25 Years of Pulses Research at IIPR

SILVER JUBILEE
1984-2009

भाकृअनुप
ICAR

Indian Institute of Pulses Research
Kanpur 208 024

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Foreword

Pulse crops have been part and parcel of Indian Agriculture and, thus, remain the subject of research investigation since the establishment of agricultural research system in the country. Initially, the research on pulses was limited to understand the local problems as the country was facing the challenge of food scarcity, and the daunting task was to achieve food security through enhanced production of rice and wheat, the staple foods for millions. Major research breakthrough in cereals in sixties has ushered the country in maneuvering food security through the Green Revolution. In the process, the pulses were marginalized and could not receive the attention they deserved. Realizing the importance of pulses in Indian agriculture and the country's prime position in the world as the largest producer and consumer, the Indian Council of Agricultural Research upgraded the Project Directorate (Pulses) as Directorate of Pulses Research in 1984 and later elevated it to Indian Institute of Pulses Research in 1993 in order to give a major fillip to basic and strategic research on pulses. These steps have been the major catalysts in organizing the pulses research in systematic manner and putting the country in global map of pulses research. Since then, the Institute has been making an impressive gain in generating basic and strategic knowledge and material for development of improved production and protection technologies.

During the 25 years of its journey, the Institute has made great strides in terms of generation of basic information and improved material along with production and protection technologies, which have been well received by farmers across the country. Some of the achievements worth mentioning are short duration varieties, rDNA technology for transgenic development, introduction of *rajmash* as winter crop in the North-East plains, new cropping systems, production technology for late sown chickpea and dwarf fieldpea, foliar spray of 2% urea, application of sulphur, pre-emergence application of pendimethalin, characterization of pathogenic variability of key pathogens and their control measures, IPM modules, identification of new heat tolerant species of EPN, characterization of ideal plant type and post-harvest machineries like IIPR *dal chakki*.

I am happy to learn that the Institute is celebrating its Silver Jubilee in 2009. On the occasion, the Institute has compiled its achievements in the form of a compendium entitled **"25 Years of Pulses Research at IIPR".** The publication gives details of the accomplishments in research and technology dissemination made by the Institute during the past 25 years in a lucid manner. Director and scientists of the Institute deserve appreciation for their sincere and dedicated efforts in bringing out this valuable publication. I hope that this compendium would be very useful for those associated with pulses research and development to disseminate these technologies to the end users and will also provide a base for future research planning with the ultimate aim of attaining self-sufficiency in pulses and promoting sustainable agriculture.

January 5, 2009

(Mangala Rai)
Secretary
Department of Agricultural Research & Education, and
Director General
Indian Council of Agricultural Research
New Delhi

Preface

In order to give an impetus to pulses research in the country, the Indian Council of Agricultural Research created the Directorate of Pulses Research in April 1984 by merging the erstwhile Project Directorate (Pulses) and the Regional Station of IARI at Kanpur. The Directorate had the mandate of coordinating the national network on pulses under the All India Coordinated Pulses Improvement Project (AICPIP) and to undertake some basic, strategic and applied research. However, shortfall in pulses production due to near stagnation in productivity, shrinkage in its area and ever rising population necessitated more focused attention on basic and strategic research in pulses to break the yield plateau. Consequently in 1993, the ICAR upgraded the Directorate to an Institute and named it as Indian Institute of Pulses Research and also trifurcated the AICPIP to give due attention to all the major pulse crops. Since then, the Institute initiated comprehensive research programmes on cropping systems, input management, conservation agriculture, soil nutrient dynamics, drought management, plant ideotypes, PGPR, biochemical basis of resistance to diseases, genetic enhancement, germplasm enhancement, genomics enabled crop improvement, molecular marker assisted breeding, development of markers, CMS based hybrids in pigeonpea, and pyramiding of resistance genes for fusarium wilt, characterization of pathogenic variability, insect biology, bio-control agents, IPM, EPN, post-harvest management and transfer of technology. During the last 25 years, the Institute has developed 22 improved varieties of different pulse crops besides sharing segregating material with NARS and evolved highly productive and efficient crop management practices and aggressively transferred them through farmers' participatory programmes, FLDs, training, *etc.*, besides generating basic knowledge on different aspects. The Institute has strengthened linkages with CG Institutes like ICRISAT and ICARDA and a large number of collaborative projects with external funding agencies have been implemented. The progress made during the last 25 years is highly rewarding. In this publication, the Institute which commemorates the Silver Jubilee Year, has elucidated the salient achievements made under different Divisions and Sections.

I would like to place on record my sincere thanks and appreciation to Drs. Shiv Kumar and Mohan Singh who have edited and synthesized the information provided by the Heads of the Divisions, and I/C Sections, Drs. Vishwa Dhar, NB Singh, Mohan Singh, Shiv Kumar, S.K. Singh, R. Ahmad and Prasoon Verma in the present form. I also express my sincere thanks to Dr. Aditya Pratap, Dr. P. Duraimurugan and Shri Brahm Prakash for providing editorial assistance in publication of the compendium. All scientists of the Institute deserve appreciation for compiling information on different aspects.

I express my sincere thanks and gratitude to Dr. Mangala Rai, Secretary, DARE and Director General, ICAR, Dr. P.L. Gautam, former DDG (CS), ICAR and Dr. S.P. Tiwari, Deputy Director General (Education & Crop Science) under whose guidance, this publication has been conceived and prepared. I am also grateful to Dr. V.D. Patil, Assistant Director General (O&P) for his continued support to the Institute. I am sure that this publication **"25 Years of Pulses Research at IIPR"** will go a long way in up-scaling research pursuit of pulse scientists and provide a road map for future research.

January 4, 2009

(Masood Ali)
Director

Contents

1. Introduction

The Indian Council of Agricultural Research established an independent unit at Kanpur on pulses research in 1984 by upgrading the Project Directorate (Pulses) and named it as Directorate of Pulses Research. The Directorate had the mandate to act as a national centre for basic as well as applied research on pulses; to monitor, guide and coordinate research on pulses in the country; and to arrange for training of scientists and extension workers engaged in pulses research and development and farmers on pulses production technology.

During the first decade of establishment (1984-1993), the erstwhile Directorate of Pulses Research (DPR) focused its research programmes on collection, evaluation, utilization and preservation of germplasm; genetic improvement of pulse crops; basic research on cytogenetics, production physiology, nutrition and grain quality and biotic stresses; breeder seed production; development of appropriate crop production technology and cropping systems both for low and high input conditions with special emphasis for rainfed situations; and development of integrated pest and disease management with special emphasis on biological and resistant varieties.

Recognizing the importance of pulses in agricultural sustainability and nutritional security, a need was felt to have a national institute exclusively dedicated to basic and strategic research on pulses in the country and hence, the DPR was elevated to an institute (Indian Institute of Pulses Research) in 1993. Accordingly, the mandates of the Institute are as follows:

- To act as national centre for basic and strategic research on pulse crops
- To monitor, guide and coordinate research on pulses in the country
- To impart training to scientists and extension workers engaged in pulses research and development
- To foster national and international collaboration for exchange of views and material
- To disseminate information on latest pulse production technology
- To serve as an information bank on different aspects of pulses for strategic planning
- To extend consultancy services and expertise

Since then the Institute has been conducting multidisciplinary research of basic, strategic and applied nature under the four specialized divisions, namely Crop Improvement, Crop Production, Crop Protection, and Physiology, Biochemistry & Microbiology. Besides Divisions, there are four sections *viz*., Agricultural Extension, Statistics & Computer Application, Agricultural Economics, and Agricultural Engineering to meet the Institute's mandates. The Institute is also the headquarters of the All India Coordinated Research Projects on Chickpea, Pigeonpea and MULLaRP crops (Mungbean, Urdbean, Lentil, Lathyrus, *Rajmash* and Fieldpea). The major research programmes during 1993-1998 were as follows:

- Developing varieties of pulse crops for improved yield and sustainability through resistance to diseases and pests
- Emphasis on research in hybrid pigeonpea
- Introduction and improvement of pulses to suit non-traditional areas
- Breeding early-maturing genotypes for increased cropping intensities
- Biotechnology and IPM approaches for pest and disease management
- Strengthening of nucleus and breeder seed production
- Collection, evaluation and preservation of germplasm
- To develop management systems for efficient use of natural resources and applied inputs in pulse crop production
- Basic research on nutrient quality and nutrient requirement, and biochemical basis of resistance to biotic and abiotic stresses
- To develop efficient post-harvest technology
- On-farm testing and transfer of improved technology
- To foster close linkages between national and international organizations

During the period, use of biotechnological interventions in the form of tissue culture and embryo rescue was initiated to overcome the sexual barriers observed in interspecific hybrids in chickpea and pigeonpea. In breeding programmes, emphasis was placed on varieties with short duration and resistance to key diseases for irrigated as well as rainfed conditions. In crop production, emphasis was laid on design and development of new intercropping systems, integrated nutrient management and weed management.

During the IX Plan, a major change in the form of multi-disciplinary approach was brought in the research programmes. The research activities were reorganized in nine major research programmes, namely genetic enhancement for yield and grain quality; cropping systems research; integrated pest management; integrated nutrient and water management; integrated management of drought; crop modeling; plant genetic resources; on-farm research and informatics and post-harvest technology. During the period, the Institute also carried out research under a large number of externally funded projects and international collaboration. This approach has resulted in development of several improved varieties and production and protection technologies which are described in the ensuing chapters.

With major advances in molecular biology research, changing scenario of global agriculture and new challenges under WTO and IPR regimes, the Institute shifted its focus more on basic and strategic research in multidisciplinary and cropping system mode and that has resulted in formulation of 51 new research projects for the period 2002-07. The major theme of the research projects was integration of advanced research tools for solving complex problems of the mandate crops. The period saw major activities in development of rDNA technology for transgenics against gram pod borer in chickpea and pigeonpea, CMS based hybrid pigeonpea technology, extra-large seeded *kabuli* varieties, DNA fingerprinting of released varieties, development of genetic and genomics resources for molecular characterization of different traits, molecular characterization of wilt pathogens, development of prediction models for key pests and diseases, bio-intensive IPM modules, Entomopathogenic nematodes, resource conservation technology, and allelopathy. The transfer of technology received a major impetus. A large number of activities such as frontline demonstrations, farmers' participatory seed production, training, farmers' fair, exhibition, IVLP, *etc.*, have been undertaken to popularize the Institute's technology. During the period, a large number of externally funded projects in collaboration with international institutes have been implemented to popularize the improved pulses production technologies among farmers through farmers' participatory approach. Under the post-harvest management, new farm machines for threshing and milling have been designed.

Systematic and concerted research efforts over the last 25 years under various research projects have resulted in increasingly more productive technologies in pulse crops, which have brought about wider adaptability, yield stability, higher yield, and market specific characteristics like seed size and colour. Focused programmes on breeding, and refinement of production and protection technologies have shown profound effect on crop productivity. The farmers have shown great interest in the Institute's varieties and technologies. The budget of the Institute increased manyfolds from Rs. 504 lakh in the VII Plan to Rs. 2337 lakh in the XI Plan.

Salient Achievements

- Twenty-two high yielding disease resistant varieties of mandated crops *viz*., chickpea (DCP 92-3, SCS 3, Shubhra), lentil (Priya, Sheri, Noori, Angoori), fieldpea (Adarsh, Vikas, Prakash, IPF 04-26), mungbean (PDM 11, Moti, Samrat, Meha), urdbean (Basant Bahar, Uttara, IPU 2-43) and *rajmash* (Uday, Amber, Utkarsh, Arun) have been developed for different agro-climatic zones.
- Six genotypes of pigeonpea *viz*., UPAS 120, PA 163, ICPL 84023, PDA 89-2E, H 28B and Hy 4 have been converted into CMS lines through backcrossing. Twenty four restorer lines *viz*., ICP 41, ICP 98-2, ICP 5774, ICP 3993, ICP 7553, ICP 9596, ICP 1763, ICP 1880, ICP 99049, ICP 2726A, ICP 2730, ICP 12630B, ICP 132A, ICP 1673, MAL 10, MAL 13, MAL 14, JBP 110, IBP 36B, DPPA 58-7, GAUT 90-1, WRG 1-2, Bahar and MAL 6 have been identified.
- High frequency and reproducible genetic transformation systems have been developed in pigeonpea and chickpea. Putative transformants of chickpea and pigeonpea with *cry 1Ac* gene are under testing in physical containment facilities.
- Fingerprinting of the released varieties of chickpea, pigeonpea, lentil, mungbean and filedpea has been completed.
- Total 6682 germplasm accessions of pulse crops (chickpea 2200, lentil 567, filedpea 487, lathyrus 287, *rajmash* 589, pigeonpea 1050, mungbean 673, urdbean 829) are maintained.
- Inheritance of important traits such as Fusarium wilt resistance, double podding, seed size and earliness in chickpea; resistance to wilt, pod fly, sterility mosaic and Phytophthora stem blight in pigeonpea; and photo-thermo-insensitivity, seed colour, pod pubescence, MYMV resistance, plant type and functional male sterility in urdbean has been worked out.
- Inter-specific hybridization between mungbean and urdbean genotypes has resulted in introgression of desirable traits like synchronous maturity and durable resistance to MYMV.
- Highly remunerative cropping systems involving pulses have been developed for rainfed and irrigated ecosystems. Some of the important crop rotations are pigeonpea-wheat, rice-chickpea / lentil, pigeonpea / rice-wheat-mungbean, *etc*.

Intercropping of chickpea with mustard in 4:1 row ratio, mungbean with sunflower in 6:2 ratio, chickpea with linseed in 4:2 ratio, potato + *rajmash* in 3:2 ratio and pigeonpea with urdbean in 2:1 ratio have been found efficient and highly productive. Mungbean and urdbean have been found most compatible for intercropping with spring-planted sugarcane.

- Production technologies for *rabi rajmash*, late sown chickpea, *rabi* pigeonpea and dwarf fieldpea have been developed.
- Incorporation of pulse crops' residue enhanced soil biological activity and yield of subsequent cereal crops.
- All pulse crops respond well to 20-30 kg / ha sulphur application resulting in significant yield increase. Soil application of 15 kg / ha of $ZnSo_4$ and 10 kg Borax proved beneficial in areas deficient in these nutrients.
- Foliar application of 2% urea at initial reproductive stage proved beneficial in increasing pulses production in rainfed situation.
- Ridge planting of pigeonpea has been found effective in realizing higher yield by ensuring desired plant stand and minimizing incidence of phytophthora stem blight.
- An effective weed control in most of the pulse crops can be achieved by pre-emergence application of pendimethalin @ 1.25 kg a.i. / ha.
- Bio-ecology of phytophthora blight and sterility mosaic disease of pigeonpea, powdery mildew of pea, rust of lentil and mungbean yellow mosaic virus has been worked out.
- Pathogenic variability of *F. udum* and *F. oxysporum* f.sp. *ciceri* causing wilt in pigeonpea and chickpea has been established at molecular level. The study showed prevalence of 3 distinct variants in *F. udum* and 5 races in *F. oxysporum* f.sp. *ciceri.*
- Massive field and pot screening has enabled to identify stable sources of resistance to major diseases in different pulse crops.
- IPM modules for wilt / root rot in chickpea, pigeonpea and lentil, sterility mosaic and phytophthora blight in pigeonpea, MYMV in mungbean and urdbean, and powdery mildew and rust in pea have been developed.
- Allelochemicals from sorghum roots have been found effective against soil-borne pathogens.

- A weather-based prediction model for outbreak of *Helicoverpa armigera* has been developed.
- Bio-intensive IPM modules for management of gram pod borer in chickpea and pigeonpea involving use of NPV, NSKE and eco-friendly insecticides (endosulfan, acephate) have been developed.
- Integrated management of root knot nematodes in chickpea has been developed involving seed treatment with latex of *Calotropis* + carbosulfan, intercropping with mustard (2:4), crop rotation with non-host cereals and deep summer ploughing.
- Two heat tolerant EPN species *viz*., *Steinernema masoodi* and *S. seemai* have been identified. These species have great potential as bio-pesticide against *H. armigera* under high temperature regimes.
- Seed smearing with mustard, coconut or mahua oil @ 10 ml per kg seed or admixing activated charcoal powder, NSK powder and Anona seed powder @ 10 g per kg seed have been found effective in reducing bruchids (*Callosobruchus chinensis*) infestation in pigeonpea.
- Two potential parasitoids of bruchids *viz*., *Uscana mukherjei* and *Dinarmus basalis* have been recorded.
- Chickpea germplasm have been classified into four major plant types based on their adaptability to different rainfed conditions. Plant types suitable for Central and South Zones have unequal primary branches characterized by erect habit, tall and main stem with few prominent primary branches *e.g.*, ICC 4958, PG 5, ICCV 92944, ICCV 96030. Plant types adapted to northern plains have numerous basal primary branches with uniform growth reaching to main stem height *e.g.*, RSG 888, KWR 108.
- Donors (ICC 4958, Vijay, ICCV 92944, Katila, PG 5) for high root biomass have been identified based on fast screening techniques. Using carbon isotope discrimination (^{13}C / ^{12}C) technique, genotypes with high water-use efficiency *e.g.*, RSG 143-1 and Vijay have been identified.
- Chlorogenic, caffeic, coumaric and other phenolic acids have shown positive correlation with resistance to Fusarium wilt in chickpea.
- Inoculation of fungicide-treated seeds with *Rhizobium* + PSB + *T. harzianum* improve nodulation in pulse crops.

- Four strains of *Azotobacter* including prominent strain A3 isolated from endorhizosphere improved chickpea growth significantly.
- A low capacity *dal* mill, popularly known as IIPR *Dal Chakki* has been developed for value addition and generating employment for rural masses.
- High yielding varieties and improved production technologies are disseminated through frontline demonstrations, on-hand training, field day, farmers' fair, and use of mass and electronic media.
- The Institute organizes several on-farm farmers' participatory trials.
- The Institute helps in augmenting seed supply and farmers' income through informal farmers' participatory seed production programmes.

2. Crop Improvement

The Crop Improvement Division with an objective of basic and strategic research on breeding, genetics and biotechnology was established in the VIII Plan when the Directorate of Pulses Research attained the status of Indian Institute of Pulses Research (IIPR) in 1993. However, breeding improved varieties of pulses had started with the establishment of Directorate of Pulses Research in 1984. Initially in the first decade (1984-1993), the major activity of the Division was development of high yielding varieties with resistance to key diseases through pure line selection and recombination breeding in all the mandate crops and genetic male sterility (GMS) based hybrids in pigeonpea. As the programme progressed gradually, well focused research programmes were started on generation of basic information on inheritance of important traits, systematic evaluation of germplasm, widening of the genetic base through distant hybridization, cytoplasmic male sterility (CMS) based hybrids in pigeonpea and development of transformation protocol in chickpea and pigeonpea. Since 2003, the Division has placed major emphasis on the following areas of research:

- Development of suitable plant types for different cropping systems
- Breeding for resistance against biotic and abiotic stresses
- Development of CMS based hybrids in pigeonpea
- Pre-breeding for widening the genetic base
- Mapping and tagging of important genes conferring desirable traits
- Genomics enabled improvement
- DNA fingerprinting of released varieties
- Transgenics for resistance against *Helicoverpa* pod borer and drought in chickpea and pigeonpea
- Genetic and linkage studies
- Maintenance breeding and breeder seed production

During the past 25 years of research, the Division has made great stride in generation of basic information, promising material and genomic resources. The crop-wise salient achievements are presented hereunder:

2.1 Chickpea

Chickpea breeding programme was initiated in the year 1983-84 with major emphasis on identification of short duration genotypes with resistance to key diseases, particularly fusarium wilt and root rots. Mutation and recombination have been used to develop short duration (PDG 84-16), wilt resistant (PDG 84-10) and erect plant type (IPC 92-39) genotypes which have been extensively used in subsequent hybridization programme. Utilization of PDG 84-16 in hybridization has led to development of the first short duration variety, PDG 84-10 that was identified for cultivation in the states of Maharashtra, Gujarat, Madhya Pradesh and South Rajasthan. Later on, emphasis was laid on development of input responsive and multiple disease resistant varieties. In late nineties, programmes on drought tolerance, plant types, multiple disease resistance and grain quality were initiated. Recently, development of extra large seeded *kabuli* varieties has received the major attention. Major achievements in chickpea are as follows:

A. Germplasm Enhancement

More than 2700 germplasm accessions have been evaluated for yield and yield attributes. Morphological characterization based on plant growth habit, flower colour, seed colour, anthocyanin pigmentation on leaf and stem, and leaf morphology has also been done. Eighty-eight selected genotypes possessing important traits were evaluated for 12 qualitative and quantitative traits. Significant variation was observed with respect to days to first flower appearance, 50 per cent flowering, days to first pod set, physiological maturity, leaflets per leaf, pods per plant, 100-seed weight and seed yield per plant (Table 2.1). Typical blue (T 39-1) to pink and white flower, erect (IPC 92-39) to prostrate growth habit (IPC 71), extra early (ICCV 96029) to late maturity, simple leaf (PDG 85-1) to multi-pinnate leaves (K 850m), and single pod to multiple pods per peduncle (IPC 99-18, JGM 1) are of high breeding value. Some of the important donors for yield and yield attributes are given in Table 2.2.

Table 2.1. Range of variation in chickpea germplasm evaluated at IIPR

Character	Minimum	Maximum
Days to 1st flower	32 (ICCV 96029)	97 (GL 84100)
Days to 50% flower	36 (ICCV 96029)	103 (GL 90168)
Days to 1st pod set	44 (ICCV 96029)	111 (GL 90168)
Days to maturity	116 (ICCV 96029)	136 (BGD 112)
Plant height (cm)	34.3 (ICC 10459)	84.3 (Phule G 95333)
Primary branches/plant	1.6 (PDG 85-1)	4 (BGD 112)
Secondary branches/plant	2 (GL 92014)	6.3 (ICCV 88503)
Leaflets/leaf	11 (BG 267)	14 (Heera)
Pods per plant	15 (BG 1053)	66 (GPF 2)
Seeds per pod	1.0 (KAK 2)	2.2 (ICCV 88341)
Yield per plant (g)	3.5 (T 39-1)	14.4 (HK 94-134)
100-seed weight (g)	10.6 (IPC 71)	35.82 (KAK 2)

Table 2.2. Important donors identified for chickpea improvement

Donor	Character
PDG 84-16	Early maturing
PDG 84-10	Tolerant to fusarium wilt and pod borer
PDG 85-1	Simple leaf mutant
DCP 92-39	Large seeded and early maturing
DCP 92-1	Double podded and round seed
DCP 92-2	Bruchid tolerant
IPC 71	Profuse branching and green seed
IPCK 96-3	Wilt resistant
IPC 94-94	Early maturity
IPC 94-19	Three seeds per pod
IPC 99-18	Triple podded
IPC 99-10	Resistant to fusarium wilt
IPC 97-29	Wilt resistant, tall
IPC 98-12	Large seeded, wilt resistant
IPC 2002-52	Resistant to fusarium wilt (race 2)
IPC 2k-25	Moderately resistant to dry root rot
IPCK 2004-1	Extra large seeded *kabuli* selection
IPC 97-72	Moderately resistant to dry root rot
IPC 2004-52	Resistant to fusarium wilt (race 2)
IPC 2006-1	Moderately resistant to dry root rot

B. Basic Studies

Comparison of different breeding methods showed that modified bulk and pedigree methods are better to handle segregating generations of crosses. Single seed descent method was effective in maintaining variability, thus allowing selection in later generations.

Besides quantitative traits, inheritance of triple flower (IPC 99-18), triple pods (KTP 1) and wilt has been worked out. A single recessive gene has been identified for conferring the triple podded/flower trait. Genetics of resistance to fusarium wilt (Kanpur race) suggested digenic inheritance.

Twenty-five diverse genotypes were evaluated for tolerance to cold during pod setting under field conditions during 1999-2000. The mechanisms for withstanding cold temperature include *per se* tolerance, avoidance and escape. Based on *per se* tolerance and avoidance mechanisms, ICCV 88503 was rated as cold tolerant genotype.

The chickpea plant adaptation to drought was studied and critical role of phenology in adaptation to high and low yielding environments was demonstrated through genotype x environment studies.

C. Genetic Enhancement

Two varieties of *desi* type *viz*., DCP 92-3 and IPC 97-67 and one *kabuli* type, Shubhra developed at the Institute have been released for cultivation in different regions of the country. The salient features are described below:

DCP 92-3: Wilt resistant variety, DCP 92-3 was released in 1998 for cultivation in high fertility and soil moisture areas of North West Plain Zone (Punjab, H.P., Haryana, Western U.P., Rajasthan and Uttarakhand). This variety does not lodge under high input conditions. The variety has medium-small yellowish seeds and the average grain yield is 22-24 q/ha. At the time of release, the variety established more than 17% yield superiority in NWPZ and 15% in NEPZ (Eastern U.P., Bihar, Jharkhand, Assam and parts of Orissa).

IPC 97-67 (SCS 3): Wilt resistant variety, IPC 97-67 (SCS 3) was released in 2005 for cultivation in rainfed areas of Jammu region of J&K. The variety has medium (19 g/100-seed weight) brown seeds and has average grain yield of 18-20 q/ha.

Shubhra (IPCK 2002-29): *Kabuli* variety Shubhra (IPCK 2002-29), a selection from a single cross (L 144 x H 82-2) following pedigree method, has been identified for cultivation in Central Zone (CZ) comprising Madhya Pradesh, South Rajasthan, Maharashtra, Gujarat, Chhattisgarh and Bundelkhand tracts of Uttar Pradesh. This variety has given >20% higher yield over the best check, JGK 1 and 24% over KAK 2 and has large seeds (34 g / 100-seed weight) and moderate resistance to fusarium wilt.

Concerted efforts on breeding for extra large seeded *kabuli* varieties have led to development of IPCK 02 having 58.4 g per 100-seed weight and 1626 kg / ha grain yield which is under testing in Central (CZ) and North West Plain Zones (NWPZ). Some of the promising lines under multilocation testing are IPCK 2004-29 and IPC 2004-90, which hold promise in terms of yield and multiple disease resistance.

D. Wide Hybridization

Studies at IIPR have resulted in identification of pre- and post-fertilization barriers in wide hybridization. The interspecific hybrids were obtained with incompatible wild species *viz*., *Cicer judaicum* and *C. cuneatum*. However, *C. yamashitae* and *C. bijugum* crosses did not result any F_1. The successful F_1 hybrids were characterized morphologically as well as cytologically (Table 2.3). The F_1 hybrid between *C. judaicum* and *C. arietinum* cv. PDG 84-10 was intermediate in morphology and showed normal meiotic behaviour. Similarly, F_1 between *C. cuneatum* and *C. arietinum* was erect and showed normal meiotic behaviour. Promising lines showing high degree of tolerance to *Ascochyta* blight, more branches, more pods and early maturity were isolated from the segregating generations of above crosses. One of the problems associated with these lines was sensitivity to root rot and high level of pod shattering. Six advanced breeding lines emanating from the cross between *C. arietinum* x *C. reticulatum* are now available for multi-location evaluation.

Table 2.3. Characterization of inter-specific hybrids of chickpea

Material	Pollen stability (%)	Pairing behaviour	Growth habit
Cicer judaicum	96	8 II	Spreading
C. arietinum cv. PDG 84-10	98	8 II	Semi-spreading
C. cuneatum	94	8 II	Intermediate
C. judaicum x *C. arietinum*	54	8 II	Intermediate
C. cuneatum x *C. arietinum*	48	8 II	Erect

2.2 Lentil

Great progress in terms of basic knowledge and promising material has been made in lentil breeding carried out under the ten research projects during the last 25 years. Realizing the fact that the local varieties grown by the farmers succumb to biotic stresses, genetic enhancement in terms of yield, disease resistance, seed size and appropriate duration has been the major goal. Medium duration with resistance to rust for North India and short duration with resistance to root diseases for central India are the key traits while making selection in segregating generation. The breeding approach followed has been hybridization among diverse genotypes for accumulation of high yielding genes and combining multiple disease resistance in high yielding background. In addition, breeding programmes for developing extra-large seeded varieties for export purpose and suitable varieties for *utera* cultivation have been pursued during the past 10 years besides mapping and tagging of genes imparting resistance to Fusarium wilt. A wide range of variation including transgressive segregation has been obtained both for crop duration and seed size from crosses between indigenous microsperma and exotic macrosperma types resulting in selection of extra short duration genotypes with large seeds and tolerance to key stresses. The progress made in lentil breeding programmes during the past 25 years has been grouped in the following subheads:

A. Germplasm Enhancement

The Institute has acquired a large number of germplasm accessions from NBPGR (2020) and GB Pant University of Agriculture & Technology (1022) besides collection through exploration from different parts of the country. In addition, a large number of introductions in the form of exotic lines and yield nurseries from ICARDA have also been accumulated to enrich the local gene pool. During the period under review, the Institute has evaluated 4865 accessions of lentil germplasm, resulting in identification of sources for yield components, phenological events, plant type traits and resistance to major stresses (Table 2.4). However, this includes duplication as well. Evaluation of germplasm accessions showed large variability in the indigenous collection (Table 2.5). Presently, the Institute holds 2435 accessions in its medium-term cold modules and deposited 452 accessions for long-term conservation in the national gene bank.

