crop.

Pigeonpea as a Rabi Crop in Deep Vertisols

Relative Performance

In experiments conducted at Hyderabad, the performance of various winter crops like cowpea, mung bean, urd bean, and safflower was assessed and compared with pigeonpea during 1977-78. These crops were planted in a deep Vertisol, after harvest of the monsoon crop of sorghum, and grown with minimum tillage under residual soil moisture. The grain yield of pigeonpea was almost twice that of other crops (Narayanan and Murthy 1980). Therefore it may be concluded that pigeonpea appears to be more profitable than other rabi crops in deep Vertisols after a cereal crop.

Varietal Performance

Three cultivars of pigeonpea—T-21, C-11, and ICP-7065--of short, medium, and long duration in the normal monsoon season were sown in deep Vertisols at four locations in Andhra Pradesh during 1977-78. They were planted in a randomized block$_2$design with four replications; spacing was 40 x 10 cm and plot size 60 m^2. The date of planting varied from location to location (Table 1).

A basal dose of 50 kg P205/ha was given, but no nitrogenous fertilizers. No irrigation was applied through the entire crop growth period.

The grain yield obtained for the three cultivars at different locations are given in Table 2. The average grain yield for the three cultivars over locations indicates that cv C-11 gave the highest yield. Similarly high yield potential of cv C-11 was reported by Narayanan and Sheldrake (1979) at Hyderabad. In the same studies they report that the best yield potential seems to be in cultivars of medium or late maturity. However the response of cultivars varied considerably at various locations. The yield levels of cvs T-21 and ICP-7065 at Nandyal were at par and differed significantly from cv C-11. The late cv ICP-7065 gave the maximum yield at Tandur, whereas the early and medium cultivars showed no difference in yield. This may be attributed to environmental factors, particularly the distribution of rainfall. Table 3 indicates that at Nandyal the rainfall in October and November contributed to the better yields of the early and medium cultivars, whereas moisture stress during the period December to March seems to have affected the grain yield of cv ICP-7065. The poor yield obtained at Rudrur is due to late planting (Table 2) and also to the lower rainfall during the growing season (Table 3). It may be noted that the yield obtained at Amaravathi was only from the second flush of reproductive growth. Yet the varietal differences were in favor of early and medium cultivars. Therefore, it seems likely that the cultivar response depends on the location, rainfall, and the time of planting.

Performance in Farmers' Fields

Based on trial results, two cultivars namely C-11 and BDN-1 were selected for planting at three locations in the farmers' fields. At Boravelly the planting was done on 10 September 1979, whereas at the other two locations it was done in the middle of October 1979. At Boravelly the monsoon crop raised was irrigated groundnut, which was harvested by the end of August; thus the field was free for planting pigeonpea. At other locations the fields were kept fallow during the monsoon season because of failure of monsoon during July-August. The data on grain yield of pigeonpea at these locations are given in Table 4. Cv BDN-1 yielded 1900 kg/ha whereas cv C-11 ranged between 1470 and 1750 kg/ha. It shows clearly that within the medium-duration group, yield potential varies when pigeonpeas are planted in the postrainy season.

Table 1. Planting dates of rabi pigeonpea at various locations in Andhra Pradesh, 1977.

Location	Date of planting
Amaravathi	6 October 1977
Tandur	15 October 1977
Nandyal	20 October 1977
Rudrur	11 November 1977

Table 2. Grain yield (kg/ha) of pigeonpea cultivars at different locations.

Location	Cultivar T-21	C-11	ICP-7065	Mean
Nandyal	792	989	713	831
Tandur	628	671	859	719
Rudrur	127	227	194	182
Amaravathi[a]	367	425	136	309
Mean	478	578	475	

CV (%) 21.0 LSD (5%) for interaction = 155
for locations = 89
for cultivars = 78

a. Due to cyclonic rains on 19 November 1977, all the flowers and pods were shed. The yields given are from the second flush.

Table 3. Mean monthly rainfall (mm) at different locations during rabi 1977-78.

Location	Rainfall (mm) Oct	Nov	Dec	Jan	Feb	Mar
Amaravathi	24.8	480.4	Nil	Nil	45.6	18.7
Rudrur	Nil	24.9	Nil	Nil	14.9	4.2
Nandyal	95.0	96.6	Nil	Nil	5.9	2.6

Table 4. Performance of pigeonpea cultivars in farmers' fields, 1979.

Location	Cultivar	Date of planting	Area sown (ha)	Yield (kg/ha)
Boravelly	c-n	10 September 1979	2.0	1500
Suryapet	C-11	16 October 1979	0.2	1750
	BDN-1	25 October 1979	0.3	1900
Nizamabad	C-11	21 October 1979	0.5	1470

Pigeonpea as a Rabi Crop in Rice Fallows

To determine the feasibility of growing pigeonpea in rice fallows, a preliminary experiment was carried out 'during rabi 1977 at the All India Coordinated Rice Improvement Project, Hyderabad. After the harvest of rice in the first week of October, pigeonpea cv C-11 was planted between the stubble rows without land preparation. The spacing adopted was 40 x 10 cm, which was equivalent to two rows of rice; total area was 54 m^2 Neither fertilizer nor irrigation was given. The grain yield obtained was 2388 kg/ha.

Encouraged by this preliminary experiment, we laid out a detailed trial in rice fallows at the experimental station at our University, to determine the best method of planting of pigeonpea and to investigate the effect of rhizobial inoculation and phosphorus application. The experiment was carried out in a split-plot design with four replications, on a plot size of 100 m^2. In one treatment pigeonpea was planted between rows of standing rice 15 days before the rice harvest. In another, the planting was done as soon as the rice was harvested. Seeds were treated with rhizobial culture and a soil application of 50 kg $P_2 05$/ha was given.

The grain yield obtained is given in Table 5. The earlier planting of pigeonpea in standing rice gave significantly higher yields than planting after rice harvest, because the growth and development of pigeonpea is affected by low temperature and short photoperiod. The yield was significantly high for rhizobial inoculation plus phosphorus application treatment. This indicates that under rice fallow conditions there is a need for phosphorus application, which in turn will help in the functioning of nodules. It is evident that the pigeonpea grown in rice fallows can tap the residual nutrients as well as soil moisture from the deeper layer of soil.

Table 5. Effect of planting time, rhizobial inoculation, and phosphorus application on grain yield of rabi pigeonpea, 1977-78.

	Yield (kg/ha)				
Planting date	Control	Rhizobial inoculation	50 kg P_2O_5/ha	Rhizobial inoculation + 50 kg P_2O_5/ha	Mean
In standing rice (13 October 1977)	1053	1084	1135	1166	1109
At rice harvest (28 October 1977)	887	939	982	1015	956
Mean	970	1011	1058	1090	

LSD (5%) for planting time = 70
for treatment = 99
for interaction = NS

Pigeonpea as a Rabi Crop in Kharif Fallow

Large areas of deep Vertisols in the western part of Andhra Pradesh are not cultivated during the monsoon *season.* The accumulated soil moisture is used for growing a rabi crop such as sorghum; this crop is harvested during the rabi season itself and the land remains fallow during the ensuing kharif. In order to use the land during this season, a system with pigeonpea as a rabi crop was tried at the Fruit Research Station, Sangareddy, using three cultivars, BDN-1, C-ll, and No. 148, planted on 14 October 1978. Plot size was 150 m^2, with five replications; spacing 40 x 10 cm. No nitrogenous fertilizer was used, but a basal dose of 50 kg P205/ha was applied. No irrigation was given; however, some winter showers were received. The crop was harvested on 2 March 1979; plants were ratooned, leaving the major portion for regeneration. Cv BDN-1 gave the highest yield of 1048 kg/ha, which was significantly higher than the other two cultivars (Table 6).

The ratoon crop continued to grow on residual soil moisture and summer showers. The plants produced good new vegetative growth because of the long-day conditions of the summer months. The foliage was then harvested by ratooning the crop in August 1979 (Table 7). Cv BDN-1 gave 4063 kg of foliage/ha, significantly higher than the other two cultivars.

Thus cv BDN-1 seems to be both a good grain yielder and a good foliage yielder under this system, and as already reported, cv BDN-1 also has a high degree of ratoonability compared with other cultivars (Narayanan 1979).

After harvesting of the foliage the crop was allowed to grow during the monsoon in order to obtain a second grain crop. All the three cultivars were badly infected by sterility mosaic virus and the crop did not grow further. These studies indicate clearly that the system of growing pigeonpea as a rabi crop in the kharif fallow to get both grain and forage yield is possible. It appears that two more additional grain crops could be harvested provided we have a cultivar that is resistant to sterility mosaic virus.

Table 6. Average yield of pigeonpea cultivars grown after kharif fallow at Sangareddy, 1978.

Cultivar	Grain yield (kg/ha)
BDN-1	1048
c-11	899
No. 148	813

LSD (5%) = 100
CV = 8%

Table 7. Forage yield of three pigeonpea cultivars.

Cultivars	Forage yield (kg/ha)
BDN-1	4063
C-11	2832
No.148	2451

LSD (5%) = 744.8
CV = 14.7%

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The Influence of Temperature and Photoperiod on Floral Development of Early Flowering Pigeonpea

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Abstract

Three early flowering lines of pigeonpea QPL2, QPL3 and Prabhat, were grown in controlled environment cabinets under 8, 16 and 24 hour photoperiods in combination with various day/night temperature regimes.

In all lines floral initiation occurred earliest under low temperatures (24/16°C) in a 16 hour photoperiod for QPL2 and QPL3 and either a 16 or 24 hour photoperiod in Prabhat. Reduction in daylength to 8 hours or increase in temperature both resulted in delays in floral initiation in all lines.

In all lines, the rate of development of the floral primordia increased with increase in both daylength and temperature.

In the evaluation of a range of *cajanus cajan* accessions in Australia, a short-statured, early-flowering plant was isolated from an Indian accession, ICP-7179, introduced from ICRISAT (Wallis et al. 1979). In the field, progeny of this plant flowered in approximately 55 days over a range of sowing dates from October to March. Flowering of late April and May sowings took 60 to 70 days. This delay appeared to be due to slower floral bud development (Turnbull, unpublished data). The response may have been due to either declining daylength or temperature, but it was not possible to separate these effects in the field. Determination of daylength sensitivity from flowering response to field sowing dates also assumes that both floral initiation and floral bud development respond in a similar manner to daylength and to the temperature regimes associated with that daylength. This may not be so. Consequently, detailed studies of floral development were undertaken in controlled environment cabinets to assess the role of photoperiod and temperature.

The work reported in this paper compares the effects of photoperiod and temperature on floral initiation and floral bud development in two lines, QPL-1 and QPL-2, of the early-flowering isolate, with that of an early-flowering Indian cultivar, Prabhat.

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Materials and Methods

Growing Conditions

Controlled environment cabinets were programmed for the required photoperiod and temperature conditions. Temperature was constantly monitored in each cabinet and varied not more than + 1°C. For the duration of each photoperiod, a combination of incandescent and cool white fluorescenet lighting provided photosynethetically active radiation (PAR) varying from 400 uE m^{-2} sec^{-1} at pot surface to 800 μE m^{-2} sec^{-1} directly beneath the light bank. Day to night transitions of temperature and photoperiod were abrupt and coincident. Relative humidity was maintained within the range of 65 to 75% during the photoperiods and 75 to 80% at night.

Seed inoculated with *Rhizobium* strain CB-756 was sown in 15 cm pots filled with a modified Californian mix of peat, sand, and a complete nutrient source.

The pots were watered twice daily with deionized water.

Measurements

Eight plants of each pigeonpea line were sampled each week. Sampling commenced 14 days after plant emergence and continued until all plants in the weekly sample had initiated floral buds. Floral initiation was determined by microscopic examination of dissected apical buds. Only main stem apices were examined, as an earlier study (Turnbull, unpublished data) had determined that this was the first site at which floral initiation occurred. Initiated apices were scored according to stage of floral development (Turnbull 1977) and the rate of growth of the primordia determined for each treatment. Using this information, time of floral initiation was recorded for the same (minimal) stage of development of the primorida in all treatments.

In selected treatments, daylength and temperature conditions were maintained until flowering had occurred. The date of first open flower, for a minimum sample of 8 plants, was recorded for each line in these treatments.

Experimental Treatments

Experiment 1

The three pigeonpea lines were grown under 8 and 16 hour photoperiods, in factorial combination with day/night temperature regimes of 24/16°C and 32/24°C. Dates of floral initiation and flowering were recorded for each line.

Experiment 2

Plants were grown in a 24-hour photoperiod (i.e., continuous PAR), with a temperature regime for each 24-hour period of 16 hours at 24°C and 8 hours at 16°C. This enabled a direct comparison of the influence of photoperiod with the 16-hour, 24/16°C treatment in Experiment 1. Floral initiation and flowering dates were recorded for each line.

Experiment 3.

A constant photoperiod of 16 hours was used with each of the following day/night temperature regimes: 24/20°C, 24/24°C, 24/28°C, 28/24°C, and 32/16°C. Days to floral initiation were recorded in all treatments.

Statistical Analyses

Analyses of variance were computed for data on time to floral initiation, duration of floral bud development, and flowering time, using a completely randomized block design. Where significant F values occurred, the LSD test was used to determine significant differences among treatment means. Due to the unequal sample numbers between treatments, requiring separate LSD values for each mean pair comparison, the largest LSD value only has been quoted. This in no way alters the significance of the results stated. The percentage of total sum of squares accounted for by photoperiod and by temperature was used as a measure of the relative importance of these sources in influencing floral behavior.

Results and Discussion

Floral Initiation

In all lines, floral initiation occurred earliest under low temperatures (24/16°C) in a 16-hour photoperiod for QPL-1 and QPL-2, and either a 16- or 24-hour photoperiod in Prabhat (Tables 1 and 2). Reduction in day-length to 8 hours (Table 1) or increase in temperature both resulted in delays in floral initiation in all lines. In all treatments, Prabhat initiated floral primordia significantly later ($P < 0.05$) than either QPL-1 or QPL-2 (Tables 1 and 2).

Table 1. Effect of photoperiod on the number of days from emergence to floral initiation (Day/night temperature, 24/16°C).

	Days from emergence to floral initiation				
Line (L)	Photoperiod (P)	8 hours	16 hours	24 hours	Mean (L)
QPL-1		27.4	20.6	24.0	24.0
QPL-2		28.4	21.3	25.2	25.0
Prabhat		34.0	28.0	27.8	30.0
Mean (P)		29.9	23.3	25.7	
LSD (0.05)	L = 0.8;		P = 0.9;	LxP = 2.0	

Table 2. Effect of temperature on the number of days from emergence to floral initiation (Photoperiod, 16 hours).

Line (L)	Day/night tempera- ture (T)	Days from emergence to floral initiation							
		24/16	24/20	24/24	24/28	28/24	32/16	32/24	Mean (LJ
QPL-1		20.6	28.8	29.4	30.6	32.3	42.6	35.0	31.2
QPL-2		21.3	35.6	31.3	32.9	34.8	41.6	34.6	33.4
Prabhat		28.0	40.8	42.0	37.3	40.4	50.2	38.0	39.5
Mean (T)		23.6	34.4	33.2	33.3	35.4	44.8	36.0	
LSD (0.05)			L = 0.7;			T = 1.2;		LxT = 2.7	

The delay in initiation under an 8-hour photoperiod (Table 1) was probably due to the slow growth rate observed in these plants, a function of the lower mean daily temperature and PAR input. Growth rate during the juvenile phase has since been shown to affect floral iniation responses in these lines (Turnbull, unpublished data).

Under continuous (24-hour) photoperiods, floral initiation in QPL-1 and QPL-2 was delayed by 3.4 and 3.9 days respectively (Table 1). Although these differences were statistically significant, they are biologically unimportant in terms of a quantitative daylength response.

Increasing the photoperiod from 16 to 24 hours had no effect on the time of floral initiation in Prabhat (Table 1). These data strongly suggest that Prabhat is day-neutral and that QPL-1 and QPL-2 also show no meaningful biological response to daylength.

Temperature was the dominant factor influencing the number of days from emergence to floral initiation, accounting for approximately 60% of the total variation (sum of squares), compared with 10% due to photoperiod. Floral initiation occurred earliest under the lowest temperature regime tested, a day/night combination of 24/16°C. Increasing either the day or the night temperature delayed floral initiation (Table 2). The greatest delay was caused by the most widely divergent day/night temperature combination tested (32/16°C, Table 2).

Floral Bud Development

In all lines, the rate of development of the floral primordia increased with increase in both daylength and temperature. These was no significant difference between the cultivars in this pattern of response. The time from floral initiation to flower opening varied from 40 days under an 8-hour photoperiod at 24/16°C, to 22 days under a 16-hour photoperiod at 32/24°C.

The rate of floral primordia development increased with increase in photoperiod. The duration of floral bud development was reduced from 31 to 24 days by increasing the photoperiod from 16 to 24 hours with the same temperature regime of 24/16°C. The 50% increase in total PAR input probably contributed to the more rapid rate of development under the 24-hour photoperiod.

Increased the day/night temperature regimes from 24/16°C to 32/24°C reduced the duration of floral bud development by 12 days under an 8-hour photoperiod and 9 days under a 16-hour photoperiod.

Flowering

As a consequence of this change in floral response to temperature, i.e., high temperatures delaying floral initiation but promoting floral bud development, the variation in days to flowering between treatments was reduced. In some cases, the rapid rate of floral bud development compensated for the delay in floral initiation, so that temperature appeared to have no effect on flowering time, e.g., Prabhat, 24/16°C versus 32/24°C.

Conclusions

Ariyanayagam and Spence (1978) stated that, "the search among the world collection of pigeonpea cultivars for genes conferring insensitivity has been without success." The work reported in this paper confirms the presence of day-neutrality in *cajanus cajan,* at least under the 24/16°C temperature regime tested. The response to 24-hour photoperiod at higher temperatures remains to be determined. For this material the importance of the difference in temperature response during floral initiation and floral bud development cannot be overstated. The potential for the plant breeder to manipulate flowering time is considerable. Generation turnover could be accelerated by manipulation of pre- and post-initiation temperature conditions. Obviously, more work needs to be carried out to determine the temperature responses of a range of maturity types before this could be used with success. These results also highlight the danger in attributing floral responses in the field to daylength alone. It is possible that in some of the so-called "daylength-sensitive" cultivars, temperature may be the main determinant of flowering time (Turnbull, unpublished data). Analysis of phenology that does not include determination of floral initiation has grossly limited value in providing an understanding of the physiological mechanisms involved in flowering.

The implications of this with regard to genetic manipulations are considerable.

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Response of Short-Duration Pigeonpea Cultivars to Sowing Time and Row Spacing

A.S. Faroda and R.C. Singh*

Abstract

Short-duration pigeonpea as a kharif crop preceding wheat is becoming increasingly popular in the wheat-growing belt of northern India. To determine optimum sowing times and find cultivars best suited to this cropping pattern, four cultivars of pigeonpea were tested under three sowing dates and four row spacings. Cultivar T-21 was found best for June planting and UPAS-120 for July planting. Maximum yield was obtained with June planting; minimum yield, with July planting. A row spacing of 37.5 cm was found optimum under Haryana conditions.

Pigeonpea is the second most important grain legume of India, the first being chickpea. Having a wide adaptability to climate and soil, it is cultivated all over the country with the exception of excessively wet or frost-prone areas. In the wheat-growing areas, the short-duration varieties of pigeonpea are becoming popular as a rainy-season crop preceding rabi wheat. It is essential to select a pigeonpea cultivar suited to this cropping pattern, so that wheat can be sown in time; however, information on optimum sowing times for pigeonpea in the wheat-growing belt of northern India is lacking, the studies reported in this paper were undertaken to fill that gap.

Materials and Methods

A field experiment was conducted at the Haryana Agricultural University, Hissar, India, during the rainy seasons of 1975, 1976, and 1977. The treatments consisted of three sowing dates (June 15, July 1, and July 15) four row spacings (25, 37.5, 50, and 62.5 cm) and four genotypes (Prabhat, UPAS-120, T-21, and Pant A-2). The treatments were replicated thrice in a split-plot design with sowing dates and row spacings in the main plots and genotypes in the subplots.

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The soils of the experimental plots were sandy loam in texture, poor in nitrogen, medium in available phosphorus, and rich in available potash. A basal dose of 40 kg P_2O_5 and 20 kg N/ha was applied at the time of sowing. The seed was treated with *Rhizobium* culture. The plant population was kept constant across the different row-width treatments by adjusting plant-to-plant distance. Presowing irrigation was given wherever necessary. One postsowing irrigation was also given in each year. Proper plant protection measures were followed. The harvestings were done from the second fortnight of October to the first fortnight of December during different years, depending on sowing time and variety.

Results and Discussion

Effect of Sowing Time

Sowing time had significant effect on growth and development. Maximum plant height, number of pods per plant, and test weight were recorded with the first date of sowing (June 15). Sowing dates differed significantly from each other in these parameters, except number of pods in 1975 and test weight in 1977 where the first two dates of sowing were statistically different (Table 1). Though the maximum grains per pod were recorded with the first sowing date, the differences with other sowing dates were significant only in 1976. Dahiya et al. (1974) obtained similar results.

In grain yield, the first two sowing dates (June 15 and July 1) were not significantly different but they were significantly better than the last date of sowing (July 15) during all 3 years as well as in the pooled data (Table 2). Singh et al.(1971), Saxena et al. (1973), Rathi et al. (1974), Ahlawat et al. (1975), Kaul and Shekhon (1975) and Rathi and Tripathi (1978) have also reported similar results.

Effect of Genotypes

The genotype T-21 produced significantly taller plants than other varieties in all 3 years. The minimum plant height was recorded in Prabhat. This cultivar produced significantly fewer pods per plant than all other varieties during 1976, than UPAS-120 in 1975, and than UPAS-120 and T-21 in 1977. However, the number of grains per pod were maximum in Prabhat during 1975 and 1976. In 1977, cv T-21 had maximum number of grains per pod. T-21 produced the boldest seeds, followed by UPAS-120, Pant A-2, and Prabhat, in that order (Table 1).

On *an* average the genotype UPAS-120 was most suitable under Haryana conditions, followed by T-21, Prabhat, and Pant A-2 in that order (Table 2). However, data in table 3 show that when the sowing was done in the middle of June, T-21 produced significantly more than other cultivars. When sowing was done in July, genotype UPAS-120 was best, closely followed by Prabhat. Cv Pant A-2 gave the lowest yield.

Table 1. Effect of sowing dates, genotypes, and row spacings on yield attributes of pigeonpea under Haryana conditions.

Treatments	Plant height(cm)			Number of pods/plant			Number of grains/pod			Test weight (g/1000 grains)		
	1975	1976	1977	1975	1976	1977	1975	1976	1977	1975	1976	1977
Sowing date												
June 15	245.9	228.1	221.7	73.22	180.92	93.61	4.03	4.24	3.41	66.10	64.32	67.81
July 1	221.7	201.3	185.9	66.24	138.84	82.01	3.89	3.90	3.30	64.82	63.33	68.44
July 15	186.2	137.9	151.3	58.63	99.06	71.51	3.98	3.87	3.42	56.31	59.90	66.33
SEm ±	2.70	3.16	4.20	3.51	7.39	1.27	0.05	0.07	0.04	0.07	0.05	0.30
CD at 5%	7.82	9.23	16.52	10.12	21.60	4.99	NS	0.22	NS	0.20	0.15	1.19
Genotype												
Prabhat	176.9	159.4	142.9	54.25	108.38	75.40	4.05	4.19	3.30	57.61	58.00	56.52
UPAS-120	218.1	183.3	185.3	68.55	133.96	87.78	3.96	4.16	3.29	63.75	64.11	65.30
T-21	248.2	214.2	214.1	65.96	157.74	89.95	3.86	3.92	3.43	63.60	66.80	67.09
Pant A-2	199.5	199.4	178.9	66.66	158.38	79.18	3.77	3.75	3.39	60.00	61.00	64.97
SEm ±	3.49	3.66	2.10	4.54	8.53	3.08	0.06	0.08	0.05	0.09	0.06	0.90
CD at 5%	10.07	10.70	5.82	13.12	25.14	8.54	NS	0.25	0.13	0.26	0.17	2.50
Row spacings(cm)												
25	217.3	191.3	187.9	63.44	122.74	73.33	3.96	3.97	3.37	62.90	63.00	65.64
37.5	218.5	186.6	187.6	67.62	133.51	78.48	3.92	3.99	3.37	61.81	63.32	66.46
50	221.3	188.3	184.5	68.67	153.92	87.47	3.91	4.05	3.41	61.85	62.50	68.87
62.5	214.6	190.0	185.3	64.39	148.27	90.24	3.87	4.01	3.37	63.12	61.10	69.12
SEm ±	1.15	3.10	1.88	0.91	6.20	2.75	0.05	0.07	0.04	0.07	0.07	0.81
CD at 5%	3.17	NS	NS	2.51	21.31	7.64	NS	NS	NS	NS	NS	2.24

Table 2. Effect of sowing dates, genotypes, and row spacings on the grain yield of pigeonpea under Haryana conditions.

Treatments	Grain yield (OOkg/ha)			
	1975	1976	1977	Pooled
Sowing date				
June 15	14.17	24.40	19.41	19.46
July 1	14.50	22.82	18.43	19.07
July 15	11.16	19.99	12.48	14.47
SEm ±	0.27	0.73	0.56	0.27
CD at 5%	0.77	2.14	2.18	1.06
Genotype				
Prabhat	13.42	22.62	15.92	17.32
UPAS-120	13.95	23.64	19.19	18.92
T-21	14.59	22.14	15.78	18.06
Pant A-2	12.17	21.22	17.48	16.38
SEm ±	0.35	0.84	0.47	0.26
CD at 5%	1.01	NS	1.30	0.71
Row spacing(cm)				
25	14.44	21.98	17.16	18.12
37.5	14.33	24.87	18.02	19.26
50	12.74	21.67	16.03	17.03
62.5	11.60	21.10	15.87	16.25
SEm ±	0.61	0.26	0.42	0.26
CD at 5%	1.68	0.72	1.16	0.71

Table 3. The effect of genotype X sowing date interaction on the grain yield of pigeonpea (pooled data).

Genotype	Grain yield (OOkg/ha) at sowing date			
	June 15	July 1	July 15	Mean
Prabhat	18.02	18.72	15.22	17.32
UPAS-120	19.65	21.42	15.68	18.92
T-21	21.73	18.16	14.30	18.06
Pant A-2	18.46	17.99	12.71	16.38
Mean	19.46	19.07	14.47	
SEm±	0.45			
CD at 5%	1.23			

Effect of Row Spacing

There was no definite trend in growth and development due to variation in row spacing. The differences were nonsignificant in plant height in 2 years, number of grains per pod in all 3 years, and test weight in 2 years. For number of pods per plant, where the differences were significant in all the 3 years, 50-cm and 62.5-cm row spacings were better than narrower row spacings in the last 2 years (Table 1).

The row spacing of 37.5 cm gave significantly more grain yield than 50-cm row spacing in the last 2 years and the 62.5-cm row spacing in all 3 years (Table 2). However, the differences between 25-cm and 37.5-cm row spacings were significant only in 1976. The row spacing of 25-cm was also significantly better than 62.5-cm in all 3 years. On an average, maximum grain yield was obtained with 37.5-cm row spacing, followed by 25, 50, and 62.5-cm in that order.

Summary

Four cultivars (Prabhat, UPAS-120, T-21, and Pant A-2) were tested under three sowing dates (June 15, July 1, and July 15) and four row spacings (25, 37.5, 50, and 62.5-cm). Cv T-21 was best for June planting, and UPAS-120 for July planting. June 15 planting gave maximum yield; July 15 planting minimum yield. A row spacing of 37.5-cm was found optimum under Haryana conditions.

Acknowledgment

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Phenological Behavior and Yield of Pigeonpea Genotypes under Different Dates of Planting and Row Spacings

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Abstract

Phenological studies in relation to grain yield of two pigeonpea genotypes (T-21 and AL-15) under four dates of sowing and four plant populations were carried out at Punjab Agricultural University, Ludhiana, during 1979. Cultivar T-21 on an average took 18, 12, and 25 days more than AL-15 for flower initiation, 75% flowering, and maturity respectively. The temperature requirement of AL-15 for all these phenophases was less than that of T-21 under all the dates of sowing. Significant positive correlation was found between temperature at maturity and seed yield. Both genotypes gave the highest seed yield and dry-matter production when sown on June 1, because of longer maturity period and high effective temperature. Effective temperature requirement and length of all the phenophases were considerably reduced when sowing was delayed to June 10, 20, and 30, which ultimately resulted in significant reduction in seed yield and dry-matter production. Plant population did not indicate any major influence on phenological behavior of the crop; however, seed yield was increased significantly with increase in plant population.

Pigeonpea is an important pulse crop of India with an area of 2.7 million ha and an average yield of 720 kg/ha. In Punjab state it has long been grown around cotton and sugarcane as a protective hedge, but has not been adopted as a sole crop because of its long duration and intolerance to severe winters. Introduction of the medium-duration variety T-21 during the mid-1970s encouraged the cultivation of pigeonpea in the state, as T-21 matures before winter sets in and can be followed by winter wheat. Though the pigeonpea area in the state is fast increasing, delayed maturity is a major obstacle to its becoming a main pulse crop in the Punjab.

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Time of sowing--because of its effect on the vegetative and reproductive phases of the crop—is an important factor influencing crop duration. Riollano et al. (1962) and Gooding (1960) reported significant influence of date of sowing on phenology of pigeonpea. Hammerton (1976) and Singh et al. (1971) reported that dates of sowing had a direct bearing on time of maturity. Another important factor that influences the growth and development of pigeonpea is the plant population. Sheldrake and Narayanan (1977) reported the effect of plant population on branching behavior of pigeonpea and Kaul et al (1980) have reported early flowering under high plant population. This paper summarizes an experiment planned to study the phenological and morphological behavior of pigeonpea genotypes under different dates of sowing and plant populations at Ludhiana, India.

Materials and Methods

The experiment was conducted at Punjab Agricultural University, Ludhiana, during the *Kharif* (rainy) season 1979, on a loamy sand soil, low in organic carbon (0.09), medium in available-phosphorus and potassium (21.0 and 187.5), with a pH of 8.2. The experiment was laid out in a split-plot design with four dates of sowing (June 1, 10, 20, and 30) and two cultivars (T-21 and AL-15) in the main plots and row spacings (25, 37.5, 50 and 75 cm) in the subplots. A uniform plant-to-plant spacing of 25 cm within the rows was maintained, thus obtaining 160 000, 106 000, 80 000, and 53 000 plants per ha under the four row spacings, respectively. A basal dose of 15 kg N and 40 kg P_2O_5/ha was applied before sowing. Data on weather during the crop season, 10% flowering, and 75% flowering and podding were recorded. The total of cumulative temperature units for each phenophase was calculated as a summation of the daily mean temperature during the period. For dry-matter accumulation,five plants were cut at ground level and the leaves, stem, and reproductive structures separated and dried in an oven at 65°C.

Results and Discussion

Phenological Behavior

Cultivar T-21 was of comparatively longer duration than cv AL-15, taking on an average 100, 107, and 149 days for flower initiation, flower completion, and maturity, respectively, as compared with 83, 93, and 124 days, respectively, in AL-15 (Table 1).

The number of days taken for completion of each phenophase varied greatly with date of sowing. Days to flower initiation, 75% flowering, and maturity were highest in the crop sown June 1, in both cultivars and were consistently reduced when the sowings were delayed to June 10, 20, and 30. The differences were much larger in cv T-21, where the vegetative phase was reduced by 24 days with the delay of 30 days in sowing from June 1 to June 30 as compared with only 6 days' reduction in AL-15. This indicates that T-21 is more photosensitive, as it started flowering the

Table 1. Days taken to flowering and maturity as affected by date of sowing of pigeonpea cvs T-21 and AL-15 at Ludhiana, India.

Date of sowing	Days to 10% flowering	Days to 75% flowering	Days to maturity
T-21			
June 1	112	118	159
June 10	104	110	153
June 20	97	103	146
June 30	88	96	138
Mean	100	107	149
AL-15			
June 1	87	98	134
June 10	82	96	127
June 20	81	91	122
June 30	81	87	113
Mean	83	93	124

week of 19 to 25 September with all dates of sowing, resulting in a reduced vegetative phase in the late-sown crop. In contrast, flower initiation in AL-15 ranged from 26 August to 19 September under different sowing dates and thus the vegetative period was curtailed by only 6 days, which indicated its relatively photo insensitive response. However, in AL-15 the reproductive phase was reduced from 47 days to 32 days when sowing was delayed from June 1 to June 30, while there was no effect on T-21. Thus ultimately the 30 days' delay in sowing reduced the life span of the crop by 21 days in both varieties; however, the maturity of the crop was delayed by 9 days. Row spacing failed to influence the number of days to flower initiation, 75% flowering, and maturity in both cultivars. This may be because there was little variation in the microclimate under different row spacings.

Temperature Requirements

Cumulative temperature at the completion of each phenophase followed almost the same pattern as phenological period (Table 2). CV AL-15, being

Table 2. Accumulated temperature at different phenophases under different dates of sowing of pigeonpea cvs T-21 and AL-15.

Date of sowing	Days to 10% flowering	Days to 75% flowering	Days to maturity
T-21			
June 1	3373	3526	4518
June 10	3115	3269	4300
June 20	2880	3034	4044
June 30	2558	2764	3734
Mean	2981	3398	4149
AL-15			
June 1	2681	3002	3940
June 10	2517	2918	3706
June 20	2467	2735	3506
June 30	2387	2534	3189
Mean	2513	2797	3585

of short duration, required fewer temperature units than cv T-21 at each phenophase under all dates of sowing. On an average, T-21 required 3734 to 4518 temperature units from sowing to maturity, whereas AL-15 required 3189 to 3940 units, depending on sowing dates, at Ludhiana. A significant positive correlation was obtained between accumulated temperature units at maturity and seed yield of both cultivars ($r = 0.91$ for T-21 and 0.97 for AL-15). The regression equations are:

T-21: $y = -2465.00 + 0.877\ x$

AL-15: $y = -783.836 + 0.523\ x$

Growth Pattern

Rate of dry-matter accumulation was higher in AL-15 during the initial stages but at a later stage (130 days), T-21 recorded higher dry-matter accumulation. Cv AL-15, being short duration, headed for maturity after 110 days, while variety T-21 continued to grow even after this and ultimately recorded more dry-matter and branches per plant. Naryanan and Sheldrake(1976) also reported similar behavior in late-maturing genotpes

The common feature in both cultivars was that during the first 50 days the dry-matter accumulation was slow; it increased rapidly after 70 days, and continued to increase up to maturity. The rate of increase was fast up to 130 days in T-21 and up to 110 days in cv AL-15; after this, it slowed down. Partitioning of dry matter into different plant parts-leaves, stem, branches, and reproductive structures—indicated that dry-matter accumulation was more in the leaves during the first 70 days; thereafter the comparative increase was more in the stem; however, after the start of pod formation dry-matter accumulation in both stem and leaves declined due to leaf senescence and translocation of photosynthates to reproductive parts.

In accordance with accumulated heat units and duration of the vegetative phase, the dry-matter accumulation was highest in the crop sown June 1, and significant reduction was recorded when sowings were delayed to June 10, 20, and 30. On an average, 32.8% reduction in the final dry matter was obtained with the last date of sowing.

Total dry-matter production decreased consistently with increase in the row spacing. The highest dry-matter yield (12 215 kg/ha) was from the closest row spacing of 25 cm, which was 6930 kg/ha more than that from the 75-cm row spacing. This may be attributed to the increased plant population per unit area and taller.plants under closer row spacing.

Yield and Yield Attributes

Different dates of sowing significantly influenced the seed yield of both cultivars. The highest seed yield (1452 kg/ha) was obtained when the crop was sown on June 1 (Table 3); with sowing delayed to June 10, 20, and 30, the seed yield was reduced by 18, 33, and 37% respectively. Similarly, the yield-contributing characters,--seed weight per plant, branches per plant, and number of pods per plant—were reduced significantly with each delay in sowing. The highest seed yield (1425 kg/ha) was obtained under the closest row spacing of 25 cm and was consistently reduced with wider row spacing. Although individual plant parameters, namely, seed weight, branches, and pods, were higher with wider row spacing, this increase could not compensate for the increase in plant population from 50 000 to 160 000 obtained by reducing the row spacing from 75 cm to 25 cm.

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Table 3. Yield and yield attributes under different dates of sowing and plant populations of pigeonpea cvs T-21 and AL-15 at Ludhiana, India.

