Chapter 7
Diversity of *Phytophthora* Stem Blight of Pigeonpea and Its Sustainable Management

S. J. Satheesh Naik, Abhishek Bohra, T. Basavaraja, R. K. Mishra, G. Padmaja, and K. N. Poornima

7.1 Introduction

Pigeonpea (*Cajanus cajan* (L.) Millisp.) is called by different vernacular names (arhar, tur, redgram, togari, kandalu, etc.), and it is an economically important grain legume of the small and marginal farmers in India. Pigeonpea is one of the major and inseparable dietary protein sources to the large mass of the Indian population (Varshney et al. 2010). Pigeonpea is cultivated as a sole crop and intercrop with rainfed cereals, millets, oils seeds, and other pulses; thereby, it enhances the system productivity and net income to the small and marginal farmers. The differences in the maturity duration of pigeonpea allow it to grow in diversified cropping systems and patterns in varied agro-eco regions of the country.

This has been a matter of concern since the per capita protein availability in India is declining steadily from 27.30 kg/year in 1950 to 10 kg/year in 2009 (Saxena et al. 2014). At present, the national harvest accounts for about 4.25 million tonnes of pigeonpea grains (http://agricoop.gov.in). However, this quantity is not sufficient to meet the domestic needs; about 0.41 million tonnes of pigeonpea is imported annually. The prevailing situation is not likely to improve in the near future by considering the 1.1% annual growth in population (World Bank 2017), plateau of pulse production, inherent low genetic variability for high yield and its attributing traits among the cultivars used in breeding programme and susceptibility of pigeonpea to major

S. J. Satheesh Naik (✉) · A. Bohra · T. Basavaraja
Crop Improvement Division, ICAR-Indian Institute of Pulses Research, Kanpur, India

R. K. Mishra
Crop Protection Division, ICAR-Indian Institute of Pulses Research, Kanpur, India

G. Padmaja
Plant Pathology, PJTSAU, RARS, Warangal, India

K. N. Poornima
Plant Biotechnology Division, ICAR-Indian Institute of Pulses Research, Kanpur, India

B. P. Singh et al. (eds.), *Management of Fungal Pathogens in Pulses*,
Fungal Biology, https://doi.org/10.1007/978-3-030-35947-8_7

diseases and insect pests (Ariyanayagam et al. 1995; Yang et al. 2006; Mallikarjuna et al. 2007; Naik Satheesh et al. 2012; Bohra et al. 2014a; Mishra et al. 2016). This opens the new avenue to use the elite genotypes and wild species into the breeding program to create unexplored genetic variability in pigeonpea through pre-breeding (Sharma and Upadhyaya 2016; Saxena and Kumar 2003; Saxena et al. 2010).

In India, the majority of the pigeonpea production comes from states like Madhya Pradesh, Maharashtra, Gujarat, Karnataka, Andhra Pradesh, Telangana, and Uttar Pradesh. In these states, medium- and long-duration pigeonpea cultivars are grown as intercrop, and it is unlikely that the cultivated pigeonpea area will increase by any significant extent to meet the entire need of the country. Hence, new production niches with early-maturing cultivars were explored. As a follow-up pigeonpea, wheat rotation was successfully introduced in the states of Punjab, Haryana, and Western Uttar Pradesh. However, the new varieties which are resistant to *Phytophthora* stem blight disease and photothermal insensitive, a major production constraint, are being marketed through local agro-dealers (Varshney et al. 2014).

The diverse growing conditions expose the pigeonpea to different biotic and abiotic stresses during its life cycle. Pigeonpea get infected by different diseases and insect pests; however, few of them only cause considerable economic losses (Nene et al. 1996; Dhar et al. 2004). After wilt (C.O: *Fusarium udum*) and sterility mosaic disease (SMD) (C.O: Pigeonpea Sterility Mosaic Virus), *Phytophthora* stem blight (PSB) caused by *Phytophthora drechsleri* Tucker f. sp. *cajani* is the third most important disease of pigeonpea in India (Kannaiyan et al. 1984; Mishra et al. 2016) causing complete crop loss upon its infection. PSB has also been reported as the most important production constraint in northeastern states of India (Mishra and Shukla 1987; Chauhan et al. 2002).