Table 2.4. Donors for various traits used in lentil breeding programmes at IIPR

Trait	Descriptor	Donors used
Plant type	Erect	Algeria, BDL 41, EC 14588, EC 157634, EC 157635, ILL 4345, JLS 1, KL 178, Precoz, Sehore 74-3, 78 S 26002, 88/886, 94/1468
	Semi-spreading	K 75, KL 113, KL 154, LG 171, L 4076, Pant L 234,Pant L 406
	Spreading	Ranjan, WBL 12
Maturity	Extra early	L 4603, 99/209
	Early	G 93, G 96, Indore local, JLS 1, KL 178, KL 180, KL 183, KL 184, KL 185, NC 62515, NC 62518, PDL-4, PKVL 1, PL 01, Precoz, Sagar Local, WBL 12
	Medium early	DPL 15, DPL 16, DPL 35, DPL 38, E 108, K 75, WBL 58
	Medium late	DPL 24, PDL 1, PDL 2, PL 77-2, LG 198, LG 224, LG 265, LH 15, PL 406, PL 639, Vipasha, VL 1, 89/799
Seed size	Small	EC 14588, EC 157635-1, E 112, HPL 4, HUL 31, LH 82-6, LG 231, LL 147, PL 77-2, PL 81-185, PL 639, RAU 101, Ranjan
	Medium large	JSL 1, KL 178, L 4163, PKVL 1, 88/142, 88/190
	Large	BDL 41, EC 15089, EC 157634-1, EC 157634, G 93, G 96, ILL 331, ILL 462, ILL 645, ILL 978, ILL 4345, Indore local, K 75, KL 178, KL 180, KL 181, KL 185, LG 171, NC 62518, Precoz
Four flowers/peduncle		88/113, 88/143
More secondary branches		KL 154
Resistance to rust		Algeria, E 108, E 343, E 348, E 355, EC 145488, EC 145495, EC 15064 , EC 157634, EC 157635, EC 157635-1, EC 157678, EC 85-22, EC 85-69, EC 22550, HUL 31, ILL 6811, ILL 9901, ILL 9903, ILL 9941, ILL 9956, ILL 9964, ILL 9969, ILL 9976, ILL 9977, ILL 9991, ILL 9972, ILL 10111, IPL 112, IPL 128, IPL 133, LL 147, LG 198, LG 224, LG 231, LG 265, LG 362, Precoz
Resistance to wilt		PL 77-2, PL 406, PL 639, RAU 101, 89/24, 89/799, HUL 31, K 75, DPL 15, DPL 16, DPL 35, ILL 241, ILL 813, EL 42, FLIP 88-37L, FLIP 90-22, PL 131, PL 95-16, L 5258, ILL 7983
Resistance to root rot		IPL 128, L 5258, L 4659, PL 131, PL 95-16,
Resistance to collar rot		IPL 128, IPL 133, PL 95-16
Wide adaptability		DPL 15, DPL 35, K 75, LG 198, LG 224, LG 265, PL 406, PL 639

Table 2.5. Variability for important traits recorded in lentil germplasm

Character	Range
Day to 50% flowering	52 - 109
Days to maturity	110 - 138
Plant height (cm)	20 - 45
Biological yield (g)	1.4 - 20.3
Branches per plant	1.3 - 4.0
Pods per plant	10 - 240
100 - seed weight (g)	1.0 - 5.1
Yield per plant (g)	0.5 - 30.0

B. Basic Studies

The Institute has taken up basic studies involving genetic, breeding and cytological aspects of the crop to strengthen its breeding programmes. Genetics of leaf tendril (tendril at the tip of leaf) and rust resistance using different populations was studied. The results showed a single recessive gene for inheritance of leaf tendril and a single dominant gene for rust resistance. Four genotypes, namely L 4076, Pant L 406, Pant L 639 and K 75 were treated with both physical and chemical mutagens in order to study chromosomal aberration and extent of variation in growth, maturity and chlorophyll characters.

Meiosis analysis of inter-specific hybrids (F_1) involving *Lens culinaris* var. Precoz and PDL 13 with *Lens orientalis* strain No.15 showed normal chromosomal behaviour with seven bivalents at diakinesis and Metaphase-I. F_1 plants obtained from *L. culinaris* var. Precoz x *L. orientalis* showed intermediate characters and 92-100% pollen fertility. Transgressive segregants for extra early types with 37 days of flowering time with normal podding were also isolated from this cross. Various multiple aneuploid stocks were maintained (consisting of 4 to 8 chromosomes) in lentil variety K 75 and L 4076. They were fertile and vigorous.

Evaluation of 31 genotypes comprising 20 exotic and 11 indigenous lines for iron and zinc contents in their seeds revealed significant variation among the genotypes for both the micro-nutrients. For Zn content, the values ranged from 3.79 (IPL 312) to 65.91 (FLIP 2003-25L) µg / g of seed with overall mean of 34.49 µg / g. The mean Zn content was higher in exotic lines (mean: 46.53 µg / g; range: 27.34-

65.91 µg/g) than in the indigenous genotypes (mean: 8.37 µg/g; range: 3.79-15.60 µg/g). Genotypes with high Zn content (>50 µg/g) are FLIP 2003-25L, FLIP 84-55L, Acc. 2313, FLIP 2002 56L, NEL 857 and Lenka. The estimates of Fe content among the lentil genotypes showed a range of 22.47 - 109.37 µg/g with mean of 46.12 µg/g. Most promising genotypes for high Fe content (>50 µg g^{-1}) are NEL 857, Pant L 5, 81S15, FLIP 2002-7L, FLIP 2003-25L, FLIP 86-38L, Acc. 2313 and FLIP 95-55L. Some of the genotypes *viz.*, NEL 857, Acc. 2313 and FLIP 2003-25L with high contents of both the micro-nutrients, Zn and Fe can be used in breeding programmes for bio-fortification of lentil varieties.

C. Genetic Enhancement

During eighties, land races were collected and evaluated besides attempting a large number of single crosses under recombination breeding. This was followed with crosses involving more parents in nineties. In total, 1025 crosses including single, three-way and double crosses were attempted to generate the variability through recombination and identify the desirable recombinants (Table 2.6). Most frequently used parents in the crossing programme were K 75, Sehore 74-3, Pant L 406, DPL 58, DPL 62, DPL 44, DPL 15, L 4076 and Precoz. This has resulted in development of 612 high yielding promising breeding lines combining resistance to key diseases, appropriate crop duration and seed size. Of them, 213 lines have been tested in AICRP trials for their performance across the countries (Table 2.7), finally resulting in the release of four high yielding varieties, namely Priya, Sheri, Noori and Angoori. These varieties are in the national seed chain with good seed indent and presently occupy sizeable areas in the recommended zone. Perusal of variety-wise breeder seed production during 2007-08 showed that IIPR produced 49.43 q breeder seed of Noori, 32.18 q of Priya and 18.10 q of Sheri. Major efforts in genetic enhancement are presented hereunder:

Table 2.6. Number of crosses in lentil attempted at IIPR during the past 25 years

Type of crosses	1982-87	1988-92	1993-97	1997-2002	2003-08
Single cross	129	175	258	126	174
Three-way cross	5	19	27	61	29
Double cross	Nil	21	Nil	1	Nil

Table 2.7. Number of promising breeding lines of lentil emanating from IIPR breeding programme and tested in AICRP from 1985-2007

Zone	AVT I	AVT II	Released
NHZ	18	4	-
NWPZ	54	18	3
NEPZ	49	9	-
CZ	47	13	1

Short duration varieties: The onset of flowering is an important phenological event, which determines duration of the vegetative phase, establishes the potential of the crop and determines the climatic conditions to which the crop would be exposed during the reproductive growth. Crosses between early and late flowering genotypes have resulted in transgressive segregants. The most frequently used donors for earliness were L 4603, 99/209, DPL 20, DPL 21, DPL 37, DPL 44, DPL 501, DPL 510, G 93, G 96, Indore local, JL 1, JL 3, JLS 1, KL 178, KL 180, KL 183, KL 184, KL 185, NC 62515, NC 62518, PDL 4, PKVL 1, PL 01, Precoz, Ranjan, Sehore 74-3, Sagar Local, WBL 12, 88/142, 89/332, 89/516, 90/50, 89/344, 98/155, 98/156 and 95/126. Total crosses attempted for incorporating earliness were 326 that resulted in 129 promising breeding lines. These lines were evaluated in AICRP trials. Finally, a variety, Noori having crop duration of 110-120 days with resistance to rust and wilt was released for cultivation in the Central Zone.

Disease resistant varieties: Breeding efforts for incorporation of resistance against rust and Fusarium wilt has been taken up since the beginning of the breeding programme. The main sources of resistance utilized for rust at IIPR were Algeria, DPL 15, DPL 16, DPL 21, DPL 38, DPL 44, DPL 501, DPL 510, 106, E 108, E 343, E 348, E 355, EC 145488, EC 145495, EC 15064, EC 157634, EC 157635, EC 157678, EC 22550, HUL 31, ILL 6811, ILL 9901, ILL 9903, ILL 9941, ILL 9956, ILL 9964, ILL 9969, ILL 9976, ILL 9977, ILL 9991, ILL 9972, ILL 10111, IPL 112, IPL 128, IPL 133, LL 147, LG 198, LG 224, LG 231, LG 265, LG 362, Precoz, PL 81-17, PL 81-185, PL 95-16, PL 406, PL 539, PL 637 and PL 639. Similarly for resistance to vascular wilt, donors like PL 77-2, PL 406, PL 639, RAU 101, 89/24, 89/799, HUL 31, DPL 15, DPL 16, DPL 35, ILL 241, ILL 813, EL 42, FLIP 88-37L, FLIP 90-22, FLIP 90-26 L, IPL 128, PL 131, PL 95-16, L 5258, L 4659 and ILL 7983 have been utilized. A total of 436 crosses were attempted for the purpose, resulting in a large number of promising breeding lines with resistance to these diseases and high yield. All the four varieties, Priya, Sheri, Noori and Angoori released from the Institute have either tolerance or resistance to these diseases.

Large seeded varieties: Traditionally in North India, small seeded varieties are grown after the harvest of rice or under the *Utera* system of cultivation in which seeds of lentil are sown in the standing crop of rice. However, bold seeded varieties are known to provide better return to farmers on account of premium price in market. Concerted efforts have led to the development of bold seeded varieties like Priya, and Noori with 2.7-3.0 g / 100 seeds. Another variety, Sheri developed by the Institute has seed weight of 3.4 g per 100 seeds. Recently, an extra large seeded variety, Angoori with 4 g per 100 seeds has been released for cultivation in North West Plain Zone.

Major characteristics and yield potential along with area of adaptation of the varieties emanated from the Institute's programme are as follows:

DPL 15 (Priya): In order to develop high yielding wilt resistant variety, a cross between Pant L 406 and L 4076 was attempted in 1983-84. Pedigree selection in segregating generations for high yield and Fusarium wilt resistance has resulted in identification of DPL 15 with semi-spreading, non-tendril plant type, green foliage, and medium large seeds (2.7 g / 100-seed). The variety has shown resistance to rust and tolerance to wilt and root rot diseases and protein content of 23.7%. Multi-location evaluation over three years (1990 to 92) showed that the variety takes, on an average, 83 days to 50% flowering and 136 days to mature with plant height of 53 cm and grain yield of 1456 kg / ha, an advantage of 17% over the best check, L 4076. It has been released for cultivation in Punjab, Rajasthan, Haryana, Delhi and western UP under normal sown conditions.

DPL 62 (Sheri): In order to combine wilt resistance and large seed size in high yielding background, a cross between JLS 1 and LG 171 was attempted and segregating population was advanced following pedigree selection for resistance to rust and Fusarium wilt and large seed size. One of the recombinants, DPL 62 having semi-spreading and bushy plant type, deep green foliage, broad non-tendril leaflets, and large seeds (3.1 g / 100-seed) with mottled seed coat showed resistance to rust, tolerance to wilt and root rot diseases and protein content of 25.2%. Multi-location evaluation over three years (1994 to 96) showed that the variety takes, on an average, 81 days to 50% flowering and 134 days to mature with plant height of 45 cm and grain yield of 1727 kg / ha, an advantage of 14% over the best check, L 4076. It has been released for cultivation in Punjab, Rajasthan, Haryana, Delhi and western UP under normal sown conditions.

IPL 81 (Noori): In order to combine earliness and resistance to wilt and rust in the most popular variety, K 75 of central India, a cross between K 75 and Pant L 639 was made and carried forward through pedigree method of selection. IPL 81 having semi-spreading plant type, deep green foliage, moderate pubescence, and medium sized seeds (2.70 g / 100-seed) with grey mottled seed coat has shown resistance to rust and tolerance to wilt and root rot diseases. Multi-location evaluation over three years (1996 to 98) showed that the variety takes, on an average, 71 days to 50% flowering and 113 days to mature with plant height of 37 cm and grain yield of 1245 kg / ha, an advantage of 23% over the check, K 75. It has been released for cultivation in Central Zone (Bundelkhand region of UP, MP, Chhattisgarh, Part of Rajasthan, Maharashtra and Gujarat) under irrigated as well as rainfed conditions.

IPL 406 (Angoori): In order to develop high yielding extra large seeded varieties of lentil for export purpose, an exotic line EC 157634 having extra large seeds was involved in hybridization programme with DPL 35, a good agronomic base derived from the cross L 1304 x K 75. Pedigree selection in segregating generations for extra large seed size and resistance to fusarium wilt and rust has resulted in identification of IPL 406 with dark green foliage and extra large seeds (3.93 g / 100-seed) having light green seed coat without spot and pink cotyledon. The variety has exhibited resistance against rust and Fusarium wilt. Multi-location evaluation showed that the variety takes, on an average, 90 days to 50% flowering and 136 days to mature with plant height of 47 cm and grain yield of 1691 kg / ha, an advantage of 13% over the best check, DPL 62. It has been released for cultivation in Punjab, Rajasthan, Haryana, Delhi and western UP under both irrigated and rainfed conditions.

D. Widening of the Genetic Base

Our analysis on genealogy of the released varieties of lentil showed that the pedigrees of 35 varieties released in the country were traced back to 22 ancestors. Of them, top ten ancestors contributed 30% to the genetic base. The most preferred parent was L 9-12 (17%) followed by T 8, JLS 2 and JLS 1 in spite of considerable variation observed for various morphological traits and reaction to biotic and abiotic stresses in the germplasm. This indicates narrow genetic base of the lentil varieties. Therefore, the major effort has been made to broaden the genetic base by crossing them with genotypes from other regions. The introduction of an early flowering line, Precoz (ILL 4605) from ICARDA in early nineties and its use in hybridization with indigenous lines has resulted in the selection of extra early genotypes. Using intraspecific variability of microsperma and macrosperma, a large number of recombinant lines have been derived and are presently at different stages of testing. Wide hybridization in lentil is just at its juvenile stage and limited success has been made while using wild species *Lens orientalis*, the progenitor of cultivated species. However, the work done so far remained to just study the crossability and phytogenetic relationships among different wild species. Limited accessions of wild species and paucity of information on the exploitable variation available in wild species has hampered their use in the breeding programme.

2.3 Fieldpea

During the last 25 years, the emphasis in pea breeding was mainly on incorporation of dwarf plant type, earliness and resistance to powdery mildew and rust diseases. Both tendril and leafy types in dwarf background have been introgressed using diverse sources of indigenous and exotic origin in hybridization programme. Various sources of leafless type like S 143, HFP 4, HUDP 7, and HFP 8909; powdery mildew resistance like HFP 4, DMR 7, PDPD 8, DPFP 2, DPFP 20, HUDP 15, and Rachna; long pods like DDR 30, Azad P 1; and earliness like Azad P 1, Pusa 10, Kiran, and PDPD 8 were involved in hybridization for development of high yielding lines with resistance to diseases. About 350 crosses were made for generating the breeding materials. Major research achievements made in fieldpea breeding programmes are presented below:

A. Germplasm Enhancement

Total 480 accessions were maintained and evaluated over the years. The observations recorded for important agronomic traits showed significant genetic variation (Table 2.8). This has resulted in identification of a large number of donors for various traits (Table 2.9), which were utilized in crossing programmes for incorporating desired traits in widely adapted varieties.

Table 2.8. Frequency distribution of qualitative attributes of 480 accessions of fieldpea

Plant descriptors	Expression	No. of accessions	Accessions
Early plant vigour	Poor	89	P 12205, P 607
	Good	117	P 774, P 867
	Very good	274	P 1589, P 781
Foliage colour	Light green	72	EC 292174, P 729
	Green	113	KPMR 18, EC 322767
	Dark green	295	EC 292170, F 4779-34
Foliage waxy bloom	Absent	41	P 1575, P 1622
	Present	339	P 578, MD 1918
Rabbit-eared stipules	Absent	177	P 1545-2, P 1601
	Present	303	P 1705, P 117-1
Flower colour	White	287	P 1679, P 73-1
	Purple	193	P 1705, P 108-4
Pod shape of distal part	Pointed	398	P 1816, EC 499761
	Blunt	82	P 1297-96, P 1707
Pod colour	Light green	77	P 1535-1, P 668-1
	Green	287	P 1436-1, P 1625
	Dark green	116	P 1545, HUDP 15
Seed surface	Smooth	363	NIC 18900, P 1789
	Wrinkled	117	EC 329558, EC 292156

Table 2.9. Promising donors for quantitative attributes in fieldpea

Character	Promising accessions
Plant height (< 60 cm)	P 1544-4, P 1457-7-1, HFP 4, P 1602, P 1613, KPMR 400
Flower opening (< 40 days)	P 1613, P 73-1, P 118-1, P 1343
No. of pods per plant (> 22)	P 1541-33, P 1548-2, P 108, P 996
Pod length (> 7.5 cm)	P 1440-21, EC 389376, P 1618
No. of seeds per pod (>7)	P 1585, P 1703, DM 173, P 62, P 73-1, P 108-4, P 91-3, P 1205

B. Basic Studies

Genetic analysis of quantitative characters: Genetic parameters controlling the expression of certain quantitative traits showed adequacy of additive – dominance model for primary branches and number of seeds. Epistasis was evident for most of the characters though additive and dominance components were also significant.

Significance of additive as well as non-additive gene effects along with duplicate epistasis suggests use of biparental mating or intermating in early segregating generations.

Genetic divergence analysis: Fifty-three lines were used to study genetic divergence following D^2 analysis. Lines were grouped into 11 clusters. Plant height contributed maximum to the genetic diversity followed by 100- seed weight, number of branches and pod length. The study indicated lack of parallelism between genetic and geographic diversity.

Molecular diversity analysis: Twenty-four most popular and widely adapted varieties were subjected to RAPD analysis to find out the genetic relatedness among them using 60 decamer primers. All the primers were found to be polymorphic and seven of them showed 100% polymorphism. Out of 579 amplified products, 433 showed polymorphism (74.8%). On an average, 9.65 bands were amplified per primer. Cluster analysis based on Jaccard's similarity coefficient using UPGMA grouped all the tall type varieties together, whereas dwarf types formed two different clusters based upon their pedigrees. The arithmetic mean heterozygosity (H_{av}) and marker index (MI) were 0.496 and 4.787, indicating efficiency of RAPD as a marker system in molecular analysis in pea.

Genetic base of released varieties: Pedigree of 33 fieldpea varieties released in India was traced back to 26 ancestors. Out of these 26 ancestors, three contributed 49% to the genetic base. T 163 was the most frequently used parent followed by EC 109196 and T 10. These three ancestors contributed 51% to the genetic base of current breeding lines being evaluated in AICRP trials. This suggests that more than 50% of fieldpea varieties and breeding lines developed in India are more or less related due to presence of T 163 in their pedigree.

Morphological characterization of varieties: A total of 43 released cultivars of pea were grouped for several agro morphological descriptors. Most of the varieties belong to the category of large seed weight. VL 3, Azad P 2, HUP 2 and JM 6 were of medium seed weight category whereas B 22 was in small seed weight group. The pea varieties were largely of early to medium flowering except DDR 23, DDR 27, Arkel, Azad P3, Azad P31, Ageta 6, VRP 5, VRP 6, VRP 22, B 22, and VL 42 which belonged to extra early flowering category. Most of the varieties were of short or long plant height except IPFD 1-10, VL 3, LFP 48, DDR 23, DDR 48, Azad P3, Azad P31, VRP 7 and VRPMR 9 which belonged to medium group category. Seed surface was smooth in all varieties except in Arkel, Azad P1, Azad P3, Azad

P31, Ageta 6, VRP 6, VRP 7, VRP 22, Azad P2, Azad P5, VRPMR 9 and Azad P4 with wrinkled seeds.

C. Genetic Enhancement

Five high yielding varieties having resistance to powdery mildew have been developed for different agro-ecological regions. This was possible due to use of diverse sources of indigenous and exotic origin in hybridization programmes followed by pedigree selection in the segregating generations. Some of the sources of leafless type, rust tolerance, powdery mildew resistance, long pods and earliness involved in hybridization for developing high yielding lines with resistance to diseases are as follows:

Leafless type	HFP 4, S 143, KPMR 144-1, HFP 8909, HUDP 15
Powdery mildew resistance	HFP 4, DMR 7, IPF 99-25, HUDP 15, IPFD 1-10
Rust resistance	FC 1, HUDP 15, EC 1, HUDP 7, IPFD 1-10
Early types	Pusa 10, DDR 23, DDR 27, Arkel, Azad P 3
High number of pods	HUDP 7, HUDP 6, EC 329550
Large seed size	MDP 2, DDR 30

Important features of the varieties developed are described below:

Adarsh (IPF 99-25): This tall type variety has been developed through pedigree selection from the cross, PDPD 8 x Pant P 5. It has recorded average yield of 2300 kg/ha, a superiority of 23% over the check in Central Zone. It possesses resistance to powdery mildew disease. The variety has been released and notified in 2004 for Madhya Pradesh, Chhattisgarh, Maharashtra, Gujarat and Bundelkhand region of UP.

Vikas (IPFD 99-13): This dwarf variety has been developed through pedigree selection from the cross, HFP 4 x LFP 80. It has an average yield of 2274 kg/ha, a yield advantage of 33% over the best check in Central Zone. The variety is highly resistant to powdery mildew and fairly tolerant to rust disease. It matures in 102 days and has white, round and smooth seeds of medium bold size (19.1 g/100-seed). The variety has been recommended for release in 2005 in the states of Madhya Pradesh, Chhattisgarh, Maharashtra, Gujarat and Bundelkhand region of UP.

Prakash (IPFD 1-10): This dwarf variety developed from the cross PDPD 8 x HUDP 7 has yield superiority of 27% and 31% over the check varieties in Central Zone and North Hill Zone. The variety has resistance to powdery mildew and has large seeds

(22 g / 100-seed). The variety has been recommended in 2006 for the states of MP, Maharashtra, Gujarat, Bundelkhand region of UP, J & K, Uttarakhand, Himachal Pradesh and Hilly regions of NEH states.

IPF 04-26: This tall variety has been developed from the cross KPMR 144-1 x Pusa 10 and recorded average yield of 2157 kg / ha in North West Plain Zone, a yield superiority of about 18% over the best check, DMR 7. It has resistance to powdery mildew disease. The variety has been identified in 2007 for Western UP, Rajasthan, Punjab, Haryana, Delhi, Plains of Uttarakhand and Himachal Pradesh.

IPF 27: This tall variety has been developed through pedigree selection from the cross Rachna x Kiran. It has the yield superiority of 15% over the check variety in the North East Plains Zone and has the average yield of 2005 kg / ha. It has resistance to powdery mildew and tolerance to rust. The variety was identified for Eastern UP, Bihar, Jharkhand, West Bengal and Assam.

Based on the performance in AICRP trials, some of the promising breeding lines having high yield, and round and white seeds with resistance to powdery mildew are as follows:

Tall type	IPF 14, IPF 17, IPF 99-26, IPF 99-31, IPF 4-6
Dwarf type	IPFD 3, IPFD 98-1, IPFD 98-7, IPFD 98-9, IPFD 98-18, IPFD 99-14, IPFD 99-15, IPFD 99-30, IPFD 1-9, IPFD 2-5, IPFD 2-19, IPFD 3-7, IPFD 6-3

2.4 *Rajmash*

Rajmash is traditionally cultivated as rainy season crop in northern hill regions in India. With the development of improved production technology and identification of suitable cultivars, it has emerged as a promising pulse crop for *rabi* season in northern plains as well. Since the crop was introduced in non-traditional area for *rabi* cultivation, variability for early duration, erect type and tolerance against frost and cold assumed greater significance since the beginning of the programme. Therefore, focused efforts were made for introducing exotic germplasm lines to develop suitable plant type for North plain zone. Bean Common Mosaic Virus (BCMV) coupled with extreme cold and frost has emerged as major constraints. Therefore, breeding programmes at IIPR aimed at developing varieties with high yield and resistance to above stresses. Breeding for attractive seed colour and large seeds has also assumed importance. As a result, four varieties have been released for cultivation in different regions. Salient achievements made in *rajmash* improvement at IIPR are presented hereunder:

A. Germplasm Enhancement

The Institute has acquired a large number of germplasm accessions through exploration and collection. Indigenous collections were made from the hills of Uttarakhand, Jammu & Kashmir and Himachal Pradesh. Special efforts were made to introduce exotic collections from CIAT (Columbia), Brazil and Slovakia. Evaluation of 432 accessions has resulted in identification of sources for yield components and resistance to major stresses (Table 2.10). Evaluation of germplasm showed large variability in the collection (Table 2.11). Presently, the Institute holds 579 accessions in its medium-term cold modules.

Table 2.10. Donors for various traits used in *rajmash* breeding programme

Specific Trait	Donors
Early maturity	HUR 137, HUR 15, ET 8391, ET 8399, ET 8, ET 8414, EC 397828
100-seed weight (> 60 g)	IC 14711, GPR 16, HURG 27, HURG 30, IC 204773, GPR 115 A, HURG 20 b, EC 324980, GPR 121 A
Plant height (36-40 cm)	T 65, IC 1100, ET 8422, ET 8456, GPR 200 A, EC 397826, ET 8402, HUR 15, EC 400442, EC 400450, ROXINHO, ET 8426
Branches per plant (> 6)	IC 18137, IC 43552, HURG 581, PI 169680, IC 18598, PI 22686, PI 163629
Seeds per pod (up to 7)	EC 7006, IC 203952, IC 43552, No. 3220, IC 16882A
Pods per plant (> 45)	PLB 36, IC 37161, IC 18114, PLB 431, EC 947870
Pod length (> 15 cm)	EC 57080, EC 57050, IC 203952, HURG 25, HURG 12A, HURG 555, HURG 133, HURG 298A
Cold tolerance	IPR 98-4, IPR 96-1, ET 84449, HURG 405, GPR 203, HURG 170, HURG 413

B. Genetic Enhancement

Genetic improvement of *rajmash* was initiated systematically at IIPR in mid eighties. With the systematic evaluation of available germplasm, a few lines were identified for growing the crop successfully in *rabi* season in North eastern plain zone. PDR 14, a selection from exotic collection EC 94453 was identified in 1987 for

Table 2.11. Variability for important traits recorded in *rajmash* germplasm

Character	Range
Days to 50% flowering	34 - 126
Days to maturity	112 - 155
Plant height (cm)	10.5 - 153
Number of primary branches	1 - 7
Number of seeds per pod	2 - 8
Pods per plant	2 - 48
Pod length (cm)	4.3 - 20
Central leaflet length (cm)	2.7 - 12.4
Central leaflet width (cm)	2.7 - 10.5
100-seed weight (g)	4.23 - 78

cultivation in plains of Uttar Pradesh, Bihar, Jharkhand, West Bengal and Assam during *rabi* season. Total 88 inter-varietal crosses were attempted to generate the variability through recombination and identify the desirable recombinants. Evaluation of segregating material has resulted in development of 34 high yielding promising lines combining resistance to BCMV and appropriate plant type. In 2001, a high yielding and BCMV resistant variety, IIPR 96-4 (Amber) was developed from Columbian accession for *rabi* cultivation in NEPZ. Extreme cold and frost have led to reduce the productivity of the crop in plains. Identification of germplasm accession from Brazilian material, EC 400431 and further selection for higher productivity and erect type has led to the development of Utkarsh (IPR 98-5). A short duration variety, Arun (IPR 98-3-1) was developed from pureline selection of EC 400418. Special features of these varieties are described below:

Uday (PDR 14): Uday is a selection from exotic collection, EC 94453. It matures in 110-115 days and gives average yield of 20 q / ha. Its seeds are large (44 g / 100-seed weight) with variegated red colour. It has been released for cultivation in North East Plains Zone (eastern and central Uttar Pradesh, Bihar, Jharkhand, West Bengal and Assam).

Amber (IIPR 96-4): This is a selection from Columbian accession, ET 8447. Its yield potential is 20-24 q / ha. It matures in 135-140 days and has resistance to BCMV and leaf crinkle disease. The 100-seed weight is 38 g. It has been released for cultivation in North East Plains Zone (eastern and central Uttar Pradesh, Bihar, Jharkhand, West Bengal and Assam).

Utkarsh (IPR 98-5): It is an ideal cultivar for *rabi* cultivation in plains. It is a selection from the exotic line, EC 400431. Its productivity ranges from 24 to 25 q/ha and matures in 125-130 days. Its attractive gulf red seed colour and 34-35 g per 100-seed weight receive consumers' preference. The variety is highly responsive to fertilizers and tolerant to BCMV and leaf crinkle. It has tolerance to low temperature (<12^0C). This variety has been released for cultivation in North East Plains Zone (eastern and central Uttar Pradesh, Bihar, Jharkhand, West Bengal and Assam).

Arun (IPR 98-3-1): This variety has been developed as selection from the exotic line, EC 400418. Its average yield is 1871 kg/ha and matures in 115-120 days. Seeds of the variety are very attractive and bold (38 g/ 100-seed weight) with gulf red colour. It has been notified for cultivation in Gujarat, Maharashtra, Madhya Pradesh and Chhattisgarh.