Treatment	Seed yield (kg/ha)	Seed wt/ plant (g)	Branches/ plant	Pods/ plant	100 seed wt (g)
Date of sowing					
June 1	1452	37.4	20.6	178	6.9
June 10	1196	33.7	17.3	164	6.5
June 20	970	24.2	15.5	129	6.1
June 30	914	18.7	15.5	115	5.8
LSD (5%)	116	4.6	1.8	7.2	0.34
Row spacing (cm)					
25	1421	18.6	16.6	128	6.3
37.5	1125	23.7	16.5	143	6.5
50	1095	29.9	17.5	145	6.2
75	890	41.8	18.5	170	6.3
LSD(5%)	111	2.5	1.2	NS	NS
Cultivar					
T-21	1174	30.2	18.2	159	6.2
AL-15	1092	26.7	16.0	134	6.4
LSD(5%)	NS	NS	1.3	5.1	NS

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Planting Density Effects on the Dry-Season Productivity of Short Pigeonpeas in the West Indies:

I. Growth and Development

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Abstract

Keatinge and Hughes (1980) have reported mean dry seed yields of short pigeonpeas to be 1.1 tonnes/ha when grown at a stand density of 200 000 plants/ha under dry season conditions in Trinidad. Work currently in progress is designed to examine whether increasing stand density to extremely high values (3000 000 to 600 000 plants/ha) will result in he interception of a significantly greater proportion of seasonal incoming solar energy due to the earlier attainment of critical leaf area index values and thus increase dry-matter production and seed yield.

The response of pigeonpea (*Cajanus cajan* [L.] Millsp.) growth to photoperiod has been noted by Spence and Williams (1972). In Trinidad (at 10° 33' N latitude), short, determinate cultivars planted during May-June reached a height of about 1.5 m and produced a crop in about 150 to 180 days, flowering in response to short daylength. Planted during December, and thus immediately subjected to flower-inducing conditions, the plants grew to about 1 m and produced a crop after 110 days. In India (at Hyderabad, 17° 32' N latitude), Narayanan and Sheldrake (1979) have noted a similar response of growth habit and duration of pigeonpea planted during October-November (short daylength) rather than in the normal June-July. The shorter growth habit of pigeonpea cultivars planted during short-day conditions enabled the investigation of high density row cropping as a method of increasing productivity.

In both Trinidad and India, the nontraditional short-day planting times coincide with the onset of the dry season, within which the crop then reaches maturity. Thus moisture-stress may be a factor limiting pigeonpea growth and yield from such plantings. Keatinge et al. (1980) noted that both leaf area index and grain yield (averages over three cultivars) were increased by the application of supplemental irrigation to a Trinidad dry season crop. If moisturestress is indeed limiting, then

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very high planting density may not result in increased yield. Sinha and Savithri (1978) suggested that dense initial stands of pigeonpea may accentuate moisture-stress effects on yield by depleting soil moisture before reproductive development occurs. Low plant densities were recommended for the conservation of soil moisture.

However, high plant densities remain a possible solution to the problem of poor interception of solar radiation by pigeonpea canopies, particularly during the period of slow early growth. Hughes et al. (1980) have shown that the length of time spent at high fractional radiation interception is an important determinant of yield in pigeonpea. In this paper we describe an investigation of the effects of, and interactions between, planting density and moisturelevel on pigeonpea growth and development in dry-season conditions in Trinidad. Particular attention is paid to the development of leaf area index and the interception of solar radiation by canopies at different densities.

Materials and Methods

The experiment was located at Texaco Food Crops Farm, St. Joseph, Trinidad. A split-plot design was adopted, and laid out in three 4 x 50m blocks. The main plots comprised the factorial combinations of two cultivars, UW-17 and UW-26, which have been described by Brathwaite(1978), and two moisturelevels (supplemental irrigation, I, and no supplemental irrigation, C). The I plots received supplemental spray irrigation at intervals of about 5 days throughout the experiment.

The subplots comprised five high stand densities:
200 000 plants/ha (167 mm between rows x 300 mm within rows); 300 000 plants/ha (167 x 200 mm); 400 000 plants/ha (167 x 150 mm); 500 000 plants/ha (167 x 120 mm) and 600 000 plants/ha (167 x 100 mm).

Planting date was 22 Jan 1980 (photoperiod 11.6 h). Seeds, pre-inoculated with Rhizobium UW-10030, were planted by hand with four to six seeds per hole. A compound fertilizer (12:12:17) was broadcast to give a rate of 40 kg/ha of nitrogen and phosphate.

During the first 15 days all plots were irrigated in order to facilitate seedling establishment. After 20 days, plants were thinned to one per hole in order to establish the required density levels.

Weed control was maintained by use of a preemergence herbicide (Amiben-Gramoxone mixture) and by regular hand weeding Damage by pod-boring larvae was controlled by application of Belmark pyrethroid insecticide at intervals of 5 days, starting at flowering. Three spray applications of the fungicide Dithane M45 were made in order to control pigeonpea rust, *Uredo cajani.*

For the purposes of growth analysis, three plants were harvested twice a week from each treatment. Leaf area for each sample was determined with an automatic area meter. Average per plant leaf area was converted to leaf area index by multiplying by established stand density. Logarithmic polynomial regression equations were fitted to the relationships between leaf area index (L) and time.

Results

Previous results (Hughes et al. 1980) have indicated a negative correlation between the time taken to reach L = 1 and dry seed yield for pigeonpea in stands of 200 U00 plants/ha. Analysis of the effect of increasing stand density, up to 600 000 plants/ha, on the time to reach L = 1 showed that this time decreased, but the magnitude of the decreases fell off with higher density levels. The effect of supplemental irrigation was not significant at this stage of growth, nor were there any significant interactions between density and moisture level. That is to say, supplemental irrigation did not significantly increase early canopy growth and development, nor did lack of it modify such increases resulting from increased stand density.

Keatinge and Hughes (1980; reported positive correlation between maximum L and dry seed yield for pigeonpea in stands of 200 000 plants/ha. The effect of increasing stand density on maximum L was modified by interactions with moisture-level and cultivar effects. In the absence of supplemental irrigation there was no difference between the cultivars, maximum L increasing from about 2 to about 3 as stand density increased from 200 000 to 600 000 plants/ha. Under irrigation, increases in maximum L with increasing density were larger. In addition, there was generally a greater response to irrigation by cv UW-26. While the response of cv UW-26 continued to increase at the highest densities, maximum L for cv UW-17 was higher at 500 000 than at 600 000 plants/ha.

Fractional daily solar radiation interception (F) *by* a canopy is a nonlinear function of L. Unit increases in L have smaller increasing effects on F as L increases. Hughes et al. (1980) estimated that 50% interception by crops of short pigeonpeas occurs when L = I, and 95% interception when L = 4.4. Further increases in L can obviously contribute little to interception.

Hughes et al. (1980) reported an increasing relationship between the proportion of incident radiation intercepted during the growing season (F, the average_of the daily F values) and pigeonpea yield. The pattern of increase in F with increasing stand density was similar in all four moisture-level and cultivar combinations, the increases tending to fall off in magnitude with higher density levels. Over the growing season, increasing stand density from 200 000 to 600 000 plants/ha increased radiation interception by about 15 percentage points on the F scale for each of the main-plot treatments. Thus the larger response of maximum L to increasinq stand density when under irrigation does not proportionately enhance interception. With respect to F, there were no apparent large-scale interactions between density and moisture-level.

The larger F response of cv UW-26 to irrigation appears to be a duration effect, the growing season being extended further than that of cv UW-17 under irrigation. When corrected for length of season, the increasing effect of supplemental irrigation on F is similar for the two cultivars.

Discussion

As stand density was increased in the range of 200 000 to 600 000 plants/ha, the time taken to reach L = 1 was reduced and there was an increase in maximum L. The absence of supplemental irrigation did not significantly retard early canopy development even at high density. With irrigation however, maximum L was higher at each density, and increased more with increasing density. Because of the nature of the relationship between interception and L, the response to irrigation in terms of overall interception was similar at each density. Irrigation resulted in increased overall interception, the differences between cultivars being largely attributable to their different responses to irrigation with respect to growing season.

In Table I a comparison is made between irrigated crops of cowpea *(vigna anguiculata)*(Littleton et al., 1979a, 1979b; and pigeonpea with respect to interception of solar radiation. The pattern of variation of L with time for cowpea shows that the crops reached maximum L values between 2.9 and 4.7 in 34 to 48 days. Our maximum L values for pigeonpea were generally higher than those for cowpea but took much longer to reach (61-83 days). Although interception by the pigeonpea canopies over the first 50 days was doubled as stand density was increased from 200 000 to 600 000 plants/ha, the 50-day value achieved at high density was below that of cowpea crops at 160 000 plants/ha (Table 1). Towards the end of the growing season, the pigeonpea crops reached and maintained L values leading to high fractional daily interception. However, only at very high density was the proportion of radiation intercepted over the growing season by the pigeonpea crops comparable with the values for the crops of cowpea. Increased early development of L is clearly an important factor in increasing overall interception.

Table 1. The fraction of solar radiation ($\bar{\bar{F}}$) intercepted by crops of pigeonpea[a] and cowpea.[b]

Crop	Stand density (plants/ha)	$\bar{\bar{F}}$ at 50 days after emergence	$\bar{\bar{F}}$ at maximum dry matter[c]
Cowpea	160 000	0.472	0.519
Pigeonpea	200 000	0.173	0.433
Pigeonpea	300 000	0.241	0.474
Pigeonpea	400 000	0.279	0.498
Pigeonpea	500 000	0.305	0.543
Pigeonpea	600 000	0.345	0.547

a. The tabulated values of $\bar{\bar{F}}$ are means of plots of cvs.UW-17 and UW-26 from the present trial which received supplemental irrigation.

b. The tabulated values of F are means of five crops of cv.TVu 4552 grown at Ibadan, Nigeria, under supplemental irrigation (Littleton et al., 1979a, 1979b).

c. Estimated from fitted regression equations. Times range from 56 to 72 days for cowpea and 68 to 89 days for pigeonpea.

The next stage of the analysis (Keatinge and Hughes 1981; involves an assessment of the extent to which increased radiant energy input to the pigeonpea crops, achieved by the use of dense stands, can be translated into increased yield. Although the use of dense stands did not accentuate moisture-stress effects on interception of radiation, grain yield depends further on the efficiency of conversion of intercepted radiant energy into chemical energy storable as assimilated dry matter, and the way that dry matter is partitioned between vegetative and reproductive parts. Yield may thus be influenced by density and moisture-level effects on these processes.

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Planting Density Effects on the Dry-Season Productivity of Short Pigeonpeas in the West Indies:

II. Yield and Moisture Supply

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Abstract

The varied levels of moisture stress imposed on the pigeonpea crop, as a result of the faster transpiration induced by increased stand density, are monitored to determine their effect on yield. In association, treatments receiving supplemental irrigation to reduce moisture stress are included in the trial to enable assessment of the extent to which current UWI-bred varieties possess drought-tolerant or drought-avoidant characteristics.

In a previous Trinidad dry-season trial, reported by Keatinge and Hughes (1980), average dry seed yield for short pigeonpea cultivars UW-17 and UW-26 was about 1000 kg/ha from unirrigated plots and about 1600 kg/ha from plots receiving supplemental irrigation. Stand density, at 200 000 plants/ha, was much greater than generally used in traditional cultivation of tall pigeonpeas. Nevertheless, interception of solar radiation by the leaf canopies, an important determinant of yield, was poor, particularly during early growth (Hughes et al. 1980). In a subsequent dry-season trial (Hughes et al. 1981] the use of stand densities up to 600 000 plants/ha improved seasonal interception in both irrigated and unirrigated plots. In this paper we present an analysis of yield data from this trial.

The increase in interception of solar radiation notwithstanding, yields from dense stands of pigeonpea may still fail to be improved because of decreased soil moisture availability, particularly during the reproductive phase (Sinha and Savithri 1978). Experiments with short pigeonpea cultivars in India and Australia provide some support for this view. In an unirrigated dry-season trial with six cultivars at Hyderabad (Narayanan and Sheldrake 1979), yield decreased as stand density increased in the range of 125000 to 1000000 plants/ha. In trials with a short photoperiod-insensitive cultivar in Queensland, Wallis et al (1979)

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reported yield increases with increasing stand density in the range of 100 000 to 500 000 plants/ha. However, this was achieved with the aid of supplemental irrigation (E. Wallis, personal communication). By including irrigated and unirrigated treatments in a trial with a range of high stand densities, we hope to be able to assess the extent to which these factors, and any interactions between them, influence pigeonpea yields under dry-season conditions in Trinidad.

Materials and Methods

The trial was set out in a split-plot design. The main plots comprised the factorial combinations of two cultivars (V: UW-17 or UW-26) and two moisture levels (M:with, I, or without, C, supplemental irrigation). The subplots comprised different stand densities (200 000, 300 000, 400 000, 500 000, and 600 000 plants/ha). Full details of these factors and general crop husbandry have been given by Hughes et al. (1981).

At final harvest, three previously unsampled 4-m rows were taken from each treatment. Plants were selected that were fully guarded and growing at the established subplot density. The number of plants sampled, the number of pods per plant, and the number of seeds per pod were recorded. Seed weight was measured after oven drying at 80°C for 48 hours. Seed yields per unit area were calculated as the products of mean yield per plant and established stand density.

During the trial, soil moisture levels were monitored to 105 cm in the profile, in 15-cm intervals, with a Wallingford 1H II neutron probe. Recordings were made twice weekly in all unirrigated and some irrigated treatments. Volumetric soil moisture percentage data were converted to moisture stress values (MPa) using soil moisture characteristic curves for the site.

Results

Individual plant yield (dry seed, g/plant) decreased nonlinearly with increasing density and also significantly decreased in the absence of supplemental irrigation (Table 1). The significant moisture x density interaction shows that the increasing effect of supplemental irrigation on individual plant yield was largest at low density. In addition, Table 1 indicates that the responses of productivity assessed as number of pods per plant were similar to those of seed yield per plant.

The effect of the experimental factors on the yield component variables (number of peas per pod and lOO-seed weight) is shown in Table 2. Neither stand density nor moisture level appears to alter the number of seeds per pod. Four seeds per pod was the average over all treatments. Moisture stress resulted in significantly lower lOO-seed weights, the reduction being more marked in cv UW-26 than in cv UW-17. One hundred seed weight was greatest at the lowest density used in the trial, but there were no significant differences between the values recorded for the higher densities.

Table 1. Analysis of variance of yield per plant

Analysis of variance		Pods/plant			Dry seed (g/pl)		
Source	df	MS	F	P	MS	F	P
Blocks	2	644.018	5.4	< 5%	68.410	4.7	<10%
V	1	682.763	5.7	<10%	44.842	3.1	
M	1	1874.886	15.8	< 1%	241.161	16.6	< 1%
V*M	1	203.873	1.7		35.346	2.4	
Residual	6	118.888			14.535		
D(lst order)	1	1186.923	90.3	< 0.1%	90.845	60.2	<0.1%
D(2nd order)	1	104.975	8.0	< 1%	6.796	4.5	< 5%
Deviations	2	8.173	< 1		0.882	<1	
D(1st)*M	1	109.443	8.3	< 1%	23.030	15.3	< 0.1%
D(2nd)*M	1	17.875	1.4		4.934	3.3	<10%
Deviations	2	5.053	< 1		1.255	<1	
D*V	4	21.773	1.7		1.994	1.3	
D*V*M	4	16.600	1.3		2.899	1.9	
Residual	32	13.143			1.509		

Pods per plant
D*M interaction table

Density	Moisture-	level C	Density means
200 000	35.0	18.3	26.6
300 000	25.4	14.2	19.8
400 000	22.8	11.7	17.2
500 000	18.9	10.6	14.8
600 000	17.7	9.1	13.4
Moisture-level means	24.0	12.8	18.4

Dry seed (g/plant)
D*M interaction table

Density	Moisture - level I	C	Density means
200 000	10.49	3.77	7.13
300 000	7.14	3.31	5.23
400 000	6.52	2.70	4.61
500 000	5.32	2.47	3.89
600 000	4.86	2.03	3.45
Moisture-level means	6.87	2.86	4.86

M means (comparisons have 6 df)
SE .=1.99; SE . of difference = 2.82
D means (comparisons have 32 df)
SE .=1.05; SE . of difference = 1.48

M means (comparisons have 6 df)
SE .=0.696; SE. of difference = 0.984
D means (comparisons have 32df)
SE .=0.345; SE . of difference = 0.501

Table 2. Analysis of variance of yield components.

Analysis of variance		100-seed weight (g)			Seeds per pod		
Source	df	MS	F	P	MS	F	P
Blocks	2	2.284	2.8		0.366	8.9	< 5%
V	1	0.114	<1		0.227	5.5	<10%
M	1	21.313	26.0	<1%	0.132	3.2	
V*M	1	6.613	8.1	<5%	0.178	4.3	<10%
Residual	6	0.819			0.041		
D	4	0.476	3.6	<5%	0.022	1.0	
D*main plots	12	0.150	1.1		0.018	<1	
Residual	32	0.134			0.021		

100-seed weight (g)

M*V interaction table

Cultivar	Moisture-level I	Moisture-level C	Cultivar means
UW-17	6.67	6.14	6.41
UW-26	7.25	5.39	6.32
Moisture-level means	6.96	5.77	6.36

SE (*V* and M means) = 0.165
SE of difference = 0.234
comparisons have 6 df.

Table of D means

Density	Mean
200 000	6.69
300 000	6.26
400 000	6.32
500 000	6.37
600 000	6.17

SE = 0.106
SE of difference=0.149
comparisons have 32 df.

When seed yield is examined on a unit area basis (Table *3)*, it can be seen that moisture level and stand density have significant influences, both being simple additive effects. Over the range of densities in the trial the effect of an addition of 100 000 plants/ha was to increase seed yield by 0.16 t/ha. However, this increase was small in scale when compared with the 1.41 t/ha reduction in yield resulting from the imposition of soil moisture stress. Keatinge and Hughes (1980) reported that cv UW-26 responded more to supplemental irrigation than cv UW-17 with respect to dry seed yield per unit area. In the present analysis, where examination of cultivar x moisture-level interactions was of relatively low priority, no statistically significant difference in the response of the cultivars to irrigation was detected. However, examination of the treatment means (Table 3) suggests that cv UW-26 may in fact yield more than cv UW-17 under supplemental irrigation.

The large reduction in yield in response to moisture-stressed

Table 3. Analysis of variance of seed yield per unit area.

Analysis of variance		Dry seed (t/ha)		
Source	df	MS	F	P
Blocks	2	8.780	4.6	<10%
V	1	6.055	3.2	
M	1	29.878	15.8	< 1%
V*M	1	4.483	2.4	
Residual	6	1.889		
D(1st order)	1	2.974	19.4	<0.1%
Deviations	3	0.031	< 1	
D*main plots	12	0.214	1.4	
Residual	32	0.153		

Dry seed (t/ha)

Table of D means

Density	mean
200 000	1.47
300 000	1.57
400 000	1.84
500 000	1.95
600 000	2.07

SE = 0.113
SE of difference = 0.160
comparisons have 32 df.

Table of M means

Moisture-level	mean
I	2.48
C	1.07

SE = 0.251
SE of difference = 0.355
comparison has 6 df.

Table of treatment means

	Main plot treatment			
Density	171	17C	261	26C
200 000	1.48	0.81	2.72	0.88
300 000	1.79	0.94	2.50	1.04
400 000	2.06	0.99	3.15	1.17
500 000	2.28	1.16	3.04	1.31
600 000	1.86	1.25	3.98	1.19

95% confidence interval of a difference between two main plot treatments at the same or at different density levels = 1.36

conditions indicates the relative sensitivity of the cultivars employed in the trial to the environmental factors associated with drought. Table 4 shows the levels of moisture stress experienced. These appear to have

Table 4. Mean moisture stress (MPa) imposed per 15 cm layer of the surface soil (0-45 cm).

Cultivar	Density x 100 000	Moisture-level	Moisture stress imposed within	
			Vegetative phase	Reproductive phase
UW-17	2	C	0.24	0.85
	3	C	0.19	0.85
	4	C	0.24	0.75
	5	C	0.31	0.95
	6	C	0.31	1.13
	3	I	0.06	0.29
	5	I	0.07	0.21
UW-26	2	C	0.15	0.74
	3	C	0.27	0.66
	4	C	0.35	1.11
	5	C	0.33	1.00
	6	C	0.40	1.22
	2	I	0.08	0.38
	6	I	0.14	0.47

been approximately three times greater in the reproductive phase than those imposed in the vegetative phase. In addition, the highest moisture stress values experienced in the reproductive phase coincide with the highest density levels.

Discussion

The results given in Table 3 indicate that the potential yield of the selected cultivars was significantly influenced by soil moisture stress and by stand density within the range 200 000 to 600 000 plants/ha. An increase in stand density from the smallest to the largest values employed resulted in a yield increase of 0.64 t/ha. In plots where supplemental irrigation was not applied, this represents an approximate doubling of yield. This is achieved by the higher plant numbers per unit area more than compensating for the reduction in 100-seed weight and per plant productivity associated with closer plant spacing. However, the gain in yield achieved by increasing stand density from 200 000 to 600 000 plants/ha under moisture-stressed conditions was considerably less than that achieved by applying supplemental irrigation. At a planting density of 200 000 plants/ha, yields of more than 2 t/ha were obtained with supplemental irrigation. Similar yields were recorded by Wallis et al. (1979). Tables 1 and 2 indicate that the loss of yield due to moisture stress was a consequence of a reduction in the number of pods per plant with a subsdiary reduction in 100-seed weight. From the values shown in Table 4 it is possible to infer that if, during the reproductive phase, the mean moisture stress imposed in the upper 45 cm of the soil profile exceeds a value of 0.5 to 0.6 MPa, it is unlikely that yield potential will be realized. Available moisture at depths below 45 cm seem to be of reduced value to the cultivars, as withdrawals from deeper layers in the profile were insignificant. This implies either that root development at depth was inadequate to supply moisture demand or that nutrient availability was impaired by dry conditions in the surface soil layers.

Hughes et al. (1981) reported that the denser stands employed in this trial increased the seasonal proportion of solar radiation intercepted by the canopies. However, the yield response to this extra intercepted radiation is lower than expected on the basis of the relationship between seasonal interception and yield reported by Hughes et al. (1980). This indicates that stand density and moisture level may affect the efficiency of conversion of intercepted radiant energy into dry matter and the partitioning of dry matter within the plant.

In conclusion, it appears that under dry-season conditions in Trinidad, increases in stand density from 200 000 to 600 000 plants/ha result in seed yields increasing up to 1500 kg/ha. Within this range, the highest densities used did *not* significantly accentuate moisture stress effects. Reduction of moisture stress resulted in substantial increases in seed yield per unit area.

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Response to Row-to-Row and Plant-to-Plant Spacing in Pigeonpea

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Abstract

*Two field experiments were conducted at ICRISAT Center during the rainy seasons of 1978 and 1979 to evaluate the response of pigeonpea (*Cajanus cajan [L.] *Millsp.) to spacing. In 1978, the effects of six different plant-to-plant spacings within widely spaced rows were compared with cvs T-21 (early), C-11 (medium), and NP (WR)-15 (late) sown on a Vertisol. In 1979, the effects of combinations of three within-row and three between-row spacings were investigated with cvs T-21 (early) and BDN-1 (medium) on an Alfisol, and with cvs BDN-1 and C-11 (medium) on a Vertisol. In 1978, yields were significantly reduced at the lowest populations tested (13 000 and 27 000 plants/ha). In 1979, spacing had remarkably little effect on yield over a very wide range of populations (33000 to 1 333 000 plants/ha). Although raising the population density above that normally recommended resulted in little extra seed yield, the production of stem material and fallen leaves was very considerably enhanced. Since both these products are of increasing value as firewood becomes scarcer and nitrogenous fertilizers costlier, there may be economic advantages in growing pigeonpeas at unusually high plant populations.*

A number of spacing trials have been carried out with pigeonpeas (*cajanus cajan* [L.] Millsp.) in different countries, with different cultivars, different soil types, and in different seasons (Sen and Jana 1956; Mukherjee 1960; Singh et al. 1971; Hammerton 1971; Spence and Williams 1972; Akinola and Whiteman 1974; Saxena and Yadav 1975; Edwards 1975; Rathi and Tripathi 1978). In some, yield fell off at population densities above 20 000 to 40 000 plants/ha (e.g. Mukherjee 1960; Akinola and Whiteman 1974; and Hammerton 1971). In others, maximum yields were obtained with populations of over 400 000 plants/ha (Edwards 1975). The large variations in the results obtained presumably reflect the differences in the conditions under which the experiments were conducted.

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In India, pigeonpeas are normally sown at the beginning of the rainy season, often as an intercrop with rows several meters apart, though sole crops of medium and late types are generally grown with row spacings of 75 to 135 cm. Early-maturing cultivars are grown as a sole crop or as distinct rows in cotton (Pathak 1970). The spacing normally recommended for medium-duration cultivars in the Hyderabad area is 75 x 30 cm or 75 x 25 cm, giving plant populations of 44 000 and 53 000 plants/ha respectively. These are the spacings usually used in yield trials of breeding material in the rainy season at ICRISAT Center.

We carried out studies to evaluate the response of pigeonpea to row-to-row and plant-to-plant spacings in order to clarify the relationships between yield and the density and geometry of planting under the conditions in which pigeonpeas are being bred and tested at this Institute.

Materials and Methods

During the rainy season, two field experiments, one in 1978 on a Vertisol and another in 1979 on an Alfisol and a Vertisol were conducted at ICRISAT Center, Patancheru, India (17.5°N, 78.5°E, at 545 m altitude). The soils are poor in nitrogen and phosphate but generally have adequate available potash. The mean annual rainfall at ICRISAT Center is 760 mm in a bimodal distribution with an average of 86% falling between June and October. Annual rainfall during 1978 and 1979 was 1142 and 732 mm respectively. In 1978, the rainfall was unusually heavy in July and August, and in 1979 the September rainfall was well above the long-term average for those months.

In 1978, the trial was sown on 2 July on a Vertisol with three cultivars, T-21 (early); C-11 (medium), and NP(WR)-15 (late). T-21 was planted with 75 cm between rows, whereas C-ll and NP(WR)-15 were planted with 150 cm between rows. The plant-to-plant spacing treatments were: 2.5, 5, 10, 20, 30, and 50 cm. All the cultivars were planted as separate experiments in four replicates (Plot size 4.5 x 8.2 m, harvested area 26 m^2). Data from each cultivar were analyzed separately as a randomized block design.

In 1979, two medium-duration cultivars (C-11 and BDN-1) were planted on 28 June on a Vertisol. One early (T-21) and one medium-duration (BDN-1) cultivar were planted on 9 July on an Alfisol. The design of the experiment was split plot with cultivars as main plot treatments and spacings as subplot treatments in three replicates (plot size 9 x 6 m, harvested area 36 m^2). The spacing treatments were varying row-to-row (30, 60, and 120 cm) and plant-to-plant (2.5, 10, and 25 cm) spacings to give a range of eight different populations 133 000 to 1 333 000 plants/ha) with nine possible combinations of spacing (Table 1). At the time of harvest, yield, yield components, stem weights (main stem + branches), and fallen leaf weights were recorded for each subplot. The harvest index was corrected to take the fallen leaves into account and was determined by the formula: grain dry weight ÷ total dry weight including fallen leaves.

A basal dose of 18 kg/ha N and 206 kg/ha P_2O_5 as diammonium phosphate was applied to the newly developed field used in 1978; and 18 kg/ha N and

Table 1. Summary of treatments and methods for two spacing trials with pigeonpea at ICRISAT Center.

Year	Soil	Spacing (cm)	Plant population(000/ha)				
			Planned	Final			
1978	Vertisols			T-21			
		75 x 2.5	533	441			
		75 x 5	267	217			
		75 x 10	133	132			
		75 x 20	67	61			
		75 x 30	44	43			
		75 x 50	27	25			
				C-11	NP(WR)-15		
		150 x 2.5	267	242	234		
		150 x 5	133	123	118		
		150 x 10	67	67	65		
		150 x 20	44	33	33		
		150 x 30	27	22	21		
		150 x 50	13	13	13		
1979	Vertisols and Alfisols			Vertisol		Alfisol	
				C-ll	BDN-1	T-21	BDN-1
		30 x Z.5	1333	1002	1015	777	746
		30 x 10	333	317	322	277	263
		30 x 25	133	126	127	126	114
		60 x 2.5	666	563	526	458	411
		60 x 10	166	165	164	140	156
		60 x 25	66	65	65	63	63
		120 x 2.5	333	270	269	226	281
		120 x 10	83	81	82	73	74
		120 x 25	33	33	33	31	31

46 kg/ha P_2O_5 as diammonium phosphate was applied to the fields used in 1979, which had been under other crops in previous years. The area was kept weed-free by periodic hand weeding. Insect pests were controlled by four sprays of 0.35% endosulfan.

Results

In 1978, when the plants were grown only in widely spaced rows, the yield was significantly higher at the closer plant-to-plant spacings (Table 2). In the early cv T-21, the yield continued to increase right up to the

Table 2. Effects of plant-to-plant spacings on seed yield of three cultivars of pigeonpea grown on Vertisol, rainy season 1978.

Plant-to-plant spacing (cm)	Seed yield (kg/ha)		
	cv T-21	cv C-11	cv NP (WR)-15
2.5	1449	1738	1096
5	1144	1737	997
10	1077	1594	1105
20	863	1511	1079
30	850	1300	855
50	730	1157	777
SE±	99	53	36
LSD (at 0.05)	300	160	109
CV (%)	20	7	7

closest spacing, whereas in the medium cv C-11 there was no significant difference in yield between 10, 5, and 2.5 cm plant-to-plant spacings, while the late cv NP(WR)-15 had an adequate population at 20 cm plant-to-plant spacing. These results indicate that the plants with longer growth duration had a better ability to compensate for low planting densities.

In 1979, on the Vertisol there was no significant difference in the mean yields of over a remarkably wide range of population densities, from 33 000 to 666 000 plants/ha. Only at the very close spacing of 30 x 2.5 cm, giving a population density of 1 333 000 plants/ha, was the yield significantly reduced (Table 3).

In agreement with the results for cv C-ll planted in wide rows in 1978 (Table 2), this cultivar grown at 120 cm between-row spacing gave a significantly lower yield at the widest plant-to-plant spacing of 25 cm than at the narrow spacing of 2.5 cm; these yields were 1132 and 935 kg/ha respectively.

On the Alfisol in 1979, as on the Vertisol, the plants showed a very considerable plasticity in response to spacing, and the yields were similar over the whole range of population densities (Table 3). The one exceptional feature of these results was that cv BDN-1 produced a

Table 3. Effect of plant population on yields and harvest index of pigeonpea grown on a Vertisol (means for cvs BDN-1 and C-11) and an Alfisol (means for cvs T-21 and BDN-1) rainy season 1979.

	Plant population (000/ha)									LSD at
	33	66	166	83	166	333	333	666	1333	0.05
	Spacing (cm)									
	120x25	60x25	30x25	120x10	60x10	30x10	120x2.5	60x2.5	30x2.5	
Vertisol										
Grain yield (kg/ha)	1019	1021	1101	1061	1084	1095	1151	1069	900	182
Stem wt. (kg/ha)	975	1663	2003	1126	2095	1918	1404	2219	2450	593
Fallen leaf wt.(kg/ha)	877	1559	1645	1075	1528	2192	1718	2404	2459	313
Corrected harvest index(%)	36.4	25.7	20.6	32.4	27.7	21.7	25.1	19.0	16.3	2.88
Alfisol										
Grain yield (kg/ha)	1031	1149	1178	1110	1394	1113	1152	1119	1091	185
Stem wt. (kg/ha)	660	1489	1899	1061	1676	1894	1401	2150	2193	664
Fallen leaf wt.(kg/ha)	554	844	1146	713	1201	1366	1054	1335	1777	449
Corrected harvest index(%)	39.5	29.5	24.1	33.9	29.2	23.3	28.7	22.4	20.0	3.61

significantly higher yield at a spacing of 60 x 10 cm than at any other spacing. This may indicate a sharply defined optimum (Table 3), or it may be due to random factors.

On both Vertisol and Alfisol, although the yield remained more or less constant over a wide range of populations, the weight of the stems and fallen leaves increased with increasing population density; consequently, the harvest index decreased (Table 3).

Between-row spacing had a clear effect on stem weight though it had relatively little effect on yield. The stem weights were lower at 120 cm than at 30- or 60-cm row spacing at similar population densities (Table 3).

The yield levels were generally higher on Alfisol than Vertisol, as were the weights of the stems. By contrast, the weights of fallen leaves were greater on Vertisol than Alfisol. On both soil types, spacing had little effect on seed number per pod or 100-seed weight, although there was a slight reduction in the former on Vertisol, and in the latter on Alfisol at the closest spacings.

Discussion

The results show that under the conditions tested, pigeonpeas have a remarkable ability to adapt themselves to a wide range of population densities and planting geometries. However, the late rains in 1979 and the relatively deep soils on which they were grown may not enable these conclusions to be generalized to conditions under which water may be more severely limiting, for example in shallow Alfisols, where high plant populations may lead to yield reductions.

Perhaps the most interesting feature of the results is that as populations were increased above the 40 000 plants/ha, commonly recommended for medium-duration cultivars, although there was little effect on grain yield, the yields of stalks and fallen leaves went up (Table 3). Both these products are of economic value; the stalks for use as firewood, and the fallen leaves, which have a nitrogen content of around 1.5% (Sheldrake and Narayanan 1979), as a means of enriching the soil. Only detailed economic calculations would show whether under given conditions the economic returns from these products would make the use of higher seed rates profitable. But in view of the rising cost of both firewood and nitrogenous fertilizer, this possibility may merit serious consideration, at least in situations where this crop is grown in relatively deep soils.

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Intercropping Studies with Pigeonpea

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Abstract

A field experiment to study the suitability of intercrops in pigeonpea was conducted at the Agricultural Research Station, Badnapur, of Marathwada Agricultural University, Parbhani, on medium black soils in 1979-80. Results indicated that grain yield of pigeonpea was not affected adversely by intercrops such as mung bean, soybean, and groundnut, while pearl millet as an intercrop in normal as well as in paired-row planting of pigeonpea retarded the yield significantly.

Further analysis showed that grain yield equivalent was increased significantly by groundnut intercropping (pigeonpea paired row two rows of groundnut) (2:2) over all the remaining treatments except pigeonpea paired row + one row of groundnut (2:1) treatment. Pigeonpea paired row/one row of pearl millet (2:1), pigeonpea : groundnut one row each alternate (1:1) and pigeonpea paired row/one row of mung bean (2:1) were the next best treatments, proved significantly superior to normal as well as paired row planting of pigeonpea and the other intercropping treatments.

Intercropping of short-duration, high-yielding genotypes of either pulse or oilseed crops has become feasible. Earlier experimental results indicated that intercropping of mung bean (Giri and De 1977, 1978); urd bean (Kalyan Singh et al.1978); mung and urd (IARI 1971; Saraf et al. 1975); mung, urd, and soybean (Surinder Singh and Singh 1976; Mahatim Singh et al. 1977; Saxena et al. 1977; Saxena and Yadav 1979; Mahatim Singh et al. 1979; in between pigeonpea rows 50 to 70 cm apart had no adverse effect on seed yield of pigeonpea. On the contrary, these intercrops give an additional yield varying with crop and season. With this information in view and considering the importance of groundnut and pearl millet in the kharif cropping pattern of the Marathwada region of Maharashtra, an experiment was carried out to find which of the intercrops--mung, soybean, groundnut, or pearl millet-- was best suited to the planting pattern chosen.

Materials and Methods

The experiment was conducted during 1979-80 under the All India

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Coordinated Pulse Research Project at the Agricultural Research Station, Badnapur, of Marathwada Agricultural University, Parbhani. The soil of the experimental plot was medium black, well drained, poor in N, medium in P_2O_5 and rich in K_2O content. The 14 treatments comprised sole pigeonpea, cv BDN-1, normal planting (50 cm x 20 cm) and paired rows (30/70 x 20 cm), and pigeonpea intercropped in various planting patterns with mung, soybean, groundnut, and pearl millet (Table 1). These 14 treatments were replicated four times in a randomized block design. A plant population of 100 000 plants/ha of the main crop (pigeonpea) was maintained in all the treatments. The plant populations of mung, soybean, groundnut, and pearl millet were maintained 200 000, 220 000, 132 000, and 220 000 plants/ha, respectively, regardless of planting method by adjusting plant-to-plant distance. Fertilizers were drilled at the rate of 25 kg N + 50 kg P_2O_5/ha to all the treatments prior to sowing.

The main crop and intercrops were sown on 28 June 1979; harvesting of mung, soybean, groundnut, pearl millet, and pigeonpea was done on 1 Sept 1979 (65 days after sowing); 15 Oct 1979 (110 days after sowing); 15 Oct 1979 (110 days after sowing); 15 Oct 1979 (110 days after sowing); and 15 Dec 1979 (170 days after sowing), respectively. During the period of experimentation 859.10mm precipitation was received in 46 rainy days.

Results and Discussion

Grain yield of pigeonpea, intercrops, grain yield in terms of pigeonpea (grain equivalent) and data on growth and development of pigeonpea under different intercropping treatments are shown in Table 1.