7.2 Economic Importance of *Phytophthora drechsleri* Tucker f. sp. *cajani*

The fungus, *Phytophthora drechsleri*, attacks to young (1–7-week-old) plants of pigeonpea, which in turn kills the young plants at the early stage of crop stand to leave large gaps in plant stands (Fig. 7.1). Yield losses are generally higher in early maturing pigeonpea in comparison to medium- and long-duration varieties, because of favorable disease triangle components in early pigeonpea.

7.3 Disease Epidemiology

The *Phytophthora drechsleri* Tucker f. sp. *cajani* survives in soil and infected plant parts as chlamydospores, oospores, and dormant mycelium. Chlamydospore is thick-walled long-term survival spores, as they are produced through asexual means of reproduction. Whereas oospores are sexual spores, these are produced from

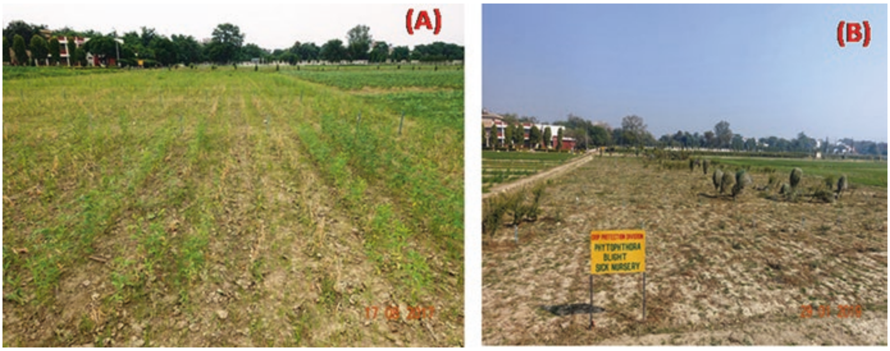

Fig. 7.1 *Phytophthora* stem blight infected field of pigeonpea at the early stage (**a**) and later stage (**b**) leaving the large gap in the plant stand

fertilization of the oogonium by an antheridium. Mycelium of *Phytophthora* is coenocytic, aseptate, hyaline, and profusely branching mainly of monopodial branches. The septa are formed at the time of reproduction.

For a successful disease triangle, moist cloudy conditions with drizzling rain are prerequisite, and temperatures between 25 and 28 °C favor rapid infections in young seedlings. The infection requires continuous wetness of plants for about 8 hours to start. As plants grow older, they gradually develop tolerance/resistance to the disease incidence, and they are generally not infected after they are 60 days old. The PSB infection occurs more in organic matter-enriched clay soil in comparison to clayey soil with little organic matter. The disease symptom appears first in low-lying areas of the field where water stagnates. High-density planting, coupled with low availability of resistant varieties, leads to enhanced PSB buildup in early maturating pigeonpea. Warm and humid conditions followed by start-up of an infection of PSB would result in rapid disease development and eventually lead to plant death. Further, speedy wind and rain splashes help to disseminate zoospores. *Phytophthora drechsleri* Tucker f. sp. *cajani* lives on different wild hosts of pigeonpea, for instance, *Cajanus scarabaeoides* var. *scarabaeoides*, a wild relative of pigeonpea, act as a collateral host for *drechsleri* Tucker f. sp. *cajani*.