2.5 Lathyrus

The programme on lathyrus started in 1992 at IIPR. The major objective of the programme was to evolve low ODAP lines. The local germplasm collected from MP, Bihar, West Bengal and Orissa was evaluated. The low ODAP lines developed by IARI were utilized in the crossing programmes. Sources of earliness and bold seededness were also used for their incorporation in low ODAP and high yielding lines.

A. Germplasm Enhancement

Two hundred and sixteen diverse lines were evaluated for various morphological traits. A wide range of variation was recorded for plant height (21-59 cm), primary branches (2-5), number of pods (18-61), seeds per pod (1-4), grain yield per plant (1.2-8.9 g) and 100- seed weight (4.5-15.7 g). Genotypes with high grain yield per plant were Bio L 212, Bio R 234, Bio L 239, JRL 47, Pusa 534 and IC 120446. Genotypes with bold seed size were Bio L 208, LS 8246, Bio R 227, Sel. 505, RLK 568 and RLK 538. Early maturing genotypes were RLK 266, RLK 287, RLK 398, RLK 539, RLS 2, IC 1204446 and IC 120524. Genotypes with higher number of pods per plant were Bio L 212, Bio R 231, Bio L 239, Bio R 234, IC 120446, DL 265, IC 120492, RLK 430 and RLK 1280.

B. Basic Studies

Variation for protein content: Twenty six genotypes (19 exotic) were evaluated to study the variation in protein content. The range of variation for exotic genotypes was 24.9 to 31.6% whereas for indigenous, it was from 20.3% to 29.5%. The protein content did not display any significant correlation with seed weight, flowering and maturity duration.

Stability for ODAP: A stability analysis was performed with 9 low ODAP genotypes under diverse locations. The most stable genotype identified for low ODAP content was Bio R 202 which may be used as donor for low and stable ODAP in breeding programme.

Genetics of yield and yield traits: Gene action for yield and its components was studied in three crosses. Both additive and non-additive gene effects were involved in the expression of number of primary branches, pods per plant and grain yield per plant. Plant height was found to be predominantly under the control of dominance gene effect. Simultaneous utilization of both additive and non-additive gene effects can be achieved by intermating of segregants in early segregating generation.

Correlation and path analysis for ODAP: A study was conducted with 11 genotypes to observe association of ODAP with yield traits. ODAP content did not correlate with any of the yield traits studied. The path analysis did not reveal any pronounced effect of ODAP on grain yield, suggesting possibility of developing ODAP free genotypes with good yield potential. Pod number, primary branches, plant height and seed weight were found to be the major yield contributing characters. Indirect selection through pod number would be highly effective as this character had the maximum direct effect on grain yield.

Reaction against thrips: A preliminary study showed reasonable variability for thrips tolerance among low ODAP genotypes. The lack of any relationship of thrips tolerance with ODAP content and crop duration suggested the possibility of developing low ODAP genotypes with tolerance to thrips in desired maturity group.

Genetic divergence: Forty-six genotypes were evaluated to study genetic divergence for yield and its components. These genotypes were grouped in eight clusters. Days to maturity and 100-seed weight were the important contributors towards the divergence and can be used as parameters while selecting parents for hybridization.

C. Genetic Enhancement

In order to incorporate earliness, large seed size and low ODAP content in widely adapted background, diverse genetic sources were used in the hybridization:

Low ODAP content	Bio R 202, Bio L 203, Bio L 212, Bio R 231, P 94-3, LS 8246, Bio L 208, LS 8545, Bio I 222
Earliness	RLS 5, RLS 3, LSD 3
Bold seededness	Bio L 208, Bio R 227
Wide adaptability	Bio L 212, P 24, LSD 3

Pedigree method of selection was followed in segregating generations of a large number of crosses. Some of the promising crosses resulting in desirable recombinants were Bio R 202 x Bio R 227, LSD 3 x Bio L 212, Bio R 202 x Bio L 222, Bio I 222 x LS 8246, Bio I 222 x Bio R 202, Bio I 222 x Bio L 203, Bio L 203 x Bio I 222, BioL 208 x NC 8a-269, Bio R 227 x Bio R 202, and Bio L 208 x P 90-2. The promising breeding lines with high yield and ODAP content below 0.2% are IPLy 9, IPLy 99-7, IPLy 99-9, and IPLy 99-12. IPLy 9 with 0.18% ODAP content recorded 15-17 q / ha grain yield in multi-location trials while IPLy 99-7, IPLy 99-9, and IPLy 99-12 recorded 28-30 q / ha grain yield with <0.2% ODAP content in station trials.

2.6 Pigeonpea

The pigeonpea breeding programmes during last 25 years were directed to generate basic knowledge on the inheritance of different traits, characterization and evaluation of germplasm, identification of donors, and generation and evaluation of breeding materials with different plant types, resistance to major biotic and abiotic stresses and higher yield in long and short duration backgrounds. Emphasis on development of hybrid technology involving genetic male sterility system was the main focus during early nineties. Later on in 1999, the focus of the programme has been directed to cytoplasmic male sterility system. Major achievements made during the past 25 years under various research projects are summarized hereunder:

A. Genetic Enhancement

Total 2000 germplasm accessions were collected through exploration and procurement from different institutions like, ICRISAT and NBPGR. These lines were evaluated and duplicates were identified and screened out from total collection. Evaluation of early and long duration pigeonpea germplasm accessions showed wide variability for qualitative and quantitative traits (Table 2.12).

Table 2.12. Variability for qualitative and quantitative traits in pigeonpea

Trait	Range in early group	Range in late group
Plant type	Determinate & Indeterminate	Determinate & Indeterminate
Stem colour	Green to dark purple	Green to dark purple
Growth habit	Spreading to compact	Spreading to compact
Base flower colour	Light yellow to dark purple	Light yellow to dark purple
Second flower colour	Yellow to purple	Yellow to purple
Streak colour on flower	Light yellow to purple	Light yellow to dark purple
Streak pattern on flower	None streak to dense streak	None streak to dense streak
Days to 50% flowering	80-105	116-153
Days to maturity	118-144	208-272
Plant height (cm)	92-162	82.0-203.6
Primary branches/ plant	2.6-18.3	5-23
Secondary branches/ plant	2.2-3.3	6-103
No. of seeds per pod	2.3-4	3-5
100-seed weight (g)	6-11.2	5.9-18.6
Grain yield / plant (g)	8-55	30-68

B. Basic Studies

Resistance to fusarium wilt: Screening of parents, F_1s, F_2s and backcross generations of ten crosses involving resistant (Banda Palera, DPPA 85-7, PDA 85-1, DPPA 85-12 and ICPL 87119) and susceptible parents (Bahar and PDA 10) under wilt sick plot suggested that the resistance to *F. udum* in all the five resistant parents is governed by a single dominant gene. Studies on allelic relationships among the resistant parents showed that the gene conferring resistance to wilt in Banda Palera, DPPA 85-7 and PDA 85-1 is different from the gene imparting resistance in DPPA 85-12 and ICPL 87119. It appears that resistance to *F. udum* is under the control of two independent loci.

Resistance to sterility mosaic: Studies involving resistant (Banda Palera, DPPA 85-7, DPPA 85-13) and susceptible (BDN 1 and ICP 8863) parents showed involvement of a single recessive gene in the inheritance of resistance to sterility mosaic disease.

Resistance to phytophthora stem blight: Crosses between resistant (KPBR 80-2-1 and KPBR 80-2-2) and susceptible (Bahar and PDA 10) parents showed involvement of two recessive genes with duplicate epistasis in the inheritance of resistance in KPBR 80-2-1 and KPBR 80-2-2. However, crosses involving other resistant parents (Hy 3C and BDN 1 indicated a single recessive gene for resistance in Hy 3C and

BDN 1. The results suggest that the susceptible parents Bahar and PDA 10 possessed two dominant genes, which may be designated as Pdr_1 and Pdr_2. KPBR 80-2-1 and KPBR 80-2-2 appeared to differ in respect of two gene pairs while Hy 3C and BDN 1 differed in respect of a single gene pair with the susceptible parents, Bahar and PDA 10.

Tolerance to pod fly: Segregation patterns in F_2 and backcross generations of different crosses involving resistant (PDA 88-2E, PDA 93-2E and PDA 89-2E) and susceptible (DA 11 and NDA 1, ICP 5174, ICP12386) parents suggested involvement of two genes with dominance of susceptibility to pod fly. The resistance is controlled by two genes (*Mor1, Mor2*) with dominant epistatic interaction in PDA 88-2E and PDA 89-2E and duplicate epistasis in PDA 92-2E and PDA 93-2E. The genes present in PDA 88-2E and PDA 89-2E (*mor1mor1Mor2Mor2*) are allelic to the genes present in PDA 92-2E and PDA 93-2E ($mor_1mor_1mor_2mor_2$). Thus, the genes present in PDA 92-2E and PDA 93-2E are allelic but different in respect of single gene present in PDA 88-2E and PDA 89-2E.

Comparison of breeding methods: Four selection procedures, namely single plant selection, mass selection, selected pod bulk, and bulk method were compared in segregating populations of four crosses for three cycles of selection. The results showed that single plant selection and mass selection are better for selecting high yielding plants in pigeonpea.

C. Genetic Enhancement

Long duration pigeonpea: In long duration pigeonpea, all the existing varieties are susceptible to at least one of the major diseases viz., *Fusarium* wilt, *Phytophthora* stem blight and sterility mosaic disease (SMD). Efforts were made to develop high yielding varieties with multiple disease resistance. For this purpose, 850 single crosses, 250 backcrosses, 200 three-way crosses and 50 double crosses were attempted involving donors with good agronomic bases. These crosses resulted in >100 multiple disease resistant lines which were evaluated in AICRP trials. Some of the promising breeding lines with multiple disease resistance developed are IPA 2000-1, IPA 2000-2, IPA 402, IPA 502, IPA 602, IPA 03-1, IPA 03-2, IPA 303, IPA 04-1, IPA 04-2, IPA 04-3, IPA 04-4, IPA 05-3, IPA 612, IPA 07-2, IPA 07-3, IPAS 08-1 and IPAS 08-2.

Short duration pigeonpea: In North India, short duration varieties cover a sizeable area under pigeonpea – wheat rotation. At present, the available varieties are small seeded and take more than 150 days to mature which delays the sowing of wheat and ultimately decreases the wheat yield. Therefore, breeding programme in short duration pigeonpea has targeted large seed size (>9 g), 125-145 days to maturity, resistance to phytophthora stem blight and semi-determinate plant type. Two entries *viz*., E 87-8 and E 87-9 showed better performance than UPAS 120. Similarly, PDA 88-1 is a promising line selected from ICP 85014, having medium seed size with determinate plant type. Variety ICPL 88027 gave 5% higher yield (15.75 q/ha) over check, ICPL 87 (15 q/ha), and ICPL 91052 (17.28 q/ha) yielded 8% higher yield over UPAS 120 (16 q/ha). Eighty seven single plant selections in selected bulk populations were carried forward in 124- 152 days maturity duration. In addition to early maturity, semi-determinate habit, high podded attribute and good plant vigour were taken into consideration in selection. In general, plants with high primary branches and podding showed high plant weight.

D. Heterosis Breeding

Initially, the programme of heterosis breeding was based upon genetic male sterility (GMS) system and a large number of agronomic bases were converted into GMS lines through repeated backcrossing. Several experimental hybrids were also developed and evaluated. Realizing the limitation in seed production of hybrids based on this system, the focus of the programme was shifted to cytoplasmic-nuclear male sterility system.

Genetic male sterility system

Broadening the base of GMS system: Four agronomic backgrounds, namely T 7, PDA 85-1, ICP 8860 and Bahar were converted as male sterile lines using ms3783 as donor. After five (BC_5F_1) generations of backcrossing, single plant selections were made from each of four progenies in order to develop heterozygous lines segregating in 1:1 ratio for male fertility and sterility plants.

Identification of new sources of male sterility: Gamma rays' treatment of 10 kR, 20 kR and 30 kR dose was applied to Manak, PDA 85-1, Bahar, T 7, and DA 11 in order to identify new sources of male sterility. In spite of evaluation of large populations for several generations, none of the plants could show male sterility.

Identification of heterotic combinations: Line x tester method was used to identify heterotic combinations in pigeonpea. Out of 27 crosses, msPrabhat NDT x ICPL 85010, msPrabhat NDT x P 610, msPrabhat DT x UPAS 120, msPrabhat DT x AF 98, msPrabhat DT x ICP 88001, msPrabhat DT x H 87-24, ms 1 x P 604 and IMS 1 x P 605 were found good specific combiners for yield per plant. Among late duration pigeonpea, KPMS 1050 x PR 5149, KPMS 1050 x ICP 3024, KPMS 1050 x DPPA 85-12, KPMS 1050 x PDA 89-2-E, KPMS 1050 x KPP 1034-33, ms3783 x ICP 7200, ms3783 x PDA 92-1, ms3783 x KPP 1034-7, msNP(WR)15 x Bahar, msNP(WR)15 x DPPA 85-12, msNP(WR)15 x DPPA 85-13, msNP(WR)15 x KPP 1034-1 and msNP(WR)15 x KPP 1034-5 were good specific combiners for yield / plant.

Synthesis of experimental hybrids: Experimental hybrids were produced using msPrabhat NDT, ms3783 and msNP(WR)15 as female parents with good general combiners as pollinators. Altogether 557 hybrids were produced. Multi-location evaluation of experimental hybrids during 1992-1996 showed that KPHT 2011 (3194 kg / ha), KPH 2016 (2812 kg / ha) and KPH 2006 (2729 kg / ha) had significantly superior yield over the check T 7 (1631 kg / ha) in late group and in early group, hybrid, IMS 1 x ICPL 84023 gave highest (1975 kg / ha) yield followed by msPrabhat DT x UPAS 120 (1595 kg / ha).

Cytoplasmic male sterility system

Identification of CMS System: Wide hybridization involving wild relative *viz.*, *Cajanus platicarpus*, *C. volubilis*, *C. albicans*, *C. scarabaeoides*, *C. sericeus*, *C. cajanifolius*, *Rhyncosia bracteata*, *R. hirta*, *R. minima* and *Dunberia ferrugines* as female parent with cultivated pigeonpea was taken up to get cytoplasmic nuclear male sterility. Two crosses, *Cajanus albicans* X PDA 10 and *C. cajanifolius* X Bahar showed promise. F_3 generation of four crosses between *C. sericeus* and *C. cajan* showed maximum number of plants with high sterility in ICPX 910073-14. The plants showing 40-70% pollen sterility were used as female for crossing with different pollen parents of *C. cajan*. In F_4 generation, plants showing 50-80% pollen sterility were used as female for crossing on plant to plant basis. In F_5 generation, the plants showing >70% pollen sterility were sib mated and crossed with different pollen parents in order to search maintainers.

Evaluation of CMS sources: Identification of CMS sources, GT 288A and 67A, led to reorient the hybrid breeding from genetic male sterility base to cytoplasmic genetic male sterility at IIPR. Among three lines tested for stability of male sterility, ICP 2039A was the only line with 100% sterility, while other two lines, ICP 2030A and ICP 2043A showed 100% and 83.33% fertility.

Diversification of CMS lines: Diversification of male sterility of GT 288A was done in the background of five agronomic bases *viz*., PA 163, UPAS 120, Hy 4, PDA 89-2E and H 28B and male sterility of 67A was diversified in ICP 84023 following the backcross method. Total six male sterile lines have been developed. Beside this, Pusa 992 and ICP 88039 are under conversion using ICP 2089A and GT 288A as CMS sources.

Identification of fertility restorers: Twenty four genotypes *viz*., ICP 41, ICP 98-2, ICP 5774, ICP 3993, ICP 7353, ICP 9596, ICP 1763, ICP 1880, ICP 99049, ICP 2726, ICP 2730, ICP 12630 B, ICP 132, ICP 1673, MAL 10, MAL 13, MAL 14, JBP 110, JBP 36 B, DPPA 58-7, GAUT 90-1, WRG 1-2, Bahar and MAL 6 were identified as restorers from 1500 genotypes, which were used as pollen parent for developing hybrids involving CMS lines *viz*., Hy 4 A, PDA 89-2E A and H28B A as female parent.

Development of CMS based hybrids: Total 101 hybrids were made involving 11 male sterile lines *viz*., ICP 84023A, 67A, PA 163A, GT 290A, GT 288A, UPAS 120A, ICP 2039A, ICP 2043A, Hy 4A, PDA 89-2EA and H 28-BA and 17 restorers *viz*., ICP 41, ICP 98-2, ICP 5774, ICP 2730, MAL 6, MAL10, MAL 13, MAL 14, JBP 110, JBP 36 B, DPPA 58-7, GAUT 90-1, Bahar, ICP 1763, ICP 1880, ICP 7353 and ICP 9596.

Evaluation of hybrids: Seven hybrids were evaluated in *kharif* 2005-06 for fertility, crop duration and grain yield. All hybrids were 100% fertile. Three hybrids *viz*., ICP 2043A x MAL 14, ICP 2043A x DPPA 58-7 and ICP 2043A x GAUT 90-1 gave higher yield than the best check, ICPL 87119. The highest yielding hybrid, ICP 2043A x MAL 14 recorded grain yield of 2054 kg / ha with 26.95% superiority over the best check ICPL 87119 (1618 kg / ha). Similarly, evaluation of nine hybrids during 2005-06 showed that four hybrids, namely GT 288A x JBP 110, GT 290A x ICP 1763, 67A x ICP 9596 and Hy 28BA x ICP 41 were 100% fertile. ICP 2043A x JBP 110 was highest yielding hybrid (1801 kg / ha) as compared to the best check, ICPL 87119 (1650 kg / ha).

Standardization of seed production of 'A' line: To standardize seed production of 'A' line, UPAS 120B and its 'A' counterpart were planted in three ratios *viz*., 1B:8A, 1B:6A and 1B:4A under isolation. The seed yield of 'A' line was highest when planted in 1:6 ratio followed by 1:8 and 1:4. Total seed yield and net return were highest in the planting ratio of 1:6, followed by 1:8 and 1:4. Input output ratio was also maximum in 1:6 followed by 1:8 and 1:4.

Molecular characterization of component lines: Molecular characterization using RAPD primers differentiated CMS line GT 288A and its maintainer. Out of 100 amplified bands, 62 (62%) were polymorphic and two primers, OPAQ 5 and OPAB 10 gave seven and five bands, respectively. With similar amplification and polymorphism magnitudes, a few maintainers (GT 288B, 67B) and restorers (ICP 41 and DPPA 85-7) have been differentiated by four unique bands.

Two CMS lines, GT 288A and 67A were compared with their maintainer lines using molecular markers. DNA amplification pattern of these maintainers was also compared with two restorers (ICP 41 and DPPA 58-7) to find B and R line specific bands. Out of 496 amplified bands, 409 (82.45%) were polymorphic. Average number of bands per primer was 9.185. Total 12 primers (OPP 14, OPP 10, OPP 12, OPP 15, OPP 16, OPP 19, OPAQ 07, OPAQ 19, OPBA 01, OPBA 13, OPBA 14 and OPBA 18) produced 100% polymorphism, whereas two primers (OPH 02 and OPH 20) did not produce any polymorphism. OPAQ 13 produced maximum number (20) of bands. Six A line (67A and GT 288A) specific bands *viz.*, $OPP08_{1220bp}$, $OPP14_{650bp,}$ $OPAQ07_{1750bp,}$ $OPAQ07_{1200bp,}$ $OPAQ07_{900bp,}$ $OPAQ07_{250bp}$ were observed and a single band specific to R lines (ICP 41 and DPPA 58-7) i.e., $OPAQ04_{3000bp}$ was also observed. These A and R line specific markers were cross validated over 44 R lines and 4 A lines. It was observed that the markers showing specificity to A and R lines are not truly linked with the genomic region and failed to identify A and R lines in early stages.

E. Wide Hybridization

The crosses were attempted with incompatible wild species, *Atylosia platycarpa* and *A. albicans*. The interspecific hybrids with *A. platycarpa x Cajanus cajan* were developed. However, reciprocal cross could not result any F_1 hybrid. The F_1 obtained using above cross was sterile. Similarly, the F_1 was obtained from cross, *Cajanus cajan* X *A. albicans*. The F_1 hybrids were characterized morphologically and cytologically. It was observed that F_1 (*A. platycarpa* X *C. cajan*) was intermediate between wild and cultivated parents. Six univalents and 8 bivalents were observed in F_1 as against 11 bivalents in both the parents. This resulted in high sterility (51.8%) between *A. platycarpa* and *C. cajan*. The fertile derivatives showed high level of variability for different qualitative as well as quantitative traits (Table 2.13).

Table 2.13. Characterization of interspecific hybrids in pigeonpea

Material	Pollen stability (%)	2n	Pairing behaviour	Growth habit
A. platycarpa	84.0	22	11 BV	Creeper
C. cajan	98.5	22	11 BV	Erect
A. albicans	92.5	22	11 BV	Creeper
A. platycarpa x *C. cajan*	32.5	22	6 UV+ 8 BV	Intermediate
A. albicans x *C. cajan*	48.6	22	6UV+ 8 BV 0.1-0.3 TV	Intermediate

2.7 Mungbean

The major constraints in achieving higher productivity in mungbean are limited genetic variability, lack of suitable plant type for different seasons, poor harvest index and susceptibility to a number of biotic and abiotic stresses. While MYMV and Cercospora leaf spot are common problems in almost all the mungbean growing regions, powdery mildew occurs in *rabi* crop in South and central parts of the country. The Institute has made systematic breeding efforts to evaluate the available germplasm and incorporate early synchronous maturity and resistance to MYMV, powdery mildew and pod shattering in high yielding background. Initially in nineties, pure line selection from indigenous land races was made, resulting in varieties like PDM 11 and PDM 54 for spring/summer season. Gradually, the emphasis was placed on recombination breeding for combining earliness with synchronous maturity and resistance to MYMV. These efforts have resulted in development of variety like Samrat, which has become one of the most popular varieties in the country. Realizing the fact that the narrow genetic base is one of the major constraints for breaking the yield plateaus, a systematic wide hybridization programme involving mungbean, urdbean and other *Vigna* species such as *V. sublobata* and *V. trilobata* was initiated in 1998. The selection criteria have been short duration, photo-thermo-insensitivity, resistance to MYMV and synchronous maturity. Mutation breeding has also been exercised for creating variability for various characters such as growth habit, profuse podding, seed size and extra earliness during this period.

In general, the major breeding objectives have been development of high yielding multiple disease (MYMV + Cercospora leaf spot) resistant varieties with crop duration of 85-90 days for *kharif* season and determinate growth habit, high harvest index and photo-thermo-insensitivity and 65-70 days duration for spring season whereas for summer cultivation, extra-early varieties of 55-60 days with synchronous maturity are the main objectives. Recently, emphasis has also been placed on development of varieties with resistance to powdery mildew for pre-*rabi* season. During the past 25 years, a great progress has been made in genetic enhancement of mungbean under the 15 research projects. Salient achievements made are presented as under:

A. Germplasm Enhancement

The Institute has acquired a large number of germplasm accessions from local as well as exotic sources during the past 25 years. A total of 673 accessions have been evaluated over the years, resulting in identification of donors for various components of suitable plant type traits and resistance to biotic stresses (Table 2.14). Range of variability for various traits reported in the germplasm is given in Table 2.15. Some of the important donors are IPM 99-6 for extra earliness and synchronous maturity, EC 39884, BDYR-1, BDIR-2, BDYR-4, Pusa Vishal, EC 369223, EC 398879, EC 39886 and ORA 24 for extra large seeds, LM 352 for multiple clusters / peduncle, LM 653 for multiple peduncle / node and AKP / NP8 / 9 for more pods / plant. These donors have been used extensively in crossing programmes for incorporation of these traits in suitable agronomic background.

Table 2.14. Useful donors identified for various traits in mungbean

Character	Donors
Large seeds (>5 g / 100 seeds)	EC 398884, EC 398897, BDYR 1, BDYR 2, BDYR 4, Pusa Vishal, EC 369223, EC 398886, ORA 24
Earliness (55 days)	IPM 99-6, IPM 02-19
Multiple clusters / peduncle	LM 352
Multiple peduncles / node	LM 653
Number of seeds / pod	NSM-079
Number of pods / Plant	AKP / NP-1819
Resistance to MYMV	ML 1818, ML 1019,UPM 98, UPM 98-1, PMB 63, ML 818, Samrat, MUM 2, ML 5, ML 6, ML 613, NBM 1
Resistance to powdery mildew	Phule M 9339, Pusa 105, ML 5, UPM 98-1, HUM 1, PMV 63, ML 131, ML 515, DMG 1030, DMG 1045

B. Basic Studies

Information on inheritance of different traits has been generated to understand the genetics of qualitative and quantitative traits besides resistance to major diseases. Segregation pattern in F_2 and F_3 generations of eight crosses involving resistant (Tarai Local, L 80, L 294-1, LM 214) and susceptible (J 45, G 65) parents suggested a single recessive gene in the inheritance of MYMV. However, modifiers present in the nucleoplasm influenced the expression of this gene. Similarly, the segregation pattern in 20 crosses suggested a single recessive gene in the inheritance of resistance to Cercospora leaf spot. Combining ability analysis for yield and plant type traits showed preponderance of non-additive gene action in the inheritance of plant height, pods / plant, pod length, biological yield, 100-seed weight and harvest index. Segregation pattern in wide crosses involving mungbean and urdbean parents showed emergence of useful recombinants for plant type and morphological traits even after 10 generations of selfing.

Table 2.15. Range of variability for quantitative traits in mungbean

Character	Range	Promising Accessions
Plant height (cm.)	15-60	CN067, CN8074, CN 8052, CN8096
Days to flowering	40-53	AKP/MP/8/9, BDYR-2,CN 9042, DMG 103
Days to maturity	56-66	BKP/NP/8/61, CN 9007, AKP/NP/8/63,CN8096
No. of primary branches	4-15	EC470090, GP274, Kopergaon-1, IC 20305
No. of secondary branches	8-23	Kopeargaon-1, JBT37/171, CN 8052, DPC109-2
No. of clusters/plant	2-12	K-369760, NO37141, Kopergaon-1, LM 58
Pod length (cm)	4.5-10.5	EC30401, IC 433, EC470096, IC325823
No. of seeds/pod	5-13	AKP/NP/8/9, DRA 224, AKP/NP/8/63, EC30400
100-seed weight (g)	2-6	EC 398886, BRS2435, IPOI359, JG1990

C. Genetic Enhancement

Total 233 crosses have been attempted during the last 25 years (Table 2.16). The most frequently used parents were Pusa Bold, BDYR 1, BDYR 2, Sona Mung, EC 398884, ML 267, EC 398897 and IPM 03-1.

Table 2.16. Number of crosses in mungbean at IIPR during the past 25 years

Period	Number of crosses	Main parents used
1984-90	59	IPM 99-125, Pusa Bold 2, BDYR 1, BDYR 2, K 851, EC 398884
1991-95	11	ML1818, ML 1019,UPM 98, UPM 98-1, PMB 63, ML 818, Samrat, MUM 2, ML 5, ML 6, ML 613, NBM 1
1996-2000	35	Pusa Bold 2, BDYR 1, EC 369223, EC 39884, EC 398879, EC 398886, Samrat, MUM 2, ML 5, ML 6, ML 613
2001-05	114	V 3561, LM 663, LM 527, LM416, LM 387, LM 95, LM 837, LM95, IC 16033, Bannan, Batani, BM 111, PDM 139, UPM 58, LM 551, EC 369223, EC 39884, EC 398879
2006-08	36	V 3561, LM 663, LM 527, LM416, LM 387, LM 95, LM 837, LM95, IC 16033, Bannan, Batani, BM 111, PDM 139, UPM 58, LM 551

Evaluation of the segregating materials has resulted in development of 312 high-yielding short duration breeding lines with resistance to MYMV. These efforts have led to the development of outstanding varieties such as PDM 11, PDM 54, PDM 139 and Meha for cultivation in different agro-climatic zones of India. The salient features of these varieties are as follows:

PDM 11: This variety was developed as pure line selection from LM 95 in 1987. It matures in 70-75 days with yield potential of 15-20 q/ha in spring and 60-65 days with 10-15 q/ha in summer season. The plant is tall (40-50 cm) erect type with medium seed size. It has resistance to MYMV and tolerance to pod shattering. This variety has been released for cultivation in spring/summer season in Central and North East Plains Zones.

Moti (PDM 54): This variety has been developed as pure line selection from indigenous germplasm in 1987. It takes 60-65 days to mature and has erect dwarf plant type (25-30 cm) with large seeds (4-5 g/100 seeds) and MYMV resistance. Its yield potential is 10-15 q/ha and 10-12 q/ha in *kharif* and summer seasons. It has been released for cultivation in South and North East Plains Zones.

Samrat (PDM 139): In order to develop high yielding extra early variety, a cross was made between ML 20/19 and ML 5. Pedigree selection in segregating generations for extra earliness and resistance to MYMV has resulted in identification of PDM 139 with erect dwarf plant type and small shining green seeds (3.80 g/100-seed). The variety has exhibited better resistance against two of the most destructive diseases *i.e.*, MYMV and powdery mildew. Multi-location evaluation showed that the variety takes, on an average, 60 days to mature with plant height of 28 cm and grain yield of 12 q/ha. It has been released for cultivation in Uttar Pradesh in *kharif* and spring/summer seasons.