Grain yield of pigeonpea showed significant differences among treatments. Intercropping with mung (2:1), with soybean (1:1 and 2:1), and with groundnut (1:1 and 2:2) did not affect the pigeonpea yield significantly in comparison to solid pigeonpea normal planting. Intercropping in the remaining planting ratios reduced the grain yield of pigeonpea significantly over solid pigeonpea. Intercropping with pearl millet in all the ratios (1:1, 2:1, and 2:2) also reduced grain yield over pigeonpea paired row planting. As Table 1 indicates, intercrops such as mung, soybean, and groundnut did not interfere with the normal growth of pigeonpea, while quick-growing pearl millet competed with pigeonpea. The reduction in yield of pigeonpea may be attributed to the shading effect of pearl millet foliage on pigeonpea. Similar results on pigeonpea with cereals intercrops such as sorghum and maize were reported earlier by Saraf et al. (1975). Further, they also observed that the yield of pigeonpea was not adversely affected by intercropping of mung, urd, cowpea, and soybean because these are short in stature, and offer less competition for light and available moisture. These observations were successively confirmed by Surinder Singh and Singh, (1976); Mahatim Singh et al. (1977); Saxena et al. (1977); Saxena and Yadav (1979), and Mahatim Singh et al. (1979).

The total grain yield of pigeonpea (grain yield equivalent, i.e., sum of actual yield of pigeonpea in the mixture and the yield of intercrop converted into pigeonpea equivalent on the price value basis) was influenced significantly by different intercropping treatments. Pigeonpea

Table 1. Yield of pigeonpea, various intercrops, grain equivalents (kg/ha) and growth and development of pigeonpea.

Treatments	Grain pigeon-pea	Yield inter-crop	Grain equiv-alent	Plant height (cm)	Bran-ches/plant	Pods/plant	'1000' seed wt.(g)
Solid pigeonpea normal planting	1019	-	1019	126.1	7.3	68.7	105.0
Pigeonpea/green gram (1:1)	831	193	1038	123.5	6.7	60.4	105.0
Pigeonpea/soybean (1:1)	1036	100	1107	128.0	8.5	66.8	104.0
Pigeonpea/groundnut (1:1)	926	813	1520	124.6	6.4	66.5	101.0
Pigeonpea/pearl millet (1:1)	413	1983	1134	123.0	6.4	50.8	98.0
Pigeonpea paired row planting	946	-	946	125.3	7.9	68.4	101.2
Pigeonpea paired/one row of green gram (2:1)	1039	233	1293	123.8	7.4	63.9	100.2
Pigeonpea paired/one row of soybean (2:1)	1031	93	1164	122.2	7.2	67.4	101.1
Pigeonpea paired/one row of groundnut (2:1)	849	1300	1795	125.4	7.0	48.6	103.0
Pigeonpea paired/one row of pearl millet (2:1)	684	2493	1591	121.1	6.1	45.0	99.0
Pigeonpea paired/two rows of green gram (2:2)	857	186	1060	124.0	7.5	48.3	100.7
Pigeonpea paired/two rows of soybean (2:2)	871	100	945	130.2	6.8	50.4	100.0
Pigeonpea paired/two rows of groundnut (2:2)	951	1293	1901	131.3	7.0	57.0	102.5
Pigeonpea paired/two rows of pearl millet (2:2)	290	1993	1015	119.4	6.3	23.4	95.0
SE ±	47.33		76.00				
LSD (5%)	133.33		210.6				

Prevailing prices (Rs/kg): pigeonpea 2.75; mung 3.00; soybean 2.00; groundnut 2.00; pearl millet 1.00

paired row + two rows of groundnut *(2:2)* resulted in a significantly higher grain yield equivalent (1901 kg/ha) than all other treatments, except pigeonpea paired row + one row of groundnut (2:1), which was the next best combination (grain yield equivalent 1795 kg/ha), Lowest grain yield equivalent (945 kg/ha) was obtained from pigeonpea paired row + two rows of soybean (2:2), which may be due to low yields of pigeonpea as well as soybean.

Thus in general, pigeonpea intercropped with groundnut (2:2) appears to be most remunerative, followed by pigeonpea intercropped with groundnut in 2:1 and 1:1 ratios and with pearl millet in 2:1 ratio.

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Pigeonpea Genotype Evaluation for Intercropping

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Abstract

Three years' data are presented from a wide range of pigeonpea genotypes intercropped with sorghum. The relative importance of a number of plant characters as possible determinants of yield in intercropping is examined. The extent to which intercrop performance of a given genotype can be predicted from its sole-crop performance is considered.

Intercropping research has mainly emphasized the identification of compatible crops and optimum plant populations and spatial arrangements; relatively little attention has been paid to identifying suitable genotypes. The improvement of crop genotypes has mostly been based on testing and selection under sole cropping, irrespective of the cropping system in which the genotypes are finally to be grown. Such an approach is questionable, particularly in the case of intercropping where the competition of an associated crop can alter genotype behavior.

Some studies have indicated that the intercrop performance of the dominant species can be highly correlated with sole-crop performance (Baker 1974; Francis et al. 1976); for the less competitive or dominated species, intercrop yields have been poorly correlated with sole-crop yields (wein and Smithson 1979; Francis et al. 1976). This suggests that higher yielding genotypes in sole cropping are not necessarily the higher yielders in intercropping and it emphasizes the need for selecting genotypes specifically for intercropping. However, Francis et al. (1978a, 1978b) have emphasized the advantages of sole-crop selection because of higher yields and greater yield differences, and for convenience in handling. Wein and Smithson (1979) suggested that early generations of cowpea for intercropping with maize could be screened under sole cropping for characters such as disease and insect resistances, plant vigor, etc., but later generations should be tested with maize.

Pigeonpea is intercropped with diverse crops, but sorghum/pigeonpea is especially important in rainfed areas of India, where sorghum is the staple food. Thus a series of experiments was established to:

* Explore the scope for selecting pigeonpea genotypes suitable for intercropping with sorghum,

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* Farming Systems Research Program; ** Pulse Improvement Program, ICRISAT.

- examine to what extent selection under sole cropping is valid for intercropping, and
- identify plant characters associated with good intercropping performance.

Materials and Methods

Pigeonpea genotypes of contrasting growth patterns were evaluated during 1977-79 in sole cropping and intercropping with a standard sorghum, cv CSH-6. The 1977 experiment was flat-planted on a medium Vertisol and included 17 pigeonpea genotypes in main plots, divided into two subplots for sole cropping and intercropping. Intercropping was in a standard row arrangement of 1 pigeonpea:2 sorghum at optimum sole-crop populations of both crops. The 1978 experiment was on a Vertisol on a 150-cm broadbed-and-furrow system. A single row of pigeonpea was planted in the center of the bed, and in intercropping one row of sorghum was added on either side at 45 cm. The design was the same as in the previous year, but a few genotypes were changed, and the total was increased to 19. In 1979, both a Vertisol and an Alfisol experiment were conducted on broadbeds. The layout was slightly modified, the sole and intercropping systems being in main plots and the genotypes in subplots. The Vertisol experiment contained 16 genotypes; the Alfisol, 12, of which eight were medium-maturing and common to both trials and the remaining four were early (140-160 days) and well adapted to Alfisols. All experiments had four replicates, except the Alfisol experiment in 1979, which had three.

All experiments were planted during the fourth week of June, and both crops were sown at the same time. In 1977, pigeonpea was thinned to 29.5 cm in rows, which gave a population of 25 000 plants per ha; however, a population of 40 000 plants per ha was used in later years. Sorghum was thinned to a stand of 167 000 plants per ha in sole and the same population was maintained in intercropping by adjusting within-row spacing. The trials were fertilized basally with 52 kg P_2O_5/ha and sorghum was later topdressed at 80 kg N/ha. Sorghum was harvested 100 to 105 days after sowing. The area was kept weed-free by hand weeding, and Thiodan(0. 35%) was sprayed on pigeonpea two or three times at podding stage to control *Heliothis* borer. Harvest areas were not less than 20 m_2.

Besides yield and yield components, a number of plant characters were measured on pigeonpea in sole cropping. These included branch number, branch length, angle of branch, canopy width at different heights, and light interception just before active growth and at full canopy spread.

Results and Discussion

Grain Yield

Grain yield of sorghum and pigeonpea genotypes in each of the 3 years' experiments are presented in Tables 1 and 2. Sorghum yields were good in 1977 and 1978 (Table 1), and exceptionally good in 1979 (Table 2) as a

Table 1. Yield and land equivalents of pigeonpea genotypes during 1977 and 1978.[a]

Genotype	1977 Yield (kg/ha) Sole	1977 Yield (kg/ha) Intercrop	1977 Land Equivalents LEP	1977 Land Equivalents LES	1977 Land Equivalents LER	Residuals
ICP-185-9	1699	850	0.51	0.96	1.47	140
ICP-6982-6	1525	842	0.57	0.99	1.56	116
ICP-1-6	1428	740	0.52	0.92	1.44	51
ICP-2223-3	1407	815	0.58	0.91	1.50	128
ICP-1	1389	757	0.57	0.85	1.43	101
ICP-2223-1	1376	885	0.63	0.84	1.48	234
ICP-830-2	1323	799	0.63	0.98	1.62	77
ICP-3156-2	1296	619	0.60	0.85	1.45	- 35
ICP-1951-1	1264	585	0.46	1.00	1.46	-145
ICP-3048-10	1226	619	0.50	0.95	1.45	- 84
ICP-3198-12	1222	512	0.42	0.82	1.24	-123
HY 3C-E-20	1185	463	0.36	0.88	1.25	-207
HY 3C-E-12	1169	503	0.43	0.84	1.27	-144
ICP-2037-7	1148	661	0.59	0.99	1.58	- 64
ICP-185-8	1106	718	0.66	0.81	1.47	86
ICP-1196-2	1063	530	0.49	0.92	1.42	-158
ICP-1900-11	1058	720	0.73	0.93	1.66	27
Mean	1287	683	0.54	0.91	1.46	0
LSD(0.05) main effect of genotypes						
Systems		74				

Genotype	1978 Yield (kg/ha) Sole	1978 Yield (kg/ha) Intercrop	1978 Land Equivalents LEP	1978 Land Equivalents LES	1978 Land Equivalents Total	Residuals
ICP-6982-6	1973	1625	0.82	0.90	1.72	156
ICP-2223-1	1904	1579	0.83	0.96	1.79	195
ICP-2223-3	1848	1610	0.87	0.94	1.81	200
HY 3C	1810	1300	0.72	0.89	1.61	-179
ICPL-76	1808	1368	0.76	1.00	1.76	35
ICPL-6	1768	1300	0.74	0.96	1.70	- 80
C-11	1761	1489	0.85	0.95	1.80	91
LRG 30	1758	1538	0.88	0.96	1.84	162
74240-F5M	1743	1464	0.84	1.02	1.86	172
ICPL-78	1735	1452	0.84	0.95	1.79	53
AS 71-37	1708	1392	0.82	0.95	1.77	- 3
ICP-1	1660	1243	0.75	0.97	1.72	-128
ICPL-79	1655	1358	0.82	0.94	1.76	- 49
BDN-1	1610	1381	0.86	0.92	1.78	- 53
ICP-185-9	1582	1331	0.84	1.00	1.84	7
ICPL-75	1581	1165	0.74	0.97	1.71	-200
ICPL-77	1463	1391	0.95	0.88	1.83	-104
ICPL-80	1432	1050	0.73	1.04	1.77	-216
74252-F4M	1430	1307	0.91	0.97	1.88	- 57
Mean	1696	1386	0.82	0.95	1.78	0
LSD(0.05) main effect of genotypes		243				
Systems		50				

a. Sorghum yield as sole crop was 3952 kg/ha in 1977 and 4588 kg/ha in 1978.

Table 2. Yield and land equivalents of pigeonpea genotypes during 1979.[a]

Vertisols

Genotype	Yield (kg/ha) Sole	Yield (kg/ha) Intercrop	Land Equivalents LEP	Land Equivalents LES	Land Equivalents Total	Residual
ICP 185-9	1648	882	0.54	0.84	1.38	54
BDN-1	1502	886	0.59	0.98	1.57	249
HY 4	1376	629	0.46	0.88	1.34	-143
ICP-1	1330	730	0.55	0.97	1.52	75
ICP-6982-6	1307	988	0.76	0.85	1.61	172
IGDT-1	1286	508	0.40	0.96	1.36	-154
C-11 (H)	1285	825	0.64	0.97	1.61	176
ICPL-77	1270	401	0.32	0.91	1.23	-331
C-11	1270	914	0.72	0.91	1.63	188
ICP-2223-3	1224	880	0.72	0.95	1.67	207
ICP-1-6	1220	780	0.64	0.90	1.54	29
LRG 30	1142	911	0.79	0.87	1.66	122
ICPL-76	1140	686	0.60	0.96	1.56	21
IGDT-2	948	624	0.66	0.94	1.60	- 67
HY 3C	666	448	0.67	0.98	1.65	-189
ICP-7035	431	303	0.69	0.92	1.61	-412
Mean	1190	712	0.61	0.92	1.53	0
LSD (0.05) Genotypes within a system		545				
Across systems		660				

Alfisols

Genotype	Yield (kg/ha) Sole	Yield (kg/ha) Intercrop	Land Equivalents LEP	Land Equivalents LES	Land Equivalents Total
AS 71-37	2095	1119	0.53	0.97	1.50
BDN-1	2067	780	0.38	0.97	1.35
HY 4	1697	587	0.35	0.77	1.12
IGDT 2	1642	922	0.56	0.80	1.36
ICP-185-9	1594	951	0.60	0.76	1.36
ICP-2223-3	1580	785	0.50	0.86	1.36
C-11	1454	1062	0.73	0.81	1.54
ICP-6982-6	1347	1097	0.81	0.85	1.66
ICP-1	1222	775	0.63	0.86	1.49
T-21	818	461	0.56	0.93	1.49
Pusa Ageti	810	497	0.61	0.88	1.49
DL 74-1	778	312	0.40	0.85	1.25
Mean	1425	779	0.55	0.86	1.41
LSD (0.05) Genotypes within a system		320			
Across systems		354			

a. Sole crop of sorghum yielded 5752 kg/ha on Vertisol and 6342 kg/ha on Alfisol.

result of well-distributed rainfall July to September. Although "full" yield of sorghum was not always obtained in intercropping, the presence of pigeonpea did not cause statistically significant reductions in sorghum yield, even when pigeonpea growth was excellent and yields as high as 1500 to 2000 kg/ha were obtained. The mean relative yield (land equivalent ratio or LER) of sorghum in intercropping was highest in the wet year of 1978 (0.95) and lowest on the Alfisol in 1979 (0.86). Sorghum yield with the different pigeonpea genotypes varied from 76 to 100% of the sole-crop yield and, though not statistically significant, there was evidence of a negative correlation between sorghum yield and pigeonpea yield. Thus it seem likely that the lower sorghum yields with certain genotypes could have been due to greater pigeonpea competition.

Pigeonpea yield was quite good with all except the *very* compact (HY-3A, ICP-7035; and early genotypes (T-21, Pusa Ageti, DL 74-1). Yields were generally better in the high-rainfall season of 1978. Intercropping reduced pigeonpea yield significantly, but the degree of yield reduction varied among genotypes and also between seasons. In 1977, yields for different genotypes ranged from 1058 to 1700 kg in sole and 436 to 885 kg in intercropping. The genotype x system interaction was not significant, but intercropping yields as a proportion of sole yields varied from 36 to 73%. Taking ICP-1 as a check genotype that was common throughout all four trials, four genotypes yielded higher than this in sole cropping, while five yielded higher in intercropping; only three were above ICP-l in both the systems. In the 1978 experiment, yields varied between 830 and 1970 kg/ha in sole crop and 790 and 1625 kg in intercropping; the interaction of genotype x system was again not significant. The relative yield of pigeonpea in intercropping was higher compared with the previous year and the range for different genotypes was much less (73 to 95%); these high relative yields were no doubt due to the better moisture conditions in the early part of the postrainy season. In sole cropping, 11 genotypes yielded higher than ICP-l but in intercropping five others were also higher yielding.

The system x genotype interaction was significant in both the trials of 1979, suggesting differences in the behavior of genotypes in sole and intercropping. In the Vertisol trial, three genotypes gave higher yields than ICP-l in sole cropping; only two of these maintained superiority in intercropping, but six others were also higher yielding than ICP-1 in intercropping. In the Alfisol trial, except for the early cultivars, all the medium ones outyielded the check, although the relative order of these genotypes was different in sole cropping and intercropping. The relative yields in intercropping varied widely in 1979 (0.32 to 0.72).

Considering the performance over three seasons, the genotypes ICP-185-9, ICP-6982-6, ICP-1-6, and ICP-2233-3 had high yield potential over the ICP-1 check and over the well-proven cultivars C-11 and BDN-1. The genotype ICP-185-9 was top in sole cropping in 2 years but did not rank so high in intercropping; the genotypes ICP-6982-6, ICP-1-6, and ICP-2233-3 were particularly promising for intercropping. The total land equivalent ratios of the medium-duration genotypes generally showed a similar order in 1977 and 1979 and varied within 1.23 and 1.67, primarily depending on the contribution of pigeonpea. They were *very* high in 1978, ranging from 1.61 to 1.88, because of high pigeonpea contribution.

Relationship between Intercrop and Sole-crop Performance

Regressing the pigeonpea yields in intercropping on the yields in sole cropping showed that intercrop performance was to some extent a reflection of sole-crop performance. However, sole-crop yields accounted for only 40% of variation in intercrop yields in 1977, 51% in 1978, 42% in Vertisols 1979 and 46% in Alfisols 1979, so considerable variation in intercrop yield remained unexplained. This suggests that specific plant characters might be associated with intercrop performance. The correlation between the rank orders of the genotypes in sole and intercropping was significant only in 1977 and 1978 (r = 0.67**) suggesting that, especially in a dry year such as 1979, the best genotypes in sole cropping are not always the best in intercropping.

The land equivalent ratios of pigeonpea in intercropping showed no relationship with sole-crop yields, indicating that the proportion of sole-crop yield that a genotype produces in intercropping is not dependent on the level of its sole-crop yield. This may indicate that intercropping performance is at least partly dependent on some plant characters not associated with sole-crop yield. For example, all the four top yielders in 1977 had an average LER of 0.55 but the lowest yielder, ICP-1900-11, which was more compact initially and spread later, gave the highest LER of 0.73; however, compactness per se did not favor high LERs because the two selections of HY3C which did not spread at all gave poor LERs. Such a clear distinction was not apparent in 1978 because of less variation in LERs, but a similar pattern could still be seen. The very compact HY-3C gave the lowest LER of this season and the semi spreading 74252-F4M and ICPL-77 gave the highest LERs. Genotypes like ICP-6982-6, C-ll, and LEG-30, which are highly spreading and bear long fruiting branches, gave intermediate values. In the experiments of 1979, the average LER value of compact (HY-4, HY-3, and ICP-7035) and determinate (IGDT-1 and IGDT-2) genotypes was much lower than that of the spreading genotypes (ICP-6982-6, C-11, and LRG-30). The drastic change in LER of ICPL-77 between 1978 and 1979 was due to segregation of the material.

Identification of Plant Characters

The identification of plant characters associated with good intercropping performance could be useful for selecting genotypes while evaluating under sole cropping and for identifying appropriate breeding parents. Thus the characters measured in the sole crops of the three Vertisol experiments were correlated with pigeonpea yield. Few correlations between individual characters and intercrop pigeonpea yield were significant in 1978, probably because of the good growing conditions and high correlation with sole-crop yield. In the other experiments, some of the characters correlated with intercrop yield were: branch number (primary, secondary at final harvest or total number at sorghum harvest), primary branch length, and light interception. Multiple correlations showed that the 40 to 51% variation in intercrop yield that could be accounted for in terms of sole-crop yield could be increased to 66 to 88% with the inclusion of primary or secondary branches and height or harvest index. The number and length of branches and the canopy spread, as indicated by light interception and canopy width, seemed important in determining the land equivalent ratio (relative yield) of pigeonpea. All these relationships suggest that genotypes that produce more and longer branches and spread well are better suited to intercropping.

It was mentioned earlier that there was some eivdence of a negative relationship between intercrop sorghum yield and intercrop pigeonpea yield, suggesting that the decreases in sorghum yield might be due to greater pigeonpea competition. Thus it might be important to ensure that pigeonpea genotypes selected for higher yields in intercropping do not offset their advantages by producing greater decreases in sorghum yield. Tables 1 and 2 give, for each genotype in the Vertisol experiments, the residuals of the linear regression line of pigeonpea intercrop yield on sorghum intercrop yield. A positive residual indicates that a genotype lies above this line, i.e., it has a higher yield than expected for a given decrease in sorghum yield. This could be a parameter to consider in identifying intercropping genotypes; thus, purely as an example, the two highest yielders in sole cropping in Table 2, ICP-185-9 and BDN-1, gave very similar yields in intercropping but the higher positive residual of BDN-1 (due to less reduction in sorghum yield) might make it the better overall prospect.

Efficiency of Selection under Sole Cropping

Using the data presented here, and additional data from the ICRISAT pigeonpea breeding program, Green et al.(1980) have indicated that selection under sole cropping at selection pressures of 20% and 33% are only 41% and 55% effective, respectively, i.e., only 41% and 55% of the genotypes identified in sole cropping were those identified in intercropping. Even with a low selection pressure of 50%, only 65% efficiency was achieved with the present data. Bearing in mind that these efficiencies do not take into account any effects on the yield of the other crop, the case for selecting actually in the intercropping situation needs to be given due consideration; it should also be appreciated that using an "additional" sorghum intercrop as described here, means that no greater land areas are required for selecting in intercropping compared with sole cropping. Perhaps a suitable compromise would be selection in sole cropping in the early generations but in intercropping from, say, the F_3 generation.

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Pigeonpea Trials in the Nira Valley of Maharashtra

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Abstract

The Nira River Valley of Maharashtra receives only about 200 mm of rainfall from June 1 to September 15, and an additional 250 mm from 15th September to about the end of October. As a result of this peculiar rainfall pattern, the monsoon crops not only need irrigation during their growth period, but they are also damaged by the late rains of September and October, just when they are ready for harvest. Trials conducted in this region from 1975 to 1979, showed that early pigeonpea varieties that matured in the first week of November were ideal as a monsoon crop in this area. With yield levels of around 2000 kg/ha and price levels exceeding Rs .250/100 kg, pigeonpea was found to be economically more remunerative than practically all the other traditional monsoon crops such as hybrid sorghum, hybrid pearl millet, hybrid maize, groundnut, or sesame.

The Nira River Valley of Maharashtra, comprised of some low rainfall areas of Pune, Satara, and Sholapur districts, has an unusual rainfall pattern. The precipitation during the southwesterly monsoon (1 June to 15 Sept.) totals only about 200 mm, while the short period between 15 Sept. and 31 Oct. is marked by *very* heavy rains, accounting for almost 250 mm (Table 1). Because this region is irrigated by the Nira Canals and also by a number of lift-irrigation schemes, the cultivators are not much hampered by the low precipitation during the monsoon months. The heavy late rains, however, invariably damage a *Kharif* (rainy-season) crop just when it is ready for harvest. As a result of this rainfall pattern, the farmers *are* generally reluctant to grow any crop during the rainy season.

With a view to determining the proper kharif crop for this area, a multilocational trial was conducted by the Nimbkar Agricultural Research Institute during the 3 years from 1977 through 1979. The crops tested were hybrid sorghum, hybrid maize, hybrid pearl millet, Spanish groundnut, jute, and pigeonpea. Table 2 gives the monetary value of these crops in Rs/ha, immediately after harvest. Pigeonpea consistently gave the highest gross returns in all 3 years; net profit from pigeonpea would be proportionately even higher, because the cost of growing of pigeonpea would be lower than all the other crops.

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Table 1. Average weekly rainfall at Phaltan, 1975 to 1978.

Month	International meteorological week	Rainfall (mm)	Month	International meteorological week	Rainfall (mm)
	14			32	10.05
	15	2.95		33	5.25
Apr	16	5.50	Aug	34	2.77
	17			35	20.60
	18	1.47			
	19	9.55		36	4.20
	20			37	5.60
May	21	9.75	Sept	38	31.70
	22	11.35		39	89.32
	23	30.60		40	48.65
	24	28.57		41	12.67
June	25	19.60	Oct	42	20.72
	26	12.30		43	12.85
				44	28.17
	27	7.20		45	7.30
	28	23.30		46	1.62
July	29	6.60	Nov	47	39.62
	30	20.40		48	14.07
	31	5.89			

Table 2. Gross value of kharif crops tested over different locations and years.

Crop	Gross value (Rs/ha) at		
	Rajale	Taradgaon	Widni
1977			
Maize	1922	1904	1900
Pearl millet	2328	1914	3015
Sorghum			2531
Peanut	7912	4125	
Pigeonpea	8528	3490	3957
LSD	1384	882	827
		Widni	Tambmal
1978			
Maize		1602	1339
Pearl millet		1996	1665
Sorghum			2080
Pigeonpea		3520	4040
LSD		509	400
			Tambmal
1979			
Maize			2160
Jute(JR0 878)			4184
Jute(JR0 7447)			4758
Pigeonpea (TT-6)			6325
Pigeonpea (T-21)			5846
LSD			1310

Because irrigation is available in this region, farmers like to grow two crops a year; but since the local pigeonpea matures only at the end of January, this crop is not grown extensively, as it makes double cropping impossible. We therefore conducted a trial to compare the performance of two early varieties (T-21 and TT-6) with the local one. The early varieties matured in the first week of November, which makes it possible to raise a second crop of wheat, gram, or sunflower after harvesting pigeonpea. The results of this trial, presented in Table 3, show that both the early-maturing varieties yielded higher than the local variety.

Large-scale demonstration plots have been planned for the 1980 kharif season in order to popularize pigeonpea in this region.

Table 3. Comparison of two early-maturing varieties with late-maturing local variety of pigeonpea.

Variety	Seed yield (kg/ha)	100-qrain wt (g)	Days to 50% flower
TT-6	2174	8.53	64
T-21	1958	6.90	59
Local	1488	7.20	71
LSD	333	0.49	

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Field and Greenhouse Techniques to Screen Pigeonpea for Resistance to Wilt

J. Kannaiyan and Y.L. Nene*

Abstract

Efficient field and greenhouse techniques were developed to screen a large number of pigeonpea germplasm accessions and breeding materials for resistance to the wilt disease caused by Fusarium Udum. *For field screening, uniform wilt-sick plots were developed in Vertisols (3 ha) and in Alfisols (0.5 ha) by repeatedly incorporating chopped wilted plant stubble into the soil and growing susceptible cultivars. In the greenhouse, a pot technique consisting of transplanting pigeonpea seedlings in pots filled with infected soil was standardized so as to supplement field screenings.*

Wilt Of pigeonpea (*Cajanus cajan* [L.] Millsp.) caused by *Fusarium udum* Butler is a serious disease in the Indian subcontinent (Butler 1906) and in East Africa and causes severe losses in yield. *Fusarium udum* is soil-borne and survives in the leftover host stubble up to 3 years. he best method of controlling such a disease would be to develop resistant cultivars. The utility of a "sick-plot" in screening against wilts and other soilborne diseases is well known. Butler (1908) initiated identification of wilt-resistant genotypes as early as 1905 at Poona in India. Subsequently, several research institutions in India succeeded in developing resistant or tolerant pigeonpea cultivars (Swaminathan et al. 1970). However, many of these cultivars did not perform uniformly at different locations. Moreover, systematic screening of the world germplasm collection on a large scale was not carried out in a uniform sick plot anywhere. We have developed effective and uniform sick plots both in Vertisols (3 ha) and in Alfisols (0.5 ha) to screen a large number of pigeonpea germplasm collections available with the Genetic Resources Unit of ICRISAT and the breeding material generated by breeders for resistance to wilt. A pot technique was also standardized to confirm resistance in greenhouse conditions. In this paper we present, step by step, details of these two screening techniques.

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Materials and Methods

Field Technique

At first we multiplied the fungus on materials other than pigeonpea stubble, but later realized that the best way is to incorporate the stubble from wilted plants into the soil and to grow wilt-susceptible cultivars. The procedure consists of the following steps:

1. A plot is chosen, preferably in a corner of the farm, isolated from other pigeonpea fields, to avoid spread of the fungus inoculum to other plots. Such a plot should have had a pigeonpea crop before, and have shown at least traces of wilt incidence.

2. Wilted pigeonpea stubble is incorporated into the soil at the rate of 27 m^3/ha. A sole crop of a highly wilt-susceptible line (e.g. ICP-2376 or ICP-6997) is planted in this plot, ensuring good plant population, and normal agronomical operations are carried out.

3. By the end of the season, we should obtain a minimum of 25% wilted plants. By chopping off the tops of the living plants we allow fresh (ratoon) growth and many plants will show wilt after the new flush.

4. Thirty days after ratooning, the whole crop is chopped and all the stubble mixed with the soil. This will help to increase the level of the fungus inoculum (to make the soil "sick").

5. In the next season a susceptible line is planted again and steps 2 and 3 are repeated. We should be able to obtain more than 80% wilt incidence.

6. In the third year screening is initiated. After every two rows of test material, *every* third row is planted with the susceptible line. These susceptible lines will serve as checks and help in monitoring as well as maintaining wilt sickness of the plot. These rows should show between 90 and 100% wilt.

7. From the fourth year onwards, we can plant one susceptible check row after every four test rows. This will permit screening of more test material and at the same time maintain the desired level of sickness.

8. Observations on wilt incidence (percentage mortality) are recorded 2 weeks before harvest in all the maturity groups.

We do not recommend planting any other crop in this wilt-sick test plot.

Greenhouse Technique

The field technique described above is useful for large-scale screenings, but for confirming resistance as well as for race studies, we use a pot technique. We studied several aspects such as soil type, seedling age, age, and quantity of inoculum for standardizing this technique. Based on these results, the greenhouse-screening procedure was developed.

1. A pure culture of pathogenic *Fusarium udum* is first obtained from infected pigeonpea in the area.

2. The fungus is multiplied on sand-pigeonpea meal medium (SPMM) (10 g pigeonpea meal, 90 g riverbed sand, and 20 ml water per 250 ml flask, autoclaved at 15 lb for 20 min). The medium in the flasks is inoculated and the flasks incubated at room temperature (30°C) for 15 days.

3. The fungus multiplied on SPMM is mixed (200 g) with 2 kg autoclaved Alfisol (obtained from a pigeonpea field where wilt was seen) and this mixture is filled in 15-cm diameter plastic pots. The pots are watered and incubated for 2 days.

4. Concurrently with step 2, polythene bags (25 x 16 cm) are filled with autoclaved riverbed sand and 50 pigeonpea seeds are sown in each bag.

5. The seedlings are removed from sand when they are 7 to 10 days old, and their'roots injured by trimming off the lower 2 to 3 cm. Up to five seedlings are transplanted into each plastic pot filled with the infected soil (step 3).

6. A susceptible (ICP-2376) and a resistant (ICP-8863) check, both inoculated and noninoculated, are kept with each batch of test material.

7. Typical wilt symptoms usually appear in 2 to 3 weeks.

8. Final observations are taken 2 months after transplanting.

Results and Discussion

By using the field-screening technique, we screened more than 11,000 materials (including breeding population, germplasm accessions, lines resistant to sterility mosaic and Phytophthora blight) were screened for resistance to wilt. Thirty-one lines have been identified as resistant in repeated tests. Resistance of these lines is being confirmed through greenhouse screening. The greenhouse (pot culture) technique is also being used to determine the existence of races in *F. udum.*

In addition to the regular screening for resistance to wilt in sick plots, a 4-year crop rotation and intercropping study has also been initiated.

In the wilt-sick plots we have observed increased populations of the cyst nematode, *Heterodera cajani* Koshy. Availability of wilt-sick plot will allow us to study *Fusarium-Heterodera* interactions.

Acknowledgment

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Greenhouse and Field Techniques to Screen Pigeonpea for Resistance to Phytophthora Blight

J. Kannaiyan and Y.L. Nene*

Abstract

More efficient greenhouse and field techniques to screen pigeonpea germplasm and breeding material for resistance to Phytophthora blight were needed. We are reporting simple and efficient techniques developed for use in both greenhouse (soil drench) and field (stem inoculation) screenings. The greenhouse screening procedure has worked very satisfactorily and a good correlation between greenhouse and field screening has been obtained.

Phytophthora blight of pigeonpea is caused by *Phytophthora drechsleri f.* sp. *cajani* in India (Kannaiyan et al. 1980). It has been reported from several states of India. In general, the blight occurs during the wet season and in waterlogged conditions and causes considerable loss in grain yields in pigeonpea. A similar disease caused by *p. parasitica* has been reported from Puerto Rico (Kaiser and Melendez 1978). One of us (YLN) was told during a trip to Central America in November 1977 that Phytophthora blight incidence is commonly observed in the Dominican Republic and Trinidad.

The most effective method of controlling the disease would be to develop resistant cultivars. Pal et al. (1970) used a "leaf scar" technique to screen a number of pigeonpea lines and identified three lines, AS-3, 2357, and 4419 as moderately resistant. At ICRISAT, it was felt that more efficient greenhouse and field techniques were needed to screen a large number of pigeonpea germplasm accessions and segregating populations generated by breeders.

Materials and Methods

Greenhouse (Soil Drench) Technique

We considered several aspects such as soil type, seedling age, water source, age,and quantity of inoculum for developing this technique. Based on the above experimental results, the greenhouse (soil drench) screening procedure was worked out as follows:

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1. *Phytophthora drechsleri* f. sp. *cajani* (P2 isolate) isolated at ICRISAT Center is grown on autoclaved V-8 juice agar (V-8 juice 100 ml, $CaCO_3$ 2 g, agar 20 g, distilled water 900 ml) or pigeonpea infusion agar (infusion from 40 g pigeonpea seed meal, agar 20 g, distilled water to make up 1000 ml) for one week at 28-30°C.

2. Five-millimeter discs of the fungus growth are transferred to 100 ml autoclaved V-8 juice broth or pigeonpea infusion broth (composition as above minus agar) in 250 ml flasks and incubated at 28 to 30°C for 2 weeks.

3. Twenty-centimeter diameter plastic pots are filled with field Alfisols and 25 seeds sown in each pot

4. Mycelial mat from each flask is removed and washed twice with water. It is then macerated in 100 ml water in a Waring blender for 1 to 2 minutes by operating the blender intermittently. This suspension is diluted with another 100 ml of water to get a final dilution of one mycelial mat in 200 ml water.

5. Five- to 10-day-old seedlings are inoculated by pouring 100 ml inoculum (step 4).

6. Susceptible (e.g. HY-3C) and resistant (e.g. ICP-2376) checks, both inoculated and noninoculated, are kept with each batch of test material for monitoring the effectiveness of inoculation.

7. After inoculation, seedlings are liberally watered (two or three times a day) to enhance development of the disease.

8. Symptoms usually start appearing in 48 hours. Final observations are taken 10 days after inoculation.

Field Screening (Stem Inoculation) Technique

The stem inoculation technique consists of seven steps:

1. The test materials are planted in a well-drained Alfisol field, following normal sowing procedures. Every tenth row is planted with a susceptible line or cultivar. This helps in monitoring the success of the inoculation procedure. All plants are inoculated the first time about 1 month after planting.

2. Isolate P2 of *P. drechsleri* f. sp. *cajani* is grown in V-8 juice agar or pigeonpea infusion agar (compositions given elsewhere) in petri dishes for 1 week at 28 to 30°C (1 week before field inoculation).

3. The mycelial mats along with medium are removed from petri dishes and the inoculum is mixed well with the medium by hand (covered with gloves) after adding 0.2% Carborundum (600 mesh).

4. A small amount of the mycelial mash (step 3) is rubbed by hand at the base of the stem of individual 1-month-old plants in the field.

5. The field is flood-irrigated immediately afterwards and again 1 week later. A second irrigation is required if dry weather prevails.

6. Typical blight symptoms appear in about 10 days after inoculation; plants showing no symptoms after the first inoculation are reinoculated (repeat steps 2 to 5) 1 month later.

7. Final observations are taken 1 month after the second inoculation.

Results and Discussion

Greenhouse (Soil Drench) Technique

The technique has worked extremely satisfactorily. A total of 3419 pigeonpea germplasm accessions and cultivars, and seven *Atyiosia* sp. (wild relatives of pigeonpea) were screened for resistance to Phytophthora blight by following this simple technique. Of these, 119 germplasm accessions and three cultivars of pigeonpea, and two species of *Atyiosia* were found resistant. Resistance of more than 90% accessions and cultivars was confirmed under field conditions by using the field screening (stem inoculation) technique. This showed an excellent agreement between the greenhouse and field screenings.