7.4 Disease Symptoms and Progress of Disease on Pigeonpea

Phytophthora drechsleri present symptomless in the rhizosphere of pigeonpea, and the infection was only evident when the favorable disease triangle exists (Stanier et al. 1971; Lewis 1973). The symptoms of the *Phytophthora* blight disease on pigeonpea have been described in detail by Pal et al. (1970) as stem rot, by Williams et al. (1975) as stem blight, and by Kaiser and Melendez (1978) as a stem canker. The most commonly preferred name for *Phytophthora* infection is the term blight to describe the disease; because all aboveground parts of the pigeonpea plant are affected, further the roots of diseased plants show no symptoms until the plant dies.

Sarkar (1988) reported that the development of PSB is positively correlated with its soil inoculum potential. Bisht (1985) and Sharma et al. (2015) found that zoospores are the primary source of inoculums. Speedy wind helps in spore dispersal over short distances during rain splash. Williams et al. (1975) found high disease incidence due to poor soil surface drainage; in contrary Singh and Chauhan (1985) reported PSB developing to an epidemic level in well-drained fields. Therefore, drainage alone is not the deciding factor for PSB epidemics. Further, Sharma et al. (2006) reported an outbreak of PSB in well-drained, partially drained, and temporarily waterlogged fields irrespective of cropping systems, soil types, and crop cultivars in the Deccan Plateau of India.

Phytophthora stem blight resembles damping off disease at the early stage of infection that causes young seedlings to die after infection. Further infected plants have water-soaked lesions on their leaves and brown to black spots, slightly sunken lesions on their stems and petioles. Infected plant parts lose turgidity and become desiccated. Lesions strap the affected main stem or a branch which leads to break at that infected point, causing the foliage above the lesion to dry up and lodging. Pigeonpea plants that are infected by blight, but not killed, often produce large galls on their stems especially at the edges of the lesions (Fig. 7.2).

Singh and Chauhan (1985) reported more rapid development of PSB at night in the field due to favorable disease development conditions; this hypothesis was confirmed under artificial darkness conditions in the greenhouse. Reddy et al. (1991a, b) confirmed the PSB infection usually occurs when there is a decrease in day temperatures of the previous week, and the difference between the maximum and minimum temperatures are the least. Studies on relationships between PSB incidence and soil nutrition indicated that in the absence of potassium (K) and high doses of nitrogen (N), PSB incidence increased (Pal and Grewal 1975). Nevertheless, the addition of K decreased disease incidence regardless of the presence of N or phosphorus (P) in the soil (Fig. 7.3).

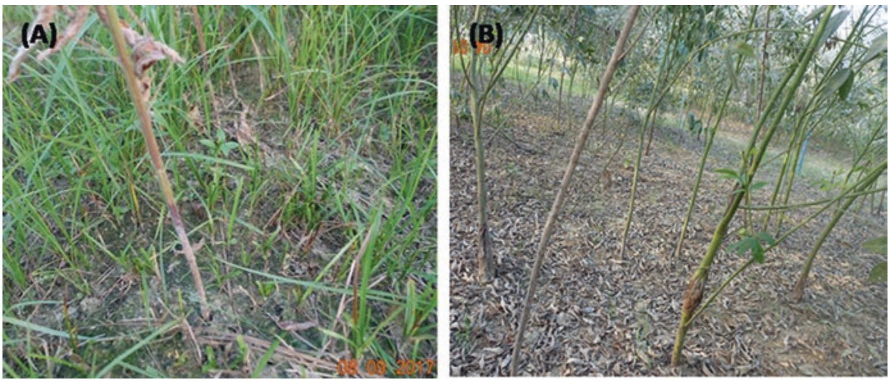

Fig. 7.2 Phytophthora infected pigeonpea plants at the early stage (**a**) and later stage with large galls on the stems (**b**)