Meha (IPM 99-125): In order to widen the genetic base of mungbean varieties and introgress useful traits from urdbean, a cross was made between mungbean variety, Pant Mung 2 and urdbean line, AMP 36. Pedigree selection for high degree of synchrony in flowering and maturity with urdbean type pod clusters and MYMV resistance has resulted in identification of IPM 99-125. Multi-location evaluation (2001-2003) showed that the variety takes, on an average, 34 days to 50% flowering, 66 days to mature, plant height of 40 cm, 100-seed weight of 3.54 g and grain yield of 14.20 q/ha. It has been released for cultivation during spring season in North East Plains Zone.

D. Wide Hybridization

Repeated use of a few parents with high degree of relatedness in crossing programme has resulted in narrow genetic base of the released varieties of mungbean. Study showed that 49 varieties developed through hybridization involved only 71 ancestors. The top ten ancestors contributed 79% to the genetic base with T 1 appearing in 35% varieties, followed by T 49, BR 2, G 65 and Madhira. Therefore, efforts were directed to involve urdbean and wild relatives like *Vigna sublobata* in crossing programme. The cross compatibility between mungbean and urdbean was established using mungbean as female parent. However, recovery of urdbean type segregants was rare and difficult to advance. In order to recover urdbean type, evaluation of large population in segregating generation was attempted. Evaluation of 645 single plant progenies of a wide cross, IPM 03-1 x SPS 5 in F_6 generation and 171 single plant progenies of two wide crosses, IPM 03-1 x SPS 5 and IPM 99-125 x SPS 5 in F_3 generation generated new variability for multi-clusters from each node, single stem type, dwarf type, extra large seeds and urdbean type plants (Table 2.17). This variability has been utilized in altering the existing plant types in mungbean as well as urdbean. Other inter-specific crosses involving mungbean with *V. sublobata* and *V. trilobata* have resulted in selection of one uniform line and single plants of great promise.

Table 2.17. Genetic variation released for quantitative traits in urdbean and mungbean crosses

Character	Wide crosses		Variability reported in germplasm
	IPM 03-1 x SPS 5	IPM 99-125 x SPS 5	
Plant height at flowering (cm)	6-52 (39.54)	6-86(39.54)	-
Plant height at maturity (cm)	7-134	48-98(53.62)	17.5-115.2
Height increase after flowering (cm)	1-48	1-25	-
Days to flowering	25-83	39-52	33-78
Seeds / pod	1-6	1-9	2.2-13.3
100-seed weight (g)	1.22-6.84	2.53-5.69	2-6
Seeds / plant	1-1109	6-910	
Primary branches	1-7	1-7	2-5
Seed yield / plant (g)	0.04-44.43	4.13-37.69	0.2-8.0

Recently, mutation breeding has been followed in which seeds of two genotypes IPM 03-1 and PDM 139 were irradiated with 40kR gamma rays (Table 2.18). Selection and generation advancement of the useful mutants resulted identification of three mutants, which have crop duration of 53-55 days with 4 g per 100 seeds. These mutants are under evaluation for yield and other parameters.

Table 2.18. Useful mutant isolated in mungbean

Year	Parental line	Mutation type	Characters
1998-99	PDM 11	Spontaneous	Tall growth habit, profuse podding, MYMV resistance, Late maturing (95-100 days)
1999-2000	PDM 54	Spontaneous	Extra early
2005	IPM 03-1 PDM-139	40 kR gamma rays	Extra early with large seeds in PDM 139 background

2.8 Urdbean

Urdbean is largely grown either as a subsistence intercrop during *kharif* season, monocrop on residual moisture in rice fallows or in spring season as catch crop. Therefore, breeding programmes at IIPR aimed at developing suitable varieties for these situations having resistance to major diseases (MYMV and powdery mildew). Attention is now being given to develop resistance against Cercospora leaf spot, leaf crinkle virus and root knot nematodes. Breeding for green seeds and large seed has also assumed importance in the recent past. Variability in the available germplasm is limited for most of the yield traits like pod length, number of pods per cluster and number of seeds per pod. The present approach in varietal development is to increase yield potential through hybridization among diverse genotypes and to accumulate high yielding genes using genotypes with superior yield components. Breeding progress for developing plant type has been slow because of limited variability for the component traits. Comparatively better progress has been achieved in specific character improvement such as MYMV resistance. A modest beginning has been made for use of mutagens in creating variability for early maturity, compact plant type and erectness. Inter-specific hybridization has also been used for creating variability for desired traits. Conventional methods have been used in the breeding programmes. These include pure line selection, back crossing and hybridization following bulk or pedigree selection. Presently, breeding for multiple disease resistance in high yielding background and mapping and tagging of genes imparting resistance to key diseases have been undertaken. The progress made is as follows:

A. Germplasm Enhancement

The Institute has acquired a large number of germplasm accessions through exploration and collection. Three explorations were conducted to collect land races and wild relatives of urdbean from Western Ghats. Total 78 wild accessions of *Vigna* species were deposited in National Gene Bank. During this period, the Institute has evaluated 734 accessions, resulting in identification of sources for yield components, components of crop duration, plant type traits and resistance to major stresses (Table 2.19). However, this includes duplication as well. Evaluation of germplasm accessions showed large variability in the indigenous collection (Table 2.20). The utility of germplasm collection is enhanced if the unique features of each accession are described and catalogued. The Institute has published a catalogue of 734 accessions for 18 descriptors. Presently, the Institute holds 829 accessions in its medium-term cold modules.

Table 2.19. Donors for various traits used in urdbean breeding programme

Specific Trait	Donors
Early maturity	UPU 83-3, PGRU 95028, KC 152, IPU 96-1, UH 82-51
MYMV resistance	DPU 88-31, NP 19, NP 21, 1346/ 4B, KU 66-10, PLU 710, PDU 6, IPU 98-8, UPU 85-86, UG 27, DUS 19
Cercospora leaf spot resistance	T 65, IC 11008
Tolerance to root knot nematode	PLU 648
Bold seeds	K 66-10, PDU 1
Seeds/pod	STY 2848, L 25-7
Pods /plant	IC 106088, UK 3
Pods/cluster	UH 84-1
Number of branches	TU 99-852, IPU 99-255
Pod length	IPU 99-239, IPU 99-79, KL 1
Prominent primary branches	DU 4
Main stem pod bearing	UG 27
Sympodial pod bearing	SPS 5 , STY 2468

Table 2.20. Variability for important traits recorded in urdbean germplasm

Character	Range
Days to 50% flowering	29 - 58
Days to maturity	54 - 101
Plant height (cm)	34 - 280
Number of primary branches	1 - 8
Number of seeds per pod	4 - 8
Number of pods per plant	3 - 259
100-seed weight (g)	2 - 5

B. Basic Studies

The Institute has taken up genetic studies of the crop to strengthen its breeding programmes. Genetics of photo-thermo insensitivity, seed colour, pod pubescence, MYMV resistance and crop duration was worked out. The results show a single dominant gene in the inheritance of photo-thermo insensitivity, MYMV resistance and pod pubescence, and two genes with dominant epistasis gene action for seed colour. Different component of crop duration showed polygenic inheritance with predominance of additive gene action. Pod bearing habit determines the plant type in urdbean. Genetic studies show involvement of two genes with inhibitory gene action for main stem bearing and a single recessive gene for the sympodial habit. Genetics of functional male sterility in one mutant with protruded stigma revealed involvement of a single recessive gene in its inheritance.

C. Genetic Enhancement

Genetic improvement of urdbean was initiated more systematically with the establishment of Directorate of Pulses Research at Kanpur in 1984. In total, 196 intervarietal and 20 interspecific crosses including wide crosses between mungbean and urdbean were attempted to generate the variability through recombination and identify the desirable recombinants (Table 2.21). The most frequently used parents are DPU 88-31, T 9, NP 21, UPU 83-3 and DU 4. Evaluation of segregating material has resulted in development of 98 high yielding promising lines combining resistance to key disease and earliness (Table 2.22). These lines have been tested in AICRP trials for their performance across the countries, finally resulting in the release of three high yielding varieties. These varieties are in the national seed chain with good seed indent and presently occupy sizeable areas in recommended zone. During eighties, land races were collected and evaluated besides attempting a large number of single crosses under recombination breeding. PDU 1 a selection from indigenous collection was identified for cultivation in NWPZ, NEPZ and Central Zone during spring season. During nineties, a high yielding and disease resistant variety, IPU 94-1 (Uttara) was developed through hybridization. This was followed by the identification of IPU 02-43 for southern zone.

Table 2.21. Number of crosses in urdbean attempted

Types of crosses	1988-92	1993-97	1998-2002	2003-08
Intervarietal	39	30	38	89
Mungbean x Urdbean	_	_	_	12
Vigna mungo x *V. silvestris*	_	_	_	8

Table 2.22. Number of promising breeding lines of urdbean emanating from IIPR breeding programme and tested in AICRP from 1985-2007

Zone	IVT	AVT 1	AVT 2
NHZ	17	2	1
NEPZ	24	4	1
NWPZ	22	6	1
SZ	19	4	2
CZ	16	3	1

Short duration varieties: Large differences exist for days to maturity within the cultivated urdbean. These differences, however, are confounded with the differences in growth habit, degree of sensitivity to photoperiod and growing environments. Short duration cultivars are often less sensitive to photoperiod. Earliness and photo-insensitivity are associated traits under major gene control. PDU 1, a selection from an indigenous collection IC 8219, was found maturing in 78 days. This cultivar was found suitable for spring cultivation. Due to increasing demands especially for short seasons between major crops in multiple cropping systems, breeding for early maturing cultivars has been emphasized. Crosses between early and late flowering have resulted in transgressive segregants. The most frequently used donors for earliness were UPU 83-3, PGRU 95028, KC 152, IPU 96-1, UH 82-51 and Pant U 19. Total crosses attempted for incorporating earliness were 70, which resulted in 12 promising breeding lines. These lines were evaluated in AICRP trials.

Disease resistant varieties: MYMV is severe problem in northern states, especially Uttar Pradesh, Bihar and West Bengal and powdery mildew is serious in southern states, especially in rice fallows. Efforts have been made for devising effective screening techniques. Excellent progress has been made in identification of potential sources of MYMV resistance. The main sources of MYMV resistance utilized at IIPR were NP 21, NP 19, DPU 88-31, DUS 19, PLU 710 and IPU 98-8. A highly resistant variety IPU 94-1 developed at IIPR derived its resistance from NP 19 while IPU 02-43 derived resistance from DPU 88-31. Cercospora leaf spot is the most prevalent disease in *kharif* season causing leaf spotting and defoliation. Yield reduction from this disease is reported to be 25% when leaf defoliation reached 75%. Resistant sources such as T 65 and IC 11008 are extensively used. Leaf crinkle and root knot nematodes are emerging as potential threat for urdbean cultivation. PLU 648 has been identified as resistant source against root knot nematode which is being utilized at the Institute.

PDU 1 (Basant Bahar): PDU 1 is a selection from IC 8219. It was released in 1991 for spring cultivation in North and Central Zones. This variety is tolerant to MYMV disease and matures in 70-80 days. The plant is erect and dwarf with light green foliage. Pods are hairy and seeds are bold. The average yield is 12-13 q/ha.

IPU 94-1 (Uttara): A high yielding variety of urdbean, IPU 94-1 (Uttara) was released in 1999 for *kharif* cultivation in North West and North East Plains Zones. It has been developed from the cross NP 19 x T 9. It has medium bold seeds (3.6 g per 100-seed weight) and 50 cm plant height. The variety is highly resistant to yellow mosaic virus and matures in 85 days. The average yield is 11-12 q/ha.

IPU 02-43: This variety has been developed from the cross DPU 88-31 x DUR 1. It was identified in 2008 for *kharif* cultivation in South Zone. It possesses resistance to MYMV and powdery mildew. It has medium bold seeds and 52 cm plant height. The variety matures in 82 days. The average yield is 10-11 q/ha.

D. Wide Hybridization

Pedigree analysis revealed that 34 cultivars developed in the country through hybridization traced back to 30 parents. The most preferred parent, T 9 was involved in 21 cultivars. In order to widen the genetic base, hybridization between urdbean and mungbean genotypes has been taken up so as to introgress desirable traits like early vigour, more seeds per pod and apical pod bearing traits from mungbean to urdbean. Wide crosses involving mungbean (MUM 2, IPM 03-1, IPM 99-125, PDM 139) and urdbean (SPS 41, SPS 5, UH 86-5) were made successfully and segregating populations were advanced with mild selection pressure for desirable combination of traits. More seeds per pod (>8 seeds per pod), more pods per plant and apical pod bearing traits have been recovered in some segregants of urdbean type.

2.9 Biotechnological Interventions

In order to strengthen the conventional methods of crop improvement, biotechnological tools have been used for genetic manipulation in pulse crops at IIPR since 1992. Initially, the work on tissue culture and embryo rescue was taken up in chickpea and pigeonpea in order to transfer genes for resistance to major diseases from wild species. Later on, the tissue culture work was extended to undertake molecular biology studies with main focus on development of transgenics and molecular markers. Major achievements made during the last 15 years are presented in the following subheads:

A. Standardization of Regeneration Protocol

Chickpea: The embryo culture technique was standardized with immature and mature embryo. The best regeneration (100%) was observed on MS salt + B_5 vitamin + 40 g/l sucrose followed by MS medium supplemented with 0.1 mg/l IBA+ 1.0 mg/l BAP (80%) and MS+0.1 mg/l NAA+1.0 mg/l BAP (75%). Among genotypes, C 235 showed 89% regeneration followed by BG 256 (81%) and K 850 (77%) irrespective of the media used. This protocol is perfect for genetic transformation as well as embryo rescue in chickpea. The best result (45.83±2.23) on direct organogenesis has been observed in MS salt + B_5 vitamin + 30 g/l sucrose without growth regulator (Table 2.23). The maximum response (shoots/explant) was obtained on MS+0.125 IBA+2.0 BAP+30 g/l sucrose (29.79±8.19).

Table 2.23. Direct regeneration from mature embryo in chickpea

Treatment (mg/l)	Mean±SE	Shoots/ explant
MS + B_5 vit.+ 30 g/l sucrose	45.83± 2.23	1.0 ± 00
MS + B_5 vit.+ 2, 3,4,3-T+ 30 g/l sucrose	15.00± 2.78	2.0 ± 00
MS + 2.0 BAP + 0.125 Kin.+ 30 g/l sucrose	00	00
MS+ 0.125 IBA+ 2.0 BAP + 30 g/l sucrose	29.50± 9.18	29.79± 8.19
MS+ 0.125 IBA+ 3.0 BAP + 30 g/l sucrose	24.48± 3.55	21.67± 2.49
1/2 MS + B_5 vit.+0.1 IAA+ 1.0 Zeatin + 30 g/l sucrose	15.83± 9.44	1.39± 0.96

One of the main handicaps in chickpea regeneration is improper rooting of elongated shoots. Experiments over a period of time improved rooting up to 75% (Table 2.24). Such plantlets with profuse rooting can be established in pot/field after proper hardening.

Table 2.24. Rooting of *in vitro* derived shoots of chickpea

Treatment (mg/l)	No. of shoots	No. of roots	%
MS + 0.5 NAA + 30 g/l sucrose	20	05	25.0
MS + 1.0 NAA + 30 g/l sucrose	16	08	50.0
1/4MS + 2.0 NAA + 10 g/l sucrose	30	20	66.7
1/4MS + 2.0 NAA + 2.0 IBA + 20 g/l sucrose	20	15	75.0

Pigeonpea: The regeneration protocol has been standardized *via* direct organogenesis in pigeonpea. The frequency of shoot induction was as high as 90%. However, efficiency of shoot induction was considerably low (2-10 shoots/explant). The rooting of shoot was also achieved upto 83%. Protocol for regeneration through cotyledonary node has also been achieved (Table 2.25).

Table 2.25. Effect of growth regulators on indirect organogenesis in pigeonpea

Concentration of growth regulator (mg/l)	Frequency (%)	Efficiency (%)	Shoots/explant	
			Mean	Range
MS+ 0.5 NAA+ 0.5 BAP	59.13± 3.25	75 ± 4.23	17.00	2-20
MS+ 1.0 NAA+ 1.0 BAP	25.12± 1.30	30± 3.30	04.24	3-5
1/2MS+ 0.5 NAA+ 0.5 BAP	19.89±1.33	25± 2.22	03.90	3-5
MS+ 1.5 NAA+ 1.5 BAP	11.00±2.45	20±2.14	06.67	5-10
MS+ 2.0 NAA+ 2.0 BAP	00	00	00	00
B5+ 2.0 NAA+ 2.0 BAP	21.29± 1.39	25±2.15	03.90	2-5
MS +B_5 vit.+0.125 IBA+2.0 BAP	88.74±5.86	90±9.34	22.78	5-30
MS + B_5 vit+ 0.25 IBA+ 2.0 BAP	10.00±1.39	20± 3.45	02.23	1-3
MS+ 1.25 2,4-D+ 0.5 BAP	00	00	00	00
MS+ 2,4-D	00	00	00	00

B. *In vitro* Selection for Salt Resistance in Chickpea

Stable salt resistant clones were isolated after three cycles of selection of callus under different concentrations of salt and salt mixture in MS medium supplemented with B5 vitamin + 0.125 mg/l IBA + 2.0 mg/l BAP + 40 g/l sucrose. Among various salts and salt mixtures, NaCl: $CaCl_2$: $MgCl_2$ (5:3:1) exhibited most stringent selection condition in terms of decreasing the number of escapes (7.22 to 15.56%) (Table 2.26). The frequency of stable resistant clones ranged from 11.11 to 61.07%. *In vitro* selected regenerants were further screened to three subsequent cycles of selection under different salts and salt mixtures. It was observed that frequency of stable resistant clones declined substantially with increasing dose of salts and salt mixtures. In general, increasing the dose of these salts increased the frequency of escapes and decreased the value of stable clones.

Table 2.26. Effect of salts on the frequency of resistant regenerants in chickpea

Salt concentration	Ratio	Total explants (a)	Resistant regenerants				Escapes (b-c/a)x100
			Selected (b)		Stable (c)		
			No.	%	No.	%	%
Control	-	295	290	98.30	265	89.83	8.47
0.25% NaCl	-	149	090	60.40	75	50.34	10.07
0.5% NaCl	-	130	075	57.69	65	50.00	7.69
1.0% NaCl	-	050	020	40.00	08	16.00	24
0.25% NaCl:$CaCl_2$	1:1	130	098	75.38	85	65.38	10
0.5% NaCl:$CaCl_2$	1:1	090	061	67.78	40	44.44	23.33
1.0% NaCl:$CaCl_2$	1:1	040	015	37.50	08	20.00	17.50
0.25%NaCl:$CaCl_2$: $MgCl_2$	1:2:1	085	073	85.88	65	76.47	9.41
0.5%NaCl:$CaCl_2$:$MgCl_2$	1:2:1	050	040	80.00	25	50.00	30
1.0%NaCl:$CaCl_2$: $MgCl_2$	1:2:1	050	020	40.00	10	20.00	20
0.25%NaCl:$CaCl_2$:$MgCl_2$	5:3:1	080	070	87.50	65	81.25	6.25
0.5%NaCl:$CaCl_2$: $MgCl_2$	5:3:1	060	040	66.67	30	50.00	16.67
1.0%NaCl:$CaCl_2$: $MgCl_2$	5:3:1	020	05	25.00	03	15.00	10

C. *In vitro* Selection against Ascochyta Blight in Chickpea

Callus culture and regeneration protocols were established on MS medium containing 2.0 mg/l 2,4-D, and 0.5 mg/l BAP+ 0.5 mg/l 2,4-D. These callus pieces were inoculated on regeneration medium containing different concentrations of culture filtrate (CF) of *Ascochyta rabiei* (Table 2.27). The selection of callus pieces was carried out for three passages. These resistant calli were transferred to regeneration medium. Resistant regenerants were tested in pots under the artificial epiphytotic conditions to assess the degree of resistance against ascochyta blight. Inhibition of growth of callus and regenerants obtained from immature embryo derived callus was observed at 0.5% of CF. Out of 486 callus pieces and 270 regenerants screened using inhibitory concentrations of CF, 50 callus pieces and 74 regenerants resumed growth. Such calli and regenerants were termed as variants.

Table 2.27. Effect of *A. rabiei* culture filtrate on recovery of resistant regenerants in chickpea

CF (%)	Total explants (a)	Resistant clones				Escapes (b-c/a)x 100
		Selected (b)		Stable (c)		
		No.	%	No.	%	
0.5	45	20	44.4	07	15.6	28.9
1.0	45	17	37.8	06	13.3	24.4
1.5	45	15	33.3	06	13.3	20.0
2.0	45	14	31.1	06	13.3	17.8
2.5	45	06	13.3	02	04.4	08.9
3.0	45	02	04.4	01	02.2	02.2

D. Development of Transgenics against Gram Pod Borer

An efficient reproducible and genotype neutral method for regenerating chickpea (C 235, L 550, DCP 92-3 and JGK 1) and pigeonpea (MAL 13, Bahar and T 7) plants has been developed using embryonic axes and cotyledonary node explants (Fig. 2.1). The system of regeneration involves induction of multiple shoot buds directly from the explants. In this system, upto 30 shoots per explant has been obtained with embryonic axes incubated on medium containing MS salts + B5

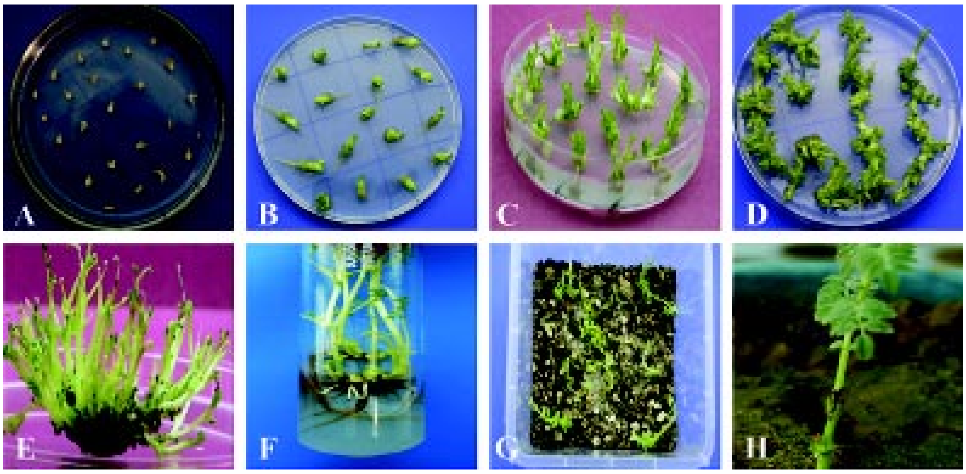


Fig. 2.1. ***In vitro*** **regeneration of chickpea (A) The explant (embryonic axes), (B) Initiation of shoot buds from the explant on regeneration medium, (C&D) Shoot proliferation after 10 days of incubation, (E&F) Individual elongated shoots rooted, (G) Plantlet in soilrite during hardening, (H) Shoots grafted on root stock.**

vitamin + 2.0 mg/l BAP + 40g/l sucrose. Addition of 1.0 mg/l GA3 in the medium resulted in elongation of the shoots after 3-4 weeks. The well-formed shoots were rooted on ½MS supplemented with IAA. This efficient regeneration system has been exploited for genetic transformation of chickpea and pigeonpea through *Agrobacterium* mediated methods.

Genetic transformation *via Agrobacterium* mediated method has been optimized using embryonic axes slices. Chickpea cv. L 550 and pigeonpea cv MAL 13 (Fig. 2.2) showed better response. A large number of genetic transformants possessing *Bt* (*Cry 1Ab*, *Cry 1Ac*) have been isolated and characterized. Molecular analysis confirmed the integration of the transgene in the genome (Fig. 2.3). Total 160 T_2 lines in chickpea and 37 T_1 lines in pigeonpea are established.

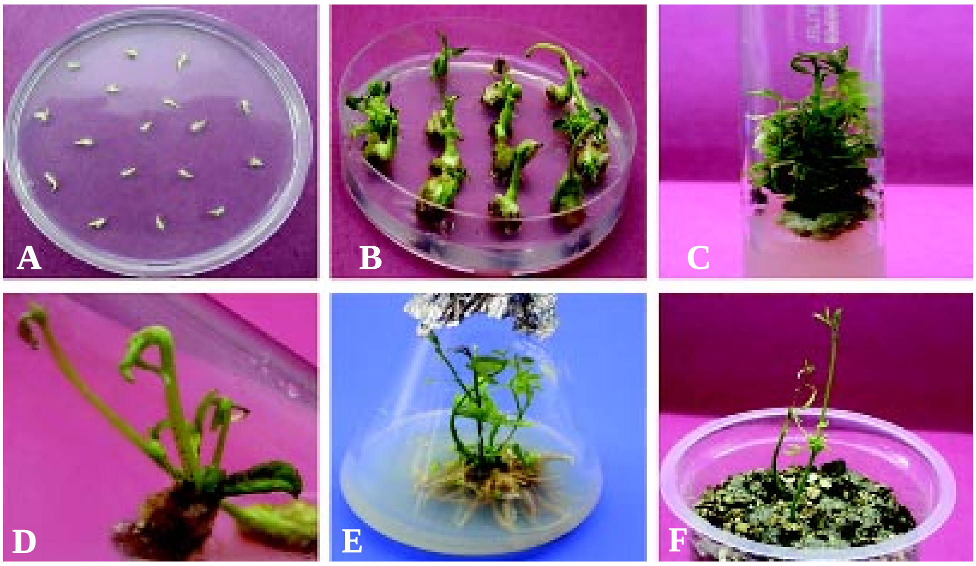
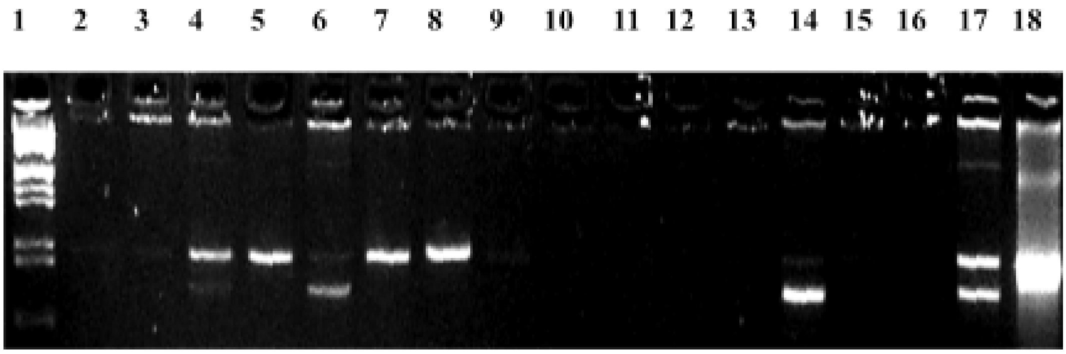


Fig. 2.2. Transforamtion and *in vitro* regeneration in pigeonpea. (A) Cocultivation, (B) 50 mg/l Antibiotic, (C) Shoot multiplication, (D) Shoot elongation, (E) Rooting, (F) Hardening

For drought tolerance, transformation using DREB gene has been performed in chickpea and pigeonpea. Putative transgenics having DREB genes are in the greenhouse.

Hardening and establishment of the explants : An efficient method has been developed for establishing the transformed plants into the green house by aseptically grafting the elongated *in vitro* raised shoots on the rootstock of the same genotype.



Lanes 1- Marker (λDNA digested with Eco RI+Hind III), 2- negative control (plasmid without *Cry1Ac* gene), 4-8, 14, 17- amplified band of 1.8 kb, 3, 9-13, 15, 16- non-amplified band 18-positive control (plasmid with *Cry1Ac* gene)

Fig. 2.3. Molecular analysis of the transformed plants in chickpea

The rootstock is prepared by cutting the shoots at the first node and making a 2 mm incision 5-7 days after germination. After grafting, the plants are covered with transparent sheets. For acclimatization, the covers are removed at regular intervals and finally removed after 7 days.

E. Isolation of Plant derived Insect Resistance Genes

Plant-derived protease-inhibitor genes are expected to be compatible with host genome and should provide synergistic effect to *Bt* transgenic for durable resistance against pod borer. Using ten legume protease inhibitor gene sequences, three pairs of PCR primers were designed and two novel PCR fragments were cloned. In addition, eight new primers were designed and these were used for PCR amplification of 24 genotypes. The distinct amplicons from six genotypes were cloned into pTZ57R/T vector of GeneJet cloning system (MBI Feremntas). The cloned fragments were transformed into *E. coli* and the isolated plasmids when checked in agarose gel, showed presence of inserts. These fragments were characterized by DNA sequencing for cloning into binary vector for plant transformation.