This screening technique was also used to determine the mode of inheritance of resistance and to evaluate the efficacy of the fungicide Ridomil to control the blight in seedling stage through seed treatment. In the early stages of our screening, we observed that the incidence of the blight varied considerably on known genotypes. Repeated subculturing of the pathogen resulted in reduced virulence; therefore, it is suggested that the fungus should be isolated afresh from diseased seedlings (frequently) to maintain the original virulence. The isolate should be tested for proper virulence on known susceptible and resistant genotypes before use.

Optimum temperature conditions are important for proper development of the disease. Kannaiyan et al. (1980) found that 27 to 33°C was best for in vitro growth of the fungus, and consistent results could be obtained only at temperatures between 25 to 35°C in the greenhouse.

Field Screening (Stem Inoculation) Technique

This technique also worked satisfactorily. In the initial stages of the development of this technique we came across a certain percentage of escapes even in the known susceptible cultivar HY-3C, and now we get above 90% blight incidence in HY-3C. This is a somewhat laborious method and we are attempting to simplify it.

At ICRISAT Center, this technique has been used in 1- to 2-ha field nurseries from the 1977 kharif season onwards. A large number of segregating populations generated by the pigeonpea-breeding unit, crossing block entries, male-steriles, All India Coordinated Project materials, germplasm accessions found resistant to blight in the greenhouse screening, wilt- and SM-resistant materials were all screened for resistance to blight by using this field-screening technique.

In addition, F_2 and F_3 generations of nine crosses involving nine susceptible parents and the resistant cultivar, ICP-7065, were screened under field conditions to determine the mode of inheritance of resistance to blight in pigeonpea.

The greenhouse screening technique is time-saving, enabling a batch of material to be screened within a 3-week period; whereas field screening requires a full season, varying with genotypes from 4 to 7 months. Normally the blight appears in the field after wet spells any time but mostly within 3 months after sowing.

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Some Aspects of Field Screening of Pigeonpea for Resistance to Sterility Mosaic

M.V. Reddy and Y.L Nene*

Abstract

The "infector row" or "spreader row" system was found to be very effective for large-scale field screenings of pigeonpea for resistance to sterility mosaic. The system consists of advance planting of a susceptible cultivar at frequent intervals in the field or at one edge of the field and artificially inoculating it through a "leaf stapling" technique. Test materials are planted at the normal sowing time, with disease-indicator rows. Plants not showing infection 30 days after planting are inoculated by the "leaf-stapling" technique. When disease development is delayed, plants not showing symptoms are topped, and the fresh regrowth is examined for symptoms. Early observations, 30 to 45 days after planting, are essential to properly detect the mild mosaic and ring spot reactions, as these might get masked with age in certain genotypes.

Sterility mosaic is one of the major disease problems of pigeonpea in the Indian subcontinent. The incidence of the disease seems to be on the increase and needs immediate remedial measures (Kannaiyan et al, these proceedings). Development of resistant cultivars appears to be the most effective method of control. To meet this objective, a large-scale field-screening program was undertaken in 1975 at ICRISAT, and several resistant lines have been identified (Nene and Reddy 1976b, Nene et al, these proceedings.) Some aspects related to the field screening for sterility mosaic resistance are discussed in this paper.

Leaf-Stapling Technique

The leaf-stapling technique that we described earlier (Nene and Reddy 1976a, 1976b) was found to be very effective in screening of materials both in pots and in the field. But for large-scale field screenings, the technique was found laborious and needed large amounts of inoculum (diseased leaves carrying the eriophyid mite, *Aceria cajani* Channabasavanna). Availability of inoculum at the beginning of the season (June-July)

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becomes a limiting factor unless one maintains a sufficient number of diseased plants with good mite population throughout the preceding summer months (March-May). It was found essential to keep potted plants in partial shade in the summer months to maintain a good mite population. This resulted in heavy colonization of the diseased plants by spider mites and severe defoliation and death of several plants. This limits the availability of inoculum for large-scale field inoculations in June-July.

Infector-Row or Spreader-Row Technique

To overcome the problems of labor and shortage of inoculum in the leaf-stapling technique, a spreader-row or infector-row system was developed and has been successfully used for large-scale field screenings for the past 3 years (1977-80). The system consists of advance planting of a sterility mosaic-susceptible cultivar at frequent intervals all over the field and artificially inoculating these plants through leaf-stapling. Both the disease and the mite vector population increase in these rows and help in the uniform spread of the disease on to the test materials when planted. The distance between the two infector rows is not critical, as the windborne mites seem to spread the disease fast. In the past 3 years, 9 to 18 m distance was tried and the disease spread was found to be satisfactory. Within 1 month after planting the disease incidence in the indicator rows was more than 85% indicating heavy disease pressure under the system. Plants that do not show infection after 30 to 45 days are inoculated by leaf-stapling. Some of the points to be noted for successful operation of the infector-row technique are:

1. Locate the plot in an insecticide-free area, where the fields in the vicinity are not likely to be heavily sprayed with insecticides; mites are sensitive to many insecticides.
2. Select an isolated plot downwind to avoid the problem of disease spread to other pigeonpea fields.
3. Plant the infector or spreader rows well before the onset of the summer, so that the mite population builds up sufficiently before the temperatures start rising and humidity decreasing.
4. For infector rows, select a cultivar (e.g., BDN-1, NPWR-15) that is not susceptible to other diseases like wilt, so that the stands are not affected. If the infector rows are to be retained for more than one season, plant a cultivar (e.g. NPWR-15) with a parennial habit.
5. Plant the infector rows across wind direction that prevails for the first 2 to 3 months after planting.
6. Avoid spraying of any insecticides on infector rows and provide sufficient irrigation, especially in summer months.
7. Prune infector rows at regular intervals to keep their growth under check and to encourage fresh growth.

Disease Spread Under Infector-Row System

During the 1976-77 and 1977-78 seasons, disease development in a susceptible cultivar (ICP-1) when planted at monthly intervals throughout the year was studied (Table 1). To obtain some information on the factors affecting disease spread, the disease incidence and mite population in the infector rows in relation to weather data were studied. The data indicated that disease incidence was related to mite population in the infector rows and that weather factors did not play a large role. Screening can be carried out at any time of the year, provided there is an adequate mite population.

Hedge System

Although the infector-row system works very well, it has some problems. Planting of the infector rows throughout the field means more work, more initial inoculation, and more irrigation during the summer. In addition, the rows occupy up to one-tenth of the total area and at least two test rows on either side of them (up to 150 cm) make *very* poor growth because of severe moisture competition from the older plants in infector rows. The nonuniform growth makes yield evaluations difficult. To overcome these problem, a "hedge" system was tried during the 1980-81 season. The system consists of growing of a four-row strip of a susceptible cultivar like NPWR-15 at only one edge of the field across and up the wind direction. The system has worked very well. Spread of the disease was good and 58 to 79% incidence could be obtained on the row 216 m away from the source within two months period. If the distance from the source is reduced, the system should work very well. Also by the end of the crop season, the susceptible checks would normally show close to 100% incidence.

Inoculations on Ratoon Growth

If the reaction of the line could be obtained by inoculating the ratoon growth after the main crop has been harvested, it would be useful in the breeding program. Inoculations on the ratoon growth of the 1976 *kharif* (rainy-season) crop in the field did not result in good disease development. These results were contrary to those obtained on potted plants in the greenhouse. It was felt that the failure in the field could be due to the high temperatures prevailing at the time of inoculation. To see whether the age of the plant at ratooning also had any effect on disease development in the ratoon growth, an experiment was conducted in the field using the susceptible cultivar ICP-1. Plants were ratooned at 30, 60, 90, and 120 days' age and the ratoon growth inoculated by the leaf-stapling technique. The infections on the whole decreased with increase in age at ratooning. It was also found that the success of infection depended upon the extent of succulence and abundance of the ratoon growth, which in turn depended on the moisture availability in the soil. The incubation period also increased with age. The results suggested that the ratoon growth is different from the seedling growth and the reactions of two were not the same.

Disease Observation

It is desirable to record disease observations at least twice: once in the

Table 1. Pigeonpea sterility mosaic incidence in cultivar ICP-1 planted at different dates under infector rows.

Date of planting	Percent disease after 4 weeks	Percent disease in infector rows	Average no. of mites/ leaflet on infector rows	Average temperature[a]		Total rainfall (cm)[a]	Average relative humidity (%)[a]	
				Maximum (°C)	Minimum (°C)		1717 hr	1417 hr
18-3-1977	85.83	51.44	59.90	37.38	22.48	1.8	61.32	23.35
18-4-1977	93.84	54.46	49.40	36.72	24.07	30.1	66.46	29.93
18-5-1977	75.70	60.40	48.10	37.29	25.12	48.3	61.09	30.90
18-6-1977	78.47	60.97	92.50	32.61	22.96	141.6	81.80	51.56
18-7-1977	88.61	45.60	50.00	30.19	23.10	165.4	90.50	64.74
18-8-1977	52.26	73.45	48.60	28.82	21.80	124.3	86.19	64.32
18-9-1977	65.49	62.83	13.00	30.97	21.64	65.1	87.53	52.86
18-10-1977	64.79	71.06	17.00	30.22	19.42	33.9	84.67	41.41
18-11-1977	6.40	61.17	6.10	28.20	16.77	77.0	85.30	39.63
18-12-1977	0.73	62.14	0.70	27.22	13.48	17.2	83.87	34.80
18-1-1978	0.70	22.22	0.00	29.22	17.25	7.6	80.35	34.70
18-2-1978	0.00	17.74	4.40	31.99	18.45	12.9	69.57	28.50

a. Averages are of the preceding 1 month.

seedling stage and the other before maturity. The early observation is essential, especially to properly monitor ring spot or mild mosaic reactions. In some genotypes like ICP-6748, it was found that these mild symptoms get masked with age. For critical studies such as inheritance of resistance, it is necessary to observe plants at frequent intervals from the early stages of infection, record the symptomsas and when they show, and uproot the plants.

In case of late infections, it is possible that the symptoms may not appear in the first growth or may not be very clear. In such cases topping the plants helps in better expression of the symptoms on the regrowth and thus better evaluation. During the 1979-80 season, when the disease development was delayed due to a low mite number in the infector rows, the average disease incidence in the indicator rows in the main crop and ratooned growth was 25.93% (range 0.00 to 100.00%) and 96.45% (range 68.08 to 100.00%), respectively.

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Survival of Pigeonpea Wilt *Fusarium* in Vertisols and Alfisols

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Abstract

Wilt caused by Fusarium udum *is a major disease of pigeonpea. The capacity of the pathogen to survive in soil in the wilted plant stubble over a 5-year period was investigated.* Fusarium udum *could be detected in Vertisols up to 2.5 years and in Alfisols up to 3 years.*

Wilt caused by *Fusarium udum* Butler as a major disease of pigeonpea was identified and described by Butler in 1906 from India. Later, its occurrence was reported from other countries (Booth 1971; Nene 1980). The fungus is soilborne on plant remains, and Subramanian (1955) stated that it survives only on the tissue that it colonized as a parasite. We did not find in the published literature any work done specifically to ascertain how long the fungus survives in wilted plant stubble. McRae and Shaw (1933) made the following statement:

> Exposed in the open the fungus in many of the stems and roots dies but when kept in a cooler room in the shade most of it survives. The source of infection then exists in the uncut portions of roots below the ploughing depth. From such parts of roots *in situ* the fungus has been isolated after two years though with difficulty, so even here it would appear that the fungus dies out, though more slowly. Disinfected rahar (pigeonpea) seed sown in land,free from a arhar crop from eight to twenty years generally produces a crop with little or no wilt, while with a shorter interval the crop comes up more or less severely wilted according to the shortness of the interval.

This indicates that the fungus survives for something less than 8 years. Agnihothrudu (1954) has shown that *F. udum* does not colonize plant debris in the soil but can survive only in tissues it had already invaded as a pathogen. It then follows that the stubble fragments may be enabling the fungus to survive in soil up to 8 years. Agnihothrudu (1955) also reported that *F. udum* survived for shorter periods in the rhizosphere soil of resistant plants than of susceptible ones. The reason for this was the presence of more fungistatic organisms like *streptonyces* spp., which are antagonistic to *F. udum* in the rhizosphere of resistant pigeon-

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*Pulse Improvement Program, ICRISAT.

pea lines. To find out how long *F. udum* survives in wilted pigeonpea stubble buried in the soil, a 5-year experiment was conducted at ICRISAT Center, and the results are presented in this paper.

Materials and Methods

This experiment was initiated in November 1974. Stubble (root system along with about 15-cm-long stem base) of naturally infected pigeonpea plants was obtained, weighed, and buried in 35-cm-diam earthen pots. Two sets were prepared, one with Vertisols and the other with Alfisols collected from ICRISAT Center. Some properties of these two soils have been indicated in Table 1. Sixty pots, 30 with Vertisols and 30 with Alfisols, were prepared and buried in the ground so that the top of each pot was in line with the ground surface. Stubble from six pots (3 Vertisols + 3 Alfisols) was removed after every 6 months, weighed, and then checked for the presence of *F. udum* through the use of modified Czapek's Dox agar[1] selective medium. The identity of the fungus was verified through microscopic observations and pathogenicity tests. In addition, assistance was sought from the Commonwealth Mycological Institute. Weather data (average maximum and minimum temperatures and rainfall) from the Agroclimatology Unit of ICRISAT were noted. The temperatures during 5 years (November 1974 to November 1979) ranged from 5.4° to 27.2°C (minimum) and 25.8° to 42.6°C (maximum). The total rainfall was 4170 mm during these 5 years.

Results and Discussion

The data obtained after 6-month intervals have been presented in Table 2. We were able to detect *F. udum* in stubble fragments from Vertisols up to 2.5 years and from Alfisols up to 3 years. The rate of decomposition of stubble buried in Vertisols was higher than in Alfisols, as indicated by the percent loss in weight of stubble at different intervals (Table 2). This may explain why the survival of F. udum in stubble buried in Alfisols extended to 6 more months than in Vertisols. In general, the rate of decomposition of organic matter was faster in Vertisols than in Alfisols. Based on this study, we were unable to understand how the fungus could survive up to 8 years as suggested by McRae and Shaw (1933).

Some studies by other workers need to be mentioned in connection with the survival of *F. udum.* Sarojini (1950) concluded through pot studies that application of zinc (20, 40, and 80 ppm) to soil in which infected stubble was buried resulted in the disappearance of the fungus in 5 to 6 weeks. Boron and manganese were less effective. Dey (1948) claimed reduction in the wilt incidence when sorghum was grown as an intercrop.

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1. Modified Czapek's Dox agar containing, in addition to normal ingredients, PCNB 500 mg; malachite green 25 mg; Dicrysticin-S (Streptopenicillin of Sarabhai Chemicals Ltd., Baroda, India) 750 mg; and yeast extract 2 g/litre of medium.

Table 1. Some properties of Vertisols and Alfisols used in the pigeonpea wilt fungus survival study.

Soil type	pH (1:2)	E.C. mmho/cm	Organic carbon (%)	Available P (ppm)	Mechanical analysis (%)		
					Sand	Silt	Clay
Alfisols	5.90	0.10	0.20	2.10	59.60	7.20	33.20
Vertisols	7.85	0.15	0.38	1.60	38.80	20.00	41.20

Bose (1938) made a chance observation of reduced wilt incidence in a field where tobacco was grown in the preceding season. McRae and Shaw (1933), through observations in permanent manurial and rotation experiments over several years, reported (a) manuring with superphosphate (7-23 kg P_2O_5/ha) and with cattle manure increased the wilt, (b) green manuring with *crotalaria juncea* (60 lb seed/acre) decreased wilt, and (c) superphosphate and green manure together increased wilt.

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Table 2. Study of *Fusarium udum* in stubble of wilted plants of pigeonpea up to 60 months after burial.

	Months after burial of wilted pigeonpea stubble																			
	6		12		18		24		30		36		42		48		54		60	
Soil type[a]	A[b]	B[b]	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Alfisols	57	+	54	+	73	+	80	+	83	+	97	+	88	-	93	-	98	-	99	-
Vertisols	63	+	51	+	75	+	91	+	89	+	99	+	96	-	100	-	99	-	97	-

a. Three replications were made for each treatment.

b. A = Average loss in weight (%); B = Presence (+) or absence (-) of *F. udum*.

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Survey of Pigeonpea Diseases with Special Reference to Wilt and Sterility Mosaic in India

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Abstract

*To study the prevalence of pigeonpea diseases, roving surveys were conducted in nine states of India during 1975-1980. Two diseases—wilt (*Fusarium udum*) and sterility mosaic* (virus ?) *—were more serious and widespread than others such as Phytophthora blight, root rots, leaf spots, yellow mosaic, bacterial canker, and powdery mildew.*

The average percentages of wilt and sterility mosaic were, respectively: Andhra Pradesh 5.3 and 1.6; Bihar 18.3 and 21.4; Gujarat 5.4 and 12.2; Karnataka 1.1 and 9.8; Madhya Pradesh 5.4 and 3.7; Maharashtra 22.6 and 1.1; Rajasthan 0.1 and 5.4; Tamil Nadu 1.4 and 12.8; and Uttar Pradesh 8.2 and 15.4. The incidence of wilt in farmers' fields varied between 0 and 96%; of sterility mosaic, between 0 and 100%.

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has a world mandate to improve five crops, including pigeonpea *(Cajanus cajan* [L.] Millsp.). Pigeonpea (PP) is an important pulse crop in most of the semi-arid tropics. About 90% of the world's pigeonpea crop area (2.4 million ha) is in India, where it is the second most important pulse crop. It is also of importance in the Carribbean and Africa. Grain yield of the crop is affected by a variety of diseases, and more than 50 pigeonpea pathogens have been reported from 23 countries. Most of these reports are from India (Nene 1980). Diseases such as the wilt caused by *Fusarium udum* Butler (Butler 1906, Kannaiyan and Nene 1981) and sterility mosaic (virus ?) have been reported serious in India but reliable estimates of incidence of only the sterility mosaic (SM) are available from two states, Tamil Nadu (Ramakrishnan and Kandaswamy 1972) and Uttar Pradesh (Nene 1972).

From 1975 through 1980, we conducted systematic surveys, in cooperation with various state agricultural universities, in the states of Andhra Pradesh, Bihar, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan, Tamil Nadu, and Uttar Pradesh; the information we obtained on the prevalence of wilt, sterility mosaic, and other diseases is presented in this paper.

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*Pulse Improvement Program, ICRISAT.

Methodology

The survey teams traveled by road along routes planned to cover the major pigeonpea-growing areas of different districts in each state. Observations were made approximately *every* 30 or 40 km, except in nonpigeonpea areas, where stops were made less frequently.

A single questionnaire (Appendix 1) was used to ensure uniform data collection on growing conditions—cropping system, soil type, etc.—and diseases observed.

For wilt, SM, Phytophthora blight (PB), Macrophornina stem canker (MSC) and yellow mosaic (YM), percentage disease incidence was calculated by counting 500 plants in random rows in a field. The percentage incidence at each location in a district was used for calculating the district average; the district averages in turn were used for calculating the state average. For other diseases the incidence was scored visually as low, medium, or high.

Results and Discussion

Andhra Pradesh

The area under pigeonpea in this state is 198 000 ha. The crop is grown in various soils, intercropped with sorghum, groundnut, pearl millet, setaria, castor, sunnhemp, chickpea, field beans, or paddy. It is rarely grown as a sole crop.

Our survey covered 19 districts. We found that, on the whole, disease incidence in the state was low and the average incidence of wilt and SM was 5.3 and 1.6%, respectively (Table 1). The incidence of wilt was above 10% in the districts of Medak, Nizamabad, Hyderabad, and Adilabad; of these, three districts are adjacent to Maharashtra state, where wilt is the major problem. SM was below 10% in districts where it was observed. Other diseases, observed less frequently were *Cercospora cajani* leaf spot, powdery mildew, YM, Phyllosticta leaf spot, bacterial leaf spot and stem canker, and MSC.

Bihar

Pigeonpea is grown on about 105 000 ha in Bihar, on loamy and red soils. The survey was made in March 1980. More than 75% of the pigeonpea fields observed had some intercrops or mixedcrop(s) such as sorghum, maize, sesame, pearl millet, finger millet, mustard, paddy, or mesta.

Our survey, covering 3000 km in 26 districts, showed that SM and wilt are important in Bihar. The incidence of wilt in individual fields ranged from 0 to 87.4% with an overal average of 18.3%. Wilt was observed in 19 out of 26 districts surveyed, and was above 10% in 15 districts; maximum incidence was in Muzaffarpur district (50.9%). SM was observed in all the 26 districts, ranging from 0 to 100%, with an overall average of 21,4%. Hazaribagh district recorded the highest overall incidence of SM (58.8%) SM incidence was above 10% in 21 districts.

Table 1. Summary of pigeonpea wilt and sterility mosaic incidence in various states of India, 1975-1980.

State	No. of districts surveyed	Total no. of locations examined	Wilt			Sterility mosaic		
			Average	District average range	Range in fields	Average	District average range	Range in fields
			(%)			(%)		
Andhra Pradesh	19	102	5.3	0-25	0-92	1.6	0-8	0-43
Bihar	26	68	18.3	0-51	0-87	21.4	0.7-59	0-100
Gujarat	11	42	5.4	0-23	0-46	12.2	0.3-35	0-92
Karnataka	14	37	1.1	0-9	0-17	9.8	0-49	0-95
Madhya Pradesh	40	136	5.4	0-43	0-96	3.7	0-49	0-99
Maharashtra	19	82	22.6	0-69	0-93	1.1	0-10	0-47
Rajasthan	12	31	0.1	0-1	0-4	5.4	0-43	0-68
Tamil Nadu	11	46	1.4	0-14	0-65	12.8	0-38	0-92
Uttar Pradesh	44	108	8.2	0-47	0-86	15.4	0-67	0-93

Macrophomina stem canker was the third important problem in Bihar, with average incidence 6.8%. Low incidence of YM, grey mildew, and Alternaria leaf spot was also observed. Alternaria leaf spot is a potentially important disease on postrainy-season pigeonpea.

Gujarat

Gujarat has 111 000 ha under pigeonpea. The crop is cultivated in black and loamy soils; about 70% of it intercropped or mixed with sorghum, pearl millet, paddy, lablab, sugarcane, sesame, cotton, mesta, maize, groundnut, or clusterbean. Postrainy-season pigeonpea is cultivated mainly in the hilly district of Dangs.

The survey, made in January-February 1980, covered 11 districts. Wilt ranged from 0 to 45.2% with an overall average of 5.4%; it was above 10% in Baroda, Broach, and Godhra districts, SM was observed in all the 11 districts surveyed and ranged from 0 to 92.2%, with an overall average of 12.2%. It was above 10% in the districts of Baroda, Bulsar, Gandhinagar, Khaira, and Surat. Low incidence of MSC, bacterial stem canker, Phoma stem canker, leaf spots, and grey and powdery mildew, and white root rot was observed.

Karnataka

Pigeonpea in Karnataka occupies about 303 000 ha, mostly on black and red soils. As in Andhra Pradesh and Bihar, pigeonpea in Karnataka is grown as an intercrop or mixed with sorghum, pearl millet, paddy, horsegram, ragi, fieldbeans, sugarcane, groundnut, setaria, or tomato.

Our survey—made in December 1976, covering 14 districts—revealed that SM is the major disease problem. The incidence of this disease ranged from 0 to 95% and the state average was 9.8%. Bidar, Belgaum, and Chitradurga districts showed above 10% SM incidence, with Bidar being highest (49.7%). Very low incidence of wilt was observed in the entire state: 0 to 17%, with an average of 1.1%. The incidence of other diseases such as Cercospora leaf spot and powdery mildew was low.

Madhya Pradesh

The crop is cultivated on 503 000 ha, on black and loamy soils, intercropped with chickpea, sorghum, cotton, pearl millet, groundnut, paddy, sesame, setaria, mesta, green gram, tomato, maize, or wheat.

Our survey (December 1977 and January-February 1978) covered 40 districts and revealed that wilt, SM, MSC, and frost damage were the common problems. The incidence of wilt ranged between 0 and 96.6% with an average of 5.4%. Wilt was observed in 27 out of 40 districts surveyed; it was above 10% in eight of these, with maximum incidence in Khargone (43.2%). The SM incidence varied between 0 and 99.6%, with an average of 3.7%. Four districts recorded above 10% SM, and Bilaspur had the highest overall incidence (49.4%). High frost damage was observed in the districts of Damon and Shahdol (up to 50%). Severe incidence of MSC was seen in Gwalior, Morena, Guna, and Betul districts. The incidence of root rot, powdery mildew, bacterial stem canker, Cercospora and Phyllosticta leaf spots, and grey mildew was low.

Maharashtra

The surveys in Maharashtra were conducted in December of 1975 and 1976 in 19 districts, where pigeonpea was grown mainly on black soil, intercropped with cotton or sorghum. Total pigeonpea area in this state is 660 000 ha, the largest in India.

Wilt seems to be the major disease problem and was recorded in 14 out of the 19 districts surveyed. The incidence varied between 0 and 93% —overall averarae of 22.6%—and highest incidence was recorded in Yeotmal district (68.8%), where a wilt-MSC complex was seen. Wilt incidence above 10% was found in 11 districts and was observed more frequently in medium to heavy black soils than in lighter ones. The incidence of SM was *very* low, ranging from 0 to 40% with an overall average of only 1%. The incidence of collar rot, bacterial stem canker, powdery mildew, and Cercospora and Phyllosticta leaf spots was also low.

Rajasthan

The area under pigeonpea in Rajasthan is only 33 000 ha, mostly in eastern and northern Rajasthan, more than 80% of it intercropped or mixed with such crops as sorghum, pearl millet, groundnut, green gram, mustard, mesta, sesame, wheat or chickpea.

The survey, covering 12 districts, showed that sterility mosaic was an important disease in Rajasthan, ranging from 0 to 68.2%, with an overall average of 5.4%. SM incidence was above 10% in the districts of Bharatpur and Tonk. Low incidence of wilt, MSC, YM, powdery mildew, and Cercospora, Phyllosticta, and Alternaria leaf spots was observed. Frost injury (2-20%) was observed in Alwar, Bharatpur, Jaipur, and Tonk districts.

Tamil Nadu

Pigeonpea is cultivated on 101 000 ha on red and black soils, intercropped with groundnut, sorghum, paspalum, pearl millet, field beans, horse gram, or castor.

In the 11 districts surveyed in December 1976, SM seems to be the major problem. It was observed in ten out of the 11 districts, with more than 10% incidence in six, maximum incidence was in Pudukottai district (37.5%). Wilt was observed only in Dharmapuri and North Arcot districts, where incidence varied from 0 to 65.4%, with an overall average of 1.4%. Low incidence of Rhizoctonia root rot, powdery mildew, Phyllosticta and Cercospora leaf spots, and bacterial leaf spot and stem canker was observed.

Uttar Pradesh

The area under pigeonpea in Uttar Pradesh is 504 000 ha, mostly clayey loam or loamy soils. More than 90% of the fields observed had some inter or mixed crop(s), such as sorghum, pearl millet, groundnut, paddy, sesame, setaria, maize, cotton, black gram, mesta, sunnhemp, castor, or tomato.

In the 44 districts surveyed in early 1979, SM, wilt, MSC, YM, and PB are important problems. Wilt was seen in 33 out of the 44 districts surveyed (average incidence 8.2%, maximum incidence in Pratapgarh district, 47.4%). SM was observed in 40 out of 44 districts, individual fields showing up to 93.2% SM with an average of 15.4%. The highest overall incidence of SM [67.3%) was observed in Azamgarh district.

The next important problem was MSC, which was observed in 18 out of 44 districts, ranging up to 45.8%, with an average of 2.5%. YM was recorded in 30 districts (average 1.8%); PB in 17 districts (average 1.3%). Low incidence of bacterial stem canker and Cercospora and Phyllosticta leaf spots was also recorded.

Acknowledgment

The valuable assistance provided by the staff of various agricultural universities is greatly appreciated.

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Appendix 1. Pigeonpea Disease Survey Questionnaire, ICRISAT 1975-1980.

1. Route ____________________ 2. Date ________________ 3. State ______________________

4. District ________________ 5. Place (nearest village/town ____________________
indicate distance)

6. Total area of the field (approx.) ____

(a) Sole/intercrop (describe) ____

(b) Percent area under PP ____

7. Stage of crop growth (i) podding (ii) podding and flowering
(iii) flowering (iv) pre-flowering

8. Diseases observed

(i) ___________________________ (a) percent (overall) _________________________

(b) % out of 500 plants ______________________

(ii) ___________________________ (a) as above ______________________________________

(b) as above ____________________________________

(In case of significant leaf spot/powdery mildew incidence, indicate severity)

9. Type of soil ____

10. Samples collected (i), (ii)
(Tick mark appropriate ones)

11. Other observations: Information given by farmer

Was the field under PP in previous years?

Is disease pattern similar in nearby fields?

Estimation of Yield Loss in Pigeonpea Due to Sterility Mosaic

M.V. Reddy and Y.L. Nene*

Abstract

The effect of sterility mosaic on yield and yield components of the early, medium and late maturing cultivars of pigeonpea was studied in both field and pot trials. In a field trial in 1975-76, the effect of the disease on yield and yield components of a medium-maturing susceptible cultivar (ICP-1), when infected at different ages, was analyzed. The incubation period was found to be longer in older plants. Infections up to 45 days mostly resulted in complete sterility, but susceptibility of the plant was found to decrease with the age. Early infections caused considerable increase in the number of secondary branches, prolonged the duration of the crop, and caused yield loss to the extent of 95%. The loss decreased with the increase in age at infection. Similar results were obtained when the experiment was repeated in the 1977-78 season. An increase in the number of tertiary branches was also found in plants infected early. In a pot trial with cv T-21, an early-maturing cultivar, similar results were obtained. The reduction in yields of a late-maturing cultivar, NP (WR)-15, which shows mild mosaic symptoms, was less.

Sterility mosaic of pigeonpea *(Cajanus cajan* [L.] Millsp.) is widely prevalent in the Indian subcontinent and up to 100% incidence was observed in certain fields (Kannaiyan et al., these Proceedings). Occurrence of complete and partial sterility in infected plants is common, but there was no precise information on the extent of loss in yield caused by sterility mosaic in pigeonpea. Field and pot experiments were conducted at ICRISAT in two seasons (1975-76 and 1977-78) to analyze the effect of sterility mosaic infection on yield and yield components of pigeonpea cultivars of different maturity groups.

Materials and Methods

1975-76 Season

ICP-1, a medium-duration susceptible cultivar, was planted in 8 isolation

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plots with four 5 m rows each, in Vertisol, during the third week of June. The inter- and intra-row spacing was 75 and 30 cm, respectively. Plants were artificially inoculated (Nene and Reddy 1976) at intervals of 15, 30, 45, 60, 75, 90, and 105 days (one plot/treatment). The plot without inoculation served as control. Observations on incubation period, infection, symptom severity, height and spread of the plant, number of primary and secondary branches, flowers, and yield were recorded. The percent loss in yield was calculated by using the following formula:

$$\text{Percent loss in yield} = \frac{\text{Yield in control} - \text{Yield in treatment}}{\text{Yield in control}} \times 100$$

1977-78 Season

Early Cultivar (T-21)

Early cv T-21 was planted in 30-cm earthen pots filled with red soil-farmyard manure mixture (1 plant/plot) and inoculated at 15, 30, 45, 60, and 75 days age. The number of plants inoculated at each age ranged from 29 to 35. A group of plants without inoculation served as control. Observations on incubation period, infection, symptom severity, number of primary and secondary branches, 100-seed weight, and yields were recorded.

Medium-duration Cultivar (ICP-1)

ICP-1 was planted in five isolation plots of ten 8-m rows each in Vertisol during the third week of June (75 x 30 cm). Inoculations were made 30, 60, 90, and 120 days after planting (one plot/treatment). The number of plants/plot ranged from 161 to 213. Observations on incubation period; infection; height of the plant; number of primary, secondary, and tertiary branches; 100-seed weight; and yield were recorded.

Late Cultivar (NP[WR]-15)

Cultivar NP(WR)-15 was planted in an Alfisol field where irrigations were provided whenever needed. Diseased plants in pots kept around the plot served as source of inoculum. Plants showing infection after 45, 90, 135, and 180 days of planting were tagged for analysis of yeild loss. The number of plants tagged at each age ranged from 25 to 79. A group of healthy plants tagged at the time of maturity served as control. Observation on the number of primary, secondary, and tertiary branches, 100-seed weight, and yield were recorded.

Results

1975-76 Season

The incubation period in 15-day-old plants was 7 days as compared with 13 to 16 days in plants 30 days old or more. The infection obtained was up to 99% in younger plants, but this decreased steeply after 75 days and onwards. Plants when infected at 45 days age *or* earlier *mostly showed* complete sterility; infection at later stages mostly resulted in partial sterility. There was no appreciable effect of infection on plant height, but infection at the age of 60 days resulted in a slightly higher spread. There was no particular effect of infection on the number of primary branches, but in plants infected early, the number of secondary branches increased considerably. Early infections also prolonged the duration of the crop, as indicated by the number of flowers present at the time of maturity. Early infections resulted in heavy yield loss compared with late infections. Table 1 shows the results of this season.

1977-78 Season

Early Cultivar T-21 (Table 2)

The incubation period increased with the age of the plant at infection and the percent infection decreased. The number of secondary branches markedly increased in plants inoculated at 15 and 30 days' age. There was no particular effect on 100-seed weight. Infection at 15 and 30 days age caused severe loss in yield and the reduction in later infections was marginal.

Medium-duration Cultivar ICP-1 (Table 3)

Inoculations at 30 and 60 days' age resulted in near 100% infection, but with later inoculations infection rate dropped sharply. The height of the plants was slightly reduced in early inoculated plants. Generally, the number of secondary and tertiary branches in early infected plants increased. There was no appreciable change in the 100-seed weight. Plants inoculated at 30 and 60 days after sowing showed high reduction in yield.

Late Cultivar NP(WR)-15 (Table 4)

The number of primary branches increased slightly in the infected plants and there was no particular effect on the secondary and tertiary branches or 100-seed weight. Early infection considerably reduced yields. Late infection gave less yield reduction.

Discussion

Sterility mosaic infection in the early stages of crop growth was found to cause heavy yield loss in early and medium-maturing susceptible cultivars of pigeonpea. The loss in late-maturing, mild mosaic cultivars was less. The reduction in yield resulted mainly from the sterility of the plants. The plants were susceptible during all stages of growth, but the increased incubation period and decreased infection in older plants appeared to be due to the longer time taken by the pathogen to move through the plant system. This is supported by the near-100% infection that is

Table 1. Effect of sterility mosaic on yield and yield components of a medium-maturing susceptible pigeonpea cultivar (ICP-1) inoculated at different ages in 1975-76 season.

Age of plants at inoculation (days)	Incubation period (days)	Percent infection	Percent partial sterility	Average height (cm)[a]	Average spread (cm)[a]	Average no. of primary branches/ plant[a]	Average no. of secondary branches/ plant[a]	Average no. of flowers at harvest/ plant	Percent loss in yield
15	7	99.0	14.5	88.4	41.9	7.4	14.2	28.1	93.8
30	13	97.5	11.0	83.8	44.2	6.2	8.2	32.5	95.0
45	15	97.6	27.3	96.5	55.5	7.5	17.8	31.8	75.4
60	15	87.2	90.4	111.6	76.1	7.9	10.5	17.2	33.0[b]
75	16	41.0	96.6	92.4	58.0	6.0	6.3	14.1	32.0
90	15	13.8	100.0	98.2	49.3	6.7	2.5	0.0	64.6
105	Not recorded	14.5	100.0	99.0	50.2	8.0	3.2	0.3	28.3
Control (No infection)	No inoculation	0.0	0.0	105.7	59.3	7.1	4.2	0.0	0.0

a. Observation based on 5 plants.

b Increase in yield.

Table 2. **Effect of sterility mosaic on yield and yield components of early-maturing susceptible pigeonpea cultivar T-21 inoculated at different ages in the 1977-78 season.**

Age of plant at inoculation (days)	Incubation period (days)	Percent infection[a]	Average no. of primary branches/plant[b]	Average no. of secondary branches/plant[b]	Average no. of flowers/plant[b]	100-seed weight (g)	Average yield/plant (g)	Percent loss in yield	Symptom severity
15	7	100.0	3.8	13.1	1.3	0.0	0.0	100.0	Mostly complete sterility
30	11	100.0	2.6	13.0	0.2	6.5	1.0	81.2	Mostly complete sterility
45	20	70.9	2.5	5.8	1.6	7.2	5.0	8.6	Mostly partial sterility
60	26	59.3	1.9	6.4	9.2	6.4	4.2	24.1	Mostly partial sterility
75	35	22.8	2.0	7.1	11.4	8.5	5.0	9.1	Mostly partial sterility
Control (No infection)		0.0	3.0	5.3	14.4	7.7	5.5	0.0	No symptoms

a. Number of plants/treatment = 29 to 30.
b. Observations based on 10 plants.