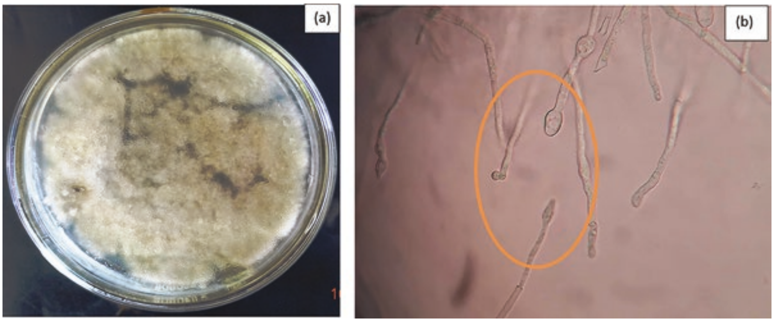

Fig. 7.3 (**a**) Cottony mycelial growth of PSB on V8 juice agar. (**b**) The hypal structure and 40× magnified papiliate hybphae of PSB

7.5 Morphological Features of *Phytophthora*

The cell wall of *Phytophthora* is made up of cellulose. *Phytophthora drechsleri* Tucker f. sp. *cajani* resembles true fungi because they grow using fine filaments called hyphae and produce spores. *Phytophthora* hyphae lack cross wall septa and diploid phase. The *Phytophthora drechsleri* Tucker f. sp. c*ajani* has terminal papillate hyphae which in turn produces the spores. The sizes of sporangia of *Phytophthora drechsleri* var. *cajani* ranging from 42 to 83 × 29 to 48 μm (average 61.8 × 37.3 μm) and the sporangial stalks is either narrowly tapered or widened somewhat at the base of the sporangium (Fig. 7.4b).

Phytophthora produces several types of substructure that are specialized for survival during the adverse condition of their life cycle. Chlamydospores and oospores are prominent spores of *Phytophthora* produced during the adverse conditions of their growth and development. Chlamydospores are thick-walled long-term survival spores produced by asexual means of reproduction, while oospores are sexual spores, which are produced from fertilization of the oogonium and antheridium.

7.6 Disease Management Techniques

In any disease management, host plant resistance is the primary step for exploring available germplasm stocks and breeding lines to identify donors. Different techniques for PSB resistance screening under field and greenhouse conditions have been reported by various researchers. Pal et al. (1970) used a "leaf scar" method to inoculate 30- to 60-day-old seedlings which are grown in pots under greenhouse conditions. This method consisted of inoculating plants at the point of attachment of leaf after its removal with mycelial mats of the fungus multiplied on potato dextrose agar. Kannaiyan et al. (1981) standardized the pot-culture drench inoculation and foliage inoculation techniques. In drench inoculation, 5- to 10-day-old seedlings raised in pots filled with sterilized field soil are drench-inoculated with the

Fig. 7.4 (**a**) Ridge planting of pigeonpea at early seedling stage. (**b**) Established pigeonpea crop on ridge planting method

macerated mycelial suspension of the fungus multiplied on V-8 juice medium (one mycelial mat in 200 ml of water). Inoculum (100 ml) was poured around seedlings. Pots were liberally watered three times a day to assure adequate development of the disease. In this technique, the disease developed after 7–10 days of inoculation. In the foliage inoculation technique, the inoculum is sprayed on 15- to 30-day-old plants grown in a pot, the plants covered with polythene bags for 48 h, kept on glasshouse benches, and later sprayed with water for 10 days. Typical blight symptoms appeared within 10 days after the inoculations.

The sick field screening of pigeonpea genotypes for *Phytophthora* blight resistance was standardized at ICRISAT and ICAR-IIPR, Kanpur, including planting of test entries with 30 cm row spacing and interplanting a susceptible cultivar (e.g., ICP 2376, UPAS 120, ICP 1134, and ICP 7119) to serve as an indicator line after every 2–4 rows. The sick field was prepared by incorporating diseased debris of susceptible cultivars; further, the inoculum load in the sick field is maintained through periodical soil sample analysis of PSB sick field. Additional sickness in the field is created by incorporating infected plant debris.