F. Understanding Plant -Nematode Interactions using RNAi

Plant parasitic nematodes cause serious damage to pulse crops. The RNAi mediated silencing of genes is a potential tool to develop transgenic plants with resistance to parasitic nematodes. In order to demonstrate principle of RNAi in fieldpea against root-knot nematodes, standardization of regeneration was taken up with six fieldpea genotypes *viz*., HUDP 15, IPF 4-26, IPF 99-25, IPFD 1-10, IPFD

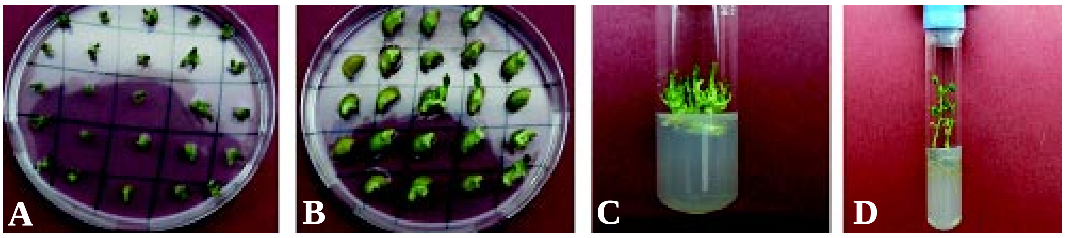


Fig. 2.4. *In vitro* regeneration of fieldpea. (A) Initiation of shoots from embryonic axes, (B) Initiation fo shoot from cotyledonary node, (C) Multiple shoot formation, (D) Rooted shoot

99-13, and IPFD 065 (Fig. 2.4). Embryonic axes and cotyledonary nodes were used as explants. Five medium combinations (MS1 to MS5) containing MS salts and B5 vitamins with different concentrations of BAP (1-8mg/l) and NAA (0.2-1mg/l) were used. The shoots produced were elongated on the medium containing GA3 (1mg/l) and then the elongated shoots were transferred to rooting medium with different auxins *viz*., IAA, NAA and IBA. Media containing MS+B5+4mg/l BAP+0.6mg/l NAA produced, on an average, 16-18 shoots/embryonic axis across the genotypes and media containing MS+B5+2mg/l BAP+0.4mg/l NAA produced 20 shoots/cotyledonary node. In case of rooting medium, 1mg/l IAA was found better across the genotypes.

G. Genomics

Paucity of polymorphic molecular markers has been a major limiting factor in application of molecular tools for genetic improvement of pulse crops. In order to develop genomic resources like polymorphic markers and molecular maps in chickpea and pigeonpea, efforts were made to design EST based SSR markers. cDNA libraries have been constructed in two varieties each of chickpea (BG 256 and WR 315) and pigeonpea (Asha and UPAS 120) and also of two wild species *i.e.*, *Cajanus cajanifolius* and *C. scarabaeoides*. Repeats containing clones have been identified for designing primers. These markers have been tested for polymorphism and now being used to map the disease resistance genes.

Parental polymorphism survey with available SSR markers: Genomic DNA from six parental lines of pigeonpea (Asha, UPAS 120, Bahar, 67 B, Type 7 and Dholi Dwarf) was isolated and parental polymorphism using 46 SSR markers (30 from pigeonpea and 16 from chickpea) have been completed. Parental polymorphism study between Asha and UPAS 120 was also done separately using 30 SSR markers from pigeonpea.

EST development: Total RNA was isolated from wild (*C. cajanifolius* and *C. scarabaeoides*) and cultivated (Bahar and ICPL 87119) lines of pigeonpea using Trizol reagent and Quiagen RNeasy kit. Poly(A)$^+$ RNA isolated from the total RNA was subjected to cDNA synthesis using LD method of SMART cDNA Library Construction Kit from Clonetech. The cDNA fragment of upto 1 kb was obtained and ligated to pJET1 vector in the ratio of 1:3 (vector : insert) and transformed into competent *E. coli* XL1 Blue cells. Transformed cells were then grown on Amp+ Tet$^+$ LA media and incubated overnight at 37°C. Positive clones were picked up and streaked on Amp+ Tet$^+$ LA media. Plasmid DNA from a total of 400 recombinant clones was isolated using QIAprep 96 Turbo Miniprep kit.

Cross genera markers transferability: Paucity of the polymorphic molecular markers in pigeonpea has been one of the major limiting factors in application of molecular tools for its genetic improvement. As the development of microsatellite markers requires considerable time, expertise and research infrastructure, transfer of markers from other related genera offers an alternative option to increase the

Table 2.28. Number of *Cicer* primer pairs amplifying PCR products in different species of *Cajanus*

Species	Genotype	Number of markers amplified	Alleles/ primer	Unique alleles	
				Name	Size (bp)
Cajanus cajan	ICPL 87119	39	2.08	STMS 23	430
	UPAS 120	38	2.16	STMS 23	430
C. cajanifolius	ICP 15632	37	2.02	TA 59 TA 130	1848 134
	ICP 15873	39	1.70	AGLC 34 GAA 45 TA 21	107 619 585
C. sericeus	ICP 15760	26	1.96	TA 140	124
	ICP 15761	40	2.05	STMS 14 TS 45	1452 1152
C. albicans	ICP 15624	27	2.30	STMS 5	525
	ICP 15622	37	1.92	STMS 5	525
C. scarabaeoides	ICP 15697	35	2.09	-	-
	ICP 15748	39	1.94	TR 1 TR 24	286 131
C. platycarpus	ICP 15666	37	1.32	STMS 24	464
	ICP 15921	38	1.94	GA 11 TS 45	623 623

number of available markers in pigeonpea. Since chickpea has been reported to share genome synteny with pigeonpea, transferability of 100 chickpea specific SSR markers was studied in two genotypes each of five wild and one cultivated species of genus *Cajanus*. The results revealed significant transferability (66%) of chickpea microsatellites to *Cajanus* (Table 2.28). Among the wild species, the maximum transferability (60%) was observed in *C. cajanifolius* and minimum (40%) in *C. albicans and C. sericeus.* Out of 100 SSRs, 43 produced amplification and exhibited extensive polymorphism in genus *Cajanus* with an average number of 4.13 alleles per SSR marker. The high level of polymorphism exhibited by chickpea specific SSR markers in the present study indicates their usefulness / utility in diversity analysis, mapping and tagging of agronomically important traits and marker assisted breeding in pigeonpea.

H. Molecular Mapping and Tagging of Fusarium Wilt Resistance

In order to map fusarium wilt resistance, identification of molecular markers revealing polymorphism between contrasting parents has been accomplished. RAPD, ISSR and STMS markers have been used to work out parental polymorphism between resistant and susceptible parents in chickpea and pigeonpea.

Survey of parental polymorphism using DNA markers showed that 45 out of 180 RAPD, 15 out of 50 ISSR and 65 out of 123 SSR markers are polymorphic in chickpea. Out of 60 new chickpea specific SSR primers (developed and synthesized in our lab from public domain databases) tested, 28 primers have shown polymorphism. Of 40 RGA markers, 20 have shown high polymorphism.

Gene pyramiding for fusarium wilt resistance genes in chickpea: Out of seven physiological races of *Fusarium oxysporum* sp. *ciceri*, races 1, 2, 3 and 4 have been reported in India. The existence of multiple races renders cultivars resistant in one location and susceptible in another location. Pyramiding of resistance genes in popular varieties was taken up for genes imparting resistance against race 1 and race 4 in widely adapted chickpea cultivars, Pusa 256, Vijay, and Phule G 5 through simultaneous step-wise backcross programme. The sources of resistance for race 1 and race 4 are WR 315 and ICC 4958 / HC 3, respectively. The resistant and susceptible genotypes taken as parent in this programme were crossed in all possible combinations. Each F_1 was backcrossed with susceptible parents to generate BC_1 population. These BC_1 populations along with their parents were raised and further backcrossing was done by phenotypic selection of parents to get BC_2 seeds. Seventy

SSR markers were screened out of which 42 were polymorphic. Three SSR primers were identified which produced amplicons specific to resistant and susceptible genotypes. These primers are potential markers linked to Fusarium wilt resistance.

I. DNA Fingerprinting of Released Varieties

DNA fingerprinting of cultivars of chickpea, pigeonpea, mungbean, urdbean, lentil and peas has been completed with PCR based markers (Table 2.29 and Fig. 2.5). Cultivar specific markers have been identified in few cases.

Table 2.29. Fingerprinting of varieties using DNA markers in different pulse crops

Crop	No. of varieties fingerprinted	Markers used	Salient feature
Pigeonpea	24	75 RAPD	Two main clusters, IPA 602 and ICPL 84023 have maximum similarity
Chickpea	86	50 SSR	Three main clusters, PG 5 and ICCV 92944 have maximum similarity
Lentil	30	39 SSR 40 ISSR	Three main clusters, LH 84-8 and NDL 1 have maximum similarity
Fieldpea	24	60 RAPD	Two main clusters DMR7 and Ambika have maximum similarity
Mungbean	24	40 RAPD	Six main clusters

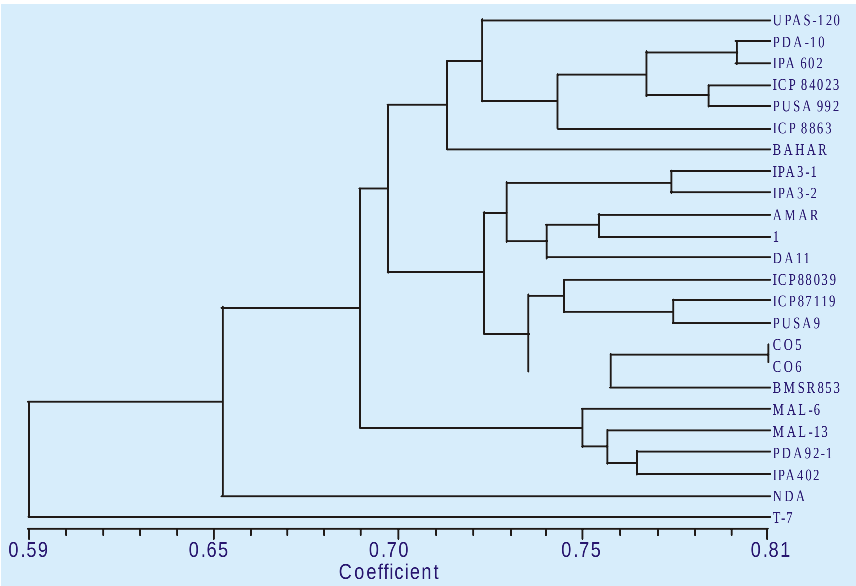


Fig. 2.5. Dendrogram of pigeonpea varieties using DNA markers

3. Crop Management

The agronomic research was initially undertaken on varietal performance, planting dates, population management and crop response to nutrient and moisture conservation. Later on, the programme was focused upon design and development of cropping systems involving pulses for rainfed as well as irrigated areas and their management in a system mode. Studies on nutrient and weed dynamics and their integrated management, conservation agronomy, allelopathy and long-term effect of pulses have been started in late nineties. The salient achievements are as under:

3.1 Cropping Systems

Pulses are generally grown in intercropping system, specially in rainfed areas. Apart from increasing profitability and resource use efficiency, they act as safeguard under adverse weather conditions. Comprehensive and systematic efforts were made to find out compatible crops, efficient genotypes, planting geometry, row orientation *etc*., for intercrops involving pulses under various agro-ecosystems.

A. Intercropping

Rainfed Ecosystem

Pigeonpea based intercropping : Availability of pigeonpea varieties having diverse growth habits has made it one of the most successful crop for intercropping. In a study involving pigeonpea with maize, urdbean and sesame, pigeonpea+urdbean was found most productive. The highest pigeonpea yield (2390 kg/ha) and pigeonpea equivalent yield (PEY) (2740 kg/ha) were obtained with Pusa 9 (pigeonpea) + DPU 88-31 (urdbean) under 2:1 row ratio. Among pigeonpea genotypes, Pusa 9, and Bahar and urdbean genotype DPU 88-31 were most compatible for intercropping.

Studies on spatial arrangement in pigeonpea+ sorghum intercropping showed that 2:1 row ratio on ridge planting system recorded higher pigeonpea equivalent yield and B:C ratio as compared to 1:1 and mixed planting system. However, the spatial arrangement varied with the variation in plant types of base crop (pigeonpea). In early pigeonpea + groundnut intercropping, 2:2 row ratio with North–South orientation was found most productive (1238 kg PEY/ha) with 90% higher land use efficiency. In long duration pigeonpea + groundnut intercropping system, semi-spreading variety Pusa 9 was more productive under 5:2 row ratio but compact type variety Bahar recorded 67% yield advantage and 46% higher land use efficiency under 5:1 row ratio. As regards spatial arrangements, 2:1 row ratio was found better than 2:2 for pigeonpea +urdbean intercropping.

Chickpea based intercropping : Chickpea is quite compatible for intercropping with *rabi* cereals and oilseeds. *Kabuli* chickpea + barley in 3:1 row ratio recorded maximum productivity and higher Land Equivalent Ratio (LER) (1.3) as compared to sole barley (Fig. 3.1). Similarly, chickpea + linseed intercropping was found highly productive and profitable than their sole cropping. Chickpea genotype KWR 108 was found more compatible than BG 256 and KPG 59 for intercropping with linseed cv. Neelam. Among three chickpea genotypes (BG 256, KPG 59 and KWR 108) and three spatial arrangements (2:1, 4:2 and 6:2), 6:2 row ratio of chickpea (BG 256) + linseed (Neelam) was found most productive (2609 kg Chickpea Equivalent Yield / ha), profitable (Rs. 18,531 / ha) and efficient (LER 1.48) system.

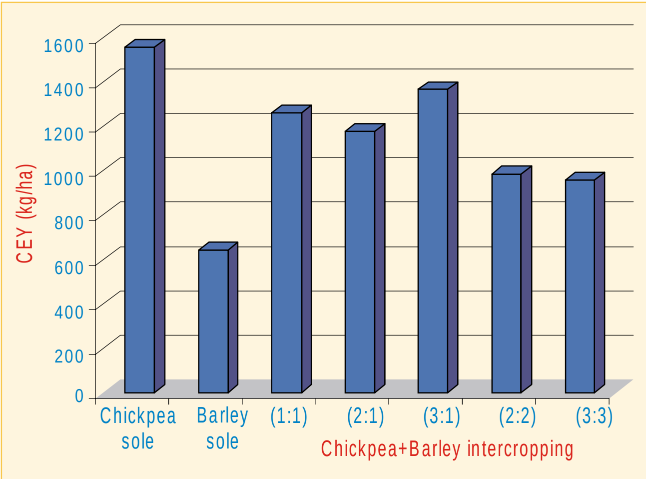


Fig. 3.1 Chickpea equivalent yield (CEY) as influenced by the row ratio of chickpea + barley intercropping system

Urdbean/Mungbean based intercropping : Urdbean and mungbean offer a compatible association with coarse cereals and spring planted sunflower and sugarcane. Development of short duration, MYMV resistant varieties in urdbean (Pant U 19, Sekhar, PDU 1, Uttara) and mungbean (PDM 11, Samrat, Pant Mung 2, Narendra Mung 1, Pusa Vishal) has given fillip to their cultivation in North India both as sole and intercrops. In pearl millet + mungbean intercropping system, mungbean genotype PDM 54 was found most compatible, followed by ML 67 and Pant Mung 2. Mungbean genotypes under paired row planting with pearl millet recorded highest yield and land use efficiency.

Lentil based intercropping : Compared to other pulses, only a few studies have been conducted on lentil based intercropping systems. However, lentil and linseed make perfect combination for intercropping as compared to other *rabi* crops in rainfed conditions (Table 3.1). Under lentil + linseed intercropping system, lentil variety L 4076 in 6:2 row ratio was found more compatible than DPL 62 and recorded higher productivity in terms of lentil equivalent yield (2171 kg/ha) and land use efficiency (21%).

Table 3.1. Yield, LER and net return in lentil+linseed intercropping system (1999-2000)

Treatment	Yield (kg/ha)		Lentil equivalent yield (kg/ha)	LER	Net return (Rs/ha)	B: C ratio
	Lentil	Linseed				
Lentil sole (DPL 62)	2118	-	2118	1.0	22025	2.88
Lentil sole (PL 4076)	1944	-	1944	1.0	19579	2.56
Linseed sole (Neelam)	-	1587	1444	1.0	15237	2.37
DPL 62 : Neelam Intercrop						
2:1	979	442	1429	0.74	13684	1.89
3:1	1344	570	1745	0.99	17096	2.33
4:2	1156	613	1714	0.93	16764	2.32
6:2	1427	599	1954	1.05	20022	2.77
L 4076 : Neelam Intercrop						
2:1	1031	613	1589	0.92	15014	2.08
3:1	1513	559	2021	1.13	20960	2.85
4:2	1323	619	1886	1.07	19172	2.65
6:2	1625	600	2171	1.21	23060	3.14

Irrigated Ecosystem

Pigeonpea based intercropping : Intercropping of early pigeonpea with groundnut (var. Chitra) provided additional yield of groundnut, which led to significantly higher pigeonpea equivalent yield and LER. Intercropping under replacement system drastically reduced the yield of pigeonpea and groundnut. Out of two early genotypes, UPAS 120 was found more compatible than ICPL 151. Intercropping of pigeonpea cv. Pusa 9 (semi-spreading type) and groundnut cv. Chitra in 5:2 row ratio was found more productive (4422 kg PEY / ha) followed by Bahar (compact) + Chitra in 5:1 row ratio. These intercropping systems were significantly superior to sole.

Chickpea based intercropping : Studies on chickpea + wheat intercropping revealed that 2:2 row ratio allowed more light interception and transmission to the lower canopy and recorded significantly higher productivity and LER than either of the sole crop. In case of chickpea + mustard intercropping, differential preference of chickpea genotypes was observed under sole and intercropping. Semi-erect *desi* genotype, BG 256 proved better under sole and erect tall genotype, BG 261 under intercropping with mustard var. Varuna (Table 3.2). Out of five *desi* genotypes, KPG 59 (1420 kg / ha) and Pant G 114 (1256 kg / ha) were found most compatible for intercropping with mustard (cv. Vardan) under irrigated conditions. The highest productivity (2609 kg CEY / ha) and profitability (Rs.17, 214 / ha) were recorded with JG 315 + Vardan intercropping. Among three *kabuli* genotypes (L 550, BG 1003 and KAK 2) and two mustard genotypes (Vardan and Varuna), combination of KAK 2 + Vardan was found most compatible for intercropping system recording higher CEY (1751 kg / ha) and LER (1.38).

Table 3.2. Genotypic compatibility of chickpea intercropped with mustard (1993-95)

Genotype	Chickpea yield (q/ha)		Mustard yield (q/ha)	Yield decrease in intercrop over sole crop (%)
	Sole	Intercrop		
BG 256	27.2	15.8	10.7	41.9
BG 261	21.8	14.7	14.0	32.5
BG 267	24.4	13.8	14.0	43.4
PBG 84-16	25.3	15.8	13.8	40.3

Sowing of chickpea with wheat / barley in 2:1 row ratio was found better than mixing and broadcasting. In chickpea + mustard cv. Varuna intercropping system, planting geometry of 6:2 row ratio was found more suitable. Planting of chickpea + mustard in North-South direction proved advantageous over East-West with the yield gain of 147 kg / ha in chickpea and 235 kg / ha in total productivity. The effect of row orientation was associated with higher PAR penetration to the canopy in North-South direction.

Urdbean/Mungbean based intercropping : Development of short duration and photo-thermo- insensitive varieties have made sunflower a promising crop in North India. In sunflower / mungbean intercropping system, mungbean genotype PS 16 with sunflower cv. Modern was found most productive in terms of sunflower equivalent yield (1804 kg / ha) followed by Samrat (1669 kg / ha). The highest LER (1.19) was recorded with mungbean cv. PS 16 + sunflower intercropping. In spring planted sunflower + urdbean intercropping system, urdbean varieties, Pant U 19 and PDU 88-31, were found equally compatible with sunflower cv. SH 3322. Among different planting geometries, 6:2 row ratio was found most suitable. Out of five genotypes each of mungbean (PDM 11, PDM 54, Pant Mung 2, PDM 84-143 and Pusa bold) and urdbean (Pant U 19, PDU 1, Pant U 35, DPU 88-31 and NDU 1), PDM 11 and PDM 84-143 in mungbean and DPU 88-31 in urdbean were found most compatible genotypes for intercropping with spring planted sugarcane and gave higher yield of pulses without significant reduction in sugarcane yield under irrigated condition (Table 3.3). Spatial arrangement of 1:2 row ratio was found ideal.

Table 3.3. Genotypic compatibility of mungbean/urdbean for intercropping with spring planted sugarcane (2000-01)

Treatment	No of millable canes ('000/ ha)	Yield	
		Sugarcane (t/ha)	Intercrop (kg/ha)
Sugarcane sole	93.5	76.2	
Sugarcane + mungbean			
PDM 11	90.1	71.2	380
PDM 54	82.3	62.0	496
Pant Mung 2	81.9	55.4	503
PDM 84-143	87.7	69.9	605
Pusa Bold	77.2	53.1	412
Sugarcane + urdbean			
Pant U 19	82.6	61.5	389
PDU 1	81.2	58.3	469
Pant U 35	77.2	59.2	373
DPU 88-31	91.9	70.2	425
NDU 1	76.8	59.2	467
LSD (p=0.05)	12.3	10.5	-

***Rajmash* based intercropping :** Intercropping *rajmash* with potato has been found quite profitable and efficient in irrigated areas of central Uttar Pradesh. On the basis of *rajmash* equivalent yield, intercropping of *rajmash* with potato was more productive and efficient under all planting geometry as compared to sole *rajmash* (Table 3.4). However, the highest productivity (3956 kg / ha) was obtained under 3:2 row ratio of potato + *rajmash* system with 48% increase in land use efficiency.

B. Sequential Cropping

Rainfed Ecosystem : Among rice-based sequences, rice - lathyrus has been found most remunerative followed by rice-linseed. Under rainfed condition, urdbean –

Table 3.4. Grain yield and LER under potato + *rajmash* intercropping system (1991-92)

Cropping system	Yield (kg/ha)			LER
	Potato	*Rajmash*	*Rajmash* equivalent	
Rajmash sole	-	2315	2315	-
Potato sole	24581	-	3090	-
Potato+*rajmash*				
2:2	14907	1778	3500	1.37
3:2	18150	1722	3956	1.48
1:2	9194	2463	3471	1.43
2:1	19861	1333	3643	1.38

lentil gave maximum yield (23.2 q/ha), but the maximum profitability and benefit cost ratio (3.02) were recorded with fodder sorghum-lentil followed by fodder sorghum-chickpea/mustard cropping sequences.

Irrigated Ecosystem : Availability of short duration varieties has led to development of successful sequential and relay cropping systems involving chickpea. Results of three years' experiments showed that rice cv. NDR 359 and chickpea cv. BG 256 were found most compatible producing significantly higher rice equivalent yield (REY), net return and benefit: cost ratio.

Among the six rice-based cropping systems under lowland irrigated conditions, rice-*rajmash*-mungbean was most productive and remunerative followed by rice-wheat-mungbean. However, B: C ratio of rice-lentil (2.64) and rice - field pea (2.38) was higher than other cropping sequences probably due to low input cost.

C. Effect of Pulses on System Productivity and N Economy

Inclusion of pulses in cropping systems increased productivity of succeeding cereal crops. *Rabi* legumes significantly increased productivity of rice as compared to wheat. In a three year study, the highest REY (15567 kg/ha) was obtained with *rajmash* as a preceding crop. Chickpea, lentil and fieldpea also improved REY over *rabi* fallow (Fig. 3.2). Catch crop of short duration summer legumes not only provided bonus yield of 7-10 q/ha but also economized N in the sequential rice crop to the tune of 34 kg/ha. Summer legumes significantly improved yield and N economy of the succeeding rice crop as compared to fallow. Among the summer legumes, the highest improvement in system productivity was recorded after mungbean followed by fodder cowpea and urdbean and contributed 21 kg N/ha to succeeding crop. Apart from adding N and improving yield of rice, these legumes gave bonus yield of 1026 kg / ha. Introduction of mungbean as summer catch crop in maize based crop sequence showed that maize – mustard – mungbean was most profitable (Rs. 51158 / ha) followed by maize – wheat - mungbean.

Increased N availability is considered as one of the important beneficial effects of pulses on the succeeding non-legume crops. Different legumes have varying capacity to leave behind N for use by the succeeding crops. Crop rotation involving *rabi* legumes, particularly *rajmash*, chickpea and fieldpea economized N to the tune of 40 kg / ha over wheat. Influence of *kharif*, *rabi* and summer season pulses on productivity and N economy of succeeding cereals was studied for two years. The study revealed soybean – wheat system as the most productive followed by pigeonpea + mungbean – wheat. Nitrogen economy due to preceding pigeonpea over sorghum was found to be 51 kg N equivalent / ha.

Fig. 3.2. Effect of pulses on rice equivalent yield

An improvement in the N budget of soil measured by NO_3-N content left after the harvest of *rabi* pulses was recorded. Chickpea ranked first (20.4 kg / ha) followed by fieldpea and lentil in contribution of residual NO_3 in the soil profile. Among the genotypes, chickpea cv. BG 1003, lentil cv. DPL 62 and fieldpea cv. Rachna were highest in increasing the nitrate content in soil.

D. Long-term Effect of Pulses in Crop Rotation

In order to study the effect of continuous application of plant nutrients on productivity of pulse based cropping systems and to monitor the changes in physical, chemical and biological properties of soil, two long-term experiments on maize and rice based cropping systems were initiated during 2003. Among the four maize-based cropping systems *viz*., maize-wheat, maize-wheat-mungbean, pigeonpea-wheat and maize-wheat-maize-chickpea, highest system productivity (3421 kg / ha

PEY) was obtained in maize-wheat-mungbean system. Significant improvement in soil health parameters like microbial biomass carbon (338 mg / g) and nitrogen fixers was also recorded in this system as compared to maize-wheat system (279 mg / g). Application of inorganic fertilizers (NPKSZnB) recorded significantly higher yield followed by organic fertilizer treatment (crop residue+ bio-fertilizer+ FYM @ 5 t / ha).

In another long-term experiment involving four rice based cropping systems *viz*., rice-wheat, rice-chickpea, rice-wheat-mungbean and rice-chickpea-rice-wheat, the chickpea equivalent yield was maximum (4155 kg / ha) in rice-wheat-mungbean system and lowest (2508 kg / ha) in rice-wheat system after four years of crop rotations and this system also maintained highest microbial biomass carbon (368 mg / g) in the soil (Fig. 3.3). Application of NPKSZnB resulted in maximum yield followed by organic treatment.

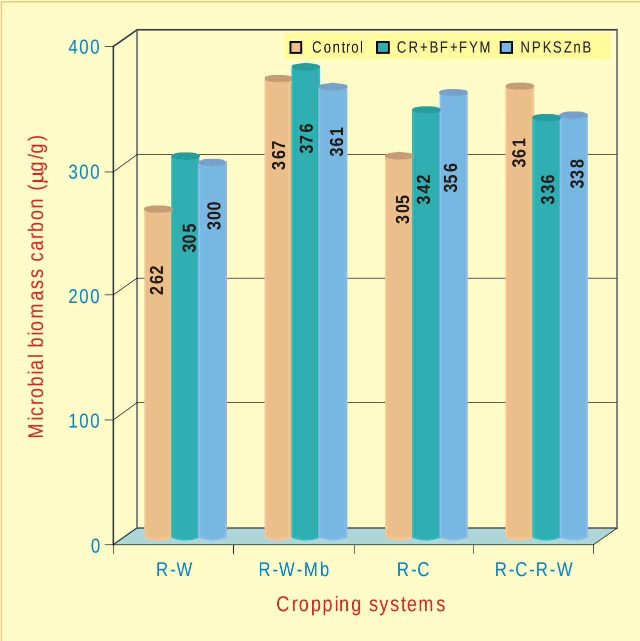


Fig. 3.3. Microbial biomass carbon in rice based cropping systems (2007-08)

E. Crop Residue Management

Incorporation of crop residues is important for improvement of soil properties and thereby increasing productivity and fertilizer use efficiency. Judicious use of crop residues has another important consideration for reducing the nutrient losses through leaching, volatilization or fixation especially under adverse conditions. Incorporation of urdbean and mungbean residue was found to be beneficial to the succeeding mustard crop in terms of higher yield (6-7%). In rice-chickpea sequence, yield of chickpea was significantly influenced by rice residue incorporation and highest seed yield was obtained with incorporation of chopped straw + irrigation +

N, while lowest yield was obtained in rice residue removal treatment (Fig. 3.4). In rice-wheat-mungbean system, incorporation of chopped residue of mungbean + irrigation resulted in maximum wheat yield (4495 kg / ha) which was significantly higher (38%) than control. Soil microbial biomass carbon was also positively influenced by the residue incorporation of urdbean and mungbean.

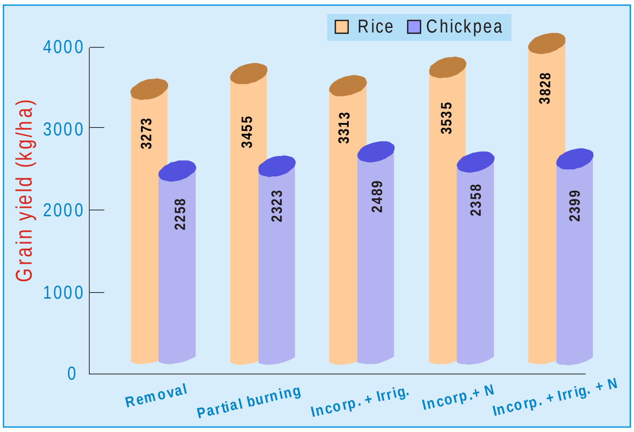


Fig. 3.4. Effect of residue incorporation on grain yield of rice and chickpea in sequential cropping (2007-08)

3.2 Nutrient Management

Nutrient deficiency in soil is the key factor for poor productivity of pulses. The extent and magnitude of nutrient deficiency has aggravated in the recent past due to intensive agriculture and indiscriminate use of plant nutrients. Research programmes on nutrient management at the Institute were focused towards soil fertility status in pulse growing regions and response of pulses and pulse based cropping systems to major, secondary, and micro-nutrients and integrated nutrient management. During 1980's, the research was mainly concentrated on major nutrients and it was extended to secondary and micronutrients after 1990's. A work programme on long-term effect of pulses in cropping systems on soil health and integrated nutrient management in pulse based cropping systems has been initiated in 2000.