Table 3. Effect of sterility mosaic on yield and yield components of medium-duration pigeonpea cultivar ICP-1 inoculated at diffetent ages in the 1977-78 season.

Age at infection (days)	Incubation period (days)	Percent infection	Average height of plant (cm)[a]	Average no. of primary branches/ plant[a]	Average no. of secondary branches/ plant[a]	Average no. of tertiary branches/ plant[a]	Average no. of flowers/ plant	100-seed weight (g)	Average yield/ plant (g)	Percent loss in yield
30	20	97.6	81.6	4.1	16.8	15.8	7.4	8.2	3.1	71.6
60	24	97.6	60.7	2.7	7.1	6.3	8.5	9.1	1.0	90.5
90	30	21.1	114.5	5.8	15.3	0.0	9.5	7.4	10.4	6.6
120	Not recorded	19.0	99.3	7.5	11.6	0.0	16.3	7.8	9.7	12.6
Control (No infection)		0.0	101.3	4.7	8.5	2.0	7.3	7.8	11.1	0.0

a. Observations based on 10 plants.

Table 4. Effect of sterility mosaic on long-duration mild mosaic pigeonpea cultivar NP(WR)-15 infected at diffetent ages in the 1977-78 season.

Age at infection (days)	Average no. of primary branches/ plant[a]	Average no. of secondary branches/ plant[a]	Average no. of tertiary branches/ plant[a]	Average no. of flowers/ plant	100-seed weight (g)	Average yield/plant (g)[b]	Percent loss in yield
45	3.7	22.0	35.0	2.0	9.0	4.9	63.7
90	4.0	31.6	71.2	2.1	7.9	8.8	34.9
135	2.7	26.1	74.6	46.2	8.5	10.9	20.0
180	2.3	33.2	61.5	14.8	8.6	16.2	19.2[c]
Control (No infection)	1.8	25.1	56.5	3.2	8.7	13.6	0.0

a. Observations based on 10 plants.
b. Observations based on 25-79 plants.
c. Increase in yield.

obtained in the ratooned growth of late-inoculated plants.

The bushiness of the infected plants in early and medium-maturing cultivars was due to the increased number of secondary and tertiary branches. The reason for relatively less reduction in yields when the plants were infected at 30 to 90 days age, depending on the maturity types, appeared to be an increased number of secondary and tertiary branches and partial rather than complete sterility. The late infections did not affect yields in the main crop, but would be of significance wherever crop ratooning is attempted.

Since the observations on the effect of the disease on yield and yield components were based on plants grown in nonreplicated isolated plots or pots, the figures do not represent absolute values but only indicate the trends.

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Entomology

Session I

Chairman : H.F. van Emden

Rapporteur : S. Sithanantham

Session II

Chairman : H.F. van Emden

Rapporteur : S.S. Lateef

Development of a Methodology for Open-Field Screening for Insect Pest Resistance in Pigeonpea

S.S. Lateef and W. Reed*

Abstract

Pigeonpea, Cajanus cajan [L.] Millsp., *suffers large losses to many insect pests but particularly to the pod borer,* Heliothis armigera (Hb.) *and the pod fly,* Melanagromyza obtusa (Mall.). *Most farmers who grow this crop do not use pesticides, so the development of less susceptible cultivars would be of great benefit to them. This paper describes the development of a methodology for the pest resistance screening program initiated at ICRISAT in 1975. As the major pests affect the crop only at the podding stage when the plants are large, open field screening appeared to be the only possible initial approach, particularly since the pests behaved atypically in field cages. Because we found considerable variation in pest damage amongst cultivars of different maturities, screening is done in narrow maturity groups within which relevant check cultivars are used as standards. Balanced lattice square designs have been found to give increased precision; hence, these are used to test the advanced selections, which are also compared under pesticide protection. The search is not only for resistance but also for the ability to yield well in spite of pest attacks and particularly for the ability to compensate for early losses. Results so far show considerable and consistent differences between plant types and selections in susceptibility to both pod borer and podfly losses, in spite of problems introduced by the high incidence of out-crossing and the considerable spatial and temporal differences in pest distribution.*

Pigeonpea, *Cajanus cajan* [L] Millsp., is of widespread importance in the subcontinent, East Africa, some parts of Latin America, and in the West Indies. More than 120 insect species have been recorded as feeding upon this crop (Davies and Lateef 1975, 1978). Attacks start at the seedling stage when beetles, in particular, can cause extensive foliar damage; such severe damage during the vegetative stage may delay flowering.

* Pulse Improvement Program, ICRISAT.

However, the plants recover well from almost complete defoliation, and insect-caused plant death is rare.

In India — where over 90% of the world's recorded production of pigeonpea is grown — and in several other countries, major loss is caused by a complex of borers that attack the flowers and pods, *Heliothis armigera* [Hb.] is by far the major component of the pod-borer complex, being most damaging in southern and central India but the podfly, *Melanagromyza obtusa* [Mall.] causes equal or greater damage in the north (Reed et al. 1980b).

Of the other lepidopteran pod borers, the plume moth, *Exelastis atomosa* W., can be particularly damaging later in the season, and the blue butterflies, Lampides *boeticus* L.and *Catochrysops strabo* F., are damaging in some areas. A hymenopteran pest, Tanaostigmodes *sp.* is common in some areas, but is not generally noticed because of its small size (Lateef 1977). Sucking bugs, particularly *ciavigraiia* spp., are also of importance in some areas.

Our surveys of pigeonpea-qrowing areas in 13 states in India showed generally high levels of pest-caused losses. In spite of such great losses, only a few farmers (<5%) use pesticides on this crop, so the development of less susceptible cultivars would be of a great benefit. For this purpose, we started searching not only for resistance but also for the ability of the plants to compensate for early losses and for high-yielding plants that will produce a crop in unprotected conditions even under high pest attacks. Work on the screening of the available germplasm and other materials for reduced susceptibility to the pod borers and podfly was initiated at ICRISAT in 1975 (Lateef 1977; Davies and Lateef 1978; Reed et al. 1980a).

Effects of Crop Timing and Growth Habit on Losses to Pests

When this work was initiated, there were few published data on the influence of growth habit, maturity, and flowering of pigeonpea cultivars on levels of pest damage (Sheriff and Rajagopalan 1971). From 1975, trials of cultivars with determinate and indeterminate growth habits, representing three maturity groups (early, medium, and late), were grown in randomized blocks with four replicates in a Vertisol area. The crops were pesticide-free, and detailed entomological counts were taken during growth. At harvest all pods from five randomly selected plants from each plot were collected, and damage was assessed by examining each pod. The results from the 1975-76 trial are furnished in Table 1. Data with similar trends were obtained from trials in subsequent years.

It was found that the relative pest status of the lepidopteran and other pod borers was considerably affected by days to flowering. Damage caused by the lepidopteran borers to pods of early and mid-maturing cultivars was high, particularly to those of determinate (pod cluster) habit. Podfly was much more important on late-maturing cultivars. In 1975 and in subsequent years, it was found that *H.armigera* attacks were at a peak in November, while podfly and hymenopteran attacks tended to

Table 1. Comparison of borer and podfly damage in determinate and indeterminate pigeonpea cultivars of differing maturities in unprotected trials on Vertisol at ICRISAT Center, 1975-76.

Days to flowering	Percentage of pods damaged			
	Determinate		Indeterminate	
	Borer	Podfly	Borer	Podfly
60	64.3	1.5		
63			45.7	2.7
103			51.1	3.1
106			41.4	3.2
112	82.5	0.6		
116	89.3	0.7		
117			72.8	3.0
121	87.8	2.1	76.1	3.3
123	76.8	0.5	68.0	4.1
126	74.2	5.0		
128	66.6	17.6		
134			61.8	12.7
136			39.5	15.5
137			58.5	20.6
150	59.0	8.4		
189	24.1	17.7		
Overall mean	69.4	6.0	57.2	7.6

CV(%) Borer damage : 16.95
Podfly damage : 15.24

LSD (0.05%)
Borer damage : 51.96
Podfly damage : 5.01

increase from December onwards. Thus, cultivars could appear more or less susceptible to pests according to whether they were fruiting during the peak pest-attack periods or not. This information could be useful in directing our selection for cultivars of suitable maturity for areas where the pests are known to be consistent in their peak infestations, but it complicates the search for resistance. The obvious means of overcoming this problem was to screen materials of each maturity group in a separate trial, using a well-known cultivar within that maturity group as the check.

Confirmatory evidence of the susceptibility of' determinate type to lepidopteran borers was obtained from other trials, in which cultivars that were segregating for plant habit were compared, as shown in Table 2. In all three cultivars the determinate types were more heavily attacked

Table 2. Pest damage on determinate and indeterminate segregants of pigeonpea cultivars of different maturities under unsprayed conditions on Alfisol and Vertisol blocks at ICRISAT Center, 1975-76.

Cultivar	Growth habit/ maturity	Alfisol					Vertisol				
		Pods on 40 plants	Borer	Podfly	Hymenoptera	Total	Pods on 40 plants	Borer	Podfly	Hymenoptera	Total
Pusa Ageti	Det.[a] (early)	3017	64.5	10.2	0.3	69.0	5221	76.2	1.2	0.4	77.5
	Seg Indet[b]	8953	25.9	8.2	3.6	36.1	8086	41.9	2.8	0.5	45.0
ICP-7050	Det (mid)	11259	23.3	13.5	2.3	39.2	5431	49.0	9.9	2.9	60.5
	Seg Indet	17582	12.1	28.1	4.1	48.6	13511	21.1	25.5	4.9	48.8
ICP-6365	Det (late)	3242	25.4	14.8	10.8	46.6	4750	42.9	21.0	5.0	65.8
	Seg Indet	8047	15.5	32.0	20.8	59.5	8449	27.1	33.3	4.1	62.4
	S.E. (Mean) ±		2.00	2.50		2.19		2.09	1.76		2.8

a. Det = Determinate.
b. Seg Indet = Segregating indeterminate.

by lepidopteran borers. More pods survived until harvest on the indeterminate types, but podfly attack was greater in these. Similar observations were recorded by Pawar and Jawale (1977).

Screening Techniques Used at ICRISAT

Screening in Net Houses

Attempts to screen pigeonpea lines in a large net house with the release of laboratory-bred *Heliothis* moths failed, for the moths were resting for most of the time on the net and egg-laying was nonuniform and indiscriminate. Also, the plants were etiolated and required a longer time to pod setting and maturity. Even if the plants and pests had reacted normally, such screening'would prove to be of limited value, for the plants are large and take a long time to grow to the susceptible stage, so enormous areas of net house would be required to accommodate the many thousands of cultivars and collections that must be screened. So a methodology for open-field screening was developed, in which we generally relied upon the natural pest populations but also introduced laboratory-reared *H.armigera* moths where egg-laying was seen to be low. Usually, however, the attacks by this pest have been greater than we require for discriminatory screening.

Open-Field Screening

Initial screening of more than 7000 germplasm accessions over the last 5 years has been in unreplicated small plots, with infestor rows of cultivars of mixed maturities sown 2 weeks before the test plots. The pod damage and yields of plants from each test entry were compared with those from check cultivars of comparable maturities. All those entries that yielded less and also suffered greater pest damage than the checks were rejected at this stage. This method of selection by rejection largely overcomes the problem of "escapes" but leaves us with comparatively large numbers of entries-to test in subsequent seasons.

The high incidence of outcrossing has plagued our screening. Many of the entries were obviously segregating, as shown by plots that contain plants of differing growth habits, flower and seed colors, and maturities. This greatly complicates our task, for in many cases we have to retest entries split for such characters. Where individual plants are noticeably higher yielding or less attacked than other plants in any entry, we harvest the seed from such plants separately and test the progeny of the single-plant selections in subsequent seasons. At the later stages of screening, we sow part of each selection in a pesticide-treated area and self each plant within a muslin bag, but this does not completely overcome the problem of outcrossing and subsequent segregation.

The reliance upon open-field screening against pests that attack at the fruiting stage on such a slow-growing crop has limited our testing to only one generation per year, severely restricting our rate of progress.

We hope to identify the mechanisms involved in resistance, for this would enable us to reduce our dependence upon open-field screening and might enable us to screen more than one generation in each year.

Most pigeonpea plants can lose all of their first flush of flowers and pods to pests but then grow on to produce a compensatory crop, provided the climate and soil water conditions are favorable. This ability to compensate is of obvious value to farmers who do not use pesticides. We have attempted to select for this character by harvesting pods from the early and mid-maturing cultivars after the first flush; we then harvest again after the second flush. This has greatly increased our volume of work but has been invaluable, for we have found marked differences in the ability of selections to compensate for early losses. Such ability to compensate may be termed "recovery resistance."

All selections of interest from the unreplicated screening are then tested in trials, each of a narrow maturity range, with increasing replication in each year. Each trial contains relevant check cultivars and lines of known high susceptibility. We reject the less promising materials at each stage. In addition to the germplasm we have also been screening materials generated by our breeders, including intergeneric derivatives obtained from crosses of pigeonpea with *Atyiosia* spp., the wild relatives of pigeonpea, which have marked resistance to some of the pests.

Advanced stage testing is in balanced lattice square design trials with 16 or nine entries in each (Table 3).

This design has been found *to* give *an increase* in efficiency, which is *very* welcome in this work, where spatial and temporal variations in pest attack result in high coefficients of variation. Advanced selections are also compared under pesticide protection.

Summary

The general sequence developed for pest resistance selection at ICRISAT is now as follows:

First year	Unreplicated screening of germplasm and breeders' materials
Second year	Two - replicate observation of selections.
Third year	Three - replicate testing of selections sprayed and unsprayed, with test material separated according to maturity. Advanced materials from the breeders are also introduced at this stage.
Fourth *year*	Four- *or* five- replicate balanced lattice square testing of promising selections, sprayed and unsprayed.
Fifth year	Continued testing for confirmation of results obtained previously, multilocation testing, and use by breeders in crossing program.

Table 3. Data from a balanced lattice square design trial with five replications, of mid-maturity pigeonpea selections, sown 26 June, 1978 in the pesticide-free area of ICRISAT Center.

Pedigree/ ICP No.	Characters[a] 1977-78 season	Pods/ plant(30 plants sampled)	Pod damage Borer	Mean (%) Podfly	Hymenoptera	Mean plot[b] yield(g)
4185-E1-EB	LB	173	26.5	12.9	4.6	425.0
4745-2-E8-EB	HY,LB	175	31.3	16.2	24.2	221.3
896-4-E1-EB	LPf,HB	145	48.3	3.1	3.4	81.4
PPE-36-2-B	HH	245	23.0	23.5	26.2	433.4
4257-E1-EB	HY	278	33.9	23.1	8.3	394.9
5036-E1-EB	HPf, HY	236	35.9	24.1	4.5	500.8
7946-E1-EB	LPf,HY	280	40.8	1.5	1.9	134.0
7088-E1-EB	HPf	182	36.5	24.6	15.1	282.1
8036-E1-EB	HY	255	30.1	24.1	11.5	376.2
4745-9-E1-EB	HY,LB	125	29.1	12.0	9.1	309.5
7176-22-E18-EB	LPf	130	37.6	9.2	10.0	155.8
4745-9-E13-EB	LB	140	25.7	14.2	9.0	296.8
8102-E1-EB	LB,HY	150	30.1	19.7	13.1	384.7
7176-29-E9-EB	HB,LPf	184	33.5	14.1	3.6	312.6
7197-EB	Check	109	38.3	11.9	11.4	196.5
C-11-EB	Check	148	48.2	14.5	1.7	276.3
SEm±			3.09	2.24	2.25	38.77
Efficiency compared with RBD(%)			120	112	109	140

a. LB = Low borer, LPf = Low podfly, HH = High hymenoptera
HB = High borer, HPf = High podfly, HY = High yield

b. Net plot harvested = 7.88 m^2

The large plant size, lengthy growing season, compensatory habit, and high incidence of outcrossing have all posed problems in the selection and screening process. We have found no plants that are anywhere near immune to any of the major pests. Results so far do, however, show considerable and consistent differences between plant types and selections in susceptibility to both pod-borer and podfly losses. We now have several promising lines that have some tolerance to pest attacks and yield a reasonable crop under heavy pest threats in the unsprayed situation. These selections are now being tested at various locations in India and abroad. Efforts are being made to ascertain the mechanisms of resistance in our laboratory.

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This work involves the meticulous recording of a large volume of data in the field and we are fortunate in having a dedicated team who have conscientiously carried out this task. We also wish to acknowledge the generous cooperation of our colleagues in the All India Coordinated Pulse Improvement Project.

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Pattern of Podfly and Pod-Borer Damage in Late Pigeonpeas

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Abstract

The pattern of podfly and lepidopteran borer infestation was studied in 16 elite late pigeonpea lines at Varanasi, Uttar Pradesh, India, in 1978-79. There were two flushes of podding, with the yield from the second flush being much higher than that from the first. Damage by lepidopteran borers was very low in the first flush but increased in the second. The podfly, Melanagromyza obtusa *was the major pest in both flushes, being found in more than 60% of the pods. There were significant differences in podfly damage among the cultivars.*

Most pigeonpeas (*Cajanus cajan* [L.] Millsp.) are grown in India for grain purposes. In general, low yields are obtained because of the damage caused by pests and diseases. Pigeonpea is a long-duration crop and is attacked by many insect pests from sowing to harvest Of these, the podfly, *Melanagromyza obtusa* (Mall.) in north India (Uttar Pradesh, Bihar, Madhya Pradesh, and certain parts of Maharashtra), where medium and late cultivars are grown, and gram pod borer, *Heliothis* armigera (Hb.) in south India, cause serious damage to this crop.

At our center in Varanasi we observed that in most of the late cultivars, a second flush of flowers is usually obtained as a result of the winter rains. This second flowering generally coincides with the first flush pod-filling stage. The observations recorded so far reveal that the podfly is active in both flushes, causing considerable damage to the crop.

The present investigation was undertaken to compare the damage done by podfly and lepidopteran borers in the first and second flowering.

Materials and Methods

A preliminary study of late pigeonpea cultivars maturing in more than

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200 days was conducted to observe the pest infestation during the kharif (rainy season) 1978 at Banaras Hindu University, Varanasi, U.P., India. The trial was planted on sandy loam soil in plots of seven rows, 5 m long and 75 cm apart, with seeds spaced at 30 cm, in a randomized block design with two replications. In each plot, five plants were selected at random and labeled for recording observations. When the first flush was mature, all the pods of each of the five sampled plants from each plot were picked separately. The pod damage caused by lepidopteran pod borers was analyzed by counting the total number of pods and the number of pods showing characteristic bore holes. The pod damage by podfly was assessed by opening 100 randomly selected pods from each plot and seed damage was recorded by counting the total number of seeds and damaged seed from the opened pods. The same procedures were also adopted for the second flush of flowers. Data on pods per plant, seeds per pod, and seed yield per plant were also recorded for each flowering.

Experimental Findings

The pest damage assessment of different pigeonpea cultivars in the two flushes is given in Table 1.

The damage caused by pod borers ranged from 0.6 to 3.3% in the first and 1.8 to 9% in the second flush. Overall pod-borer damage showed no significant differences among cultivars, but a statistically significant difference between the two flushes, and a significant interaction of cultivars with flowering flush was recorded.

The podfly damage to pods ranged from 31.0 to 86.5% and 48.0 to 79.0% in the first and second flushes, respectively. In both flushes, highly significant differences were observed among the cultivars. The difference between the flushes was nonsignificant but the interaction of cultivars with flushes was statistically significant.

The differences among cultivars in seed damage caused by podfly were highly significant in both the flushes, ranging from 11.5 to 63.1% in the first and 25.3 to 46.1% in the second. It was further observed that the difference in seed damage between the flushes was significant, and the interaction of cultivars with flushes was highly significant.

The data on yields and their components are presented in Table 2. Differences in pods per plant and seeds per pod were significantly different among cultivars, flushes, and their interaction. Number of pods per plant ranged from 49 to 231.5 and 101 to 550 in the first and second flushes respectively. The average pod number in the second flush (376.7) was more than three times that in the first (123). Seed yield per plant ranged from 11.1 to 49.2 g and 26.0 to 196.9 g in the first and second flushes, respectively. The average seed yield per plant from the second flush (84.3 g) was higher than from the first (31.7 g).

Discussion

The present investigation was undertaken to study the extent of damage

Table 1. Pest damage assessment in two flushes of flowers in late pigeonpea cultivars tested under untreated conditions, Varanasi, 1978-79.

Cultivar	Pod damage (%)						Seed damage by podfly (%)		
	Pod borer			Podfly					
	First Flush	Second Flush	Mean	First Flush	Second Flush	Mean	First Flush	Second Flush	Mean
38-1	0.6	4.9	2.8	53.5	49.5	51.5	30.7	27.1	28.9
66-1	2.4	2.3	2.4	31.0	52.0	41.5	11.5	28.9	20.2
77-5	1.0	5.3	3.1	54.0	50.5	52.3	25.7	29.2	29.0
84-1	0.6	3.4	2.0	42.0	61.5	51.8	19.7	38.5	29.1
106-1	0.6	5.2	2.9	63.0	62.0	62.5	40.8	30.3	35.6
108-3	1.0	3.5	2.2	51.5	59.0	55.3	25.4	31.2	28.3
110-1	0.7	5.2	3.0	55.0	59.0	57.0	29.5	33.8	31.7
119-1	3.0	6.7	4.9	82.5	68.5	75.5	50.0	39.6	44.8
119-2	1.1	9.0	5.0	79.0	79.0	79.0	45.8	46.1	46.0
119-3	2.4	3.4	2.9	86.5	65.0	75.8	57.4	36.1	46.8
120-2	0.6	5.4	3.0	73.0	73.0	73.0	43.0	39.0	41.0
121-4	3.3	1.8	2.5	62.0	59.5	60.8	37.9	25.5	31.7
121-5	0.8	2.5	1.7	77.0	69.5	73.3	43.6	35.9	39.8
126-4	0.6	4.8	2.7	60.5	58.5	59.5	37.5	34.1	35.8
137-1	1.6	1.9	1.7	80.5	57.0	68.8	49.6	27.0	38.3
T-7	1.9	6.3	4.1	82.5	48.0	65.3	63.1	25.3	44.2
Mean	1.4	4.5		64.6	60.8		38.2	33.0	
SEm ± for cultivars	0.71			4.75			4.33		
CD (5%)	NS			13.71			12.49		
SEm ± for flushes	0.25			1.68			1.53		
CD (5%)	0.73			NS			4.42		
SEm ± for(cultivars x flushes)	1.01			6.72			6.12		
CD (5%)	2.90			19.39			17.66		

Table 2. Yield assessment in two flushes of flowers in late pigeonpea cultivars tested under untreated conditions, Varanasi, 1978-79.

Cultivar	Pods/Plant			Seeds/Pod			Seed yield/plant (gm)		
	First Flush	Second Flush	Mean	First Flush	Second Flush	Mean	First Flush	Second Flush	Mean
38-1	231.5	515.6	373.6	2.9	2.8	2.9	47.6	75.9	61.8
66-1	93.6	326.4	210.0	3.5	2.9	3.2	24.9	62.3	43.6
77-5	198.0	337.5	267.8	3.3	3.1	3.2	23.7	62.4	43.1
84-1	226.3	445.4	335.9	3.1	3.1	3.1	46.3	64.5	55.4
106-1	54.8	392.3	223.6	2.9	2.8	2.8	11.1	71.0	41.1
108-3	174.7	443.8	309.3	3.2	3.1	3.2	42.4	69.3	55.8
110-1	131.1	531.9	331.5	3.1	2.9	3.0	28.2	78.7	53.5
119-1	115.0	528.5	321.8	4.0	3.3	3.6	43.4	196.0	119.7
119-2	63.4	370.6	217.0	3.7	3.6	3.7	24.4	122.0	73.2
119-3	104.0	550.0	327.0	4.1	3.7	3.9	24.9	134.5	79.7
120-2	109.7	238.7	174.2	3.8	3.8	3.8	49.2	68.9	59.1
121-4	105.0	178.4	141.7	3.3	4.1	3.7	48.9	42.2	45.6
121-5	49.0	371.6	210.3	4.0	3.9	3.9	22.6	162.3	92.5
126-4	121.4	170.6	146.0	3.1	3.1	3.1	25.3	26.0	25.7
137-1	55.7	101.0	78.4	3.4	3.4	3.4	19.3	33.1	26.2
T-7	134.5	524.8	329.7	3.0	2.9	2.9	25.6	79.6	52.6
Mean	123.0	376.7		3.4	3.3		31.7	84.3	
SEm ± for cultivars	40.24			0.09			5.09		
CD (5%)	116.08			0.25			14.68		
SEm ± for flushes	14.23			0.03			1.80		
CD (5%)	41.04			0.09			5.19		
SEm ± for (cultivars x flushes)	56.91			0.12			7.20		
CD (5%)	164.16			0.35			20.76		

caused by podfly and pod borers in the first and second flushes of late pigeonpeas in north India and to examine the feasibility of utilizing the second flush for optimum grain yields. Earlier work was confined to the ratoonability of pigeonpeas either for forage followed by grain yield (Killinger 1968) or for seed (Sharma et al. 1978).

This study showed that the overall damage in the second flush was higher than in the first, for although there was little difference in the percentage of damage caused by pests in the two flushes, the much greater pod number in the second flush resulted in a much greater loss in yield. This may be correlated with the high pest population during the second flush. Ahmad (1938) recorded that the percent pod damage by podfly was very low (11.0) in December and January but rose to a maximum (42.7) in April. In north India (particularly eastern U.P. and western Bihar) the occurrence of winter rains usually helps the pigeonpea crop to overcome moisture stress, and induces a second flowering. The rise in temperature during March hastens the development of the newly formed pods, which may mature about 2 weeks later.

Sharma et al. (1978) reported only vegetative growth for the late-maturing cultivars (ACT-3 group) at Hyderabad in the second flush (after ratooning). However, in the present study, higher yields were obtained from the second flush than from the first, due to the increased pod number per plant.

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Podfly Susceptibility in Pigeonpea: Some Aspects of Oviposition Preference

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Abstract

Podfly, Melanagromyza obtusa *(Mail.), is a major pest of pigeonpea in most areas of India and in other countries of Asia. The ecology of this pest is being studied at ICRISAT, and methods for recording populations are being developed. Oviposition preferences in pods of differing ages and in different areas of the pod wall are described. Preliminary studies indicate that the abundance of glandular hairs, the concentration of tannin-like substances beneath the outer epidermis, and the thickness of a fibrous cell layer above the inner epidermis may influence differences in oviposition preference both in pigeonpea and in* Atylosia *spp. A water spray on the pods of some varieties led to a marked increase in oviposition and infestation. This is considered to be related to physical or chemical changes in the pod surface rather than to a simple humidity effect. This factor could be of importance in the relative susceptibility of cultivars in areas where rain or heavy dew are likely during the pod-formation period.*

The podfly, *Melanagromyza obtusa* (Mall.), (Diptera: Agromyzidae) is a major pest of pigeonpea in most areas of India and is known .to occur in several other countries in Asia (Santok Singh and Ipe 1973). Differences in the susceptibility of various cultivars to attacks by this pest have been reported by Bindra and Jakhmola (1967), Srivastava and Srivastava (1971), Veda et al. (1975), Kooner et al. (1976), and Davies and Lateef (1976). The available evidence indicates that there is a good chance of selecting for useful plant resistance against this pest.

Very little has been reported concerning the relationship of the various plant characters and susceptibility to this pest, but Veda et al.(1975) found a weak positive correlation between pod width and podfly infestation. As the egg is laid into a pod and the insect develops to the adult inside that pod, the only stage at which this insect can select a hostplant is the adult stage, up to egg-laying. Consequently, we studied oviposition in relation to pod characters in a wide range of

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pigeonpea genotypes. The preliminary results from these studies are *briefly described in this report.*

Egg Distribution in Pods

In a preliminary study in December 1978, all the pods from eight plants of Pusa Ageti, 11 of T-21, and 19 of ICP-1 were stripped and examined for eggs. There were few podfly eggs at this time, but there was an apparent tendency for more eggs to be laid in the pods on the upper portions of the plant, for we recorded 1.1, 1.3, and 1.7 eggs per plant from the pods collected from the bottom, middle, and top of the plant respectively.

In studies of egg distribution in pods of different ages, we found 20 eggs per hundred tender pods (up to 10 days after flower), 21 eggs per hundred partly mature pods (11-20 days), and none at all in mature and dry pods. We therefore decided to concentrate our studies of oviposition and egg distribution on young pods up to 20 days after flower opening.

Site of Oviposition within the Pod

Pods in samples of 50 each—total 7200 tender and 6650 partly mature—were taken from a range of cultivars at different times and examined for podfly eggs; the portion of the pod wall through which each egg had been inserted was carefully recorded. For this purpose we divided the pod surface area into three roughly equal portions: the dorsal surface, which lies each side of the suture from which the seeds grow; the lateral surfaces or sides of the pods; and the ventral surface each side of the ventral suture. We recorded the following distribution of eggs per hundred pods examined:

		Dorsal	Lateral	Ventral	SE(m)
Determinate Cultivars	Tender pods	0.7	5.0	10.5	±1.46
	Partly mature pods	0.9	4.9	14.5	±1.64
Indeterminate Cultivars	Tender pods	O.b	2.6	9.1	±0.64
	Partly mature pods	0.7	3.0	12.6	±0.82

Thus more than two-thirds of the eggs laid were inserted through the ventral third of the pod wall in both ages of pods, in determinate and indeterminate cultivars.

In a series of laboratory tests, pods that were attached to branches, but held in abnormal orientations were exposed to ovipositing flies in laboratory cages. Here we found a tendency for the flies to oviposit into the anatomically ventral portion of the pod wall, regardless of whether that portion was held ventrally, dorsally, or laterally. When the egg is laid through the ventral surface of pods up to 20 days old, it is laid into an unobstructed lumen, with little chance of the obviously fragile egg being squashed against the developing seeds. This behavior may be crucial for the successful ovipositʼion of this insect, for we have observed eggs and other stages of this insect in legumes that have pods With lumens, such as *Tephrosia purpurea, Rhynchosia minima,* and *R.aurea,* but not in legumes with pods that have little or no lumen. We regard with suspicion the reports of this pest from plants such as *Abeimoschus escuientus* and *Sesamum orientale* where the egg would have to be laid into solid tissue, even though we have recovered from the petioles of these plant flies that look superficially like *M. obtusa.*

Pod-Wall Characters in Plants with Differing Susceptibilities to Podfly

Extensive screening of the available germplasm in open field tests from 1975 to 1978 gave us selections of pigeonpea that were consistently more and less susceptible to podfly infestation. Four selections from each of the more and less susceptible categories were grown in a trial during the 1978-79 ratny season. Samples of young pods (1 week after flower opening) were fixed on 3% gluteraldehyde (in a phosphate buffer of pH 6.8) postfixed in osmium tetraoxide and then embedded in glycol methacrylate. Transverse sections to two microns thick were cut with glass knives and then stained with toluedene blue.

On examination, the sections showed some differences that appeared to coincide with the known differences in podfly susceptibility among the selections (Table 1). The pods from the less susceptible selections generally had fewer glandular hairs and more intense staining in the subepidermal layer. The intense staining was thought to be associated with greater contents of polyphenols. The differences were not entirely consistent for ICP-7176, had very little polyphenol in the subepidermis, so differing markedly from the other three less susceptible selections. It was also recorded that the number of glandular hairs per unit length of pod wall and the intensity of staining of the subepidermal cells both tended to be less in the older pods (7 to 14 days after flower). In these pods, however, the walls of the subepidermal cells had thickened and some of these cells were darkly stained, indicating the presence of polyphenol concentrations.

We also examined pods from three species of the wild relatives of pigeonpea: *Atyiosia albicans* (relatively susceptible to podfly), *A. scarabaeoides*, and *A. cajanifolia* (both relatively resistant). There were a few glandular hairs on pods of *A.cajanifoiia* but none on the other two species. All three had dark-staining cells in the subepidermis and mesophylI, but these were relatively fewer in *A.cajanifoiia.* A thick layer of fiber cells just beneath the inner epidermis was evident in *A.cajanifoiia* and *A.scarabaeoides,* while in *A.albicans* this layer was much thinner. This layer might offer a barrier to oviposition. In the mesophyll of *A.albicans*, we noticed stone cells (sclereids), which were not seen in the other two species.

Effects of Water Sprays on the Pods

Early attempts to increase the podfly incidence in screening trials by spraying pods with honey and yeast showed that pods from the water-sprayed

Table 1. Anatomical characters observed in the pod walls of selections of pigeonpea known to be more and less susceptible to podfly.

Pigeonpea cultivar	Podfly damage in pods[a] (%)	Anatomical characters of 7-day-old pods	
		Abundance grading of glandular hairs on epidermis[b]	Presence of polyphenols in subepidermis[c]
Less Susceptible.			
ICP-3193-12	7.9	1	2
ICP-4427	3.5	1	2
ICP-7176-1	11.2	1	0
ICP-7176-3	7.2	1	2
Susceptible			
ICP-2223-4	31.6	2	1
HY3C-7-26	32.5	2	0
ICP-6443	23.9	2	0
ICP-4745-9	24.1	2	1

a. Mean for 3 years' assessment in unsprayed crops.

b. Scoring based on visual scoring: O-Nil, 1-Few, 2-Many.

c. Scoring based on blue staining in subepidermis: 0-Nil, 1-Little, and 2-Much.

controls had the greatest incidence of podfly. In many subsequent tests we have in general found that there is an increase in oviposition by podfly in-pods that have been washed by a water spray. Data from one of the many trials are presented in Table 2. Here we placed fine mesh net bags over groups of flowering terminals on plants, keeping these in place for 3 days to ensure that no podfly eggs could be laid. We then removed the bags and sprayed some groups of terminals with water, leaving

Table 2. Podfly oviposition in pods of water-washed and nonwashed terminals on five pigeonpea cultivars, Entomology nursery, ICRISAT Center, 1978-79.

Cultivar	No. of replications	Mean eggs laid by four adults/3 days (estimates/100 pods)	
		Water-washed	Nonwashed
Pusa Ageti	6	3.8	0.4
T-21	6	18.4	2.1
ICP-1	13	3.7	0.3
ICP-6915	10	8.9	6.6
NP(WR)-15	9	1.0	0.6
Mean		7.2	2.0

the others as unsprayed controls. The bags were then replaced, but this time each contained four pairs of podflies. Three days later, all the terminals were harvested and carefully examined for podfly eggs. More eggs were laid in washed pods in all the cultivars, but there were clear differences between cultivars in the response to washing: in T-21 there was nearly a tenfold difference between washed and unwashed pods, but in ICP-6915 the difference was less than two fold.

In another trial we studied the effects of a series of washings at weekly intervals on whole plants of five cultivars and compared the data from these with records from untreated plants. The number of developing stages of podfly (eggs, larvae, and pupae) were counted from samples of 50 pods collected just before each weekly washing. The following mean data were observed:

Mean number of developing stages of podfly observed in samples of 50 pods collected in each week after the first washing.

Treatment	Week					Mean
	1	2	3	4	5	
Washed	18	7	15	24	16	16
Control	14	4	6	15	7	9

Thus at every sampling date there were more podfly in the pods from the washed plants.

In spite of very large variations in the incidence of podfly infestations recorded within the samples from individual treatments, water spraying of young pods invariably led to some enhancement of the number of podfly eggs laid in those pods. Increased humidity around the pods might not have played a role, because fewer eggs are laid on unwashed pods even when flies were caged directly on the pods, and also because the pods soon dry after washing but the effects of the washing appear to persist for several days. Washing apparently has some comparatively long-term effect on the pod-wall either physically, perhaps by making the pod wall softer and so more easily penetrable by the podfly's ovipositor, or chemically, perhaps by washing off or disrupting a deterrent exudate. Ipe (1974) indicated that the fly makes a choice of pod by hovering over pods for a considerable period, but once the fly has settled it invariably attempts to oviposit. This may indicate that a short-range olfactory stimulus or deterrent is involved. This factor is of obvious importance in our screening studies for the susceptibility of some selections to podfly attack may be affected considerably by rainfall at the young pod stage.

We intend to follow up these preliminary studies with further studies on the effect of washing on a range of cultivars in field and laboratory tests. We also hope to study the chemicals that might be involved.

Conclusions

These preliminary studies indicate that there may be several factors involved in the inherent susceptibility of individual cultivars of pigeonpea and *Atyiosia* spp. to podfly attacks. There is a clear need for much more detailed observation of the insect, the plants, and their interaction. An understanding of the mechanisms influencing the susceptibility of any cultivar to podfly attack would be invaluable in our screening and breeding for resistance, for it might enable us to screen more effectively and in more than one generation of plants each year.