Agronomic intervention plays an important part in the management of PSB disease. The desiccation of pathogenic spore and dormant mycelium through summer solarization or summer ploughing of field is being done to avoid the inoculum load. Practicing the ridge planting method is highly advantageous to drain excess rainwater since pigeonpea requires well-aerated soil for its growth and development. After the onset of monsoon, timely sowing is highly advisable for establishing early growth and in turn keeping away the disease incidence, because older plants are more resistant to *Phytophthora* blight disease due to systemic acquired resistance. Select fields with no previous record of PSB, and avoid sowing pigeonpea in fields with low-lying patches that are prone to temporary waterlogging. Use wide inter-row spacing for good aeration and plant growth.

Although several fungicides have proved effective in the control of PSB, however, systematic studies on the control of soilborne diseases like PSB using fungicides are limited. In a pot experiment, Pal and Grewal (1983) reported Brestan-60 effective in controlling PSB in 1-month-old plants when applied before inoculating with PDC. Significant control of blight (>90%) was achieved with metalaxyl (1.75 g a.i kg^{1} seed) in a greenhouse experiment (Agarwal 1987; Bisht and Nene 1988). However, Chaube et al. (1987) reported the poor efficacy of metalaxyl applied as a seed dressing in protecting older pigeonpea plants against PSB. At the later stage of PSB, the infection plant develops galls and makes them susceptible to lodging during intercultural operation and speedy wind. Sheila and Nene (1987) reported reduced PSB incidence with the spray or soil drench with two phytoalexins like Phytoalexin-84 and Induce. Park et al. (2007) claim that the direct application of slow-releasing phosphorous acid formulations (curdlan or pestan) using a carrier coated with polysaccharides resulted in an excellent control of PSB disease of pepper. They further suggested that the application of formulation product once or twice during crop season can control *Phytophthora* diseases on various crops. However, there is no evidence in pigeonpea to say this product can be used for the management of PSB in pigeonpea.

Practicing of the integrated disease management (IDM) technology is essential for economical and sustainable means to control PSB. Moderate levels of host plant resistance-bred varieties can be combined with other cultural practices, and application of minimal dosage of fungicide for control of PSB would save large input cost to farmers. The recommended IDM practices include (a) use of pathogen-free seed, (b) seed treatment with fungicide, (c) crop rotation, (d) raised bed planting, (e) adequate field drainage, and (f) use of disease resistant variety, and strategic application of fungicides will help in the management of disease in a sustainable manner.

7.7 Future Prospective and Conclusion

Phytophthora blight (*Phytophthora drechsleri* f. sp. *cajani*) is one of the major yield limiting factors of short-duration varieties of pigeonpea (*Cajanus cajan*). For eco-friendly and sustainable management of the disease, antagonists

(*Pseudomonas fluorescens*, *Bacillus subtilis*, *Trichoderma viride*, and *T. hamatum*) were evaluated widely and used as bioagents and can be integrated with fungicides for effective management of PSB disease. Commercially available metalaxyl formulation – Ridomil MZ – is also at a par with apron in respect to efficacy against *P. drechsleri* f. sp. *cajani*, and they could be integrated with *P. fluorescens* and *T. viride* for better and eco-friendly management of *Phytophthora* blight of pigeonpea. Ridomil MZ has an additional advantage that it possesses different modes of action and there is a lower chance of cross-resistance with metalaxyl-resistant populations. Mancozeb in combination with metalaxyl was found to be highly effective at reducing disease. However, the chemical method of controlling PSB is not economical and eco-friendly. Therefore more focus is needed for the development of resistant varieties for sustainable management and for higher productivity per unit area.

Acknowledgments We are thankful to the Director, ICAR-IIPR, Kanpur, for extending facilities.

Bibliography

Agarwal SC. Fungicidal control of stem blight of pigeonpea caused by Phytophthora drechsleri Tucker f.sp. cajani. Indian J Plant Prot. 1987;15:35–7.