A. Nutrient Availability in Pulse-growing Soils

Carbon : Low carbon content is a common feature of most of the degraded and rainfed lands but these soils have great potential for carbon accumulation. Characterization of ten soil profiles of pulse growing regions of India representing Inceptisol, Vertisol and Alfisol during 2000-01 indicated that all ten profiles were low in organic carbon (<0.5%) despite long-term cultivation of pulses on these soils. The organic carbon content in different soils followed the order Vertisols > Inceptisols > Alfisols.

Major Nutrients : Attempt was made to prepare fertility status maps in major pulse growing districts of India. Out of 135 pulse growing districts, 105 were low and 30 medium in available N status; 68 were low and 63 medium in available P status; and 23 were low, 45 medium and 67 high in available K. Sulphur deficiency ranged from 40-60 % in 44 districts whereas 43 districts showed 20-40% deficiency. Available P was medium in all soil except in Bangalore soils, which were high in available P content. Alluvial soils were low whereas black soils were relatively high in available K content. Distribution of different forms of potassium was also studied in pulse growing soils. Vertisols showed higher water soluble potassium as compared to Alfisols and Inceptisols. Alfisols showed less than 400 mg / kg of reserve K whereas rest of the profiles showed above 600 mg / kg. Low to medium available K in Inceptisols and low available as well as reserve K in Alfisols indicate the need to re-look into K fertility management for obtaining higher productivity of intensive cereal-pulse based systems on these soils. Potassium release pattern of pulse growing soils indicated potential contribution of sub-soils in potash needs of plants, as many of the pulse crops have deep taproot. Inceptisols contained higher reserve K than Vertisols and Alfisols. Alfisols showed maximum P fixation capacity (92.7%) followed by Vertisols (86.5%) and Inceptisols (76.6%) whereas Vertisols showed highest K fixation as compared to other soil types.

Sulphur and micronutrients : Deficiencies of sulphur among secondary nutrients, and zinc and iron among micronutrients are observed more frequently now and becoming major constraint for increasing productivity of pulses. A total of 220 soil samples in three districts of Uttar Pradesh (124 from Fatehpur, 30 from Unnao and 66 from Hamirpur) under pulse based cropping systems were analysed during 2001-02 for available sulphur, zinc and iron contents. Results revealed that more than 90% of samples were low in sulphur and iron in all three districts. Available zinc was also low in 82% of samples in Fatehpur, 55% in Hamirpur and 17% of samples in Unnao districts.

In pulse growing soil profiles of India, available S content was found to be below critical limit (<10 mg / kg) in Inceptisols (7.7 mg / kg), Vertisols (6.7 mg / kg) and Alfisols (6.2 mg / kg). Studies on fractionation of soil sulphur revealed that most of the soil profiles under pulses registered decrease in organic and total S fractions with depth. Higher organic and total S was observed in Vertisols followed by Inceptisols and Alfisols whereas adsorbed S was more in Alfisols. Evaluation of soil test methods for available sulphur revealed that 0.15% $CaCl_2$ and Morghan's reagent were efficient extractants for assessing available S supply and predicting crop response to applied sulphur in pulse growing soils.

Zinc deficiency in 82 districts was to the extent of 50-60% and 34 districts showed 40-50% deficiency of zinc. Characterization of ten soil profiles of pulse growing regions of India representing Inceptisol, Vertisol and Alfisol indicated that Iron deficiency was recorded at two locations (Delhi and Faizabad) while zinc deficiency was noticed in most of the soils of pulse growing areas.

B. Nutrient Responses

Chickpea : Pulses largely meet their nitrogen requirements through biological nitrogen fixation and consequently need only a starter dose of 20-25 kg N / ha for an early head start. Experimental results have revealed good response to 20 kg N / ha in chickpea. However, late sown chickpea planted after rice responded well to 40 kg N / ha mainly due to low native Rhizobia in rice fields. Among different genotypes of chickpea, response to N application was highest in K 850 (2652 kg / ha) followed by BG 256 (2608 kg / ha), Radhey (2434 kg / ha) and BG 261 (1434 kg / ha).

Studies on phosphate nutrition showed that seed yield of *kabuli* chickpea cv. L 550 significantly increased with 30 kg P_2O_5 / ha (2978 kg / ha) as compared with no P application (2220 kg / ha). Further increase in P level to 60 and 90 kg / ha did not prove beneficial for the crop. Application of phosphate solubilizer (PSB culture) along with P fertilizers was found to be beneficial. As regards schedule of P application, full dose of P as basal application produced maximum yield (3066 kg / ha), which was at par with split application.

Significant increase in grain yield (9.1%), straw yield (9.6%) and protein content (4%) was obtained with application of 20 kg S / ha. Application of micronutrients (Zn, Mo, and B) alone or in combination of two did not influence grain and straw yields significantly but a combination of all the three micronutrients (Zn+B+Mo) resulted significant increase in grain yield.

Lentil : Application of P @ 30 and 60 kg / ha increased the seed yield by 89 and 163 kg / ha, respectively over control (912 kg / ha). Seed yield of lentil increased significantly with application of phosphorus solubilising culture *viz*., VAM and Microphos (1043 and 1018 kg / ha) as compared with no culture (926 kg / ha). Application of 30 kg phosphorus and 20 kg sulphur increased the yield significantly over control. Significantly positive effect of P, irrigation and PSB inoculation was observed for growth and yield parameters.

Fieldpea : Fieldpea grown under irrigated conditions has shown positive response to higher dose of fertilizer application. Experimental results showed that application of 40 kg N / ha and 60 kg K_2O / ha produced 19% and 8% more seed yield of dwarf fieldpea cv. HFP 4 than respective control. Dwarf genotypes (HUDP 15, HFP 4) recorded higher grain yield with close spacing of 25x10 cm with application of 60 kg N / ha. Productivity of tall types was not affected by population density and N levels.

***Rajmash* :** It is well established that soil moisture and native rhizobial population have significant impact on response to applied N. *Rajmash* that has been introduced as a winter crop in frost-free belt of North India and does not nodulate with native rhizobial strains and therefore responded well to 120 kg N / ha. The response was 24.8, 29.5 and 34.9 kg seed / kg nitrogen at 40, 80 and 120 kg N / ha, respectively. Split application of nitrogen (½ basal and ½ at first irrigation) gave significantly higher yield (3069 kg / ha) as compared to full basal and three splits of N doses (Fig. 3.5).

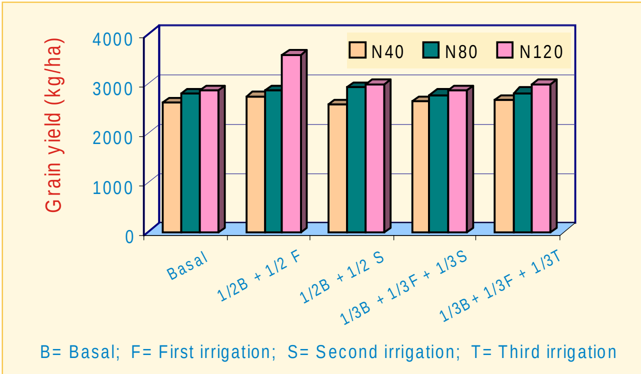


Fig. 3.5. Effect of time and level of N application in *Rajmash*

Pigeonpea : Among different genotypes, Pusa 85 showed higher response to 60 kg N / ha (1243 kg / ha) than Pusa 14 and DA 11. Application of 80 kg K_2O / ha produced higher yield (1450 kg / ha) as compared to 40 kg K_2O / ha (1304 kg / ha) and control (933 kg / ha). Application of 40 and 80 kg K_2O / ha gave higher K use efficiency of 9.3 and 13.2 kg seed / kg K_2O, respectively. *Rabi* pigeonpea responded positively up to 60 kg N, 60 kg P_2O_5 and 40 kg K_2O / ha, the yield increase with respect to control being 14.3, 18 and 6.3%, respectively. Interaction effect of N and P application was significant and maximum seed yield was recorded with the application of 60 kg N + 60 kg P_2O_5 / ha (1253 kg / ha).

Urdbean/Mungbean : Significant response was observed up to 20 kg S / ha and the mean response at this level of sulphur application was 166 and 194 kg / ha. Balanced application of N, P, K, S and Zn significantly increased the yield of mungbean (2154 kg / ha) and urdbean (1958 kg / ha). Different sources of sulphur like gypsum, pyrite and SSP were almost identical in their efficacy. Among the micronutrients, response to zinc was observed and application of 25 kg $ZnSO_4$ / ha increased the seed yield of urdbean by 20.1%. Molybdenum application also favourably increased the yield of mungbean and response up to 4g Mo pelleting per kg seed of mungbean during summer season was observed under Kanpur conditions.

Foliar application of nutrients : Foliar application of 2% urea at 75 DAS increased the grain yield of chickpea by 11% under rainfed conditions. Growth and yield attributes were also increased significantly due to foliar spray of urea. Significant increase in leaf nitrogen content (lower leaves) and SPAD value was also recorded due to foliar spray of 2% urea (Fig. 3.6). Under late sown conditions, foliar spray of nutrients significantly increased the biomass as well as grain yield. Maximum protein content was observed with 2% urea spray at branching + pre-flowering (20.9%) followed by 2% DAP at pre-flowering (20.8%) and 3% DAP either at pre-flowering or at branching + pre-flowering (20.5%). Maximum grain yield (860 kg / ha) of *kharif* urdbean was obtained due to foliar spray of 2% urea which was at par with 2% DAP spray (819 kg / ha).

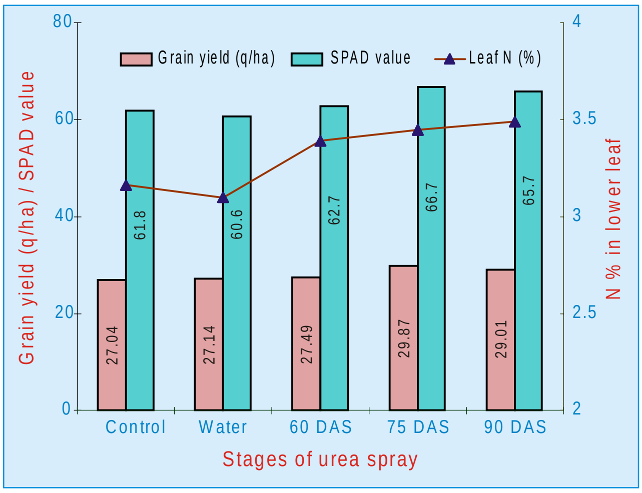


Fig. 3.6. Effect of foliar application of 2% urea on yield, leaf N content and SPAD values in chickpea under rainfed conditions (2007-08)

Foliar spray of 0.2% borax at 50 and 60 DAS increased the grain yield (1590 kg / ha) of chickpea significantly and 0.1% NH_4-molybdate spray also resulted in significant increase in yield (1497 kg / ha) as compared to water spray (1404 kg / ha). In *kabuli* chickpea, spraying of borax @ 0.2% produced higher seed yield (1769 kg / ha) with yield gains of 589 and 209 kg / ha over water spray and 0.01% ammonium molybdate. Quantitative response of borax application was higher in HK 89-96 and L 550 as compared to BG 267 and BG 1003.

C. Nutrient Use Efficient Genotypes

It is important to identify the genotypes with high nutrient use efficiency and understand the mechanism of differences in response to fertilizer and soil nutrients in order to breed for high nutrient use efficiency. Out of 10 chickpea genotypes, BG 372, Pant G 114, KWR 108 and DCP 92-3 were rated as efficient zinc users whereas DCP 92-3, BG 372, CSG 8962 and KPG 59 were rated as efficient sulphur user genotypes. Of the four genotypes, L 550 gave highest seed yield (1608 and 1538 kg/ha) followed by BG 267. Out of 10 genotypes of urdbean, Uttara, TU 94-2 and KU 96-3 were rated as efficient zinc users. Lentil Genotypes DPL 62, K 75 and L 4147 were rated better with respect to native zinc utilizing capacity.

D. Nutrient Management in Cropping Systems

Sequential cropping : In early pigeonpea – wheat rotation, application of phosphorus @ 30 kg/ha to pigeonpea crop had positive impact on seed yield of pigeonpea (1105 kg/ha) over control (925 kg/ha) and also resulted in significant increase in seed yield of wheat. In rice-chickpea system, the highest CEY (4328 kg/ha) was recorded with 40 kg P_2O_5/ha applied to chickpea, which was higher than control (3744 kg/ha). In sorghum+mungbean–lentil cropping system, application of 60 kg P_2O_5/ha significantly increased the seed yield of sorghum + mungbean by 28% whereas lentil responded significantly to 30 kg P_2O_5/ha.

Increase in crop intensification and use of chemical fertilizers pose threat to availability of secondary and micro-nutrients in soil. Low or no use of organic manure adds to the severity of problems. Most of the times plants do not show clear deficiency symptoms of secondary and micro - nutrients, but studies showed increase in yield with the application of these nutrients. The study on effect of S application in pigeonpea-wheat rotation revealed that application of 20 kg S along with phosphorus @ 30 kg P_2O_5/ha resulted in highest yield of pigeonpea (927 kg/ha) as compared to their individual applications. Seed yield of succeeding wheat was also considerably increased (3249 kg/ha) by the residual effect of *kharif* treatment. Further study on micronutrient application to pigeonpea-wheat rotation revealed that application of RDF + Zn + B + Mo recorded highest seed yield (985 kg/ha) of pigeonpea and the yield of succeeding wheat was also highest (5,104 kg/ha) with the same treatment. In rice-lentil system, application of 60 kg phosphorus, 30 kg S, 15 kg $ZnSO_4$ and 5 kg borax per ha recorded significantly more lentil yield (1,646 kg/ha) than other treatments.

Intercropping : Fertilizer recommendation based on the sole cropping may not meet the nutrient demand of the component crops in the intercropping system, because competition between component crops for nutrient use is more pronounced in the intercropping system. Effect of nitrogen in combination with irrigation was studied in chickpea + mustard intercropping system on alluvial soil. Yield of chickpea was high at 30 kg N / ha and mustard at 60 kg N / ha. Application of N as basal dose proved beneficial to chickpea whereas split application of N enhanced the mustard yield. Two-year study on phosphorus management in pigeonpea + sorghum intercropping revealed that application of 30 kg P_2O_5 / ha gave significantly higher yield (2306 kg / ha) as compared to no P_2O_5 (1957 kg / ha). However, further increase in P application did not increase the seed yield significantly. Phosphorus solubilising bacteria (PSB) and *Rhizobium* bacteria inoculation enhanced the pigeonpea yield by about 10%. In sorghum+mungbean – lentil cropping system, grain yield of lentil was significantly increased (1532 kg / ha) when preceding sorghum crop in *kharif* season received 60 kg phosphorus / ha and mungbean residue incorporation was done as compared to control (1234 kg / ha). Lentil responded to direct application of 30 kg P_2O_5 / ha only. In *rajmash* + potato intercropping system, full recommended dose of fertilizers to potato + half recommended dose to *rajmash* proved quite productive with yield advantage of 24% (LER=1.24) followed by full recommended dose to both intercrops in additive series (LER=1.20) indicating thereby that *rajmash* in intercropping with potato needed half of its recommended dose of fertilizers to give higher yield advantages.

In chickpea + mustard intercropping system, application of S had significant positive effect on grain and straw yields of chickpea as well as mustard. Maximum grain yield of chickpea (544 kg / ha) and mustard (1284 kg / ha) was observed by application of 20 kg S. In lentil + linseed intercropping system, combination of 40 kg P_2O_5 and 15 kg S significantly increased the seed yield of lentil (1508 kg / ha).

E. Integrated Nutrient Management

Intensive agriculture with very high nutrient turnover in soil-plant system coupled with low and imbalanced fertilizer use resulting in deterioration of native soil fertility poses a serious threat to long-term sustainability of pulse production. In India, short supply of indigenous fertilizers and their exorbitant costs, mainly of P and K, have further aggravated the problem. Integration of chemical, organic and biological sources and their efficient management have shown promise in sustaining the productivity and soil health. Application of 5 t FYM / ha significantly increased the seed yield of pigeonpea and residual effect of FYM resulted in significant increase in grain yield of wheat in pigeonpea – wheat system. Chickpea also responded positively to application of 5 t FYM / ha. Application of phosphorus @ 40 kg P_2O_5 / ha along with 20 kg N / ha and bio-fertilizers (*Rhizobium* and PSB) significantly increased the yield (1833 kg / ha) of chickpea as compared to control (1111 kg / ha) in alluvial soil. The PSB was effective in increasing yield when applied along with P fertilizers.

Application of FYM + 20 kg $ZnSO_4$ or 50 kg $FeSO_4$ / ha was found beneficial in increasing the seed yield. Amrit sanjeevani (cow dung 175 kg + groundnut cake 5 kg + urea 7.5 kg + SSP 5 kg + KCl 5 kg / ha) improved the chickpea yield by 7%. Rice – chickpea was found most productive and profitable system (Rs. 30,777 / - net returns / ha) with 60 kg P_2O_5 / ha applied to rice, 40 kg P_2O_5 / ha applied to chickpea along with 5 t compost / ha applied to rice. Rice cv. NDR 359 and chickpea cv. BG 256 were found to be the most productive genotypes in rice – chickpea system. In maize-chickpea system, seed yield of chickpea significantly increased with application of 30 kg S and 5 t FYM / ha. Residual effect of *kharif* applied S was not conspicuous where there was no direct application of S to chickpea.

3.3 Weed Management

A. Major Weed Flora

Initially, research on weed management was focused upon estimation of yield losses caused by different weed flora in different pulse crops and cropping systems involving pulses. The major weed flora associated with pulses were recorded (Table 3.5). In pigeonpea + sorghum intercropping, narrow leaved weeds and sedges affected pigeonpea yield to a greater extent than dicot weeds (Fig. 3.7). It was found that narrow leaved weeds and sedges caused 38% yield loss and posed serious threat to

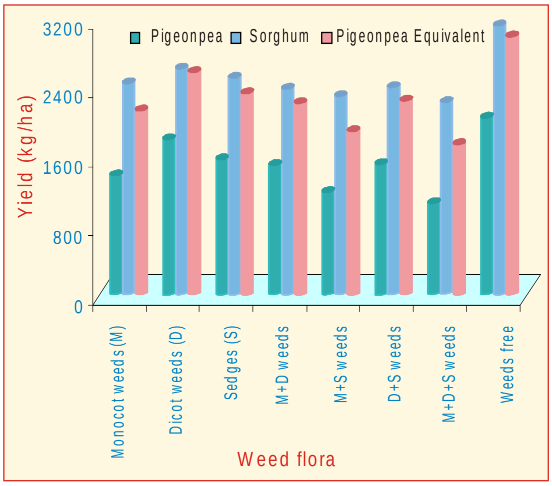


Fig. 3.7. Effect of different weed flora on yield of pigeonpea and sorghum under intercropping system

Table 3.5. Major weeds associated with pulses

Season	Type of weeds	Name of weeds
Kharif	Non -grasses	*Digera arvensis, Commelina benghalensis, Celosia argentea, Cucumis trigonus, Trianthema monogyna, Euphorbia hirta*
	Grasses	*Digitaria sanguinalis, Cynodon dactylon, Panicum sp. Echinochloa colonum, Dactyloctenium aegypticum, Setaria glauca, Eleusine indica*
	Sedges	*Cyperus rotundus*
Rabi	Non -grasses	*Chenopodium album, Solanum nigrum, Anagallis arvensis, Vicia sativa, Fumaria parviflora, Asphodelus tenuifolius, Convolvulus, Melilotus indica, Medicago denticulate*
	Grasses	*Phalaris minor, Avena ludoviciana*
	Sedges	*Cyperus rotundus*
Spring / Summer	Non-grasses	*Chenopodium album, Amaranthus viridis, Portlaca quadrifida, Trianthema monogyna*
	Grasses	*Setaria glauca, Cynodon dactylon, Eleusine indica, Digitaria sanguinalis, Panicum maxicum*
	Sedges	*Cyperus rotundus*

pigeonpea+sorghum intercropping system. But in urdbean – chickpea cropping system, the dicot weeds reduced chickpea yield more (53.3 %) than the monocots (37.6 %).

B. Critical Period of Crop-weed Competition and Yield Losses

Critical period of crop-weed competition varies in different crops. For evolving efficient weed management practices, it is imperative that critical period of crop - weed competition is ascertained. Studies showed that in dwarf pea, the critical period was the first 40-60 days while in pigeonpea+sorghum intercropping under rainfed conditions, it was up to 60 days of sowing. Unchecked weeds caused 20-97% yield loss in different pulse crops (Table 3.6).

Table 3.6. Yield losses in different pulse crops due to weeds

Crop	Losses (%)
Chickpea	29-70
Pigeonpea	21-97
Urdbean	44-83
Mungbean	40-50
Lentil	70-87
Pea	25-35
Rajmash	20
Late sown chickpea	38-70
Kabuli chickpea	85

C. Weed Dynamics

Research focus on weed dynamics was placed from 1989-90 onwards. Experiments on *Cyperus* infestation in different crop sequences revealed that different crops had variable intensity of nutsedge infestation. Lowest nutsedge infestation was recorded with sesamum crop. Better control of nutsedge in urdbean was obtained with manual weeding. Weed management techniques had variable response on weed shift. Therefore, experiments were carried out to assess the effect of management practices on weed shift in urdbean, urdbean-chickpea, rice-lentil, maize-chickpea and chickpea +mustard cropping systems. The density and biomass of weeds like *Cyperus rotundus*, *Digera arvensis*, were lower in manual weeding while these were lower in *Chenopodium album* due to pendimethalin 1.0 kg a.i./ha + one manual weeding in urdbean – chickpea cropping system. In maize based cropping systems, the density and biomass of *C. rotundus* were lower in maize+*til*, pure *til*, urdbean pure, maize+urdbean and maize+soybean. But contrary to nutsedge, the *Echinochloa colonum* population and biomass were maximum in sole *til* (sesame). Further, it was found that N doses did not have significant impact on the density and biomass of *C. rotundus* as well as *T. portulacastrum*, but the sources of N significantly affected their density and biomass. Application of 50% N through neem-cake and 50% through inorganic fertilizer resulted in the lowest weed biomass (15.7 g / m^2) over application of N through inorganic sources only.

D. Weed Control Measures

Tillage : Effect of tillage on weed infestation was studied during 2004-06. The results revealed that summer ploughing significantly reduced the density and biomass of purple nutsedge (*Chenopodium album*) and increased rice yield to the tune of 58.2% as compared to control in rice – chickpea system. Summer ploughing as well as weed control treatments applied to rice crop did not influence the density and biomass of purple nutsedge and other weeds in chickpea crop. Under zero tillage, the density of purple nutsedge was found significantly higher in comparison to normal tillage in rice–lentil system. Trials on management of *Cyperus* in pulses like mungbean, urdbean, *etc.*, showed that two cross ploughings by soil turning plough at an interval of 21 days during summer reduced nutsedge population by 21%.

Chemical control : Among herbicides, pre-sowing incorporation of basalin @ 0.5-1.0 kg a.i./ha and Ronstar @ 0.75 kg/ha were found most effective in controlling weeds in chickpea, lentil, mungbean, pigeonpea and urdbean. Pre-emergence application of pendimethalin @ 1.25-1.5 kg a.i. / ha was most effective in controlling broad leaved weeds in all the pulses and in pigeonpea+urdbean and chickpea + mustard intercropping systems. In frenchbean, pendimethalin @ 0.75 – 1.50 kg a.i. / ha or metachlor @ 0.50 – 1.0 kg a.i. / ha was found very effective. Application of butachlor @1.5 kg a.i. / ha or 2, 4-D EE @1.0 kg a.i. / ha in rice crop and pendimethalin @ 1.5 kg a.i. / ha in lentil were found effective in controlling weeds in rice-lentil system. Nutsedge plants treated with glyphosate in stale bed recorded 54% nutsedge killing efficiency.

Integrated weed management : Studies on integrated weed management showed that effective weed control in late sown chickpea, summer mungbean and chickpea + mustard intercropping was obtained with pendimethalin @ 0.75-1.0 kg a.i. / ha + one hand weeding at 40- 50 days after sowing. Weedicides like Alachlor, Oxyflurofen, Isoproturon, Pendimethalin, 2,4-D EE, anilophos, atrazine, 2,4-DSS alone or integrated with hand weeding were also tested and found effective in controlling the weeds in urdbean, mungbean, lentil, pea and chickpea crops, and in rice-lentil, maize-chickpea, chickpea+mustard and pigeonpea+sorghum cropping systems.

Weed management in intercropping : Intercropping enhances crop canopy and thus suppresses weeds. Short duration legumes *viz*., urdbean, mungbean, soybean and cowpea when grown with pigeonpea under intercropping system suppressed weed flora considerably. Highest suppression ability was recorded with cowpea (45.8%) followed by urdbean (41.5%) and mungbean (38.2%) (Fig. 3.8). Intercropping of safflower, linseed and wheat with chickpea also exhibited significant suppression of weeds (43-60%).

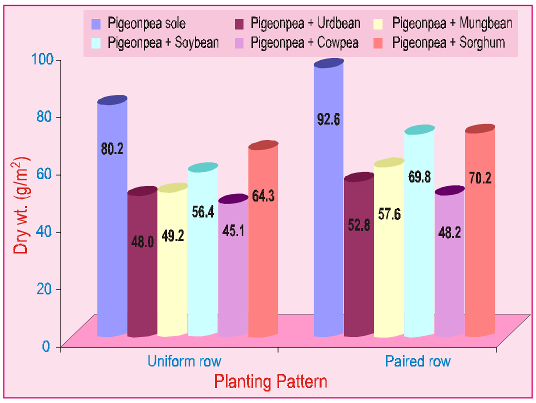


Fig. 3.8. Dry weight (g/m^2) of weed in pigeonpea as influenced by intercropping and planting pattern

2.4 Irrigation Management

Systematic research on irrigation water management was carried out during the period 1983 to 2007. Findings of these researches are presented crop-wise.

A. Chickpea

In chickpea, pre-plant irrigation + one irrigation at pre-podding stage increased the grain yield to the tune of 77% over no irrigation (1248 kg/ha). Contrary to a misbelief that irrigation at 50% flowering is harmful to chickpea, the results showed that chickpea productivity considerably increased by applying one irrigation at 50% flowering/pod development stage or two irrigations, one each at branching and pod development stage, depending upon winter rains.

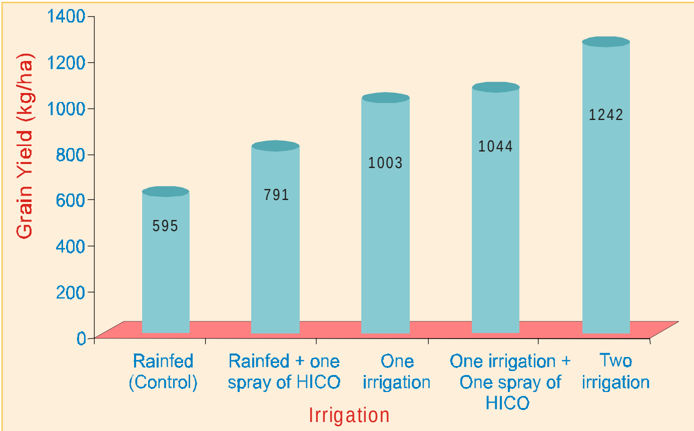


Fig. 3.9. Effect of irrigation and antitranspirant on grain yield of chickpea

Under rainfed conditions, use of anti-transpirant (HICO) gave significantly higher seed yield (33%) over control but no such improvement was recorded in irrigated condition (Fig. 3.9). Tillage practices and mulch also helped in improving water use efficiency under rainfed conditions. In chickpea, deep tillage and cultural mulch recorded 33 and 31.6 % higher yield over zero tillage. Deep tillage gave 65% higher WUE over zero tillage and maintained higher profile moisture content throughout the growth period.

Studies on methods and depth of irrigation showed that maximum grain yield and water use efficiency of chickpea could be obtained with 3.0 cm irrigation water in FIFB (Flood irrigated flat bed) and 1.5 cm in FIRB (Furrow irrigated raised bed) system. Raised bed planting outyielded flat planting by 18.8% and also increased both water use and water use efficiency in chickpea.

B. Lentil

It has been found that lentil gave higher yield when one irrigation was provided at 55-60 days after sowing. In heavier soil where sufficient moisture was not present, one pre-sowing irrigation was found sufficient to harvest a bumper crop of lentil. Raised bed planting saved 20-25% irrigation water and increased the grain yield.

C. Fieldpea

In dwarf pea, irrigation at branching and flowering stage was found to be critical which produced highest grain yield of 2650 and 2733 kg / ha as against 1816 kg / ha under control. However, highest yield (3521 kg / ha) was recorded in dwarf fieldpea with three irrigations, one each at 45 DAS, 50% flowering (80 DAS) and podding stage. Irrigation scheduling based upon evaporation demand revealed that IW / CPE 0.8 gave the highest grain yield of 2958 kg / ha closely followed by IW / CPE 0.6 (2777 kg / ha).

D. *Rajmash*

Rabi rajmash responded to three irrigations, one each at 25, 75 and 100 days after sowing. Irrigation given at the above three stages yielded 1711 kg / ha more yield over no irrigation (Fig. 3.10). Further, the 25-day crop stage proved to be most critical one. Irrigation scheduled at IW / CPE 0.8 proved to be the best as it gave 1917 kg / ha yield in comparison to 1528 kg and 294 kg / ha with 0.6 and 0.4 IW / CPE, respectively. Further, irrigation scheduled at 60 mm CPE (3-4 irrigations) produced highest grain yield (2199 kg / ha) over no irrigation and 100 mm CPE (2 irrigation).