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Relative Susceptibility of Pigeonpea Cultivars Against Podfly *Melanagromyza obtusa* Malloch under Field Conditions

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Abstract

Melanagromyza obtusa *is a major pest of pigeonpea in India. As the chemical control of this podfly is difficult and costly, a search for pigeonpea plants that are less susceptible to this pest is being undertaken at Kanpur, India. In an initial attempt to screen germplasm in 2 years, the infestation in the pods of germplasm accessions varied from 0 to more than 80% in each year. However, all of the accessions with little or no podfly infestation in the first year's test had moderate to high infestations in the second year of testing. It was concluded that the screening for resistance will not be easy and that the high incidence of outcrossing in this crop leads to variability in the progeny of the selections. There is a need to select single plants and then to test the selfed progeny from these.*

Varying estimates of losses due to podfly attack have been reported. Ahmad (1938) estimated the grain damage was as high as 40 to 60% in Pusa (Bihar) and 63% in Delhi. Gangrade (1963) assessed the grain damage to be 11.4 to 86.4%, and Bindra and Jakhmola (1967) recorded the .average grain damage of 11.2 to 15.8%.

One method of controlling the podfly and other pod borers is through the repeated use of insecticides; however, factors such as the undesirable effects on the environment and the high cost limit use of insecticides. Luginbill (1969) stated that the ideal method of combating insect attack on plants is to grow insect-resistant varieties. Therefore, identification and development of resistant/or tolerant cultivars would go a long way in the development of an effective, economical, and safe control measure for the podfly. Consequently, an effort has been made to study the host-plant reactions of some of the available germplasm to podfly infestations at Kanpur in northern India. This paper embodies the results obtained from initial studies conducted during 1978-79 and 1979-80.

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Materials and Methods

Pigeonpea germplasm lines were screened for natural podfly infestations. The degree of infestation among these unreplicated lines was evaluated by recording percent pod damage. Four to five hundred mature pods collected from 4 to 5 plants by stripping all the pods from five or six branches per plant were examined for each cultivar. Based on the characteristic damage symptom of the "window" or exit hole, podfly-damaged pods were counted and those with no external damage symptoms were then opened and the contents examined. Of the 659 germplasm lines that were screened during 1978-79, 58 lines that had pod damage below 5% were reevaluated in a three-replicate trial during 1979-80, together with 21 pigeonpea lines reported to be fairly resistant to this pest received from other institutes in India. Cultivar T-17 was used as a check. Percent podfly damage was assessed from five plants selected at random from each plot and recorded separately. The preliminary screening was also continued during 1979-80 with the evaluation of 430 more germplasm accessions. ICRISAT provided 18 cultivars of early, medium, and late groups, which were also tested together with relevant checks at Kanpur during 1979-80.

Results and Discussion

Summaries of the data on percentage of pods damaged by podfly in the unreplicated germplasm lines are given in Table 1. Of 659 entries tested, samples from nine accessions were free from damage and 49 others had less than *5%* damaged pods. The majority of the accessions (72%) had 5 to 20% pod damage.

In 1979-80, out of 430 accessions sampled, nine had no damage and 47 others had less than 5% of the pods damaged. In this year again, most accessions (68%) were in the 5 to 20% pod-damage range.

In the 1979-80 replicated test of the 58 lines selected from the 1978-79 germplasm trial, 21 promising lines received from other centers and check T-17, all the entries had *more* than 20% of their pods damaged. The mean percentage of pods damaged in these entries ranged from 22.8 to 63.5; in the check entry, T-17, 36.7%. The coefficient of variation for percent damage was high at 75.7%, showing *very* large differences between samples of each selection. Only NP-56 (22.8%), Benipoda (23.4%), and C0-3(24.0%) had significantly less damage than the check. Thus, this testing revealed an inconsistency in results from year to year, with entries selected for low damage in the first year giving variable and relatively high damage levels in the second.

This inconsistency may be attributed to the heterozygous nature of the plants. To check on this, we selected 12 plants from 10 cultivars from this trial, all of which were recorded to have less than *5%* damage. The progenies of these plants will be selfed for two generations in an attempt to produce near-homozygous lines and these will then be retested and selected.

In another trial in 1979-80 we tested 18 lines -- sent to us by ICRISAT — that had been found to have differing susceptibilities to pest

Table 1. Results of pigeonpea germplasm screening against podfly during 1978-79 and 1979-80 at Kanpur, India.

Class	Range of pod damage (%)	1978-79		1979-80	
		No. of germplasm lines in each class	% in each class	No. of germplasm lines in each class	% in each class
1	NIL	9	1.4	9	2.1
2	0.1 - 2.5	10	1.5	9	2.1
3	2.6 - 5.0	39	5.9	38	8.8
4	5.1 - 10.0	222	33.7	121	28.1
5	10.1 - 20.0	254	38.5	170	39.5
6	20.1 - 40.0	87	13.2	70	16.3
7	40.1 - 80.0	24	3.6	12	2.8
8	80.1 - 100.0	14	2.1	1	0.2
	Total	659	100.0	430	100.0

damage. In this trial we found that none of these lines gave lower pod-fly damage ratings than our check cultivars.

Conclusions

The data from these trials indicate that the widely prevailing concept amongst entomologists, that one or two seasons' screening of pigeonpea cultivars will result in the identification of resistant material, is at least open to question. The fact that 3 to 40% outcrossing occurs in pigeonpea (Sen and Sur 1964; Khan 1973) makes selection for resistance *very* difficult. The majority of the germplasm accessions tested were obviously *very* variable. It would therefore seem more profitable to select single plants that show less susceptibility and then reselect within the selfed progenies derived from these plants. A program along these lines is now being followed at Kanpur.

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Entomological Studies in Intercropped Pigeonpea Systems at ICRISAT Center: Future Developments and Collaborative Research Needs

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Abstract

This paper highlights some research results on pest numbers, pest/parasitoid/'predator relationships and insect induced yield losses in intercropped pigeonpea in various crop combinations and with different plant populations, pesticide use, soil type, locations, and seasons. The role of kharif sorghum in the buildup of parasites of major pests of pulses is mentioned. The influence of climatic effects affecting migration in Heliothis armigera *(Hubner) and causing disequilibrium with native biotic control agents on pigeonpea is discussed. Attention is drawn towards the need to gather more base entomological data from replicated and representative intercropping trials in both research stations and on farmers' fields. These will initially be surveys on small farmers' holdings, concentrating on a few typical situations and using large blocks and locations as replications under low fertility situations. Future developments and collaborative research needs on intercropped pigeonpea systems are discussed.*

The practice of intercropping or mixed cropping of red gram, *cajanus cajan* (L.) Millsp. is common on the Indian subcontinent and is a rule rather than an exception (ICAR 1970). On dryland farms, cotton, groundnut, and cereals are commonly grown as companion crops with red gram. Despite the predominance of low-input traditional intercrop systems in developing countries in the tropics, such systems have received inadequate research attention. The belief that intercropping as traditionally practiced is outdated, unproductive, and is only a transitional phase in agricultural development still persists. The trend in research on sole crops is still so strong that agricultural scientists of most developing countries still give little attention to research on intercropping systems. Fortunately, there is a growing realization of the importance of catering to the needs of the subsistence farmer and this demands far more input into the study of traditional systems of crop production.

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The insect-pest and vector relationship in intercrops is *very* complex and highly dynamic. Of all research contributions on the entomological aspects in pigeonpea in the last decade, we could find only three (Bhatnagar and Davies 1979; Satpathy et al. 1977; Singh and Singh 1978) that dealt with the pest situation in intercrops, demonstrating the imbalance that still exists in setting up the priorities and direction of entomological research on pigeonpea. One of these papers reviewed the pest-parasite situation in intercropping systems, its influence on crop losses, pesticide use, and likely pest-management strategies in intercrop subsistence farming. The other two papers presented results of experiments with a variety of grain legumes and cereals intercropped with pigeonpea in small plots ranging from 0.025 to 0.075 ha.

Given the cereal/legume bias of ICRISAT's mandate and considering the national and international importance of *Heliothis armigera* (Hubner), this noctuid was selected for detailed study. It was necessary to concentrate on a few crop combinations to establish appropriate plot and sampling methodologies and to attempt to obtain some basic information on the pest situation in mono- and inter-crops. Attention was focused on pigeonpea/cereal combinations in view of their importance in the Indian subcontinent. Hopefully, these research findings will serve as a base for formulation of future viable pest-management systems for intercrops in the semi-arid tropics. Such data are being accumulated and have been periodically detailed elsewhere (Bhatnagar 1980; ICRISAT 1976, 1977, 1978, 1979, 1980).

Methodology

Experimentation using several crop combinations in 1974-76 demonstrated the importance of studying pigeonpea cultivars grown in a few combinations typical of the region if data of practical value and relevance were to be obtained. Subsequently, plots of monocrop, mixed (within lines), and intercrop (between lines) combinations of sorghum and pigeonpea were sown, using locations as replications. Plant populations were carefully controlled. Damage caused and yield losses in sole, mixed, and intercrops were studied, using suitable methodologies, pest numbers, and pestrparasite ratios.

The need for large plots that act as "ecological units" and provide a more realistic "field" situation limits experimentation on intercropping systems. However, on these large plots (minimum size 0.35 ha) real pest and parasite/predator shifts, differential pest and parasite levels between crop systems, and insect-induced yield losses were sampled and assessed without affecting pest levels. Sampling procedures for several pest species, particularly for the podfly, *Melanagromyza obtusa* (Mall.) are often destructive, and this again necessitated large plots.

Data from ICRISAT Center were compared with those obtained from plots sown on farmers' fields in the adjacent village sites. All plots were of comparable size and were sown under typical low-fertility conditions. During 1977-78, mixed crops were grown only at ICRISAT Center, as the local farmers refused to use hybrid sorghum in a mixed crop combination. These farmers also refused to grow sole-crop pigeonpea unless suitable protection measures were provided. Useful additional comparisons were made using data from frequent off-station surveys in the districts of Andhra Pradesh, Maharashtra, and Karnataka, and those obtained from the fields in villages where, ICRISAT is currently conducting intensive socio-economic and anthropological surveys.

Summary of Results

Pest Situation and Losses

The numbers of eggs and larvae of *H. armigera* on pigeonpea and of adults trapped in light traps, were higher on Vertisols than on Alfisols at the ICRISAT Center. Oviposition per 100 terminals was heavier on widely spaced pigeonpea. On pigeonpea (cv ICP-1) at the research farm and in the adjoining Villages sites, the first peak of oviposition occurred in early November over 3 years (1977-80). In some seasons, this resulted in a total loss of the first flower flush on the pesticide-free Vertisol areas of the research farm, as the high larval population consumed buds, flowers, and developing pods. A second flower flush in intercrops and even a third flush in sole-crop pigeonpea were observed in these situations. Consequently, there was a greater reduction in yield in the pesticide-free areas of Vertisols than in Alfisols at the research farm, despite the fact that far more pods were produced in the crops on the Vertisols.

Pesticides indirectly affected and altered the flowering trends, pest numbers, and parasitism levels in intercropping trials. During 1977-78, sprayed pigeonpea (ICP-1) intercropped with sorghum (CSH-6) on deep Vertisols was harvested in 169 to 170 days compared with 260 to 270 days on unsprayed plots.

There were no significant differences in pest numbers, and insect-induced final yield losses between mixed and intercrops of pigeonpea at equal plant populations. However, significant differences in relation to these factors were observed between sole-crop and intercropped blocks, even when plant populations of pigeonpea were equal. Significantly more eggs and larvae of *H. armigera* per 100 pigeonpea terminals and a greater percentage of pod damage were recorded from the intercrops than from the sole-crop blocks. However, as the yields from sole-crop blocks of pigeonpea were higher than from intercrop blocks, the actual weight losses were greater from sole-crop blocks. Data were obtained on seed-weight loss on intercropped pigeonpea at two plant population levels during 1978-79 using the actual weights of damaged and undamaged pods and seeds and calculating the potential yields if all pods had been undamaged. Losses were significantly higher ($P < 0.05$) on intercrops at 50 thousand (81.0%) than at 30 thousand plants/ha (70.0%) for the pods produced as a result of the first flower flush in low-fertility unsprayed areas. However, the differences in final losses in yield (56 and 50%) were not statistically significant. The compensatory ability of pigeonpea cultivars is therefore likely to be an important attribute of cultivars selected for subsistence crop systems.

At the adjoining village sites, pest numbers, parasitism levels, and yield losses on pigeonpea were lower than at ICRISAT Center. At one site in 1977, irrigation of hybrid sorghum at flowering (late September) resulted in increased flower production on pigeonpea compared with that in nonirrigated fields. The irrigated crop also carried higher numbers of *H. armigera* eggs and larvae. This increased the insect-induced yield loss significantly ($P < 0.05$) on the irrigated (45.0%) compared with that on nonirrigated (18.0%) intercropped pigeonpea. A lower yield of pigeonpea was obtained from the irrigated field (446 kg/ha) compared with unirrigated sites (534 kg/ha).

Pest-Parasite Relations

Data obtained at ICRISAT showed that a few important hymenopteran egg and larval parasites build up in *H. armigera* on sorghum. These parasites give little advantage to the associated pigeonpea as they do not subsequently transfer in appreciable numbers on to *Heiiothis* in pigeonpea. Egg parasitism levels on pigeonpea were always low (less than 1%) in contrast to the levels on sorghum (up to 80%). A similar trend was noticed in our survey data. Of 27 parasite species recovered from ten pest species of sorghum (excluding *Heiiothis)* only one was subsequently found, in *very* low numbers, on two of the 16 other pest species studied on pigeonpea.

On pigeonpea, the dipteran parasites on *Heiiothis* larvae were more common than hymenopteran ones. These dipterans did not reduce larval population and damage on pigeonpea appreciably, and were of lesser importance since they mostly killed *Heiiothis* in the prepupal or pupal phase, after the larvae had already caused pod damage. Overall parasitism levels were higher at the research center than in the adjoining village sites, with peaks occurring late in the season. A presumed entry of immigrant moths in the winter months in some seasons further created a disequilibrium with the native parasitic fauna, leading to a rapid increase in larval populations on pigeonpea.

Surveys on Parasite Levels

Surveys in Andhra Pradesh, Karnataka, and Maharashtra states in India confirmed that dipterans were the dominant larval parasites of *Heiiothis* on pigeonpea while hymenopterans were predominant in sorghum (August-October) and chickpea (November-March). Crops, cropping patterns, cropping intensity over large areas, and seasons had an important effect on distribution and abundance of parasites. Parasitism levels by dipterans were lower in paddy-growing areas but higher in cotton-growing regions of Andhra Pradesh and Maharashtra, possibly because of a transfer of parasites, which develop on the bollworm complex in cotton, to intercropped pigeonpea.

Use of insecticide drastically affected parasitism levels. The levels were particularly low on intercropped pigeonpea in the Gulbarga and Bellary districts of Karnataka, and the Tandoor region of Andhra Pradesh, where farmers commonly apply two or more insecticidal sprays against *Heiiothis.* Farmers indicated that the commonly used insecticides were not always effective. Possible reasons are adulteration, use of old stock, and faulty (time and method) spray applications. Another possibility is the development of resistance in *Heiiothis* populations against widely used pesticides, particularly as a result of intensive insecticide use on hybrid cotton and possible subsequent immigration of moths to pigeonpea. However, there is no research evidence on resistance in *Heiiothis* to pesticides in India.

Data obtained from a few villages in Andhra Pradesh and Maharashtra, in collaboration with the economics group of ICRISAT, have indicated that low plant populations with high pest numbers, absence of egg parasites, and low larval parasitism by hymenopterans were mainly responsible for heavy yield losses resulting in low yields on intercropped pigeonpea.

Future Developments and Collaborative Research Needs

Results obtained so far have helped to clarify the status of *Heiiothis* in the widely grown cereal/legume intercrop systems of the Indian subcontinent and reveal and identify some of the basic reasons for the serious insect damage caused to intercrop pigeonpea. However, further ecological studies, including those on pest-parasite relations, are crucially important to understanding pest problems in intercrop pigeonpea systems. More attention needs to be paid to collaborative surveys of biotic control agents of key pests in relation to other specific intercrops to explore the possibility of utilizing these in future on-farm collaborative pest-management projects in intercrops in the real-world situation.

It is essential that collaborative multidisciplinary research and surveys in intercropping are immediately intensified. The research and survey approach described in this paper will have to be extended to other important crop combinations such as cotton/pigeonpea and groundnut/pigeonpea on large plots, using locations as replications. Sole-crop plots are needed to monitor differences in status of pests and diseases, if they exist, and comparisons made with off-station situations. Various cultural practices in both existing and improved intercrop systems are major factors in insect-pest and disease-vector population dynamics and need immediate attention and investigation. In preliminary field-scale experimentation during 1979-80, a significantly high ($P < 0.05$) incidence of sterility mosaic disease was observed in intercrop blocks compared with sole pigeonpea blocks (Bhatnagar, unpublished data).

Studies relating to the effects of cropping systems, plant phenology, cultivars, plant populations, spatial arrangements, fertilizer and pesticide levels and methods of application on key pests such as legume borers and podfly, their ratios to parasites and predators, and losses in intercrops are vital for the formulation of future integrated pest management on present and proposed intercrop systems. The suggested work needs to be intensified in collaboration with national coordinated research programs and agricultural universities, and there is a special need for closer collaboration between scientists for a realistic multidisciplinary research approach to intercrop systems.

Development of pest management recommendations on *Heiiothis* and evaluation of effects in a few important pigeonpea intercrop systems need immediate attention. Subsequently, on-farm operational-scale pest-management tests under the farmers' level of technology will be essential. A strong temptation to run "on-farm" tests with researchers' level management must be resisted; in the final analysis, it is the farmer, with limited resources, who will manage the farm.

There is every indication that one or two insecticide sprays may be necessary for obtaining the full benefit from growing pigeonpea as an intercrop. In this context, timing of sprays and the use of controlled droplet application could be of considerable importance in minimizing disturbance of the ecosystem. The assessment of pesticide application will be complex, because long-term trends may be involved, particularly if sprays are recommended and used over large areas.

Future research on the status of parasites in the pigeonpea crop is obviously important in view of the results obtained. It will be necessary to determine and relate the complex role of physical and chemical factors involved in preferential parasitization by dipterans compared with hymenopterans, and the reasons for lack of native egg parasites in pigeonpea. The understanding of these relationships is crucial to the development of future integrated pest-management practices in intercrops.

More ecological work and further gathering of base data from the real-world situation on farms are essential also to fill gaps in our knowledge of specific crop systems and immigration of *Heliothis.* A light-trap grid will hopefully become fully operational in India in the next few years, so that information on migratory movements of *H. armigera* can be obtained. The described approach is essential for the research and development necessary for management of key pests in present and proposed intercrop systems in the tropics. There are no shortcuts.

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Synthetic Pyrethroids for the Control of the Pigeonpea Pest Complex

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Abstract

Field trials of different insecticides were conducted on pigeonpea at Ludhiana, Punjab, India, 1977 to 1980. The insecticides were directed against jassids Empoasca *spp. during the vegetative stage and against the pod-borer complex, which is dominated by* Heliothis armigera, Exelastis atomosa, *and the podfly,* Melanagromyza obtusa. *The use of pesticides generally resulted in substantial increase in yield. However, pyrethroids gave a higher reduction in pest damage than all the conventional insecticides.*

Pigeonpea, *Cajanus cajan* (L.) Millsp., is one of the main pulse crops of India. It is generally grown during the rainy season; the warm humid weather is conducive to the development of insects, and a number of insect pests damage the pigeonpea crop. During the vegetative growth of the plant, sap-sucking insect pests, including jassids *Empoasca moti* P. and *E. terminalis* D., sometimes assume the pest status and cause damage to the growing plants; however, the major losses are caused by the pests occuring during the late growth stage of the plant. Amongst these are the pod-borer Complex comprising *Heliothis armigera* H., *Exelastis atomosa* W., *Lampides boeticus* L., *Melanagromyza obtusa* Mall., and *Cydia critica* M.

A number of insecticides have been tested for their efficacy against pigeonpea pests, and monocrotophos, quinalphos, carbaryl, phosalone, and endosulfan have been found promising. In the early 1970s, certain chemicals of plant origin were also found effective against crop pests. However, natural pyrethrin and related synthetic pyrethroids such as allethrin, bioallethrin, resmethrin, bioresmethrin, cismethrin, and ethanochrysanthemate are unstable in air and light. Hence the insecticidal properties of some photostable synthetic pyrethroids have been evaluated by Elliott et al. (1973, 1974, 1978). Pyrethroids have a long record of safe use, despite surprisingly high intravenous, but low oral, toxicity to mammals (Barnes and Verchoyl 1974; Wickman and Chadwick 1975). By the middle of the 1970s, about half a dozen synthetic pyrethroids such as fenvalerate, decamethrin, permethrin, and cypermethrin became available.

These synthetic pyrethroids have been tested on a number of crops by various researchers, e.g. by Cantu and Wolfenberger (1970), Breese (1977),

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Lhoste and Piedallu (1977), Ruscoe (1977), and Sukhija et al. (1980) on cotton; against *Heliothis armigera, Pectinophora gossypiella,* and *Anthonomus grandis* by Voon and Chung (1979) on tobacco against *H. armigera;* by Collingwood and Bourdouxhe (1980) on tomatoes against *H. armigera;* and by Dilbag Singh (1980, unpublished) on brinjal and tomatoes against *Leucinodes orbonalis* Gues. and if. *armigera.*

We therefore decided to test some of the available synthetic pyrethroids against the insect pests of pigeonpea at Ludhiana, Punjab, to assess their efficacy in comparison with conventional insecticides.

Materials and Methods

A set of eight conventional insecticides was tested during the crop season of 1977, against the pigeonpea borer complex. Similarly, during the 1978 crop season, a set of 11 insecticides, including the eight of 1977, was tested against pigeonpea borers. All the insecticides significantly brought down borer attack, monocrotophos, quinalphos, carbaryl, phosalone, and endosulfan being the most promising. During the crop season of 1979, a field trial was laid out with these five insecticides and four available synthetic pyrethroids—permethrin (Ambush 50 EC), cypermethrin (Cymbush 25 EC), decamethrin (Decis 2.5 EC), and fenvalerate (Sumicidin 20 EC). The trial was repeated during the 1980 crop season (Table 1). All trials were sprayed twice with manually operated knap-sack sprayers. The first spray was given when the crop attained 50% flowering and the second 15 days after the first application.

Since the pigeonpea jassids, *E. moti* and *E. terminalis,* during certain years assume the status of serious pests, a parallel field trial was also laid out during the 1979 crop season to test the efficacy of the fenvalerate (Sumicidin 20 EC) in comparison with nine promising conventional systemic insecticides for the control of jassids. The trials were laid out in a randomized block design (RBD), with three replications for the borer complex and four for jassids. Plot size for all trials was between 15 and 20 m^2 .

To assess the incidence of pod-borer damage, 200 pods from each plot were collected at harvest and examined for damage (Table 1). The data have been statistically analyzed by converting the percent borer damage using angular transformation.

In the trials for jassid control, the population of the pest was recorded with the help of a split cage (60 cm height, 50 cm diameter) made of a wooden frame, covered with black cloth on all sides except, one, which had a glass pane. During observations, this glass slide was kept facing the sun, so that the jassids, being phototactic in behavior, migrated towards the pane, enabling counting. Jassid population was recorded from three spots of each replication, selected randomly, one in the middle and one on either side of the plot. The pest population, comprised mostly of adult jassids, was recorded twice, 48 hours and 7 days after the treatment (Table 2). The data have been statistically analyzed by transforming the jassid population in $\sqrt{n + 1}$.

Table 1. Efficacy of selected insecticides in control of the pod-borer complex in pigeonpea, Ludhiana, Punjab, India, 1977-80.

Treatment	Dose (a.i.g/ha)	Pod-borer damage(%) 1977	1978	1979	1980	Grain yield(kg/ha) 1977	1978	1979
Monocrotophos(Nuvacron 40E)	350.0	13.8(21.80)[b]	14.3(22.23)	11.1(19.44)	12.5(20.73)	1194	1369	1087
Quinalphos(Ekalux 35 EC)	612.5	4.8(12.64)	10.8(19.17)	7.9(16.26)	22.9(28.59)	1133	1301	920
Carbaryl(Hexavin 50 WP)	1000.0	17.4(24.67)	6.3(14.51)	4.4(12.06)	10.4(18.80)	1133	1197	1213
Phosalone(Zolone 35 W/v)	612.5	15.3(23.06)	20.3(26.7)	12.1(20.34)		950	812	1787
Endosulfan(Hexasulfan 35EC)	612.5	14.5(22.38)	11.6(19.90)	9.7(18.16)	8.3(16.77)	1128	1297	1407
Dimethoate(Rogor 30 EC)	262.5	14.7(22.55)	25.1(30.04)			1044	1223	
Formothion(Anthio 25 EC)	875.0	12.4(20.62)	29.9(33.17)			1026	635	
Fenitrothion(Folithion 50EC)	280.0	12.4(20.62)	20.3(26.78)			1100	1008	
Phenthoate(Phendal 50 EC)	612.5		25.2(30.12)				1001	
Chlorpyriphos(Dursban 20EC)	576.4		23.1(28.92)				1962	
Trizophos(Hostothion 40 EC)	282.6				11.8(20.06)			
Fenvalerate(Sumicidin 20EC)	90.0			6.9(15.25)	0.7(4.78)			1113
Permethrin(Ambush 50 EC)	90.0			4.0(11.58)				1627
Cypermethrin(Cymbush 25 EC)	90.0			6.8(15.09)				1427
Cypermethrin(Cymbush 25 EC)	37.5				4.8(12.62)			
Decamethrin(Decis 2.5 EC)	90.0			3.5(10.77)				2300
Decamethrin(Decis 2.5 EC)	12.5				1.6(7.17)			
Neemseed kernel extract	5.0[a]		18.0(25.13)				594	
Karanj oil	0.2[a]				12.8(20.99)			
Control		36.5(37.14)	44.1(41.63)	15.2(22.94)	25.9(30.62)	888	875	1213
LSD(5%)		(4.65)	(9.02)	(6.43)	(8.60)	202	N.S.	N.S.
SE							461.4	413.5

a. Concentration in percent.
b. Figures in parentheses are the transformed values. Quantity of spray solution @ 875 liters/ha.

Table 2. Efficacy of insecticides for the control of pigeonpea jassid.

Treatment	Dose (a.i. g/ha)	Jassid population/cage* 48 hours after spray	
		48 hours after spray	**1 week after spray**
Fenvalerate	175	1.1 (1.42)	6.2 (2.68)
Monocrotophos	175	1.3 (1.53)	4.5 (2.34)
Formothion	175	3.0 (2.00)	3.2 (2.05)
Dimethoate	175	3.3 (2.03)	3.5 (2.12)
Methyldemeton	175	3.2 (2.03)	4.2 (2.27)
Quinalphos	175	5.6 (2.56)	6.8 (2.78)
Phenthoate	175	7.7 (2.93)	7.9 (2.96)
Phosphamidon	175	7.8 (2.94)	8.6 (3.08)
Endosulfan	175	10.5 (3.36)	6.7 2.76)
Malathion	175	15.6 (3.94)	10.3 (3.33)
Control	-	38.1 (6.20)	24.8 (5.73)
LSD (5%)		(0.75)	(0.49)

* Figures in parentheses denote the means of jassid population transformed $\sqrt{n + 1}$.

Results and Discussion

As table 1 shows, the incidence of the borer complex during 1977 and 1978, with conventional insecticides, was significantly lower than with no treatment. During 1979 and 1980, the incidence of borers in the treatments ranged from 3.5 to 12.1 and 0.7 to 22.9% in comparison with 15.2 and 25.9%, respectively, with no treatment. All the pyrethroids were superior to the conventional insecticides in reducing borer damage.

In the case of jassids the use of all the insecticides under test was significantly better than no treatment; 48 hours after treatment, fenvalerate was significantly better than all the conventional insecticides except monocrotophos which was at par with it. However, the persistence effect of pyrethroids (tested 1 week after the initial treatment) was lower than that of the traditional insecticides.

The results of these trials indicate that in the field the pyrethroids control lepidopterous, dipterous, and heteropterous pests several times more effectively than the most potent compounds of other principal groups of insecticides. Elliott et al. (1978) have inferred that the recent more stable pyrethroids, harmless to mammals and birds and notphytotoxic, combine the high insecticidal activity of the earlier pyrethroids with suitable persistence, so that they could be expected to control well a broad spectrum of plant pests. Similarly, Voon and Chung (1979) have concluded that synthetic permethrin is *very* effective against the larvae of many pest species of Lepidoptera, including *H. armigera* on tobacco. Collingwood and Bourdouxhe (1980) have recorded that decamethrin showed high insecticidal activity against H. *amigera* on tomatoes. Dilbag Singh (unpublished)[1] observed high mortality of tomato borer *H. armigera* with permethrin, cypermethrin, decamethrin, and fenvalerate. The results we have obtained also confirm the findings of previous researchers that the pyrethroids effectively reduced damage due to the borer complex in pigeon-pea.

The findings of various research workers reveal that synthetic pyrethroids may soon constitute a powerful group of insecticides for crop pest control. However, toxicity of pyrethroids to some beneficial insects, including honeybees cannot be ruled out, and appropriate field precautions will have to be observed in their use (Breese 1977; Elliott et al. 1978). Similarly, due consideration will have to be given to the cost of applying pyrethroids compared with conventional insecticides.

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Pests of Pigeonpea on the Northern Coast of Peru

Oscar Soto Pflucker

Abstract

Pigeonpea is a minor crop in Peru, but of increasing importance; total area under pigeonpea at present is estimated at 480 ha. The insect pests of this crop have received little attention. This paper reviews the available literature and adds to the present knowledge of the status of the pests on this crop.

Pigeonpea, which is known in Peru as "Frijol de palo" or "lenteja," is grown as a minor crop on t..e northern coast from sea level up to 80 m. It is usually grown in hedgerows or in small garden patches of less than half a hectare each. Statistics published by the Ministry of Agriculture and Food (1976) record that the Lombayeque and Piura regions grow a total of 110 ha of this crop under irrigation, with yields of 1400 and 3000 kg/ha, respectively, for consumption as green peas. Formerly, this crop was largely ignored in spite of its relative tolerance of drought and salinity, these being two major problems in this area. More recently, both growers and consumers are taking a greater interest in the crop for this high protein food is being increasingly used as a green vegetable, mixed with rice, meat, and fish. Generally, the insect pest problems on the crop have been considered to be relatively small, but there are indications that some of the pests will have to be controlled with pesticides.

Review of Available Literature

There are only a few references to the pests of pigeonpea in Peru. Wille (1934) mentioned that *cajanus cajan* could act as a secondary host for the cotton bollworm, *Heliothis virescens.* Subsequently, there appears to be no published report on the insects of this crop until 1963, when an Agriculture Ministry bulletin reported "Frijol de palo" as a secondary host of *Eutinobothrus gossypii* (Pierce), a root-mining weevil that is a destructive pest of cotton.

Korytkowski and Torres (1966) provide us with the only detailed description of the entomofauna of this crop; a translated summary of their report follows.

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Thysanoptera

Leucothrips theobromae (Thripidae) and *Liothrips* sp., possibly *L. ilex* (Phoethripidae), are found on the lower surfaces of leaves, on buds and flowers and inside pods when these have been damaged by podborers. These thrips are not considered to be of any importance, except on newly emerged seedlings where they can cause damage.

Homoptera

Cercopidae

Clastoptera variabilis adults are small, 3 to 5 mm long, brown-grey in color. They are found feeding on the upper secondary branches and jump when disturbed. The nymphs excrete a foamy liquid which surrounds and protects them. Large infestations will lead to yellowing and even death of the upper branches of the plant but the lower portions will remain healthy.

Membracidae

Aconophora concolor (Darninae), *Enchenopa monoceros* and *Spongophorus* sp. (Membracinae) can be injurious, the first being of greatest importance because of its large populations, *A. concolor* adults are green, 7 mm long, with a characteristic sharp horn projecting forward from the protothorax. *E. monoceros* adults are a little larger, yellow-brown in color; *spongophorus* sp. has a similar protothoracic horn which is curved up and back. All these insects lay masses of eggs on the basal surfaces of the branches. The nymphs and adults feed by puncturing and sucking the young branches; this causes yellowing of the upper leaves.

Cicadellidae

Two species of Cicadellidae were observed; *Empoasca fabae* (Jassinae) and *Dikraneura* sp. (Typhlocybinae), the latter being more numerous and common. The injury caused by these insects appears to be of no economic importance.

Aleurodidae

Specimens were found on the lower surfaces of leaves, usually on older plants. The genus and species could not be determined, but they were classified in the Aleurodidae. The adults were about 2 mm long, yellow, with white wings. The nymphs were black, but were covered with cotton-like waxy white threads.

Coccidae

Four species Of Coccidae were found, *Saissetia hemisphaerica, Ceroplastes* sp. (Lecanunae) *Hemichionaspis minor* and I*cerya purchasi.* These could be of economic importance. Severe attacks were seen on the basal portions of stems and these could result in plant death.

Coleoptera

Chrysomelidae

Cry*ptocephaius castaneus* (Chrysomelinae) was found feeding on foliage. The adults were 3 to 5 mm in length, brown-yellow, with a typical spot on the protothorax. The elytra had dark red punctuations. The damage caused by these pests is of no economic importance.

Curculionidae

Zurus aurivilianus adults are about 4 mm long and covered with attractively colored scales. The females lay their eggs in the pods in which the larvae develop; they are also found in buds.

Lepidoptera

Phalaenidae

Heliothis virescens is the most injurious insect on pigeonpea. The females lay great numbers of eggs on buds, flowers, and young pods. The small larvae feed upon the flowerbuds and young pods. The large larvae feed on and in the large pods.

Saturnidae

The larvae of *Automeris* sp feed on foliage, eating the leaflet borders and leaving a small portion around the central vein. The adult is a large moth, up to 80 mm long. The fore wings have three stripes and the hind wings each have a large circular spot. The larvae are black with light-green, long poisonous hairs.

Korytkowski and Casanova (1966) recorded heavy parasitism by *Campoletis perdistinctus* in larvae of *H. virescens* collected from pods of *Cajanus cajan* in 1963-64.

Alata (1973) supplied a large list of destructive insects that have been recorded on "Frijol de palo" but none are considered to be of economic importance.

Author's Observations

Recent observations by the author, confirmed by the farmers, indicate that the insect pests found on pigeonpea have changed little since 1966, with the exception of *clastoptera variabilis,* which is now found more frequently.

Eutinobothxus gossypii was also found in the 1979-80 summer, with larvae injuring the roots of this crop in an area of cotton, which was also severely infested. This is the first reported case of such damage since 1963, and the injury to the pigeonpea was not much. It does confirm, however, that pigeonpea can act as a secondary host for this pest which was formerly serious only on cotton.

The adults of *E. gossypii are* up to 3.5 mm long, dark red or black. The head is tucked under the protothorax, which is covered with punctuations and hairs. The elytra are furrowed with lines and also have punctuations and hairs. The adults cannot fly and they feed on foliage and stem bark. The females lay their eggs beneath the bark near the soil surface; taking advantage of bark wounds, the larvae, which are yellowish white with a dark brown head, feed and form galleries between the phloem and xylem. The life cycle is about 1 month on cotton in the summer time and is probably similar on pigeonpea.

It appears that *Heiiothis virescens* attacks on pigeonpea are in close relation to the attacks on cotton. In recent years, cotton-growing areas have diminished because of droughts, and infestations of *H. virescens* have also decreased. It is also possible that the entomofauna on pigeonpea grown near cotton is affected by the aerial application of pesticides on the crop. This can also be expected to affect parasitism levels, but it is Still possible to find *Campoletis perdistinctus* in *H. virescens* larvae on the cotton.

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Seasonal Occurrence and Population Dynamics of *tur* Pod Bug, *Clavigralla gibbosa* Spinola

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Abstract

Studies at Jabalpur, Madhya Pradesh, India, showed that the tur *(pigeonpea) pod bug,* Clavigralla gibbosa *Spin., remained active from 1 October 1978 to 14 April 1979 and fed on maturing crops of pigeonpea in succession. As one crop matured, the bug migrated to another crop bearing flowers and green tender pods. The weather appeared to play an important part in regulating the populations of the pest. Nymphal colonies of the bug were killed by heavy precipitation. It was found that different meteorological parameters appeared to influence the population buildup of pod bug, either singly or in combination. Average temperatures ranging from 21 to 26°C in combination with average humidities ranging from 35 to 75% and a little rainfall were found to be most conducive for the population buildup. Maximum temperatures below 24°C and above 34°C, average temperatures below 21°C and above 26°C, average humidities below 35 and above 75% and heavy rainfall adversely affected the populations.*

The tur pod bug, *clavigralla gibbosa* Spin., is one of the important pod-damaging insects of pigeonpea, *cajanus cajan* (L.) Millsp. Next to the grain pod borer, *Heliothis armigera* Hb., and podfly, *Melanagromyza obtusa* (Mall.), it is the most serious pest causing losses to pigeonpea in Madhya Pradesh (Odak et al. 1976). Feeding by nymphs and adults of this bug causes premature shedding of flower-buds, flowers and pods, deformation of pods, and shriveling of grains, resulting in substantial losses to pigeonpec crops. (Bindra 1965; Mishra and Odak 1979).