AICRP on pigeonpea, project coordinators report 2015. IIPR, Kanpur.

Ariyanayagam RP, Nageshwara A, Zaveri PP. Cytoplasmic genic male sterility in interspecific matings of pigeonpea. Crop Sci. 1995;35:981–5.

Bisht VS. Phytophthora blight recent studies. Pigeonpea Pathology Progress Report, ICRISAT, Patancheru, AP, India: Legumes Program; 1985. 44pp.

Bisht VS, Nene YL. A selective medium for Phytophthora drechsleri f. sp. cajani causing pigeonpea blight. Int Pigeonpea Newslett. 1988;8:12–3.

Bohra A, Saxena RK, Saxena KB, Sameerkumar CV, Varshney RK. Advances in pigeonpea genomics. In: Gupta S, Nadarajan N, Sen Gupta D, editors. Legumes in the Omic Era: Springer, New York, Heidelberg Dordrecht, London, 2014a. p. 95–110.

Bohra A, Singh IP, Yadav AK, Pathak A, Soren KR, Chaturvedi SK, et al. The utility of informative SSR markers in the molecular characterization of cytoplasmic genetic male sterility-based hybrid and its parents in pigeonpea. Natl Acad Sci Lett. 2014b;38:13–9.

Chaube HS, Razdan VK, Singh US. Effect of metalaxyl on growth, sporulation and sporangial germination of *Phytophthora drechsleri* f. sp. *cajani*. Int Pigeonpea News lett. 1987;6:59–61.

Chauhan VB, Singh VB, Singh AK. Status of Phytophthora blight of pigeonpea in eastern Uttar Pradesh. Ann Pl Protec Sci. 2002;10:402–4.

Dhar V, Singh RA, Gurha SN. Integrated disease management in pulse crops. In: Masood A, Singh BB, Kumar S, Dhar V, editors. Pulses in new perspective. Kanpur, India: Indian Society of Pulses Research and Development, IIPR; 2004. p. 325–44.

Dhar V, Reddy MV, Chaudhary RG. Major diseases of pigeonpea and their management. In: Masood A, Kumar S, editors. Advances in pigeonpea research; 2005. p. 229–61.

Gooding HJ. The agronomic aspects of pigeonpeas. Field Crop Abstracts. 1962;15:1–5.

Gupta AK, Singh IS, Reddy MV, Bajpai GC. Genetics of resistance to P3 isolate of Phytophthora blight in pigeonpea. Euphytica. 1997;95:73–6.

Kaiser WJ, Melendez PLA. Phytophthora stem canker disease of pigeonpea in Puerto. Rico PI Dis Rep. 1978;62:240–2.

Kannaiyan J, Nene YL, Raju TN, Shiela VK. Screening for resistance to Phytophthora blight of pigeon pea. Plant Dis. 1981;65:61–2.

Kannaiyan J, Nene YL, Reddy MV, Ryan JG, Raju TN. Prevalence of pigeonpea diseases and associated crop losses in Asia, Africa and Americas. Trop Pest Management. 1984;30:62–71.

Lewis DH. Concepts in fungal nutrition and the origin of biotrophy. Biol Rev. 1973;48:261–78.

Mallikarjuna N, Jadhav D, Reddy MV, Dutta TU. Introgression of Phytophthora blight disease resistance from Cajanus platycarpus into short duration pigeonpea [Cajanus cajan (L.) Millsp.]. Indian J Genet. 2005;65:261–3.

Mallikarjuna N, Sharma HC, Upadhyaya HD. Exploitation of wild relatives of pigeonpea and chickpea for resistance to Helicoverpa armigera. SAT eJ. 2007;3:1–4.

Mallikarjuna N, Jadhav DR, Srikant S, Saxena KB. *Cajanus platycarpus* (Benth.) Maesen as the donor of new pigeonpea cytoplasmic male sterile (CMS) system. Euphytica. 2011;182:65–71.