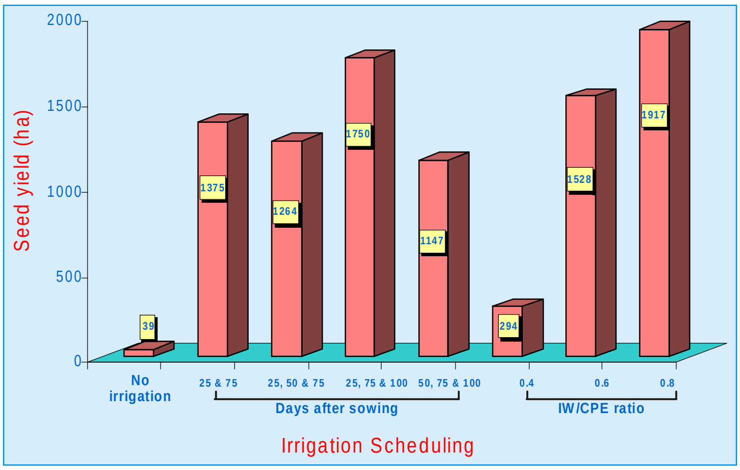


Fig. 3.10. Seed yield of *rajmash* by irrigation scheduling

E. Pigeonpea

Kharif pigeonpea often suffers due to waterlogging. It has been found that sowing on ridges provided better plant stand and yield. Moisture regimes significantly influenced grain yield of *rabi* pigeonpea. Branching stage was the most critical stage for irrigation. Depending upon winter rain, *rabi* pigeonpea responded to 2-4 irrigations. Two irrigations one each at branching and flowering gave highest yield (870 kg/ha), the response over control (no irrigation) being 253 kg/ha. However in 1997-98, four irrigations gave significantly higher yield (1800 kg/ha) than all other treatments (Fig. 3.11). Based on IW/CPE ratio, irrigation provided at 0.4 ratio gave highest yield in rabi pigeonpea (1026 kg/ha).

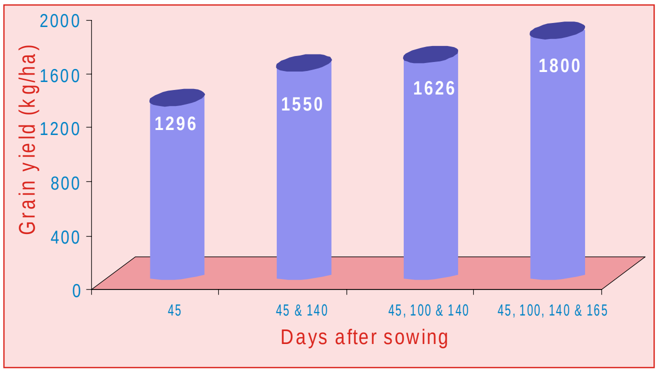


Fig. 3.11. Effect of irrigation on yield of *rabi* pigeonpea

F. Summer Mungbean

Experimental results showed that the first irrigation should be given 20 days after sowing and subsequent irrigation at 10 days interval. Delay in application of first irrigation (30 DAS) could not reverse the growth and yield, even if subsequent irrigations were given at short intervals (Table 3.7).

Table 3.7. Effect of irrigation schedule on yield of summer mungbean

Irrigation schedule		Yield (kg/ha)
First irrigation at (DAS)	Subsequent irrigation at (days interval)	
20	10	948
20	20	849
20	30	521
30	10	677
30	20	547
30	30	432
LSD (P=0.05)		112

3.5 Allelopathy

Allelopathy in its simple form deals with the injurious effect of one plant species on other if grown in the vicinity. Studies on allelopathic aspects of sorghum and linseed root exudates were initiated in 2000. Initially, techniques for collection and extraction of root exudates were standardized. Subsequently, the allelochemicals were characterized and their biocidal effects on pathogens, nematodes and weeds were studied.

A. New Techniques

Authentic and very viable techniques were developed at IIPR, Kanpur for both *i.e.*, to collect root exudates as well as to extract and fractionate the allelopathic compounds up to absolute purity.

Fig 3.12. sorghum and sesame grown in root exudates trapping system.

Root exudates trapping system : The technique is an innovative and simple root exudates trapping system (Fig. 3.12) made with the help of buchner funnels (110-mm diameter) and conical flasks (500-ml capacity) in which the plants of study crops can be survived up to ripening or maturity and exudates from the plant roots can be taken regularly without causing any harm to the plants grown. The technique is not only feasible for collection of root exudates of crop plants but it can also be used successfully for any plant including higher trees with slight modifications.

Column chromatographic technique : Column chromatographic method was standardized and employed for recovery of allelocompounds. To extract the compounds from the root zone water, column should contain four bands of ten gram each of ceralites *viz*., IR-410, IR-400, IRC-50, and IRC-410 with one band of approximately 10 g of silica gel at bottom. This technique can be implemented successfully for some selective molecules of interest after proper selection of ion absorbing resins and other parameters as per the requirement of molecules of interest.

Partition and fractional crystallization technique : At initial phase of technique, allelopathic compounds obtained from the concentrated water were successfully fractionated into two major groups *i.e.*, polar and non-polar by partitioning it with equal amount of ethyl acetate. In this procedure, ethyl acetate layer extracts the maximum amount of non-polar compounds whereas polar compounds are retained with the water layer. Both the layers after proper drying are processed separately for recovery of allelocompounds into single identity in maximum possible purity by fractionally and repeatedly crystallizing them in different polarity of solvents. By following these approaches, 5, 7 and 7 allelomolecules from the root exudates of sorghum, sesame and linseed, respectively, were isolated successfully in above 98% purity.

B. Characterization of Allelochemicals

Sorghum (dynamics and formation of allelocompounds) : Based on weekly recovery of allelofractions, it was observed that the relative composition of fractions changed systematically with the stage of crop. It changed originally from 13.62%, 14.79%, 21.47% and 23.24% in August to 26.40%, 6.09%, 2.5%, 34.52% and 30.46% in last week of October for the fractions A, B, C, D and E, respectively. In exudate, material concentrations of polar and least polar fractions *viz*., E (23.24-30.46%), D (27.47-34.52%) and A (13.62-26.40%) showed continuous increasing trend whereas the concentrations of non–polar fractions *i.e.*, B (14.79-6.09%) and C (21.47-2.5%) continuously decreased with crop age.

HCN content study and its relationship with root exudates : A field experiment under three artificially created moisture regimes *i.e.*, irrigated, partially irrigated and no irrigation revealed that the leaves contained more HCN than shoots irrespective of moisture regimes. Soil moisture regime significantly influenced HCN content in the leaves. A 30-35 day old crop grown under well-irrigated condition contained only 85 mg HCN per kg of dry leaves, which increased to 108 mg/kg under partial irrigated condition. The crop grown under no irrigation condition recorded maximum HCN content (275 mg/kg), which was three times higher than that in irrigated condition. The HCN content was 35, 50 and 50 mg/kg in shoots of the crop grown under well irrigated, partial irrigated and no irrigation conditions, respectively. The H^1NMR analysis of the allelocompounds recovered from the crop grown under severe stress condition revealed the reverse trend which indicates that the function of enzymes involved disturbed under drought and the initial compound remained unconsumed which gives rise to HCN under severe drought.

Inorganic elements and free radical secreted as root exudates of sorghum : In sorghum root exudates, certain inorganic elements were detected with first fraction (Fraction D). Three paramagnetic elements *viz*., Mn^{++}, Cu^{++}, and Fe^{+++} were detected in the crude form of Fraction D where the inorganic elements remained compounded with organic molecules.

C. Biocidal Properties

Anti fungal effect : Non-polar fraction based EC formulation was found very active against seven fungal pathogens *viz*., *Fusarium udum, Fusarium oxysporum* spp. *Ciceri, Rhizoctonia bataticola, Sclerotium rolfsii, Choenephora cucurbitarum, Sclerotinia sclerotiorum* and *Alternaria alternata* of pulse crops in variable degree. It was found highly lethal to *Sclerotinia sclerotiorum* giving LD_{50} value of 17 ppm followed by 22 ppm against *Sclerotium rolfsii* (Fig. 3.13). Against two wilt pathogens *viz*., *Fusarium* *udum* and *Fusarium oxysporum* f. sp. *ciceri*, the prepared formulation showed relatively higher LD_{50} values of 250 and 270 ppm, respectively. The EC was also found very effective against *Rhizoctonia bataticola* (*Macrophomina phaseolina*) which caused dry root rot and stem canker in different pulse crops. The LD_{50} value for this pathogen was recorded as 182 ppm. It also gave good control of *Alternaria alternata* and *Choenephora cucurbitarum* responsible for causing seed rot, leaf spots and seedling blight in pulse crops. The LD_{50} values for them were recorded as 146 and 87.5 ppm.

Fig. 3.13. Impact of allelochemicals of sorghum on mycelium growth of *Alternaria alternata* and *Sclerotium rolfsii*

Five extracted compounds were also tested separately against four soil borne fungi. All compounds were found effective against all the four pathogens in variable degree. Against *Fusarium udum*, ECs obtained from non polar fractions *viz*., D&E were found more toxic with LC_{50} values of 94.2 and 86.9 ppm compared to the compounds A, B, & C derived from non – polar and medium polar fractions. The LC_{50} values of these formulations against *Fusarium udum* were recorded as 110.6, 133.7 & 112.2 ppm, respectively. *F. oxysporum* spp. *ciceri* was found most sensitive to the compound C (LC_{50} 34.9) derived from non–polar fraction whereas not much difference in the LC_{50} values of the remaining compounds *viz*., A, B, D and E was observed. The LC_{50} value of these compounds against the same fungus was found in the range of 70 – 90 ppm. *R. bataticola* was found sensitive to all the five compounds with LC_{50} values ranging from 70–90 ppm. All the compounds were found extremely toxic against *S. rolfsii* with very less LC 50 value (19.0 ppm).

Effect of toxic formulations on sclerotia formation : Allelochemicals cause considerable delay in sclerotia formation in both the pathogens and the effect was found more pronounced at higher concentrations *viz*., 75, 100 and 125 ppm. Apart from this, a drastic change was also observed in morphology of both fungi at higher concentrations. Comparatively less number of sclerotia was formed even at lower concentrations *i.e.*, 25 & 50 ppm. The effect of chemical was also observed on size and biomass of sclerotia. The reduction in number and size of sclerotia in both the fungal species increased with the increase in concentration. The viability of sclerotia was also reduced from 93.7% in untreated to 43.7% at 250 ppm. Thus, the allelochemicals derived from sorghum root exudates have been found detrimental to all the seven important pathogens of pulse crops.

Nematicidal effect : Results indicated that formulations developed especially from the non-polar fraction *viz.*, C and B of sorghum exudates exhibited severe impact on the mortality and paralyses of second stage juveniles of *Meloidogyne javanica* in comparison to the formulations developed from polar fractions *i.e.*, D and E. Maximum juvenile mortality at different exposure times was achieved with the formulations developed from highly non-polar fraction *i.e.*, C followed by the formulations developed from B, A and E fractions whilst, the EC (emulsion concentrate) formulation developed from highly polar fraction (D) was found practically ineffective as it could not produce significant mortality even at 2000 µg/ml, the highest concentration tested at maximum time of exposure (72 h). The results indicated that the polarity of the allelocompounds of sorghum root exudates is the key factor in imparting toxicity against second stage juveniles of *M. javanica*. Therefore, the formulation developed from fraction C (highly non-polar) was found detrimental to the juveniles at extremely low concentrations ranging from 150-350 µg/ml (Fig. 3.14).

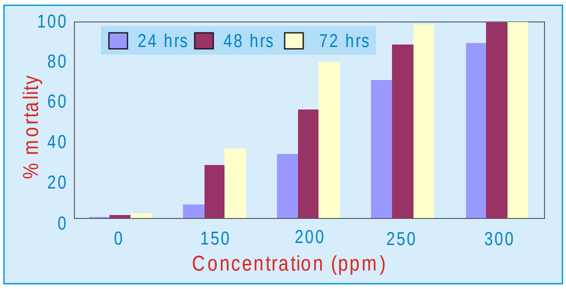


Fig. 3.14. Effect of non-polar formulation of sorghum on mortality of *M. javanica* juveniles at different durations of exposures

Effect of non-polar formulation on egg hatch : EC formulation developed from compound C was also tested for its efficacy against egg masses of *M. javanica*. Results indicated that all the concentrations of formulation were quite effective in reducing egg hatching. A linear correlation was observed between egg hatch and the concentration of the formulation. Maximum reduction (97%) in egg hatching was observed at 200 µg/ml concentration (Fig. 3.15).

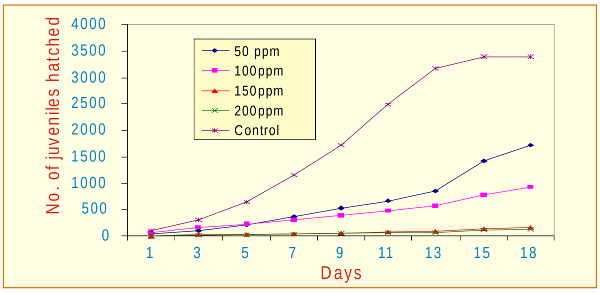


Fig. 3.15. Effect of non-polar EC formulation of sorghum on egg hatch of *Meloidogyne javanica*

D. Herbicidal Action of Sesame Allelo-molecules

Effect on germination : A considerable impact of emulsion concentrate formulation prepared from isolated mixture of sesame root exudates was observed on the germination of purple nutsedge. Its EW formulation not only severely inhibited germination but also caused considerable delay in germination of purple nutsedge. Nearly 40% inhibition in germination was observed in 80, 120, and 240 µg allelocompounds per gram of soil over control. The magnitude of inhibition was not found directly proportional to concentration, but increase in concentration was directly associated with delay in the germination of nutsedge tubers.

Effect on germinated tubers : At initial stage (up to 15 days), no significant influence of allelochemical was observed on growth and development of nutsedge. However, after one month, degradation started in the roots of treated plants at all treatments and, hence, suppression in root and shoot of treated plants became visible. Toxicity symptoms at root tips of germinated tubers were observed initially. After one and half month, the major roots continued to grow but were short compared to control. After two months, root of the treated plants degraded completely in all the treatments, resulting in death of the plants.

Effect of formulations on growth and development : EC formulation developed exclusively from non–polar fractions of sesame was found 100% detrimental to *C. rotundus* at 100 µg / g of soil in pot experiments. Apart from inhibitory effect, the formulation developed from hexane soluble fraction also exhibited great impact on the morphology of the plants. At higher concentrations (60 µg / g and above), it severely prohibited the plants to induce new shoots but main shoot continued to elongate and forced the plant to flower (Fig. 3.16).

Fig. 3.16. Impact of non-polar compound on morphology of purple nutsedge plants

Effect of EW formulations on roots and newly formed tubers : Observations on the roots and number of new tubers revealed that ECs developed exclusively from non-polar fractions drastically reduced the tuber formation tendency of nutsedge. Upto 95 – 99% reduction in tubers and root biomass was noticed in both of the ECs at the highest concentration (90 µg / g). Average biomass of tubers survived in treated pots also reduced from 0.172 g in control to 0.009 g in the same treatment of completely non-polar EC *i.e.*, hexane soluble. Almost same kinds of results were obtained from the EC developed from ethyl acetate soluble fraction.

Effect of sesame allelo-compounds on other weeds : Apart from *Cyperus rotundus*, a great impact of sesame allelochemicals was also observed on other important weeds of pulse crops especially grown in winter legumes.

Effect on germination : Significant effect of assayed formulation was observed on germination of all the test weeds. Emulsion concentrate formulation not only severely inhibited the germination but also caused considerable delay in germination of all the weeds. The magnitude of inhibition and delay in germination of all the weeds increased linearly with increase in concentration. At 240 mg concentration EW formulation, maximum inhibition in germination was recorded in *Chenopodium album* (80%) followed by *Anagalis arvensis* (75%), *Melilotus alba* (65%), *Spergula arvensis* (60%), *Fumaria parviflora* (55%) and *Vicia sativa* (50%). Formulations at higher concentrations (120 mg and above) caused considerable delay in germination of test weeds over control.

Effect on shoot growth : Approximately 2-10% and 5-15% inhibition was observed in shoot length and shoot biomass of test weeds at the lowest concentration (40 mg) over the control. Effect of formulation increased linearly with concentration level. Maximum inhibition in both shoot length and shoot biomass was observed at 280 mg. Depending upon the test weed species, the magnitude of inhibition based on shoot length and shoot biomass varied due to wide genetic variability in their canopies. The magnitude of inhibition in terms of shoot length at 280 mg/g concentration followed the order: *Chenopodium album* (65.43%), *Spergula arvensis* (64%), *Fumaria parviflora* (61.89%), *Anagalis arvensis* (50.68%), *Melilotus alba* (47.75%) and *Vicia sativa* (46.24%) whereas, the magnitude of inhibition as per shoot biomass followed this order: *Chenopodium album* (85.8%), *Fumaria parviflora* (81.57%), *Vicia sativa* (52.4%), *Spergula arvensis* (49.27%), Anagalis *arvensis* (46.07%) and *Melilotus alba* (41.93%).

Effect on root growth : Approximately 10-15% inhibition in root length and biomass of test weeds was observed at 40 mg/g over control. The inhibition in root length and root biomass increased linearly with concentration level. At 280 mg/g concentration, it drastically inhibited the root growth of the weed species tested. Formulations at 280 mg/g concentration were more toxic to *Chenopodium album*, inhibiting the root length and biomass by 74.2% and 89.3%. The magnitude of inhibition in root length of the remaining weeds at this concentration followed this order: *Anagalis arvensis* (73.9%), *Melilotus alba* (71.4%), *Fumaria parviflora* (71.1%), *Vicia sativa* (69.2%) and *Spergula arvensis* (65.6%). The formulation with concentration of > 280 mg/g inhibited the root development of all the test weeds completely.

4. Crop Protection

Systematic and comprehensive research on pulse pathology and entomology was initiated in 1978. Nematology programme was added during 1987 under Entomology section. During the IX Plan, the Pathology, Entomology and Nematology sections were merged and a Division of Crop Protection was created in 1995 to undertake basic and strategic research on pulse diseases, insect-pests and nematodes. Initially the major thrust was on

- Identification and characterization of key diseases, insect-pests and parasitic nematodes affecting pulse crops
- Standardization of screening methods for host plant resistance and identification of resistance sources against major diseases, insect-pests and nematodes
- Epidemiology and bio-ecology of major diseases and insect-pests
- Development of management options for key diseases and insect-pests
- Post entry quarantine for detection of seed borne viruses in exotic germplasm

As we entered in the 21st century, studies on bio-control of major diseases and pests including nematodes, management of stored grain pests and development of forecasting / forewarning systems for the major diseases and pests have been added. During the X Plan, the research programmes of the division were reoriented to focus on basic and strategic research. While identification of resistant sources continued as major programme, studies on variability in major pathogens at macro and molecular levels were initiated to support resistance breeding programme. Crop-wise achievements made during the past 25 years at the Institute are summarized hereunder.

4.1. Diseases

A. Chickpea

During the last 25 years, investigations were carried out on wilt, dry root rot, ascochyta blight and botrytis grey mould diseases affecting chickpea. Wilt caused by *Fusarium oxysporum* f.sp. *ciceri* has, however, been the most important and widely occurring disease of chickpea. Various aspects of the wilt were investigated with the major emphasis on identification of resistance sources. Biological control of wilt pathogen through *Trichoderma* isolates has also been investigated. Of late, emphasis has been placed on characterization of cultural, morphological, pathological and molecular variability in *F. oxysporum* f. sp. *ciceri*. Emergence of dry root rot caused by *Rhizoctonia bataticola* has also attracted attention.

Wilt (*Fusarium oxysporum* f.sp. *ciceri*)

Wilt caused by *F. oxysporum* f.sp. *ciceri* is the most wide-spread disease in chickpea. Studies were predominantly conducted on its management with major focus on host plant resistance and biological control. During the last five years, emphasis has been placed on variability in the wilt pathogen.

Pathogenic variability: Wilted plant samples collected from 12 chickpea growing states covering 130 districts has resulted in collection of 326 isolates of *F. oxysporum* f.sp. *ciceri*. Studies on conidia size revealed 98 isolates with small (12.5 - 30 µ length), 75 with medium (15.0-37.5 µ) and 142 with large (20.0-45.0 µ) conidia. Out of 326 isolates, 115 recorded slow growth (up to 70 mm/7 days), 126 medium growth (>70-79 mm) and 85 fast growth (> 79 mm). Pathogenic reaction on susceptible cultivar, JG 62 revealed 13 isolates as weak (<30% wilt), 70 as moderate (31-50% wilt) and 243 as strong (>50% wilt) in their pathogenic ability. Based on pathogenicity and cultural and morphological studies, 307 isolates could form 27 groups. Studies conducted at IIPR in collaboration with JNKVV and IARI using representative isolates from 27 groups with 10 differential genotypes of chickpea (JG 62, JG 74, JG 315, BG 212, CPS 1, C 104, Annegiri, Chaffa, K 850) indicated presence of six races (1, 2, 3, 4, 5 and 6) in the country. Race 2 was most prevalent and widely distributed. The study indicated the presence of race 1, 2, 3, 4, 5 in U.P., race 2 in M.P., race 1, 2, 4, 6 in Rajasthan, race 1, 4 in Haryana, race 1 in A.P., race 2 in Gujarat, race 2, 5 in Chhattisgarh, race 6 in Jharkhand and race 3 in Punjab. However, this distribution is incomplete and requires further studies with more isolates.

Molecular characterization of 24 isolates of *F. oxysporum* f.sp. *ciceri* from Bundelkhand using RAPD and SSR primers revealed three major clusters. Fourteen isolates representing seven states were grouped into five clusters using RAPD and SSR primers. Cluster I included 3 isolates from U.P., Cluster II included 2 isolates each from A.P. and Karnataka, Cluster III included 2 isolates from M.P., Cluster IV had one each from Gujarat and Chhattisgarh and Cluster V consisted one each from Gujarat, Chhattisgarh and Maharashtra. Cluster analysis with ITS-RFLP primers also resulted in four clusters. However, there was no geographical specificity among these isolates.

Management

Major focus has been on identification of stable wilt resistant donors, seed treatment with fungicides and bioagents and intercropping.

Host plant resistance: Screening of germplasm accessions and promising breeding lines over the years in wilt sick plot has resulted in identification of stable resistant sources against wilt pathogen. These donors are ICC nos. 1132, 2862, 2644, 2664, 3345, 4483, 6687, 6817, 9023, 9032, 9041, 10384, 10630, 10803, 11224, 11233, 11322, 11329, 11550, 11551, 12223, 12263, 12408, 81001, 85221, H 86-72, H 82-2, H 86-156, KPG 142-1, KPG 143-1, Avrodhi, ICCV 10, ICCV 90201, KBG 2, GL 91061, KWR 108, ICCL 81002, ICCL 81010, ICCC 32, ICCC 42, DCP 92-3, IPC nos. 2004-03, 2004-52, 2005-41, 2005-46, 2005-59, 96-38, 97-7, 99-4 and 99-10. Recently, race specific screening has been initiated to identify race specific donors so as to develop multi race resistant varieties.

Biological control: Antagonistic efficiency of *Trichoderma viride* and *T. harzianum* against different isolates of *F. oxysporum* f. sp. *ciceri* was studied *in vitro*. Junagadh, Jabalpur and Dholi isolates of Foc were highly sensitive to *T. viride* with >85% growth inhibition after 96 hrs of incubation whereas Kanpur, Ludhiana, Jammu and Bharari isolates exhibited 70% inhibition. Sehore and Rahuri isolates exhibited 40-50% growth inhibition. Kopergaon isolate was found least sensitive to *T. viride* with 28% inhibition. Rahuri, Ludhiana, Dholi, Bharari and Jabalpur isolates were found highly sensitive to *T. harzianum* with 81.4 to 90.3% growth inhibition. Sehore, Jammu and Junagadh isolates exhibited 70-76% inhibition while Kopergaon and Kanpur isolates exhibited growth inhibition below 70 per cent. These findings clearly indicated that as compared to *T. viride* all the isolates of *F. oxysporum* f. sp. *ciceri* were more sensitive to *T. harzianum*. Jammu and Dholi isolates were equally sensitive to both *T. viride* and *T. harzianum*.

Integrated management: An integrated management module combining different management options has been developed for wilt management in chickpea for Uttar Pradesh (Table 4.1).

Table 4.1. Integrated wilt management module for chickpea in UP

Component	Practices
Field	Deep summer ploughing, field sanitation
Resistant varieties	JG 315, Avrodhi, DCP 92-3, JG 74, BG 372, KWR 108
Seed treatment	*Trichoderma viride* + carboxin (4+1 g/kg seed) or carbendazim+ thiram (1+2 g/kg seed)
Sowing date	Normal
Spacing	Normal
Cropping system	Intercropping with linseed, wheat or mustard

Dry root rot (*Rhizoctonia bataticola)*

Pathogenic variability: In pathogenicity test of 24 isolates of *R. bataticola* from different districts of U.P., 6 were found weakly pathogenic with <50% seedling mortality, 11 moderately pathogenic (54.8%) and remaining highly pathogenic (Table 4.2).

Table 4.2. Relative pathogenicity of *R. bataticola* isolates from U.P.

Pathogenicity	Seedling mortality	Isolates from
Weak	10-50%	Mandhna, Chaubeypur (Kanpur), Konch, Kadora (Jalaun)
Moderate	>50 to 80%	Pama Tikiri, Harihar (Sultanpur), Gabraha, Bilhana (Kanpur), Mahuaboth, Rath (Hamirpur), Dakar (Jalaun), Talbehat (Lalitpur), Rehmatnagar (Lucknow) and Khelwa (Gonda)
High	>80 to 100%	Bhitiraut (Gorakhpur), Vashi (Gazipur), Sigramau (Jaunpur), Khwabpur (Gazipur), Gulalpur (Barabanki), Rath, Gohand

Variation in growth pattern: Twelve isolates of *R. bataticola* were studied for variation in their growth on PDA. Isolates from Pama Tikiri, Harihar (Sultanpur), Rath, Kabrai, Charkhari (Hamirpur), Bhitiraut (Gorakhpur) and Mandhna (Kanpur) were grouped as fast growing while isolates from Mokama (Bihar), Mahuaboth (Sultanpur), Talbehat (Lalitpur), Gohand and Panwari (Hamirpur) showed medium growth. In a similar study, 11 new isolates from Khuchkipur, Bilhana, Rajepur, Malo and Gabraha villages of Kanpur district, IIPR, ICRISAT (A.P.), Sehore (M.P.), Durgapura (Rajasthan), Badnapur (Maharashtra), and Gulbarga (Karnataka) showed average width of mycelium from 0.725 µm (Sehore isolate) to 8.34 µm (ICRISAT isolate). Based on the average mycelium width, Badnapur, IIPR, Gabraha and Khuchkipur isolates were very close to each other with average width varying from 6.31 to 6.95 µm. Durgapura and Rajepur isolates had average mycelium width of 7.61-7.88 µm while Gulberga and Malo isolates showed average mycelium width of 3.71 and 1.725 µm, respectively. All the isolates differed from each other in their sclerotia size (L+W) with a range from 0.52 µm in Sehore isolate to 138.4 µm in ICRISAT isolate. Based on average mycelium width and sclerotia size, these 11 isolates were categorized in four distinct groups.

Effect of inoculum levels on germination and seedling mortality : Study on the effect of inoculum level of *R. bataticola* on germination and seedling mortality of susceptible cultivar of chickpea, JG 62, showed that up to 10% inoculum levels had no adverse effect on seed germination while 15 and 20% inoculum levels decreased seed germination by 6.7 and 13.4%, respectively. The decrease in germination was attributed to pre-emergence mortality. The higher inoculum levels (15 and 20%) (w / w) also caused seedling mortality to the tune of 50.7 and 87.6%.

Antagonistic efficiency of *Trichoderma* : Antagonistic efficiency of *Trichoderma viride* and *Trichoderma harzianum* was evaluated against 11 isolates of *R. bataticola.* It was observed that *T. harzianum* was more efficient in inhibiting the growth of Bilhana and Durgapura isolates while *T. viride* was more efficient against IIPR, Badnapur, Gulberga and ICRISAT isolates. Both *T. harzianum* and *T. viride* were found equally efficient against Khuchkipur, Rajepur and Sehore isolates. The study showed that bioagent for dry root rot management should be selected on the basis of its efficiency against the local isolate of *R. bataticola.*

Resistance sources : In screening against dry root rot, none of the genotypes was found resistant. However, ICC 2644, ICC 10384, ICC 10630, ICC 11224, ICC 11332, ICC 12441, ICC 12450, ICCV 10, ICCL 81002 and ICCL 81010 showed moderate resistance against the disease.

Chickpea stunt virus

Study on the effect of stunt disease on yield parameters showed that the disease adversely affects plant growth and yield parameters (Table 4.3). Among seven genotypes, BGD 123 was found least sensitive to stunt infection with minimum effect on yield parameters while CSJ 126 was highly sensitive with maximum reduction in pod bearing branches, pods, seeds and seed weight.