The activity of this pest on pigeonpea has been reported from October, or pod formation, to the maturity of the crop (Gangrade 1961 ; Kapoor 1966; Chaudhary 1967, 1973; Bindra and Harcharan Singh 1971). There is little or no literature reporting the activity of this bug on pigeonpea types of different maturities. Studies on the population dynamics of other bugs, including coreid and lygaeid bugs (Vema et al. 1978) and the green stink bug, *Nezara viriduia* (Zile Singh 1973), are available. But only one report is available on the population of dynamics of the tur pod bug, in a study

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of the seasonal occurrence of all pests of an early pigeonpea type (Singh and Singh 1978).

The present study was therefore conducted to determine the activity and seasonal occurrence of tur pod bug on early, medium, and late types of pigeonpea. Its population fluctuation in relation to different meteorological conditions was also studied to determine the conditions favoring the development and multiplication of the pest.

Materials and Methods

Population counts of the tur pod bug, *c. gibbosa,* were recorded by taking biweekly observations on the number of eggs, nymphs, and adults on 25 randomly selected plants of each maturity group of pigeonpea: early (T-21), medium (No. 148) and late (NP[WR]-15 and GWL-3) each grown on a 180 m^2 area in the same field of the Livestock Farm of J.N. Krishi Vishwa Vidyalaya, Jabalpur. Observations were taken during the period from 3 Oct 1978 to 14 Apr 1979.

The average weekly populations of eggs and bugs (total of nymphs and adults) per 25 plants were calculated and are presented in Table 1, along with the average weekly meteorological data. The weeks from 1 Oct 1978 to 14 Apr 1979 were represented as standard weeks.

Results and Discussion

The bugs were first recorded on the early-maturing crop of pigeonpea in the last week of September 1978. Regular observations were therefore started from the first week of October, i.e., the 40th standard week. Eggs, nymphs, and adults of the bug were recorded on the early type from the 40th to the 51st week; on the medium type from the 45th to 5th week; and on the late type from the 4th to the 15th week (Table 1). Gangrade (1961), Bindra and Harcharan Singh (1971), and Chaudhary (1973) have also reported the activity of the bug to continue from October, or pod formation, to the harvest of the crop. Kapoor (1966) and Chaudhary (1967), however, reported its activity beginning the last week of November.

It was observed that the pest appeared in sequence in these varying maturity crops of pigeonpea. No sooner had one crop started maturing, the bugs migrated to the next crop bearing flowers and green pods. Thus the population seemed to be influenced primarily by the stage of crop, and there was a dispersal throughout the active season, with adults seeking crops with buds, flowers, and/or developing pods. Verma et al. (1978) also recorded a direct relationship between the abundance of a lygaeid bug and the number of flowers on its host plants.

During the first 7 weeks, i.e., from the 40th to 46th standard week, there was a progressive increase in the number of eggs and populations of nymphs and adults. During this period, maximum temperatures fluctuated between 30 and 31.8°C and average temperatures between 22.5 and 26.3°C, while the average relative humidity showed a decreasing trend, dropping to 58.3% in the 46th week, and rainfall was very light.

Table 1. Average weekly counts of eggs and bugs (nymphs and adults) of *Clavigralla gibbosa* Spinola on different maturity groups of pigeonpea under varying meteorological conditions, 1 Oct 1978 to 14 Apr 1979, Jabalpur, India.

Standard week	Early-maturing variety		Medium-maturing variety		Late-maturing variety		Temperature (°C)			Humidity (%)			Rainfall (mm)
	No.of eggs	No.of bugs	No.of eggs	No.of bugs	No.of eggs	No.of bugs	Min.	Max.	Ave.	Morning	Evening	Ave.	
40	82	29.5	0	0	0	0	21.2	31.4	26.3	88.7	62.7	71.9	0.3
41	100	62.0	0	0	0	0	18.1	31.8	24.9	73.4	55.1	64.2	0
42	148	82.5	0	0	0	0	16.3	31.5	23.9	73.0	56.2	64.6	0
43	223.5	123.0	0	0	0	0	15.9	30.8	23.8	71.8	57.7	64.7	0
44	264.0	99.5	0	0	0	0	18.1	30.5	24.3	78.0	55.1	66.5	0.3
45	460.0	73.5	39.5	12.5	0	0	17.1	31.5	24.3	73.8	55.0	64.4	0
46	515.5	138.5	104.0	40.0	0	0	15.1	30.0	22.5	72.2	44.5	58.3	0
47	308.5	159.0	131.5	59.0	0	0	15.4	31.5	23.4	65.2	43.0	54.1	0
48	226.5	126.5	130.5	56.0	0	0	13.8	23.0	18.4	79.2	71.5	75.3	78.7
49	137.0	47.5	61.5	15.0	0	0	11.8	22.4	17.1	92.0	64.7	78.3	9.7
50	34.5	19.5	82.5	38.5	0	0	9.67	24.0	16.8	82.7	57.1	69.9	0
51	21.5	19.0	80.0	47.5	0	0	9.60	24.6	17.1	78.5	51.2	64.8	0
52			63.0	49.0	0	0	6.05	22.9	14.4	72.1	44.5	58.3	0
1			39.5	30.5	0	0	8.71	25.3	17.0	76.8	47.1	61.9	0
2			31.5	31.0	0	0	9.75	25.7	17.7	73.1	42.7	57.7	0
3			25.5	31.0	0	0	13.7	25.4	19.5	83.7	65.1	74.4	9.3
4			22.5	24.0	9.0	1.0	13.5	22.4	17.9	88.2	72.7	80.4	0
5			18.5	25.0	5.5	1.5	11.9	23.0	17.4	89.2	65.0	77.1	25.5
6					6.5	4.0	9.88	22.6	16.2	88.1	57.8	72.9	17.6
7					13.0	2.5	13.3	25.7	19.5	80.0	51.4	65.7	9.0
8					16.5	7.5	13.0	27.3	20.8	76.4	41.2	58.8	3.8
9					17.0	5.5	11.6	28.7	20.1	62.5	36.0	49.2	0
10					44.0	25.5	14.1	28.2	21.1	75.4	45.1	60.2	2.2
11					74.0	56.5	13.8	30.7	22.2	48.5	23.1	35.8	0
12					65.0	57.0	16.5	34.0	25.2	52.5	30.7	41.6	0
13					57.0	39.0	18.4	36.0	27.2	46.4	24.2	35.3	0
14					28.0	25.0	19.8	34.7	27.2	41.5	27.2	34.3	0
15					19.5	13.0	21.0	39.1	30.0	38.5	21.7	30.8	0

There was an abrupt reduction in the number of eggs, nymphs, and adults during the 49th and 50th weeks, probably because of heavy rainfall during the 48th and 49th weeks. The early instar nymphs might have been knocked down and killed by the heavy rain, resulting in reduced bug populations on the early- and medium-maturing crops during the 49th to 51st weeks. From the 52nd week onwards, the population of the bug started decreasing on the medium-maturing crop, perhaps because of the *very* low average temperatures (below 20°C). Further reduction in the number of eggs, nymphs, and adults on the medium-maturing crop from the third week onwards may be attributed both to rainfall and to the maturity of the crop. On the late-maturing crop, it was probably the rainfall that kept the population of nymphs and adults low from the fifth to the eigth week. From the ninth week onwards, there was an increase in the bug population, which may have been caused by the higher average temperatures and scanty rainfall in the preceding weeks. Singh and Singh (1978) reported the effect of rainfall during the preceding period on the population buildup of insect-pests of pigeonpea, including *c. gibbosa.* During the 14th and 15th weeks, there was again a maturity effect, coupled with very low humidity (below 35%) and *very* high average temperature (above 30°C), which adversely affected the bug population on the late-maturing crop of pigeonpea.

It is thus evident that average temperatures ranging from 21 to 26°C, coupled with relative humidities ranging from 35 to 75% and light rainfall, favor the development and multiplication of *C. gibbosa.* On the other hand, average temperatures below 21°C or above 26°C and *very* high or *very* low average humidities (above 75 or below 35%), coupled with heavy rainfall, adversely affect the populations of the bug.

Of the various meteorological factors considered, rainfall seemed to have the greatest influence on the population buildup of the pest. A little rainfall was conducive to the development of the bug whereas heavy rainfall reduced the populations. Zi le Singh (1973; also reported a similar effect of heavy monsoon rains on the population of *Nezara viriduia* on soybean. Singh and Singh (1978) on the other hand, reported that uniformly distributed rainfall influenced the population buildup of c. *gibbosa* on early-maturing varieties of pigeonpea. Their findings regarding the favorable influence of a higher range of temperature (around 28 ± 2°C) and a higher range of humidity (80 ± 5%) on pest buildup of pigeonpea are similar to those reported in the present study, which also agree with the findings of Verma et al. (1978) on a coreid bug, *Leptocorisa acuta.*

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Microbiology

Session I

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Populations of Cowpea Group *Rhizobium* in Semi-Arid Tropic Soils

J.V.D.K. Kumar Rao and P.J. Dart*

Abstract

The numbers of cowpea group of Rhizobium, which nodulate pigeonpea in some Alfisol and Vertisol fields at ICRISAT Center, were estimated by the most probable number (MPN) method, using a serial dilution-plant infection technique with siratro (Macroptylium atropurpureum) in test tubes. Pigeonpea, especially the small-seeded cultivar ICP-7332, grown in test tubes was also found to be suitable for the MPN method. There was usually a large variability in Rhizobium numbers between sites within fields. Generally, the Alfisols contained more rhizobia than the Vertisols. Soil type and depth also affected the population. Some soils on ICRISAT site had fewer than 100 cowpea rhizobia per gram soil.

There have been some reports of pigeonpea nodulating poorly in field surveys (Rewari 1979; IARI 1971; Kumar Rao and Dart unpublished).

In establishing the need for legume seed inoculation in any situation, the natural occurrence of the appropriate nodule bacteria is a valuable diagnostic aid. Many determinations have been made of *Rhizobium* numbers in arable soils in temperate regions. $_5$In New York soils, *R. leguminosarum* numbers ranged from less than 10 to 10^5 /g, whereas the numbers of JR. *trifolii* ranged from 2500 to 10^6/g (Wilson 1939). Weaver et al. (1972) found a widerange in the counts of *R. japonicum* (from less than 10 to more than 10^6 /g of soil) in soils at 52 sites in Iowa. As far as we know, there are no such studies made in tropical regions. The present study reports the number and distribution of the cowpea group of *Rhizobium,* which are generally known to nodulate pigeonpea in some Alfisol and Vertisol fields typical of the semi-arid tropics, in an attempt to help us predict the response to *Rhizobium* inoculation.

Materials and Methods

Soil samples were collected as follows:

1. A split soil-sampling tube of diameter 2.5 cm and 45 cm length was used to collect samples from 0-30 cm depth when the soil was relatively loose. Sampling caused little soil compression.

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2. Pits were dug manually up to the desired depth when the soil was hard, e.g., the Alfisols in the dry season.

3. When the soil was not hard, a Gidding's mechanical corer (4 cm dia) was used to collect samples to a depth of about 160 cm.

4. Some pits were dug by a mechanical shovel.

After collection, soil samples were refrigerated until analysis. Populations of cowpea group rhizobia in each sample were estimated using a serial dilution-plant infection-most probable number method with siratro *(Macroptylium atropurpureum)* as the test plant. Siratro seedlings were grown aseptically from sterilized seed sown in 18 x 150 mm test tubes containing Jensen's nitrogen-free agar medium (Vincent 1970). Each tube was inoculated with a 1-ml aliquot of a tenfold serial dilution of soil and incubated in a light chamber with a 16-hr light and 8-hr dark period at a temperature of 28 + 2°C for 30 days. The most probable numbers of rhizobia present in the soil samples were estimated from the pattern of nodulation that developed, using suitable tables developed from Fisher and Yates (1963) or Brockwell et al. (1975). Rhizobial populations are expressed as $\log_{10}$ MPN per g dry weight of soil. Moisture percent of the soil samples was estimated by drying to a constant weight in a hot air oven at a temperature of 105°C.

Siratro is normally used as a trap host for cowpea rhizobia. Initial tests of pigeonpea as a trap host favored the use of a small-seeded cultivar, ICP-7332, but subsequently ICP-1 was also found to grow and nodulate satisfactorily in 25 mm x 200 mm tubes. During the latter stages of these investigations it was found that some isolates from siratro nodules did not nodulate pigeonpea. In view of this apparent specificity, it is possible that numbers of rhizobia infecting pigeonpea may be overestimated.

Results and Discussion

Rhizobium Distribution in Different Fields

During September 1976, soil samples of 23 different fields comprising 15 Vertisols and 8 Alfisols at ICRISAT Center were collected. From each field, four samples each weighing about 100 g,were collected at random from within a 0.1 ha area from the top 0 to 30 cm depth and mixed well. From this, a subsample of 100 g was used for counting *Rhizobium* populations and measuring the moisture content. The information on standing crops and the *Rhizobium* populations and moisture content are presented in Table 1 and Table 2. Generally, Alfisols contained more rhizobia than the Vertisols, 5 out of 15 Vertisol fields examined had fewer than 100 rhizobia/g of soil. In Alfisols, the population was generally more than 10^4 and could be as high as 10^6 rhizobia/g of soil. In both the Vertisols and Alfisols examined, the *Rhizobium* population does not appear to be related to the moisture content as populations of about 10Vg of dry soil were observed when the moisture content was as low as 4.8% in the Vertisol and 2.8% in the Alfisol. At 15 bar pressure, these Vertisols contain about 20% water (w/w) and the Alfisols about 7%. Similarly, there was no relation between *Rhizobium* count and the type of crop, be it a legume or a cereal, or intercropping. In the fallow field, the population was as high as 10^4/g dry soil and comparable to cropped fields. This is an indication that the cowpea group of rhizobia possessed a high degree of saprophytic competence in some situations, i.e., the ability to survive in the absence of the host plant. At the same time, it is hard to understand the reasons for very low populations in some of the Vertisol fields, although salinity is probably one of the factors responsible for the low numbers observed in field B-10 (E.C. = 3.5 m mhos/cm). Similarly, the reasons for relatively high Rhizobium numbers in Alfisols are also not clear.

Table 1. Populations (MPN) of cowpea group rhizobia in some Vertisols at ICRISAT Center, Hyderabad, India, rainy season, 1976.

Field	Log_{10} MPN	% Moisture	Crop or crops at sampling time
BW-2	6.07	25.2	Maize/pigeonpea intercrop
BA-25	5.09	34.0	Pigeonpea
ST-1	5.08	31.8	Pigeonpea
BW-4	4.27	25.3	Fallow
BW-7	4.26	23.0	Maize/pigeonpea intercrop
B-5	4.25	22.0	Pigeonpea
M-14	4.19	4.8	Sorghum/pigeonpea intercrop
BW-6	3.71	21.4	Maize
BW-3	3.26	24.7	Maize/pigeonpea intercrop
B-2	3.08	29.1	Pigeonpea
B-4	2.29	29.0	Pigeonpea
BW-5	2.28	26.1	Maize
BW-8	2.02	15.5	Maize/pigeonpea intercrop
B-10	1.68	18.3	No crop (saline soil)
BW-1	0.00	21.4	Maize/pigeonpea intercrop
Mean	3.44		

Table 2. Populations (MPN) of cowpea group rhizobia in some Alfisols at ICRISAT Center, Hyderabad, India, rainy season, 1976.

Field	Log_{10} MPN	% Moisture	Crops at sampling time
RW-2D	5.4	8.5	Pigeonpea
RA-17	5.01	11.0	Pigeonpea
RA-25	5.03	15.5	Pigeonpea
RW-2	4.99	5.4	Millet/pigeonpea intercrop
R-10	4.98	2.8	Pigeonpea
RA-26	4.66	8.1	Pigeonpea (healthy)
RA-26	4.21	9.6	Pigeonpea (unhealthy--mosaic virus)
R-1	4.21	10.7	Pigeonpea
Mean	4.81		

Variability in *Rhizobium* Numbers within Fields

In order to study the distribution and variability in populations of cowpea rhizobia, soil samples were collected from different Alfisol and Vertisol fields of ICRISAT Center as follows: nine sites in an area of 0.1 ha in each field were sampled at three different depths~0 to 10 cm, 11 to 20 cm, and 21 to 30 cm—per site. Thus a total of 27 samples per field were collected and analyzed. The mean numbers and ranges (log MPN g-1 soil) of rhizobia estimated at various depths from nine sites within each of two ICRISAT fields in March-April 1977 were as follows:

	0-10 cm	11-20 cm	21-30 cm
Vertisol	3.65(2.76-4.26)	3.69(2.23-5.26)	2.72(1.23-3.77)
Alfisol	4.55(3.23-5.26)	4.72(4.26-5.26)	4.83(4.26-6.26)

In general, there is great variability in *Rhizobium* numbers between depths at a given site, and a given depth between sites within a field. A similar trend was observed in the other fields examined. The reasons for such variability in *Rhizobium* numbers within a given field *are* not clear, although variations in effectiveness of field populations of *R. trifoliii* were reported by Gibson et al. (1975).

Soil Depth and *Rhizobium* Numbers

Pigeonpea is a deep-rooted crop, and roots can grow to a depth of 200 cm. We examined the distribution of *Rhizobium* at soil depths ranging from 0 to 160 cm at different sites (Table 3).

Table 3. Population of cowpea group rhizobia (log 10 MPN g^{-1} dry wt soil) at different depths of two Alfisol and two Vertisol fields.

Soil depth (cm)	Alfisol				Vertisol			
	Field A[a]		Field *B*[b]		Field C[c]		Field D[d]	
0-5	3.20	(9.7)[e]	4.53[f]	(9.4)	3.23	(20.6)	5.40[f]	(21.4)
5-10	4.31	(10.2)			3.17	(25.2)		
20-30	5.02	(6.9)	3.97	(9.2)	3.77	(24.1)	4.91	(20.9)
50-60	4.67	(11.0)	2.48	(11.7)	2.77	(28.3)	4.64	(14.1)
100-110	4.22	(13.0)	1.68[g]	(11.5)	1.57	(33.7)	3.04[g]	(12.9)
150-160	3.32	(13.3)	0.00	(17.0)	1.62	(29.8)	2.80	(19.0)

a. Average of two replications on a 4 x 16 m grid covering 0.1 ha in RW2b field, ICRISAT Site, Patancheru.
b. Average of ten replications in nursery field, ICRISAT, Patancheru.
c. Average of four replications on a 4x16 m grid covering 0.1 ha in BW-4 field, ICRISAT Site, Patancheru.
d. Average of three replications in M-11 field, ICRISAT Site, Patancheru.
e. Value in parentheses is moisture percent of sample on a dry wt basis.
f. Sample collected from 0-10 cm soil depth.
g. Sample collected from 90-100 cm soil depth.

In one Alfisol field, the *Rhizobium* population was less affected by soil depth, remaining high (10^4/g dry soil) throughout the profile, with a slight reduction at a depth of 150 to 160 cm (10^3/g). In another field, however, the population declined with depth, the reduction being more pronounced below 100 cm in the soil profile. Similar patterns have been observed in Vertisol fields. It would be difficult for pigeonpea to nodulate at lower depths in those fields where *Rhizobium* numbers declined with depth. It is not known whether pigeonpea rhizobia would travel along with the root system in the rhizosphere as the root grows through the soil. Studies on pigeonpea rhizosphere and nonrhizosphere counts of cowpea group *Rhizobium* indicated that there was a marked rhizosphere effect of pigeonpea on cowpea rhizobia, numbers increasing from 1.3 x 10^3/g in the bulk soil (mean over 110 cm depth) to 9.1 x 10^4/g (Table 4).

The present study on distribution of cowpea group rhizobia in soils indicated that the populations varied in the same field and also with soil type and depth. Hence seed inoculation with an effective *Rhizobium* is a prerequisite for good nodulation especially in those soils having few rhizobia. Even in those soils where the soil rhizobial populations are relatively high, it is currently considered advisable to inoculate the seed at sowing, as an insurance against poor nodulation, particularly in view of great variability observed in the same field.

Table 4. Population of cowpea group rhizobia (log_{10} MPN g^{-1} dry wt of soil) in rhizosphere and nonrhizosphere of pigeonpea cv ICP-1 grown in a Vertisol, kharif 1978.

Soil depth (cm)	Rhizosphere	Non-rhizosphere
0- 20	5.71	4.01
20- 30	7.27	2.29
30- 40	6.15	4.28
40- 50	4.34	3.60
50- 60	4.73	3.79
70- 80	4.34	2.89
80- 90	4.31	2.29
90-100	2.90	2.66
100-110	5.19	3.17
Mean	4.96	3.12

ICP-1 inoculated with *Rhizobium* at sowingtime and sampled 180 days after sowing.

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Evaluation of *Cajanus cajan* (L.) Rhizobia

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Abstract

Five Rhizobium isol*ates, PBH-8/7, PBH-8/2 (HAU), F-4 (IARI), IHP-159, and IHP-149 (ICRISAT) were* selected for testing *under pot culture and field conditions. Based on nodule number, nodule dry weight, plant nitrogen, nitrogenase activity, and grain yield, isolate PBH-8/7 was found to be the most effective. The ability of PBH-8/7, F-4 and IHP-149 to compete with native rhizobia on cv UPAS-120 was studied by the immune diffusion technique in pots with unsterilized soil from the same field where the field experiment was laid out; PBH-8/7 isolate was found to have the best competitive ability over native rhizobia.*

The legume-.Rhizojbium symbiosis is probably the major source of fixed nitrogen on a global basis. Pigeonpea is infected by rhizobia taxonomically grouped with the cowpea miscellany group. The success of the inoculant strain depends upon the efficiency and competitive dominance. Once a strain becomes established in the soil, it is difficult to replace completely with a more suitable one. A survey of pigeonpea growing areas has revealed that in general the nodulation status with regard to native rhizobia is poor. It is important, therefore, that an efficient culture be screened and used, particularly when the crop is being newly introduced to this area.

Among *kharif* (rainy-season) pulses, pigeonpea has the highest yield potential. This kharif legume is grown mainly as a border crop or mixed crop in the irrigated or relatively high rainfall areas of Haryana State. However, the cultivation of the late-maturing varieties is limited to Gurgaon and Ambala districts. In recent years, with the release of two early-maturing varieties, Prabhat and UPAS-120, sole-crop pigeonpea cultivation is gathering momentum in the state, and the area under this crop is steadily increasing. The present investigation was conducted with the objective of selecting the most efficient and competitive rhizobial strain suited to local agroclimatic conditions.

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Materials and Methods

Cultures

Three standard pigeonpea rhizobia isolates were obtained from ICRISAT, Hyderabad (IHP-149, IHP-159), and IARI, New Delhi (F-4). Two other cultures under study were PBH-8/7 and PBH-8/2, isolated from Bhiwani district. All inocula were prepared as single strains in a charcoal base or as a cell suspension.

Screening Experiments

These were conducted in modified Leonard jars (Leonard 1943) and also in "chillurn" jars in which the normal inverted bottle is replaced by an earthenware container of essentially similar shape. Use of this material allows for cooling of the assembly by evaporation from the earthenware surface. Measurements in summer have shown reduction of soil temperature from 46.5°C to 34°C.

Seeds of pigeonpea cv UPAS-120 were rinsed with 95% ethanol sterilized mercuric chloride and washed thoroughly. Prior to sowing, seeds were treated with a thick *Rhizobium* suspension of each isolate. Seven seeds were planted in each unit and thinned to five after germination. Sterilized Jensen's (1942) nutrient solution was supplied to each unit at 2-day intervals.

Pot Experiments

Surface soil was collected from the field where the subsequent field experiment was laid out. Clay pots 25 cm in diameter, holding 4.5 kg soil each, were used. A basal dose of superphosphate 40 kg P205/ha was added to the soil at the time of sowing. Seven seeds sown into each of three replicate pots were reduced to five after germination. Inoculated seeds of cv UPAS-120 were first treated with molasses solution and then coated with charcoal-based inoculants of each Rhizobium strain. All plants were sampled 60 days after sowing for nodule number, nodule dry weight, plant dry weight, and plant nitrogen. The plants and nodule samples were dried at 80°C.

For the competition study in which three strains were used, two plants from each treatment were collected and all the nodules removed. Rhizobia were isolated from each individual nodule by streaking the crushed nodule fluid on yeast extract mannitol agar plates, and isolates were maintained at 4°C on plates. Titer value of antisera developed against PBH-8/7, F-4, and IHP-149 by using Kremer and Wagner's (1978) protocol for immunization was determined by the standard tube agglutination method. The titer values were 1/12,800, 1/64 00 and 1/6400 for PBH-8/7, F-4, and IHP-149, respectively.

Field Experiment

A field experiment was conducted during the kharif season (July-September)

1978 to observe the effect of the same five strains of pigeonpea rhizobia on grain yield of cv UPAS-120. The experiment was sown at Haryana Agricultural University, Hissar, in a randomized block design with three replications. The plot size was 5 m x 2 m_2 with rows spaced 50 cm and plants spaced 20 cm apart. A basal dose of P2O5 at the rate of 40 kg/ha was given to each treatment.

Plants were sampled from each replicate 60 days after sowing, and the same measurements made as in the pot experiment.

Nitrogenase Assay

Nitrogenase activity of nodule samples was measured by acetylene reduction assay (Hardy et al. 1968). Nodules were removed gently from the roots of pigeonpea plants of each treatment sown in pots, washed, dried in folds of filter paper, weighed to record nodule fresh weight, and transferred to screw-capped 20-ml test tubes fitted with a serum cap or septum. One ml of air from each tube was taken out and 1 ml of acetylene was injected with a syringe. These tubes were incubated at room temperature for half an hour, then tested for acetylene reduction by gas chromatography, using a flame ionization detector.

Experimental Results and Conclusions

Screening Experiments

In view of previous problems with obtaining nodulation using the usual modification of the Leonard jar technique under our conditions, initial screening was done with both Leonard jar and chillurn jar. The screening was done on five strains during July-September in a screenhouse. On the basis of nodule number, nodule dry weight, plant nitrogen, and plant dry weight after 45 days, PBH-8/7 was ranked first in both assemblies, although superior results obtained with chillurn jars are shown in Table 1.

Pot Experiments

PBH-8/7 was ranked best on all criteria (Table 2) and was significantly superior to the other strains in nodule number and dry weight, shoot dry weight, and shoot nitrogen. All the other strains gave comparable results and were superior to the uninoculated control.

The ability of these strains to compete with the native soil strains was also examined in pots.

Observations recorded by the immune diffusion method are summarized in Table 3. The results indicated that 81.48%, 71.05%, and 69.05% of the nodules formed in inoculated pigeonpea plants were by isolate PBH-8/7, F-4, and IHP-149, respectively. Thus it was inferred that isolate PBH-8/7 possesses the highest competitive ability over native rhizobia.

Table 1. Screening of pigeonpea rhizobia isolates in Leonard jars and "chillum" jars.

Treatment	Nodule no./plant		Nodule dry w/plant (mg)		Shoot dry w/plant (g)		Shoot nitrogen/plant (%)	
	Leonard	Chillum	Leonard	Chillum	Leonard	Chillum	Leonard	Chillum
PBH-8/7	29	51	141	165	1.328	1.418	2.45	2.56
PBH-8/2	23	46	130	155	1.146	1.246	2.38	2.38
IHP-159	14	36	98	126	1.046	1.240	2.41	2.42
IHP-149	15	45	99	152	1.141	1.236	2.36	2.46
F-4	15	41	88	140	1.124	1.224	2.28	2.44
Control					0.841	0.912	2.16	2.26

Table 2. Screening of pigeonpea rhizobia isolates under pot culture conditions.

Treatment	Nodule no./plant	Nodule fresh w/plant (g)	Nodule dry w/plant (mg)	Shoot dry w/plant (g)	Shoot nitrogen (%)	Nitrogenase activity (nM of ethylene produced/g/h)
PBH-8/7	20	1.646	98	1.91	2.63	276.74
PBH-8/2	16	1.076	47	1.62	2.48	15.286
IHP-159	14	1.248	56	1.34	2.56	222.29
IHP-149	16	1.386	72	1.42	2.54	190.12
F-4	15	1.095	62	1.51	2.52	128.16
Control	4	0.841	14	1.22	2.40	24.02
SE	0.8606		1.7847	0.0115	0.0108	
LSD (5%)	2.6516		5.4988	0.0354	0.0333	
CV %	10.48		5.31	1.33	0.74	

Table 3. Competitiveness of inoculated pigeonpea rhizobia with native rhizobia under pot culture conditions studied by immune gel diffusion technique.

Isolate no.	Number of nodule isolates	Number of homologous isolates	Number of heterologous isolates	% homology
PBH-8/7 (HAU)	54	44	10	81.48
F-4 (IARI)	38	27	11	71.05
IHP-149 (ICRISAT)	42	29	13	69.05
Control	5		5	

Field Experiment

In all the treatments there was a significant increase in grain yield over the uninoculated control. The maximum grain yield was observed with treatment PBH-8/7 (2700 kg/ha), which was a 45% increase over the uninoculated control, and the strain was again superior on all other criteria (Table 4).

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Table 4. Effect of pigeonpea rhizobia inoculation on grain yield of UPAS-120 under field conditions.

Treatment	Nodule no./plant	Nodule dry w/plant (mg)	Shoot dry w/plant (g)	Shoot nitrogen (%)	Grain yield (kg/ha)	Increase in grain yield over control (%)
PBH-8/7	28	68	2.7	2.68	2700	45.16
PBH-8/2	24	54	2.1	2.59	2260	21.50
IHP-159	16	24	1.8	2.44	19.66	5.69
IHP-149	24	16	1.4	2.57	2073	11.45
F-4	14	42	2.1	2.58	2463	32.41
Control	5	8	1.2	2.31	1860	
SE	0.9526	1.6330	0.0816	0.0082	0.1442	
LSD (5%)	2.9351	5.0314	0.2516	0.0251	0.4449	
CV %	8.95	8.01	7.51	0.395	11.25	

Field Populations of Rhizobia and Response to Inoculation, Molybdenum and Nitrogen Fertilizer in Pigeonpea.

A.L. Khurana and S.S. Dudeja*

Abstract

In farmers' fields and soils collected from these fields in Haryana, nodulation of pigeonpea was generally poor. On one field at Haryana Agricultural University (HAU), the application of molybdenum or inoculation increased nodulation, total plant nitrogen, total dry matter and grain yield significantly; however, the interaction of molybdenum and inoculation was non-significant. Nitrogen application did not produce significant nodulation or grain yield responses, although positive trends were present.

Among the kharif pulses grown in India, pigeonpea is the most important. With the release of early-maturing varieties (UPAS-120, Prabhat, and T-21) that have the potential to replace a part of the area in cotton, bajra, and other kharif crops, its cultivation is gaining momentum in Haryana, Punjab, and Rajasthan. Intensive research work is under way to study various aspects of increasing production of this crop. Seed inoculation with efficient strains of pigeonpea rhizobia to establish an effective *legume-Rhizobium* symbiosis is one of the cheapest and most important inputs in pulse cultivation. Molybdenum may limit nitrogen fixation, since it is required in greater amounts for symbiotic nitrogen fixation than for host legume growth under all circumstances (Robson 1978). Increased yield with application of molybdenum along with inoculation in different pulses are reported by several workers (Hulamani et al. 1972; Dhillon et al. 1977; Kabeerathumma et al. 1977). Response of the pigeonpea crop to inoculation and nitrogen fertilizer is also variable, depending on the native rhizobia present in the soil and its nitrogen level. Therefore the present report deals with the field population of rhizobia and response to inoculation, molybdenum, and nitrogen fertilizer under field conditions.

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Distribution of Native Pigeonpea Rhizobia in Haryana Soils

The formation of nodules on pigeonpea by native rhizobia was studied in a survey of farmers' fields in the districts of Hissar, Bhiwani, Mohindergarh, Ambala, Gurgaon, and Sirsa in Haryana. Soil samples (top 15 cm soil) were also collected during 1977-80 from various locations of Hissar, Bhiwani, Mohindergarh, and Rohtak district, where pigeonpea was growing during the kharif season. The soil samples were moistened and placed in polythene bags and pigeonpea seeds (UPAS-120) were sown into these bags and allowed to grow. After 45 days, the plants were uprooted and the degree of nodulation was determined. The majority of the soil samples produced few nodules; by the same criterion, the nodulation status of plants observed in farmers' fields was considered poor (Table 1).

Table 1. Modulation status of pigeonpea grown in farmers' fields and in soils collected from Haryana.

District	Nodulation status					
	Poor		Moderate		Good	
	F	S	F	S	F	S
Hissar	8	112	1	5		
Bhiwani	3	61	1	2		
Sirsa	4					
Ambala	5					
Mohindergarh	3	39	2			
Gurgaon	3					
Rohtak		36		5		

Poor = Nodule number below 10;

Moderate= Nodule number 11-20;

Good = Nodule number 21-30.

F = Farmers' field; S = Soils collected from various districts.

Response of Pigeonpea to Molybdenum

A field trial was conducted with cv UPAS-120 at HAU Farm, Hissar. The farm soil was of pH 7.4 with organic carbon 0.27%, medium nitrogen and phosphorus levels, and high potassium levels. The effect of molybdenum in the form of sodium molybdate as used by Iswaran, Rao, and Sen (1971), Dhillon et al. (1977), and Kabeerathumma et al. 11977) (at 0.48 kg Mo/ha) was evaluated. Molybdenum (at 0.45 kg/ha) was applied in soil along with the seed, and foliar spray (at 1.25 kg/ha) was done after 15 days of planting. A basal dose of 40 kg P205/ha was added at sowing time. The seeds were inoculated with strain F4 (IARI, New Delhi) and strain PBH 8/7 (HAL), Hissar). The treated seeds were sown in randomized plots measuring 5 x 4 m^2 at the seed rate of 15 kg/ha in four replications. Spacing between rows was 50 cm and between seeds in the row, 20 cm.

Observations on nodule number and nodule dry weight were recorded after 45 days. The plant nitrogen was estimated by the micro-Kjeldahl method (A0AC 1955). The crop was harvested after 131 days. The results indicated that there was a significant increase in nodule number, nodule dry weight, total plant nitrogen contents, and total dry-matter production by inoculation either alone or in combination with molybdenum (Table 2). The increase in grain yield with application of molybdenum or rhizobial inoculation was significant; however, their interaction was non significant (Table 3). The increase in grain yield with strain F4 was higher (32.6%) than with strain PBH 8/7 (23.5%) in combination with molybdenum (soil and foliar application). Pigeonpea responded more to soil application of molybdenum as compared with foliar application. No toxic effect of foliar spray on plants was observed.

Response of Pigeonpea to Nitrogen

A field experiment was planned to observe the response of pigeonpea to nitrogen with and without inoculation. The seeds of pigeonpea cv T-21 were inoculated with a peat-based culture of the F4 strain, and 25 kg N/ha in the form of urea and a basal dose of 40 kg P205/ha as .a single superphosphate were supplied. The field soil was sandy loam, with soil pH 7.4, soluble salts (EC) 0.24 mmhos/cm with organic carbon 0.42%. The levels of nitrogen, phosphorus, and potassium were 323, 47, and 634 lbs/acre, respectively. The observations on nodule number, nodule dry weight, and plant nitrogen were recorded after 40 days of sowing.

A trend towards slightly higher nodule number and nodule dry weight with inoculation was not significant (Table 4). Similarly, total nitrogen per plant tended to be higher than in the noninoculated control. Similar trends towards increased yields with either inoculation or nitrogen application were evident, but results were not significantly different.

Table 2. Response of pigeonpea to molybdenum and inoculation.

Treatment	Nodules/ plant	Nodule dry wt/plant (mg)	Nitrogen uptake/plant (mg)	Total dry matter (kg/plot)
Uninoculated	2.7	32.3	137.16	8.62
PBH 8/7	4.5	33.3	279.80	10.37
F_4	6.0	42.0	264.00	9.37
Soil molybdenum	3.5	32.7	218.61	10.37
Spray molybdenum	3.5	33.0	141.42	9.75
PBH 8/7 + Soil Mo	4.6	43.7	331.48	9.75
PBH 8/7 + Spray Mo	4.6	39.0	280.10	9.50
F_4+Soil Mo	6.6	47.0	351.60	10.52
F_4+Spray Mo	6.5	44.0	267.47	10.12
Soil Mo+Spray Mo	6.0	33.0	221.51	9.25
PBH 8/7+Soil Mo+Spray Mo	4.5	36.0	331.58	10.37
F_4+Soil Mo+Spray Mo	6.0	45.3	352.11	10.37
SE	0.59	1.71	3.16	0.45
LSD(5%)	1.73	5.02	7.98	1.28

Table 3. Effect of molybdenum application and *Rhizobium* inoculation on grain yield of pigeonpea.