Mishra AN, Shukla P. Prevalence of Phytophthora blight of pigeonpea in Uttar Pradesh. Indian Phytopath. 1987;40:56–8.

Mishra RK, Naimuddin, Saabale PR, Naik Satheesh SJ, Krishna K, Singh F, Singh IP. Evaluation of promising lines of pigeonpea for resistance to wilt caused by *Fusarium udum* Butler. J Food Legume. 2016;29(1):64–6.

Naik Satheesh SJ, Byre Gowda M, Venkatesha SC, Ramappa HK, Pramila CK, Marry Reena GA, Ramesh S. Molecular diversity among Pigeonpea genotypes differing in response to Pigeonpea sterility mosaic disease. J Food Legumes. 2012;25(3):194–9.

Nene YL, Sheila VK, Sharma SB. A world list of chickpea and Pigeonpea pathogens. 5th ed. Patancheru, India: ICRISAT; 1996.. 27pp

Pal M, Grewal JS. Utilization of different nitrogen sources by Phytophthora drechsleri var. cajani. Indian Phytopathol. 1975;28(4):499–501.

Pal M, Grewal JS. Chemical control of Phytophthora blight of pigeonpea. Indian Phytopathol. 1983;36:380–1.

Pal M, Grewal JS, Sarbhoy AK. A new stem rot of arhar caused by Phytophthora. Indian Phytopathol. 1970;23:583–7.

Park HJ, Kim SH, Jee HJ. A new formulation system for releasing of phosphorous acid in soil for controlling Phytophthora diseases. Plant Pathol J. 2007;23:26–30.

Reddy MV, Nene YL, Raju TN, Sheila VK, Sarkar N, Remanandan P, Amin KS. Pigeonpea lines field-resistant to Phytophthora blight. Int Pigeonpea Newslett. 1991a;13:20–2.

Reddy MV, Sarkar N, Nene YL, Raju TN. Predisposing factors for Phytophthora blight of pigeonpea. Indian Phytopathol. 1991b:268–70.

Reddy MV, Raju TN, Sheila VK. Phytophthora blight disease in wild pigeonpea. Int Chickpea Pigeonpea Newslett. 1996;3:52–3.

Sameer Kumar CV, Singh IP, Suyash BP, Myer GM, Kumar VR, Saxena RK, Varshney RK. Recent advances in Pigeonpea [*Cajanus cajan* (L.) Millspaugh) Research, In: II International Conference on Bio-Resource and Stress Management, January 07–10, 2015, Hyderabad; 2015.

Sarkar N. Epidemiological studies on Phytophthora blight of pigeonpea. Pulse pathology Progress report 53. Patancheru, AP, India: Legumes Program ICRISAT; 1988. 17pp.

Saxena KB, Kumar RV. Development of cytoplasmic nuclear male-sterility system in pigeonpea using C. scarabaeoides (L.) Thours. Indian J Genet. 2003;63:225–9.

Saxena KB, Kumar RV, Dalvi VA, Mallikarjuna N, Gowda CLL, Singh BB, et al. Hybrid breeding in grain legumes: a success story of pigeonpea. In: Khairwal MC, Jain HK, editors. Proceedings of the International Food Legumes Research Conference. New Delhi; 2005.

Saxena KB, Sultana R, Mallikarjuna N, Saxena RK, Kumar RV, Sawargaonkar SL, et al. Male-sterility systems in pigeonpea and their role in enhancing yield. Plant Breed. 2010;129(2):125–34.

Saxena KB, Singh IP, Kumar RV, Hingane AJ, Mula MG, Patil SB, Kumar CVS. Challenges and opportunities of breeding early maturing pigeonpea hybrids. J Food Legumes. 2014;27(1):1–8.

Sharma S, Upadhyaya HD. Pre-breeding to expand primary genepool through introgression of genes from wild Cajanus species for pigeonpea improvement. Legume Perspectives. 2016;11:17–20.