Treatment	Grain yield (kg/ha)			
	Uninoculated	PBH8/7	F4	Mean
No Molybdenum	1141	1268	1232	1214
Soil Molybdenum	1178	1341	1503	1341
Spray Molybdenum	1159	1250	1449	1286
Soil + Spray Molybdenum	1268	1404	1513	1395
Mean	1187	1316	1424	

	Ino	Mo	Ino x Mo
SE	0.22	0.26	0.45
LSD(5%)	0.64	0.74	NS

Table 4. Response of pigeonpea to nitrogen and *Rhizobium* inoculation.

Treatment	Nodules/ plant	Nodule dry wt/ plant (mg)	Nitrogen uptake/ plant (mg)	Yield (kg/ha)	Increase in yield over control *(%)*
Noninoculated control	5.9 ±1.5	12.1 ±4.0	51.75	1941	
Inoculation	7.0±1.1	15.3 ±2.0	73.75	2341	20.6
25 kg N/ha	5.0±1.3	12.8±3.0	70.50	2254	16.1
Inoculation + 25 kg N/ha	6.4±1.8	13.5 ±3.2	67.83	2223	14.5
SE				0.349	
LSD(5%)				NS	

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Studies on the Response of Early-Maturing Cultivars of Pigeonpea to Rhizobial Inoculation

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Abstract

In field studies conducted at Kanpur, India, inoculation of pigeonpea cultivar Prabhat responded to rhizobial strain KA-I with significantly increased grain yield during kharif 1975. During kharif 1976, pigeonpea cv T-21 responded significantly to six Rhizobium *strains, KA-1, Bactofel, E-6, E-2, E-3, and KA-8. During kharif 1978, under demonstration trials on cultivators' fields, inoculation of cv T-21 with strain KA-1 and addition of phosphate increased grain yield by 167 and 175 kg/ha at two sites.*

India is the major producer of pigeonpea and contributes more than 90% of the total world production (Sharma and Green 1975). Inoculation of pulse crops with effective strains of rhizobia has now become a common practice in temperate and tropical countries for getting optimum yields of pulses. However, in some cases the inoculation response is meager and uncertain, which warrants constant efforts to find more efficient strainsof rhizobia. In the present investigation, some rhizobial strains have been screened for their effectiveness under natural field conditions on two early cultivars of pigeonpea, Prabhat and T-21, grown in Uttar Pradesh. The best strain obtained has been demonstrated on cultivators' fields for its performance in association with phosphate application.

Materials and Methods

During kharif 1975, five Rhizobium strains (E-2, E-3, E-4, E-6, and KA-1) were tested on cv Prabhat under field conditions at Research Station Pura (Kanpur). During kharif 1976, the same strains plus a further two strains (Bactofel and KA-8) were tested at the same station on cv T-21. A basal dose of 50 kg P205/ha in the form of single superphosphate was applied. During kharif 1978, two demonstrations as unreplicated trials were conducted in the villages of Tons and Singaranpurwa in Kanpur district with T-21 and strain KA-1. Inoculation response was adjudged with and without

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phosphate at the rate of 50 kg P205/ha as single superphosphate. At all sites, the soil was sandy loam in texture, pH 7.0 to 7.5, total nitrogen ranging from 0.040 to 0.058 and available P from 4.0 to 6.8 ppm. In the demonstrations, nitrogen at the rate of 10 kg N/ha was given in the form of urea, applied basally.

Results and Discussion

Considerable variations among strains was observed in the inoculation response of the crop (Table 1). In 1975, with cv Prabhat, only strain KA-1 increased the yield significantly over no inoculation. However, during 1976, with T-21, six strain, including KA-1, were effective over native flora. Strains E-3, E-4, and E-6 were effective with T-21 in 1976 but ineffective with Prabhat in 1975, showing the specificity of the interaction between pigeonpea cultivars and rhizobial strains. A significant interaction between variety and strain has also been reported in other pulse crops (Bajpai and Gupta 1977). This finding suggests that strains should be screened for a particular cultivar, although strict comparisons should be made during the same season to avoid further interaction with dates. The strain KA-1 appeared to be a broad-spectrum strain.

In demonstration trials (Table 2), inoculation of pigeonpea cv T-21 with strain KA-1 increased the yield by 125 and 175 kg/ha without and with phosphate at one location and 95 and 167 kg/ha at the other location in the same order, respectively, indicating thereby that efficiency of Rhizobium was increased by the phosphate application. The results suggest that full benefit of inoculation can best be achieved when the pigeonpea is fertilized with phosphorus.

Table 1. Strain variability of pigeonpea rhizobia in relation to crop response.

Kharif 1975 (cv Prabhat)		Kharif 1976 (cv T-21)	
Strain	Yield (kg/ha)	Strain	Yield (kg/ha)
Uninoculated	1200	Uninoculated	1590
KA-1	1800	KA-1	2480
E-2	1230	E-2	1840
E-3	1250	E-3	1850
E-4	1300	E-4	1720
E-6	1380	E-6	2290
		Bactofel	2030
		KA-8	1950
'F' test	sig.		sig.
SE[a]	140		120
LSD (5%)	310		250

a. Standard error of difference of two treatment means.

Table 2. Performance of strain KA-1 on cultivators' fields in pigeonpea cv T-21, kharif 1978.

	Yield (kq/ha)			
Location	Control	With inoculation	With 50 kg P_2O_5/ha	With 50 kg P_2O_5 + inoculation
Village Tons, Kanpur	1631	1756	1842	2017
Village Singaranpurwa, Kanpur	1263	1358	1397	1564

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Interaction Studies Between Strains of *Rhizobium* and Pigeonpea Genotypes

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Abstract

The interaction between.three strains of Rhizobium *(F-4, K-1, IHP-195) and three cultivars of pigeonpea (T-21, P-4-4 and P-8-9) was studied under field conditions during kharif 1978 at Punjab Agricultural University, Ludhiana. In 1979, the experiment was repeated with two additional strains (A-l-36 and Badnapur). On an average,* Rhizobium *inoculation increased the grain yield by 9.3 and 28% over the uninoculated control in 1978 and 1979, respectively. The interaction between pigeonpea cultivars and* Rhizobium *strains was significant. The best combinations were T-21 x F-4, P-4-4 x IHP-195, and P-8-9 x F-4 in 1978; T-21 x Badnapur, P-4-4 x IHP-195, and P-8-9 x Badnapur in 1979.*

Symbiotic nitrogen fixation takes place more effectively if an interrelationship is established between a particular legume cultivar and a specific strain of *Rhizobium* (Dart et al. 1976). The genetic constitution of the host plant in relation to that of microsymbiont determines its nodulation characteristics (Nutman 1956). Variable compatibility of *Rhizobium* strains with their host genotypes is known in pigeonpea (Singh et al. 1979). Pigeonpea promises to be the future kharif pulse crop of Punjab state because of its high potential and competitive ability with other kharif crops; therefore, we have attempted to find the best strain-genotype combination through studies of the interaction between different strains of *Rhizobium* and pigeonpea genotypes.

Materials and Methods

Field experiments were laid out for two consecutive years, 1978 and 1979, at the experimental farm, Punjab Agricultural University, Ludhiana, on a loamy sand soil (pH 8.2-8.4) in a split-plot design (net plot area 8 nr) with three varieties of pigeonpea (T-21, P 4-4, and P 8-9) in the main plots and Rhizobium strains along with an uninoculated control in the subplots. Pigeonpea seeds were inoculated with peat-based *Rhizobium*

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cultures prior to sowing. In 1978, three strains of *Rhizobium* (F-4 from IARI, KA-1 from Kanpur, and IHP-195 from ICRISAT) were included in the trial; in 1979, two additional strains (A-l-36 of Durgapura and Badnapur strain) were used. A basal dose of 50 kg P2d5/ha was supplied.

Results and Discussion

Data on ancillary characters of pigeonpea are presented in Table 1. In 1978, inoculation with all the three strains of *Rhizobium* increased significantly the number and dry weight of nodules over the non-inoculated control. The differences in plant height were nonsignificant, but dry weight of plant increased significantly with the strain F-4 only. While nodule dry weight was significantly higher in P 4-4 and P 8-9 than in T-21, the varietal differences with respect to nodule number, plant height, and plant dry weight were nonsignificant. Interaction between strains and genotypes for all the characters except plant height was significant.

During 1979, nodule number increased significantly with inoculation by all the strains of *Rhizobium* except KA-1. Likewise, inoculation increased the nodule dry weight significantly with all except A-l-36. However, inspite of this, significant differences were found in plant height with F-4 and A-l-36. Plant dry weight responses were also observed with F-4, KA-1 and Badnapur strains. Interaction of pigeonpea cultivars and strains of *Rhizobium* was significant with respect to all the characters.

There was a significant increase in.yield in 1978 with all the three *Rhizobium* strains, giving an average increase of 9.3% (Table 2). No significant differences among cultivars were observed. Strain F-4 resulted in the highest average increase in yield (13.2%). A similar trend was observed in its effect on ancillary characters (Table 1). During 1979, all the five strains of *Rhizobium* increased the yield significantly, with an average increase of 28%. The highest average increase of 49.1% was obtained with the Badnapur strain. Differences in grain yield among varieties was also significant.

Genotype x strain interaction was significant during both years. The genotype-strain specificity reported in pigeonpea by Singh et al.(1979) is also well established in crops like soybean (e.g. Johnson and Means 1960), chickpea (Bapat et al. 1977), mung bean (Nagaraj Rao 1978), and cowpea (Gowda 1978).

The genotype-strain specificity is of immense importance for effective symbiosis, as evidenced by the genetic compatibility of strain F-4 with cvs T-21 and P-8-9 in the first year. However, in the second year, F-4 performance was not superior to IHP-195 with cv T-21, and with P-8-9 none of the four strains, F-4, KA-1, IHP-195 and A-l-36 was better than the control. During both years, strain IHP-195 was specific for P-4-4. Thus, while variation in symbiotic efficiency leads to the possibility of selecting genotypes responsive to *Rhizobium* for improved crop yields from year to year, variation possibly associated with site-to-site variation remains to be explained. The consistent performance of the Badnapur

Table 1. Effect of *Rhizobium* strains on ancillary characters of pigeonpea genotypes.

Treatment	1978 (45 days after sowing)				1979 (52 days after sowing)			
	Nodule no./plant	Nodule dry wt/plant (mg)	Plant height (cm)	Plant dry wt/plant (g)	Nodule no./plant	Nodule dry wt/plant (mg)	Plant height (cm)	Plant dry wt/plant (g)
Strain								
Uninoculated control	3.7	18.2	28.2	0.99	2.0	14.8	37.7	1.94
F-4	5.4	24.3	32.7	1.36	5.4	24.0	48.4	2.14
KA-1	5.3	23.2	31.2	1.17	2.4	19.1	45.4	2.30
IHP-195	4.6	23.8	31.3	1.21	3.4	18.9	42.3	2.09
A-1-36					3.8	18.0	47.4	2.10
Badnapur					3.7	21.2	45.4	2.19
Genotype								
T-21	4.7	17.2	31.3	1.25	4.7	22.6	46.7	2.01
P-4-4	4.8	26.7	30.2	1.16	3.5	20.0	45.1	2.06
P-8-9	4.8	23.3	31.0	1.14	2.8	15.5	41.5	2.31
CD 5%								
Strain	0.8	4.3	NS	0.31	1.2	4.0	8.9	0.20
Genotype	NS	6.0	NS	NS	NS	NS	NS	NS

Table 2. Effect of *Rhizobium* strains on grain yield (kg/ha) of pigeonpea genotypes.

Treatment	Genotype (1978)				Genotype (1979)			
	T-21	P-4-4	P-8-9	Mean	T-21	P-4-4	P-8-9	Mean
Strain								
Uninoculated control	621	644	677	647	1171	960	1093	1075
F-4	749	618	832	733	1572	1205	1103	1293
KA-1	649	617	787	684	1406	1341	885	1211
IHP-195	629	802	683	705	1710	1610	960	1427
A-1-36					1635	1543	905	1361
Badnapur					1916	1560	1340	1603
Mean	662	670	745		1568	1370	1048	
LSD (5%)								
Strain	35.0				121.6			
Genotype	NS				130.4			
Strain x genotype	60.6				210.7			

strain in one year raises the hope of selection of a wider spectrum strain.

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Allantoin Content and Nitrogen Accumulation in Relation to Dry Matter Accumulation and Yield in *Cajanus cajan* Cv Prabhat

Renu Khanna-Chopra and S.K. Sinha*

Abstract

Dry matter accumulation, nitrogen accumulation, and allantoin content were studied in different plant parts of Cajanus cajan *cv Prabhat during growth and development to analyze the cause of low yields. Crop growth rate and nitrogen accumulation were very slow upto 7 weeks. Subsequently,* a *sharp rise in both crop growth rate and nitrogen accumulation was observed until flowering. During pod development, nitrogen accumulation did not keep pace with the crop growth rate. Allantoin accumulation was observed in all plant parts 30 days after sowing. The rate of allantoin accumulation increased until flowering and declined drastically during pod development. Allantoin was not detected in any plant part 37 days after flowering. This is suggestive of the importance of soil nitrogen during pod development.*

Availability of reduced nitrogen is a major factor limiting dry matter production and yield in grain legumes (Sinha 1978). Biological nitrogen fixation and nitrate assimilation represent the major sources of reduced nitrogen for plant growth and seed yields in legume crops. The relative contribution of the two processes varies at different stages of growth and development in different legumes (Thibodeau and Javorsky 1975; Franco et al. 1979). The ureides allantoin and allantoic acid feature predominantly in the soluble nitrogen of vegetative and reproductive Organs Of nodulated plants Of *Glycine max* and *Vigna unigiculata* (MatSU-moto et al. 1977; Herridge et al. 1978) and in xylem sap of nodulated plants Of *Pisum* sp. and *Phaseolus vulgaris* (Pate 1971) and *Vigna unguiculata* (Herridge et al. 1978).

cajanus cajan is an important pulse crop in India. It is mostly grown under unirrigated conditions and is a poor yielder. The objectives

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of this work with field-grown *cajanus cajan* early cultivar Prabhat were to: (1) determine the seasonal profiles of dry matter accumulation, leaf area index, and nitrogen accumulation, and (2) to study the relationship between allantoin accumulation and nitrogen accumulation.

Materials and Methods

Pigeonpea cv Prabhat was sown in the field on 11 July 1979 with a basal fertilizer dose of 20 N : 40 P : 40 K/ha. The seed was treated with *Rhizobium* culture before sowing and sown in rows 40 cm apart. Plant population was maintained at 30 plants/m^2. Irrigation was given to supplement the long breaks in the monsoon in August and early September at the vegetative and flowering stages, respectively.

Dry-Matter Analysis

Sampling for dry weight analysis in different plant parts was done on a unit area basis at fortnightly intervals, starting with 1-month-old plants. The plant parts were separated and oven-dried at 80°C. All observations were recorded in triplicate and analyzed statistically.

Leaf Area

The leaf area of randomly selected leaves was measured on an automatic area meter, model AAM-7. The same leaves were oven-dried at 80°C and dry weight was recorded. Leaf area per unit land area (LAI) was computed.

Nitrogen Estimation

Total nitrogen content in different plant parts was estimated by following Novozamsky et al.(1974). Allantoin content in different plant parts was measured fortnightly, starting from 36-day-old plants. The plant extract was prepared following the procedure of Matsumoto et al. (1977). One gram fresh weight of plant material was ground with 10 ml of 0.05M phosphate buffer, pH 7.5, and 0.05g PVP. The homogenate was centrifuged at 10 000 x g for 5 minutes. The clean supernatant was assayed for allantoin. Allantoin and allantoic acid were estimated according to the method of Young and Conway (1942), by which the sum of allantoin and allantoic acid is measured.

Results and Discussion

Dry Matter Accumulation

Dry matter accumulation and leaf area development was *very* slow up to 7 weeks of growth. Six-week-old plants accumulated $25g^{-2}$ dry matter having LAI of 0.26 only. Subsequently a sharp increase was observed in both the characters up to flowering staqe. Maximum dry matter accumulation occurred in the fortnight preceding flowering, resulting in the highest CGR of 13.78g^{-2} day^{-1}. LAI was highest (3.96) at the flowering stage; subsequently, a continuous decline was observed in LAI, until it became negligible at the time of harvest. This was due to shedding of leaves during pod development. However, dry matter continued to accumulate after flowering, though at a slower rate. Of the total dry matter, 55.2% accumulated before flowering, 44.8% after flowering.

Nitrogen Accumulation

Nitrogen accumulation examined during growth and development revealed a pattern similar to that observed for dry matter accumulation. However, the highest rate of nitrogen accumulation preceded the highest crop growth rate (CGR). Nitrogen accumulation rate was highest in plants between 8 and 10 weeks old, while CGR was highest in plants 10 to 12 weeks old. The plant accumulated 9 g N M^{-2} during its entire growth period. Of this, 68.5% was assimilated before flowering, while only 31.53% was assimilated during pod development. Hence nitrogen accumulation did not keep pace with CGR after flowering.

Allantoin Accumulation

Allantoin accumulation was observed in 36-day-old plants. The allantoin content in the various plant parts was added up to give allantoin content per plant. Allantoin content increased from 0.430 mg/plant in 36-day-old plants to 3.48 mg/plant in 86-day-old plants at flowering. Subsequently, during pod development, a sharp decline was observed. Forty-six days after'flowering, allantoin was not detected in any plant part. This indicates thatduring pod development, biological nitrogen fixation is gradually becoming nonfunctional.

In *Glycine* max, allantoin concentration is significantly correlated with nodule weight particularly during the reproductive stages. Decrease in allantoin accumulation was parallel with the poor formation of nodules (Matsumoto et al. 1977). Hence the accumulation of allantoin in the aboverground parts of the pigeonpea plant could become a criterion to determine the presence or absence of biological nitrogen fixation. However, the accumulation per se would be influenced by the metabolism of the compound in different plant parts.

Allantoin and nitrogen accumulation in different plant parts examined during growth and development is shown in Table 1. Nitrogen content in stem and leaf was low during first 4 weeks after sowing. Subsequently, a higher rate of nitrogen accumulation was observed until flowering. After flowering, the sharp decline in nitrogen content of leaves and petiole coincided with the rapid increase in nitrogen content in developing pods. Allantoin accumulation was highest in the stem before flowering and in the leaves after flowering(Table 1). During the mid and late stages of pod development, allantoin was not detected in any plant part.

Table 1. Allantoin content (mg/plant) in plant parts during growth and development in *Cajanus* cajan cv Prabhat.

Days after sowing	Root	Stem	Leaf	Fruits	Total
36	4.0	8.5	418.0		430.5
46	22.5	451.0	287.0		760.5
56	58.0	628.0	517.4		1198.4
71	128.0	1139.0	672.0		1939.0
86	134.0	2345.0	997.0		3476.0
104	0	267.0	313.0	281.0	1007.0
132	0	0	0	0	0

Conclusions

This study reveals that in pigeonpea cv Prabhat, the dry-matter accumulation and nitrogen accumulation is very poor until 6 weeks after sowing. Allantoin accumulation starts 5 weeks after sowing. Subsequently, crop growth rate picks up, due to the increased rate of dry-matter and nitrogen assimilation. Log phase of growth and nitrogen accumulation is observed in 6- to 10-week-old plants. Subsequently, nitrogen accumulation rate is unable to keep pace with the crop growth rate during flowering and pod development. This results in mobilization of nitrogen from the vegetative plant parts to the developing pods. Leaves and flowers are shed; leading to a considerable loss of carbon and lowering of LAI. Crop growth rate also declines during pod development. Allantoin accumulation is observed during early fruit development, subsequently, however, allantoin is not detected in any plant part.

Hence there appears to be a reasonable correlation between allantoin content, nitrogen assimilation, and dry-matter accumulation. Since most of the allantoin is present in the upper portion of the plant, it may be possible to use allantoin content as a measure of reduced nitrogen assimilation capacity. This would be useful, because of the difficulty in excavating the root system to determine nodulation in this plant.

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Effect of Different Plant Growth Media on Modulation, Growth and Nutrient Uptake of Pigeonpea

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Abstract

A sand:vermiculite:grit (SVG 1:2:2 v/v) medium in pots produced better nodulation, plant growth and nutrient uptake of pigeonpea than sand alone or an Alfisol or Vertisol soil. Addition at the rate of 35 kg P/ha single superphosphate (on a surface area basis) stimulated pigeonpea nodulation, plant growth and nutrient uptake (N and P) in both Alfisol and Vertisol soils. Application of farmyard manure (FYM) at 10% (v/v) inhibited nodulation, although it significantly increased root and shoot weight in Alfisol, Vertisol and sand. It also increased N and P uptake significantly, the increase being substantial in Alfisol and sand but less in Vertisol. The inhibitory effect of FYM on nodulation was greater at an application rate of 30% (v/v) than at 10%.

Pigeonpea is grown in most tropical countries, although production outside India is small. It is often grown on marginal lands with no fertilizer addition. In experiments where fertilizers have been applied, the response has been variable. Pietri et al. (1971) observed no response to fertilizers (N, P, K, Mg, Ca and Si) for pigeonpea grown on an Oxisol (a clay soil). However, a small application of N (Dalai, 1974) and moderate to heavy applications of P (Choudhury and Bhatia, 1971; Dalai and Quilt 1977; Kalyan Singh et al. 1978; ICRISAT Annual Report for 1978-79), resulted in increased grain yields. Addition of soil with a high organic matter content to the sand growth medium stimulated pigeonpea growth (Dart et al. 1976). The present study compares nodulation, growth and nutrient uptake of pigeonpea in four growth media - Alfisol and Vertisol soils characteristic of much of the semi-arid tropics, sand, and a sand-vermiculite-grit mixture.

Materials and Methods

The four growth media used - Alfisol soil, Vertisol soil, sand alone, and sand-vermiculite-grit mixture (SVG) in the ratio of 1:2:2 v/v

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were amended and compared (treatment details in Table 1).

Table 1. Effect of different culture media on nodulation and growth of inoculated pigeonpea cv ICP-1 grown for 6 weeks in pots.

Medium	Nodule No/Plant	Nodule dry wt. (mg/plant)	Root dry Wt. (mg/plant)	Shoot dry wt. (mg/plant)
1. Alfisol				
1.1 Alfisol soil unamended	28	23	177	377
1.2 Alfisol + 35 kg P/ha[a]	44	58	250	812
1.3 Alfisol + 25 ppm N[b]	44	50	178	642
1.4 Alfisol + complete trace element solution	42	24	185	437
1.5 Alfisol + $ZnSO_4.7H_2O$ (25 kg/ha)[c]	51	40	174	492
1.6 Alfisol + 10% v/v FYM[d]	38	24	329	997
2. Vertisol				
2.1 Vertisol unamended	34	61	175	581
2.2 Vertisol + 35 kg P/ha[a]	36	84	206	720
2.3 Vertisol + 25 ppm N[b]	31	81	189	701
2.4 Vertisol + 10% v/v FYM[d]	22	38	253	734
3. Sand[e]				
3.1 Sand alone	21	31	165	408
3.2 Sand + 25 ppm N	21	25	164	402
3.3 Sand + 200 ppm N	16	11	157	369
3.4 Sand + 10% v/v FYM	6	51	269	1042
3.5 Sand + 30% v/v FYM	1	1	280	1552
4.1 Sand+vermiculite+grit	57	75	247	767
CV %	31.6	25.2	14.8	12.9
C D. at 5%	10	11	31	88

[a] P added as single superphosphate incorporated in the top 8 cm of soil in the pots. Amount calculated on a surface area basis.

[b] Pots were watered throughout with nitrogen-free nutrient solution containing 25 ppm N as ammonium nitrate.

[c] $ZnSO_4.7H_2O$ was dissolved in water and added to wet soil on the top of the pots. Amount calculated on a surface area basis.

[d] FYM (Farmyard manure) incorporated throughout the soil.

[e] S and treatments watered with nitrogen-free nutrient solution with addition of N as ammonium nitrate as indicated.

Pigeonpea seeds of cv ICP-1 were inoculated with a peat culture of an effective *Rhizobium* strain IHP-195 and sown in 15 cm height x 15 cm diameter plastic pots on 3 Nov. 1978. The pots were kept in a plastic house illuminated with three bulbs of 250W from 0500 hr to 0700 hr and again from 1730 to 2000 hr to delay flowering. Pots were laid out in randomized block design with eight replications per treatment. In the week after sowing, deionized water was used for watering all the pots until the seeds had germinated and emerged. From the second week onwards, a modified Long Ashton, nitrogen-free nutrient solution was used for watering treatments, 1.3, 2.3, 3.1 to 3.5 and 4.1. The composition of the nitrogen-free nutrient solution is (g/litre of deionized water): $MgSO_4.7H_2O$ 0.233; K_2HPO_4 0.175; Na Fe EDTA 0.0408; K_2SO_4 0.277; trace elements solution 1.0 ml; pH 6.8; stock trace element solution (g/1); Mn Cl_2. $4H_2O$ 1.81; Cu $SO_4.5H_2O$ 0.08; $ZnSO_4.7H_2O$ 0.22; H_3BO_3 2.86; $NaMO_4$. $2H_2O$ 0.025; $CoSO_4.7H_2O$ 0.286. For treatments with nitrogen fertilizer application, ammonium nitrate was added to the nutrient solution to give 25 or 200 ppm N. Treatment 1.4 was watered only with trace elements at the same rate as in the complete nutrient solution.

The water content of the pots was maintained at around two-thirds of the water-holding capacity of the medium. This was done by weighing a few pots from each treatment and calculating the loss of weight from the previous watering. All pots receiving nutrient solution (treatments 1.3, 2.3, 3.3 to 3.5 and 4.1) were flushed through with deionized water once a week to prevent salt accumulation.

The plants were harvested on 23 Dec. 1978, 50 days after sowing. Nodules were separated from the roots and counted. Shoot, root, and nodules were dried separately in an oven at 80° C and weighed. Shoot and root samples were ground in a microhammer mill, whereas nodules were ground in a mortar with a pestle. The plant samples for total N and P were digested with H_2S0_4-selenium catalyst (Technicon 1972).

Results and Discussion

Table 1 gives details of the nodulation and plant growth in the different treatments. Nodulation and growth of pigeonpea was greater in the SVG medium than the unamended Alfisol, Vertisol and sand. The greater water-holding capacity and better aeration of the SVG medium is a likely reason for this. The superiority of the SVG medium was also reflected in the greater total uptake of N and P by the plants (Table 2).

Table 2. Effect of different plant growth media on nutrient uptake by pigeonpea.

Medium	Shoot N percent	Shoot N content	Shoot P percent	Shoot P content	Total N (mg/plant)	Total P (mg/plant)
1. Alfisol						
1.1 Alfisol soil unamended	2.16	8.14	0.11	0.41	11.23	.67
1.2 Alfisol + 35 kg P/ha	2.63	21.36	0.15	1.22	27.63	1.63
1.3 Alfisol + complete trace element solution	2.08	9.09	0.10	0.44	12.21	.6
1.4 Alfisol + 25 ppm N	2.69	17.27	0.20	1.28	21.69	1.59
1.5 Alfisol + $ZnSO_4.7H_2O$ (25 kg/ha)	2.54	12.50	0.13	0.64	16.08	.86
1.6 Alfisol + 10% v/v FYM	2.88	28.71	0.31	3.09	36.31	3.77
2. Vertisol						
2.1 Vertisol unamended	3.00	17.43	0.23	1.34	22.61	1.75
2.2 Vertisol + 35 kg P/ha	3.02	21.74	0.26	1.87	28.20	2.47
2.3 Vertisol + 25 ppm N	3.18	22.29	0.31	2.17	28.97	2.9
2.4 Vertisol + 10% v/v FYM	2.66	19.52	0.26	1.91	25.50	2.51
3. Sand						
3.1 Sand alone	2.22	9.06	0.16	0.65	12.67	.83
3.2 Sand + 25 ppm N	2.52	10.13	0.17	0.68	13.98	.87
3.3 Sand + 200 ppm N	3.60	13.28	0.13	0.48	16.67	.68
3.4 Sand + 10% FYM	2.37	24.70	0.31	3.23	32.44	3.86
3.5 Sand + 30% FYM	3.23	50.13	0.35	5.43	57.05	6.1
4.1 Sand + vermiculite + grit	2.81	21.55	0.22	1.69	29.68	2.2

Most grain legumes require a large amount of phosphorus for a good growth, and this in turn requires a high concentration of available P in the root medium, usually induced by fertilizer application or by development of mycorrhizal associations. The Alfisol and Vertisol soils used in the present study were deficient in P (Table 3).

Table 3. Total N and P content of the Alfisol and Vertisol soils and FYM.

Medium	% N	% P
Alfisol	0.92	0.013
Vertisol	0.57	0.020
Farmyard manure	1.17	0.390

Addition of 35 kg P/ha (treatments 1.2 and 2.2) stimulated nodulation and nitrogen fixation, with a 115% increase in dry matter over plants grown in unamended Alfisol soil; 24% increase for the Vertisol soil. Dalai and Quilt (1977) also reported a significant increase in response to dry matter production by pigeonpea at 6 weeks after sowing following super phosphate application (22-109 kg P/ha) before sowing.

Unamended Alfisol soils in the semi-arid tropics are generally deficient in available zinc for plant growth. Adding zinc sulfate to the Alfisol soil increased nodulation by 78%, plant growth by 31%, N uptake by 43%, and P uptake by 39% over unamended soil. However, addition of trace elements, including zinc, did not affect either nodulation, plant growth or nutrient uptake in Alfisol, perhaps because the trace element solution contained too little zinc.

Adding 25 ppm N to the nutrient solution had no effect on plants grown in sand, but nodulation, plant growth, and nutrient (N and P) uptake were stimulated in both Alfisol and Vertisol soils. Surprisingly, nodules were formed in the presence of continuously supplied nutrient solution containing 200 ppm N. Although the N concentration in the dry matter (% N) for plants receiving 200 ppm N in sand culture was marginally higher than that for nodulated plants supplied 0 ppm N, the plant growth was much poorer, for reasons that are not clear. It could be that the nodules were ineffective, as evident from the small size, and also that tbe root development was not as good as expected to utilize more of available N.

Addition of farmyard manure (FYM) stimulated both root and shoot development considerably in Alfisol, Vertisol, and sand, although nodulation was reduced in sand, with virtually no nodules formed with addition of 30% v/v FYM to sand. In Vertisol soil, the nutrient uptake was not much affected by FYM addition, whereas in Alfisol soil and sand, N uptake was increased by three times and P uptake by six and four times, respectively. In sand, increasing FYM from 10 to 30% doubled the nutrient uptake. Dart et al. (1976) reported that *cajanus cajan* grew better in root media high in organic matter. Possible explanations for increased growth and nutrient uptake may be that more nutrients (N and P as indicated in Table 3) become available and possibly the farmyard manure supplies a plant hormone or absorbs excess seedling-produced hormone. These results suggest that legume growth can be improved by supplying FYM, especially in tropical soils where organic matter levels are generally low.

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Studies on Nodule Damage in Pigeonpea

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Abstract

Pigeonpea nodules at ICRISAT Center were found to be damaged extensively by insects during 1976-77. Surveys in 1977-78 revealed that this problem was also prevalent in farmers fields around all the three villages sampled. The major cause of damage has been identified as the larva of a platystomatid fly, Rivellia angulata *Hendel. This is probably the first report of this species infesting pigeonpea, although several other species of this genus are known to cause damage in other legumes in different parts of the world. This species has now been found also infesting a weed legume,* Vigna triloba, *which is a new record.* Kharif *(rainy season) pigeonpea crops suffer more damage than* Rabi *(post rainy) crops, but crop maturity duration does not seem to affect the damage levels. The damage seems to be conditioned by the seasonal insect populations rather than by crop or nodule age at a given time. Pesticides applied to soil could be useful in effectively controlling the damage. Bioecological studies on the insect are being continued.*

Increasing the availability of biologically fixed nitrogen to crops is one of the important avenues for improving crop yields (Hardy and Havelka 1975). In crop legumes, damage to nodules by soil fauna, particularly insects, reduces the amount of nitrogen fixed. Larvae of the bean beetle, *Ceratoma trifurcata* (Forster) were the first to be recognized in such damage (McConnell 1915a) and reduction in yield (Leonard and Turner 1918) in cowpeas. Several other insects are now recognized as damaging the nodules including many groups of coleopteran (McConnell 1915b; Mulder 1948; Masefield 1958; Gupta and Janardan Singh 1978) and dipteran larvae dominated by genus *Rivellia* (Seegar and Maldagne 1960; Diatloff 1965; Eastman and Wuensche 1977; Nair 1978; Siddarame Gowda and Siddappaji 1979). Poor stands of blue lupine in South Carolina were believed to be caused by *sitona* larvae eating the nodules, thereby allowing ready invasion of the roots by other soil microorganisms (Farrar and Anderson 1953). We report here some studies made at ICRISAT during the period 1976-80 relating to nodule damage in pigeonpeas.

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Nodule Damage: Early Observations at ICRISAT Center

During 1976-77, damaged pigeonpea nodules were found in several field experiments. At that time there were no reports available either on the occurrence of such damage in India or on the source of such damage in pigeonpea anywhere else.

Early observations in the kharif field experiments indicated that a few nodules were damaged within 30 days after planting, with the proportion of damaged to total nodules per plant increasing rapidly after 60 days, even though the total number of nodules also increased. The extent of nodule damage seemed to be greater in Vertisols than in Alfisols (Table 1).

Table 1. Nodule damage in pigeonpea (cv ICP-1) grown in Alfisol and Vertisol fields at ICRISAT Center, 1976-77 rainy season.

Crop age (days)	Total nodules/ plant		Damaged nodules/ plant		Damaged nodules (%)	
	A	V	A	V	A	V
30	41	29	2	3	4.9	10.3
60	60	25	10	5	16.7	20.0
100	NS	59	NS	28	NS	47.5
120	131	200	97	192	74.0	96.0
Mean	77	78	36	57	46.8	73.1

A = Alfisol; V = Vertisol; NS = not sampled, as soil was dry and hard.

The extent and onset of damage followed a similar pattern for medium-duration ICP-1 and long-duration NP(WR)-15 in the kharif and rabi seasons in the same year.

The nodule number in both varieties was several times greater in kharif than in the rabi season. A greater number of damaged nodules per plant, but less percent damage, were observed in the kharif season than in the dry rabi season for both the cultivars.

Surveys in Farmers' Fields

To obtain information on the extent of this problem, surveys were made during the 1977-78 rainy season in farmers'fields in three villages in cooperation with the ICRISAT Village Level Studies Program. Pigeonpea was intercropped with sorghum, groundnut, and cotton, and nodule damage was observed in all the fields, the range over the locations in the final sampling (70 days) being 3.7 to 65.2% (Table 2). As found earlier at ICRISAT, the greater the nodule number, the larger was the percentage of nodules damaged, as in Kanzara village locations compared with the other two villages, Aurepalle and Dokur. The nodule damage *(%)* increased with the age of the crop between 20 and 70 days, as it did also at ICRISAT Center.

Table 2. Survey of pigeonpea nodule damage in farmers' fields at three locations, 1977-78 rainy season.

Villege (Soil type)	Location no.	Nodule no./plant[a] 15 days	40 days	70 days	Nodules damaged (%) 25 days	40 days	70 days
Dokur (Alfisols)	1	13.2	9.3	19.9	1.5	7.5	6.5
	2	6.6	10.1	73.9	1.5	5.0	3.7
	3	5.4	10.5	13.5	0.0	1.9	7.4
	4	7.3	11.0	15.6	12.3	10.9	9.0
	Mean	8.1	10.2	30.7	3.8	6.3	6.7
Aurepalle (Alfisols/ Vertisols)	1	5.5	4.2	6.8	3.6	9.5	23.5
	2	3.8	6.6	10.7	0.0	16.7	16.8
	3	13.9	20.5	23.3	0.0	5.4	10.7
	Mean	7.7	10.4	13.6	1.2	10.5	17.0
Kanzara (Vertisols)	1	29.0	33.5	38.2	1.7	10.4	14.9
	2	19.8	45.5	19.8	6.1	18.9	65.2
	3	32.4	31.5	32.5	4.9	14.0	18.5
	4	36.8	48.9	32.7	19.6	10.4	20.2
	Mean	29.5	39.9	30.8	8.1	13.4	29.7
Overall mean		15.1	20.2	25.0	4.4	10.1	17.8

a. Mean of 10 plants sampled/location.

Fauna Associated with Nodule Damage

The fauna associated with damaged nodules were surveyed at ICRISAT Center during 1977-79. A dipteran larva was frequently associated, though we also came across collembola beetle larvae, mites, and nematodes. The dipteran larvae are generally pearly white to cream colored, growing from about 2 mm at hatching to about 10 mm prior to pupation. We reared the larvae on nodules in the laboratory and the adults emerged after about