Sharma M, Pande S, Pathak M, Narayana RJ, Anilkumar P, Reddy M, Benagi D, Mahalinga VI, Zhote DM, Karanjkar KK, Eksinghe PN. Prevalence of Phytophthora blight of pigeonpea in the Deccan Plateau in India. Plant Pathol J. 2006;22:309–13.
Sharma M, Ghosh R, Tarafdar A, Telangre R. An efficient method for zoospore production, infection and real-time quantification of Phytophthora cajani causing Phytophthora blight disease in pigeonpea under elevated atmospheric CO2. BMC Plant Biol. 2015;15:1–12. https://doi.org/10.1186/s12870-015-0470-0.
Sheila VK, Nene YL. Efficacy of Phytoalexin Formulations against Phytophthora drechsleri f.sp. cajani. Int Pigeonpea Newslett. 1987;6:61–2.
Singh UP, Chauhan VB. Relationship between filed levels and light and darkness on the development of Phytophthora blight of pigeonpea (*Cajanus cajan* (L.) Millsp.). Phytopathol Z. 1985;114:160–7.
Spence JA, Williams SJA. Use of photoperiod response to change plant design. Crop Sci. 1972;12:121–2.
Stanier RY, Doudoroff M, Addberg EA. General microbiology. 3rd ed. London: Macmillian; 1971.
Subbarao GV, Johansen C, Kumar RJVDK, Jana MK. Salinity tolerance in F1 hybrids of pigeonpea and a tolerant wild relative. Crop Sci. 1990;30:785–8.
Tikka SBS, Parmar LD, Chauhan RM. First record of cytoplasmic-genic male sterility system in pigeonpea (*Cajanus cajan* (L.) Millsp.) through wide hybridization. Gujarat Agric Univ Res J. 1997;22:160–2.
Upadhyaya HD, Reddy KN, Sastry DVSSR, Gowda CLL. Identification of photoperiod insensitive sources in the world collection of pigeonpea at ICRISAT. SAT eJ. 2007;3(1):1–4.
Vales MI, Srivastava RK, Sultana R, Singh S, Singh I, Singh G, Patil SB, Saxena KB. Breeding for earliness in pigeonpea: development of new determinate and nondeterminate lines. Crop Sci. 2012;52:2507–16.
Van der Maesen LJG. Pigeonpea: origin, history, evolution and taxonomy. In: Nene YL, Hall SD, Sheila VK, editors. The pigeonpea. Wallingford: CAB International; 1990. p. 15–46.
Varshney RK, Penmetsa RV, Dutta S, Kulwal PL, Saxena RK, Datta S, et al. Pigeonpea genomics initiative (PGI): an international effort to improve crop productivity of pigeonpea (*Cajanus cajan* L.). Mol Breed. 2010;26:393–408.
Varshney RK, Terauchi R, Mc Couch SR. Harvesting the promising fruits of genomics: applying genome sequencing technologies to crop breeding. PLoS Biol. 2014;2:100–883.
Wanjari KB, Patil AN, Manapure P, Manjaya JG, Manish P. Cytoplasmic male-sterility with cytoplasm from Cajanus volubilis. Ann Plant Physiol. 2001;13:170–4.
Williams FJ, Amin KS, Baldev B. Phytophthora stem blight of Cajanus cajan. Phytopathology. 1975;65:1029–30.
World Bank Annual Report 2017. Washington, DC: World Bank. https://doi.org/10.1596/978-1-4648-1119-7
WWW.agricoop.nic.in/imagedefault1/Pulses.pdf
WWW.agricoop.nic.in/site/default/files/3rdAdv150216Eng.pdf
Yang S, Pang W, Harper J, Carling J, Wenzl P, Huttner E, et al. Low level of genetic diversity in cultivated pigeonpea compared to its wild relatives is revealed by diversity arrays technology (DArT). Theor Appl Genet. 2006;113:585–95.