Table 4.3. Effect of chickpea stunt virus on yield parameters (2002-03)

Genotype	Per cent reduction per plant					
	Plant height	No. of main branches	No. of pod bearing branches	No. of pods	No. of seeds	Seed weight
BGD 122	29.9	33.3	23.0	52.0	52.7	58.5
BGD 123	14.2	0.0	11.0	37.8	40.0	71.5
BG 256	23.8	33.0	20.0	69.4	67.6	70.5
BG 1095	34.3	50.0	31.5	85.4	84.4	87.9
CSJ 126	25.5	28.5	90.0	97.0	97.1	98.2
H 96-112	24.6	50.0	31.2	54.7	55.3	59.0
RSG 807	34.5	0.0	12.5	50.0	54.2	71.6

Multiple resistance

Nineteen genotypes of chickpea have been identified as having multiple disease resistance:

Wilt + collar rot	:	FG 703
Wilt + root rot	:	K 1116, KPG 116-3
Wilt + stem rot	:	WCG 95-50, RSG 143-1
Wilt + BGM	:	PGL 725, GL 91059, GL 91078, PGL 146, GL 91035, PGL 745, PGL 989, GL 88341, GL 89035, GL 91058, GL 91059, GL 91145, GL 92014, GL 94059

B. Lentil

Wilt caused by *Fusarium oxysporum* f.sp. *lentis* and rust caused by *Uromyces fabae* are the two main diseases affecting lentil production in the country. Wilt is found in all lentil growing areas whereas rust is more severe in northern states. The aspects of wilt disease studied at IIPR included host plant resistance, pathogenic variability and its management. In case of rust, host plant resistance was given main attention besides its eco-biology and integrated management.

Wilt (*Fusarium oxysporum* f.sp. *lentis*)

Disease status: Wilt is the most serious disease of lentil. Mortality due to wilt in Bundelkhand region is estimated to be as high as 70-80%.

Pathogenic variability: Studies on variability in *F. oxysporum* f.sp. *lentis* started only recently (2005). About 150 isolates collected from the major lentil growing states have been characterized for morphological, cultural and pathogenic characters. Study revealed vast variability in the pathogen. Colony colour ranged from white to pink and dark purple, and substrate colour from light cream to dark brown. Variability in their virulence ranged from weak to high. Morphologically also the isolates varied greatly from few to abundant macroconidia. Based on cultural and morphological characters, these isolates were categorized into 43 groups.

Host plant resistance : Screening of 500 lines for wilt resistance in identification of six lines, namely Pant L 77-2, Pant L 406, L 9-12, DPL 37, DPL 44, and DPL 58 as stable sources of resistance.

Management: Various fungicides and bioagents were tried as seed treatment to control the disease. Carbendazim + thiram and bio-agent, *Trichoderma viride* in combination with Vitavax were the best treatment for reducing wilt incidence and increasing the grain yield (Table 4.4).

Table 4.4. Effect of seed treatment on wilt and grain yield

Seed treatment	% wilt reduction	% yield increase
T. viride + Vitavax (4g + 2g/kg)	32.6	59.47
Carbendazim (Bavistin - 2g/kg)	47.3	115.13
Thiram (2g/kg)	32.8	96.90
Thiram + Carbendazim (Bavistin) (2g+1g)	53.6	156.34

Rust (*Uromyces fabae*)

Rust, the most important foliar disease of lentil, mainly occurs in epiphytotic form in *Tarai* region of U.P. and Bihar, Punjab and Madhya Pradesh.

Eco-biology: Studies were undertaken to find out the most vulnerable crop stage and weather conditions favourable for the development of rust. Observations on disease development revealed that the disease appeared in the first week of March irrespective of the crop stage.

For better screening against rust, replacement of lentil infector, Sehore 74-3 with rust susceptible genotype of pea, KFPD 1, increased the disease severity in test entries of lentil by 20 to 285% with average increase of 48%.

Management

Cultural practices: Studies revealed that sowing lentil at the end of October results in least disease intensity (13.45%) and higher grain yield (1322 kg/ha) in rust susceptible variety, Lens 830 (Table 4.5). Therefore, sowing crop at the end of October or in first week of November is best option for managing rust disease in lentil.

Table 4.5. Effect of sowing dates on development of rust in lentil (2002-03)

Sowing dates	Susceptible variety, Lens 830				Yield loss (%)	Resistant variety, Pant L 406	
	Unprotected		Protected			% rust	Yield (kg/ha)
	% rust	Yield (kg/ha)	% rust	Yield (kg/ha)			
29/31 October	13.45	1322	7.80	1468	9.94	0	1665
5/7 November	18.85	1138	10.00	1475	22.89	0	1705
12/14 November	38.05	1151	22.25	1391	17.04	0	1570
19/21 November	60.30	872	38.55	1171	28.40	0	1531
26/28 November	69.60	831	38.95	1103	28.03	0	1332
3/5 December	78.15	724	40.35	937	28.76	0	1235

Host plant resistance: Screening of 1000 lines against rust using infector row technique has resulted in identification of stable resistant sources such as Pant L 639, Pant L 406, Precoz, DPL 62, DPL 32, DPL 4, L 9-12, and Vipasha.

Chemical control: Three sprays of Dithane M 45 @ 0.25% or Sulfex @ 0.3% starting at the appearance of the disease reduced the rust intensity to 16.5 and 12.5%, respectively. Another study revealed effectiveness of zinc sulphate in reducing rust to 23.7%.

Integrated management: Attempts were made to develop an integrated method for managing rust by integration of sowing date, host plant resistance and fungicides. In rust susceptible varieties, two fungicidal sprays reduce the rust intensity by 57% whereas in moderately resistant variety, only one fungicidal spray reduced rust intensity to 51%. Therefore, early sowing (end of October or first week of November) of moderately resistant varieties with need-based fungicide spray offers effective strategy to manage lentil rust.

C. Fieldpea

Powdery mildew caused by *Erysiphe pisi* and rust caused by *Uromyces viciae fabae* syn. *U. fabae* are the major diseases of fieldpea. During the last 25 years, emphasis has been laid on standardization of screening techniques and identification of resistance sources. In addition, studies were also taken up on disease succession, epidemiology and management aspects.

Disease status and succession: Downy mildew, black root rot, powdery mildew and rust are economically important diseases of pea in the Indo-Gangetic plains. Downy mildew (*Peronospora pisi*) is sporadic and does not attain severe status every year. Black root rot (*Fusarium solani*) shows high incidence during December-January in frequently irrigated soils, especially in sandy or sandy loam soils. Powdery mildew and rust appear almost simultaneously during mid February-March. Early seedling mortality due to damping off and root rots is nominal. Among viruses, pea mosaic incidence is important which may range from 0.8-11.7%.

Standardization of screening technique: Initially, powdery mildew and rust development was very erratic and no standard technique was available to create high disease pressure in the screening nursery. Research at IIPR has led to development of a standard method to create high disease pressure in the screening nursery for powdery mildew. This includes delayed sowing by one month, use of susceptible variety KFPD 1 as infector row, 100 kg N in two split doses (50% basal + 50% after 1 month of sowing), one spray of 2% urea in February and one additional irrigation in the first fortnight of March. A rating scale (0-5) has also been devised for scoring genotypes against powdery mildew.

Host plant resistance: Screening of a large number of genotypes against powdery mildew using infector-cum-spreader row technique showed 116 genotypes as resistant. Of them, 23 (KPMR 516, KPMR 615, KPMR 602, KPMR 619, P 3, KPMR 493, P 4, 6238A, KPMR 284, KPMR 27, KPMR 16, HUDP 8, KPMR 7, PM 5, JP 21, KSP 22, KPMR 226, KPMR 212, HUP 15, PM 6, KPMR 46, DMR 34, JM 6) are highly resistant.

For rust disease, high degree of resistance has not been found. However, 55 genotypes with 11-20% rust severity have been graded as moderately resistant to rust. Some of these genotypes are HUDP 10, HUP 15, KPMR 412, HUDP 19, KPMR 465, IPF 98-7, DDR 60, DMR 38, ET 45191, EC 34365, KPMR 65-1, JP 1100, JP 868, DPFPD 8, IPF 98-18, HFP 9423, Pant P 11, HUP 19, LFP 283, DMR 41, and IPF 98-9.

Influence of powdery mildew invasion on rust: Study conducted on seven pea genotypes showing variable susceptibility to powdery mildew revealed that spray of carbendazim reduced powdery mildew severity in all the genotypes with consequent increase in rust severity, possibly due to the reduced surface area covered by the powdery mildew or due to the reduced competition by powdery mildew for nutrients as both are obligate parasites. The mean increase of rust was 0.45% at every 1% reduction in powdery mildew severity.

Effect of intercropping: Evaluation of different *rabi* pulse crops as sole and intercrop with different row combinations showed that intercropping pea with fababean reduced rust and powdery mildew, possibly due to better aeration and less humidity inside the crop canopy. On the other hand, intercropping pea with lentil increased lentil rust as a result of higher humidity due to the shade effects of pea (Table 4.6).

Table 4.6. Influence of legume hosts on pea diseases (2003-04)

Cropping system	Rust (%)	Powdery mildew (%)
Fieldpea sole at 40 cm. row spacing	9.8	12.6
Pea + Lathyrus (1:1) at 30 cm. row spacing	6.7	11.7
Pea + Lentil (1:1) at 25 cm. row spacing	3.9	8.4
Pea + Fababean (1:1) at 25 cm. row spacing	3.8	8.9
Pea+Lentil + Lathyrus (1:1:1) at 25 cm row spacing	4.0	9.6
Pea + Lentil + Fababean + Lathyrus (1:1:1:1) at 25 cm row spacing	9.7	6.7
CD (P = 0.05)	2.45	4.05

Management

Cultural practices: Soil moisture and humidity in crop canopy influences development of powdery mildew and rust. Evaluation of five irrigation schedules using three varieties showed that irrigation after 90 days of sowing significantly increased powdery mildew and rust. Irrigation in December-February increased downy mildew. Irrigation after 110 days of sowing further increased powdery mildew and rust diseases. For obtaining maximum yield, irrigation at 90 DAS is most important (Table 4.7).

Table 4.7. Influence of irrigation schedule on diseases and yield (2003-04) in pea

Irrigation schedule	PM (%)	Rust (%)	DM (%)	Alternaria leaf spot (%)	Yield (kg/ha)
Pre-sowing	2.0	3.1	2.0	0.6	2807
Pre-sowing + 2nd Feb	3.6	6.9	4.5	1.8	2892
Pre-sowing + 20th Feb	5.7	10.4	6.2	2.5	3148
Pre-sowing + 20th Jan & 20th Feb	6.1	13.1	5.5	2.9	3145
Pre-sowing + 20th Dec, 2nd Feb & 10th Mar	8.8	14.5	5.8	1.9	2823
CD (P = 0.05)	3.3	3.4	2.0	0.9	300

Chemical control: Among five fungicides evaluated for the management of powdery mildew, 0.05% penconazole has been found most effective followed by 0.1% dinocap and 0.3% wettable sulphur. Even sprays of plain water reduced the disease and increased grain yield. The benefit: cost ratio was 1:6.3 for penconazole, 1:5.5 for wettable sulphur and 1:5.4 for dinocap. It was least for carbendazim.

Fungicidal spray schedules: Total 14 spray schedules of fungicides were evaluated for their effect on powdery mildew and rust. Spraying of 0.125% copper oxychloride or 0.25% mancozeb in mid-January has been quite effective in reducing the disease severity. Powdery mildew and rust diseases could be reduced by sulphur or mancozeb spray during the 2^{nd} week of February and sulphur spray in the 1^{st} week of March. Thus, spray schedule of Mancozeb-mancozeb-sulphur, Mancozeb-sulphur-sulphur, Copper oxychloride-mancozeb-sulphur or Copper oxychloride-sulphur-sulphur were highly effective and gave 600-700 kg/ha additional yield.

Use of zinc sulphate for rust management: A field experiment was conducted to find out effective, eco-friendly and economic chemical for rust management under late sown conditions. The results revealed that 1^{st} spray of 0.1% zinc sulphate at disease appearance and 2^{nd} spray with 0.3% wettable sulphur after 15 days was highly economical and eco-friendly schedule for rust management. Two sprays of 0.25% mancozeb was the next effective schedule. Even one spray of zinc sulphate also gave effective disease control and higher yield. In another study, two sprays of 0.2% mancozeb, first at rust inception and subsequent spray 10 days after gave benefit: cost ratio of 6.05. Even one spray at disease appearance gave benefit: cost ratio of 4.77. The study showed that spray given immediately after the disease appearance is highly effective.

Integrated management: Integrated management of powdery mildew and rust by combining host resistance, fungicidal spray and sowing date was developed. Field experimentation showed that sowing crop up to 16^{th} November significantly lowers rust and powdery mildew as compared to late sown crop. Two sprays of 0.3% wettable sulphur significantly reduce both diseases. Powdery mildew ranged between 11-15% showing no influence of sowing date, variety or spray (Table 4.8). The effect of fungicide spray was more pronounced on last sown crop and in disease susceptible variety.

Table 4.8. Effect of sowing date, variety and spraying on rust and powdery mildew in pea (2002-04)

Component	Treatment	Rust severity (%)	PM severity (%)	Yield (kg/ha)
Sowing date	1st November	3.5	6.1	2677
	16th November	6.0	7.7	2542
	1st December	10.4	11.2	2100
	CD at 5%	4.0	3.0	-
Variety	Rachna	6.3	5.3	2538
	T 163	9.2	13.7	2410
	CD at 5%	2.9	4.0	-
Spraying	No spray	8.6	21.2	2368
	2 sprays of wettable sulphur	5.1	7.4	24.95
	CD at 5%	-	3.8	12.1

D. *Rajmash*

Rajmash was introduced by IIPR as *rabi* crop in North Eastern Plain Zone. Initially, it was considered as relatively free from diseases as compared to other pulse crops. Over the years, some of the major diseases like Bean Common Mosaic Virus (BCMV) started appearing on the crop. The work done on *rajmash* pathology includes status of various diseases, identification of sources of resistance against BCMV and stem blight and their management, and seed pathology.

Disease status: Common mosaic disease caused by BCMV is the most important disease in winter sown *rajmash*. In susceptible genotypes such as HUR 15, the incidence may go as high as 60 per cent. Stem blight caused by *Sclerotinia sclerotiorum* is irregular and confined to low lying areas. Its severity and incidence depend on the winter rains. Two other diseases that are likely to pose serious problem in *rajmash* production are ashy stem blight and root rots. Ashy stem blight occurs when the crop is in seedling stage while root rots and collar rots are of common occurrence especially in early sown crop when the temperature is relatively higher. Root rot caused by *Rhizoctonia solani* and collar rot caused by *Sclerotium rolfsii* occur at seedling stage whereas the root rot caused by *Fusarium* spp. occurs at flowering / podding stage. Leaf spots are of common occurrence at later stages with low severity. Powdery mildew, rust and anthracnose are recorded as minor diseases and were of irregular occurrence. Rust and powdery mildew have been recorded for the first time on this crop from Kanpur. Diseases in *rajmash* along with their causal agents encountered at Kanpur are given in Table 4.9.

Table 4.9. Diseases of *rajmash* and their causal agents

Disease	Causal agents
Common mosaic	Bean common mosaic virus
Stem blight	*Sclerotinia sclerotiorum*
Ashy stem blight	*Macrophomina phaseolina*
Root rot (seedling stage)	*Rhizoctonia solani*
Root rot (podding stage)	*Fusarium* spp.
Collar rot (seedling stage)	*Sclerotium rolfsii*
Powdery mildew	*Erysiphe polygoni*
Rust	*Uromyces appendiculatus*
Leaf spot	*Alternaria alternata*
Anthracnose	*Colletotrichum lindemuthianum*

Effect of seed borne infection of BCMV on growth and yield: Seed borne infection of BCMV in *rajmash* (var. Uday) greatly influenced the growth and yield attributing factors and grain quality. Grain yield per plant was drastically reduced by 85%. Seeds from the infected plants were comparatively smaller, dull in colour and lacked texture.

Standardization of screening technique for stem blight : Since the occurrence of stem blight was irregular in *rajmash*, a reliable and effective technique for screening against stem blight was required. Experiments at IIPR showed that the method involving placement of *S. sclerotiorum* colonized *rajmash* grain near the base of the plant is the best for screening against stem blight (Table 4.10). For raising inoculum, even broken and immature seeds of *rajmash* can be used.

Table 4.10. Effect of inoculation method of stem blight fungus on plant mortality in *rajmash*

Inoculation method	Plant mortality (%)
Placing of sclerotia near the collar region	26.33
Placing of 5 mm disc of young culture of *S. sclerotiorum* near the base of the plant	46.67
Mixing of *S. sclerotiorum* colonized straw in the soil @ 20 g	46.67
Oat grain on a petal colonized with *S. sclerotiorum* mycelium placed near the base of the plants	73.33
Rajmash grains colonized with *S. sclerotiorum* placed near the base of the stem	100.00

Sources of resistance: Screening of 545 genotypes of *rajmash* against BCMV under field conditions has identified 12 genotypes (ET 8447, ET 8411, ET 8418, ET 8449, ET 8430, VLF 104, BPG 116306, Vermelho 2152, PJ 164631, ET 8416, EC 156011 and EC 156059) as stable sources of resistance against BCMV. Similarly, 177 genotypes screened against stem rot fungus showed only one genotype, HURG 25 as tolerant with 37.5% mortality.

Management of BCMV: BCMV is seed borne and spreads in the field mainly through aphid, *Aphis craccivora*. The management of BCMV was attempted through vector control using insecticides. The results at IIPR showed that foliar spray of monocrotophos @ 0.1% at 30, 45, 60 and 75 days after sowing alone or in combination with soil application of phorate @ 1.0 kg a.i. / ha effectively reduces the incidence of BCMV and crinkle diseases in *rajmash*.

Seed mycoflora: Seed mycoflora of *rajmash* genotypes with different seed coat colour was studied using blotter paper method. Maximum frequency of *Aspergillus flavus* and *Penicillium* spp. was recorded on unsterilized seeds of white seeded variety, HURG 19 (Table 4.11). White seeded variety also harboured maximum number of

Table 4.11. Seed mycoflora of different genotypes of *rajmash* (1999-2000)

Fungi	Frequency of the different fungi					
	HURG 19 (white seed)		ET 8497 (red-white mottled seed)		HURG 12 B (Dark red purple seed)	
	*US	*SS	US	SS	US	SS
A. flavus	40	0	13.33	-	20.00	3.33
A. niger	30	0	33.33	-	6.67	-
Alternaria spp.	3.3	0	-	-	13.33	-
Curvularia spp.	6.67	10	3.33	-	-	3.33
Penicillium spp.	53.33	3.3	30.00	-	13.33	-
Fusarium spp.	10.0	-	-	-	6.67	-
Chaetomium spp.	3.33	-	-	-	-	-
Cladosporium spp.	6.67	-	-	-	3.3	-
Helminthosporium spp.	3.33	3.3	-	-	-	-
Periconia spp.	3.33	-	-	-	-	-
Nigrospora spp.	-	-	-	-	-	-
Rhizopus spp.	3.33	-	-	-	-	-
Mycelia sterilia (white)	-	-	6.67	-	-	-
Mycelia sterilia (dark coloured)	-	-	-	-	-	-
Unidentified	-	-	-	-	13.33	-

* US = unsterilized, SS = sterilized

fungal genera as compared to varieties with red and white mottled and dark purple red seeds. Surface sterilization of seed with 2% sodium chlorite for 2 minutes reduce the fungi population substantially. These results indicated that seed coat colour had a marked influence on the seed mycoflora. White seeded genotypes appear to harbour more number of fungal species in higher frequency as compared to dark red-purple, red-white mottled, and black coloured seeds.

E. Pigeonpea

The major diseases causing enormous losses to pigeonpea are Fusarium wilt (*Fusarium udum*), sterility mosaic (Pigeonpea sterility mosaic virus) and phytophthora blight (*Phytophthora drechsleri* f. sp. *cajani*). Under specific situations, cercospora leaf spot (*Cercospora* spp.), stem canker (*Macrophomina phaseolina*), alternaria blight (*Alernaria alternata, A. tenuissima*) and powdery mildew (*Leveillula taurica*) also cause significant damages to the crop.

Wilt, sterility mosaic and phytophthora blight have been identified as major problems in *kharif* crop while sterility mosaic and alternaria blight in pre-*rabi* pigeonpea. Major research achievements at IIPR made under different projects on these diseases are described in the ensuing paragraphs:

Fusarium wilt (*Fusarium udum*)

Economic importance and epidemiology: In the main *kharif* crop sown during the second fortnight of July, wilt usually appears 65-70 days after sowing (DAS) and attains maximum severity 180-210 DAS when the crop is in podding stage. Infection has, however, been recorded as early as 18 DAS under high inoculum and congenial conditions. Yield losses in pigeonpea genotypes varying in susceptibility / resistance have been computed as

Y1 = 1.452 + 0.747 x1 (7.9% in resistant varieties)

Y1 = -8.228 + 1.023 x1 (12.6% in moderately resistant varieties)

Y1 =-5.545 + 1.027 x1 (85.4% in highly susceptible varieties)

Being primarily soil borne, incidence of pigeonpea wilt depends on physical, chemical and biological conditions of soil and type of host response. Studies at IIPR have shown that 20-25^{0}C soil temperature at 15 cm depth and 10-12% soil moisture at 1200 hrs are optimum conditions for disease development. The disease incidence mainly depends on saprophytic activity and survival of inoculum in soil, which is favoured by the presence of host substrate or stubbles. Thus, the disease incidence increases when susceptible varieties are grown in the infested soil continuously.

Studies on the survival of *F. udum* revealed that the fungus survives in soil throughout the year. Survival of the fungus through seeds has been 5-8% in diseased plant of susceptible variety, Bahar. The pathogen can survive in the soil up to three years. Other factors influencing survival and infection are soil aeration, soil fertility level and presence of plant biomass. High inoculum density increases its saprophytic activity in the soil. Studies showed that wilting in susceptible variety 'Bahar' was noticed at inoculum density of above 33 cfu per g soil. Increase in inoculum to 167 cfu per g soil caused around 70% wilting.

Survival of inoculum through seeds helps not only in perpetuation but also in spread of the disease to new areas. The extent of seed transmission has been observed between 2.5 and 19.5% in different genotypes. Spread of the disease from plant to plant occurs through root contact, irrigation, rainwater and termites.

Variability in *F. udum* : Differential reaction of wilt resistant genotypes over years and locations necessitated studies on the pathogenic variability in *F. udum*. Initial studies revealed occurrence of three variants of *F. udum* from IIPR and adjoining areas of Kanpur Dehat district in Uttar Pradesh. Subsequent studies under the ambit of the "National Network Project on wilt of crops" coordinated by the Institute has assessed the extent of variability using 716 isolates representing the national collection. Based on the cultural and morphological characteristics and relative pathogenicity, 31 distinct clusters of isolates were identified. Using a set of pigeonpea differential genotypes, representative isolates have been grouped into five distinct variants. Prevalence of all the five variants has been indicated in different districts of Uttar Pradesh (Tables 4.12 and 4.13).

Table 4.12. Reaction of pigeonpea differentials to representative isolates of *F. udum* (2000-01)

Genotype	Wilt reaction					
	Strain 1*	Strain 2*	Strain 3*	F3 (Variant 2)	F8 (Variant 4)	F17 (Variant 5)
ICP 2376	S	S	S	S	S	S
C 11	R	S	S	S	R	S
ICP 8863	R	R	S	R	R	R
ICP 9174	R	R	R	R	S	S
	Gwalior Akola N-Isolate	Dholi Kanpur Varanasi Bangalore	Patancheru Rahuri Badnapur Gulbarga	Kanpur	Kanpur	Kanpur

* Reported earlier under ICAR-ICRISAT collaborative programme

Table 4.13. Variability of *F. udum* in Uttar Pradesh

Variants	Districts
1	Sultanpur, Lucknow, Basti, Jaunpur, Kasuambi, Bahraich, Sitapur, Kanpur (IIPR)
2	Kanpur (IIPR)
3	Mirzapur, Badaun, Shahjahanpur
4	Kanpur (IIPR)
5	Kanpur Dehat, Varanasi, Banda

Studies on molecular characterization through DNA fingerprinting were undertaken with an objective to find out species and variant specific markers in *F. udum*. Initially, the protocol for RAPD and SSR amplifications was standardized. Subsequently, 24 *F. udum* isolates from different districts of U.P. were studied. With RAPD primers, 21 isolates were grouped in two main clusters and three isolates from IIPR Kanpur, Sultanpur and ICRISAT (reference isolate) took independent position, indicating prevalence of five groups (Fig. 4.1, 4.2). The SSR primers differentiated these isolates into two main clusters.

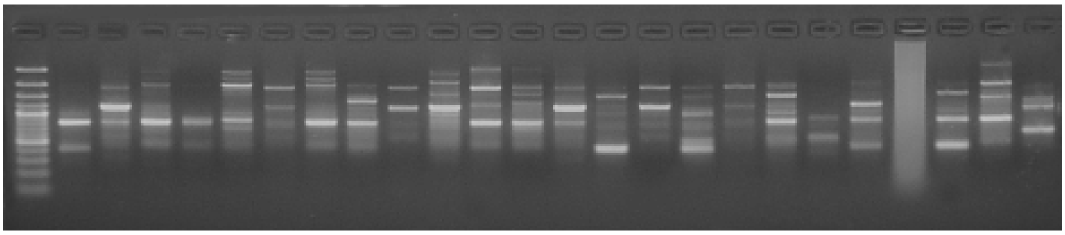


Fig. 4.1. RAPD profile of 24 *Fusarium udum* isolates using OPA 2 primer

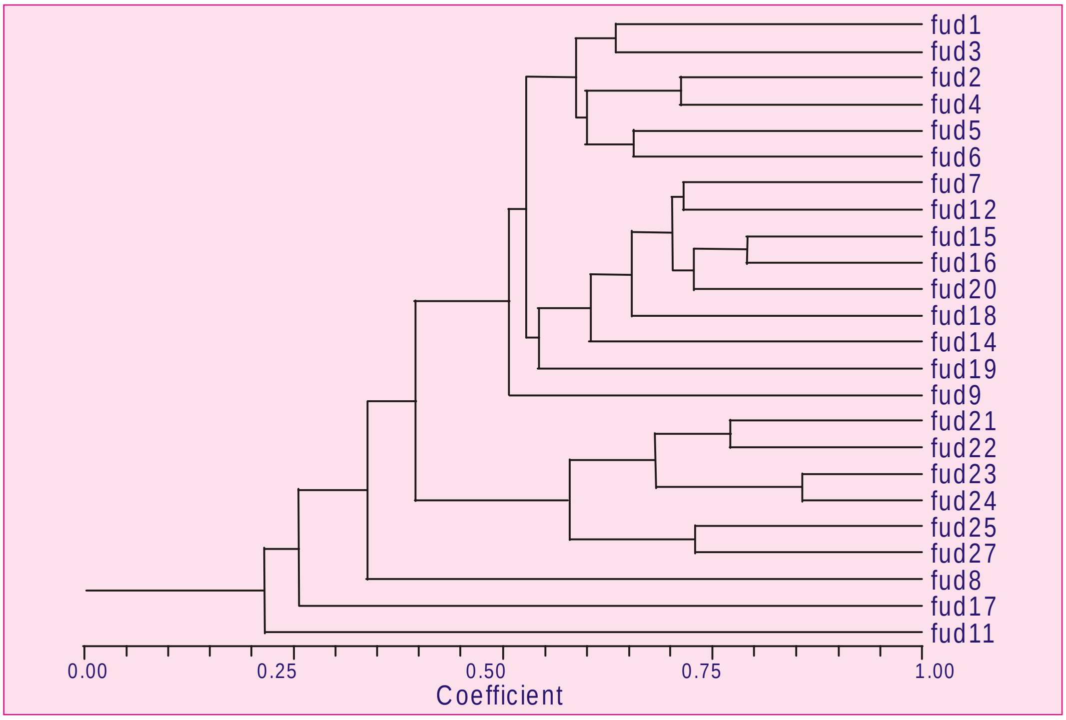


Fig. 4.2. Dendrogram showing relationship among 24 isolates of *F. udum* using RAPD primers

Further studies with 32 representative isolates of *F. udum* from U.P., Bihar, Andhra Pradesh and Karnataka using RAPD and SSR primers indicated three pathogenic variants (Fig. 4.3 and 4.4).

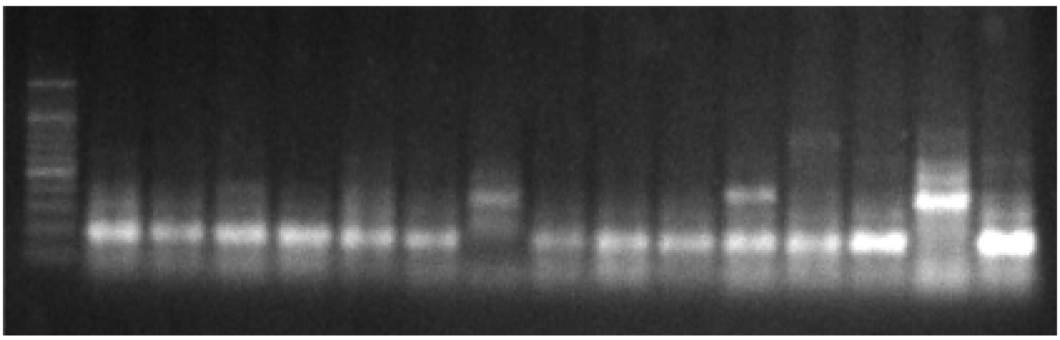


Fig. 4.3. SSR profile of 32 isolates of *F. udum* (lane 2-33) using SSR 9 primer

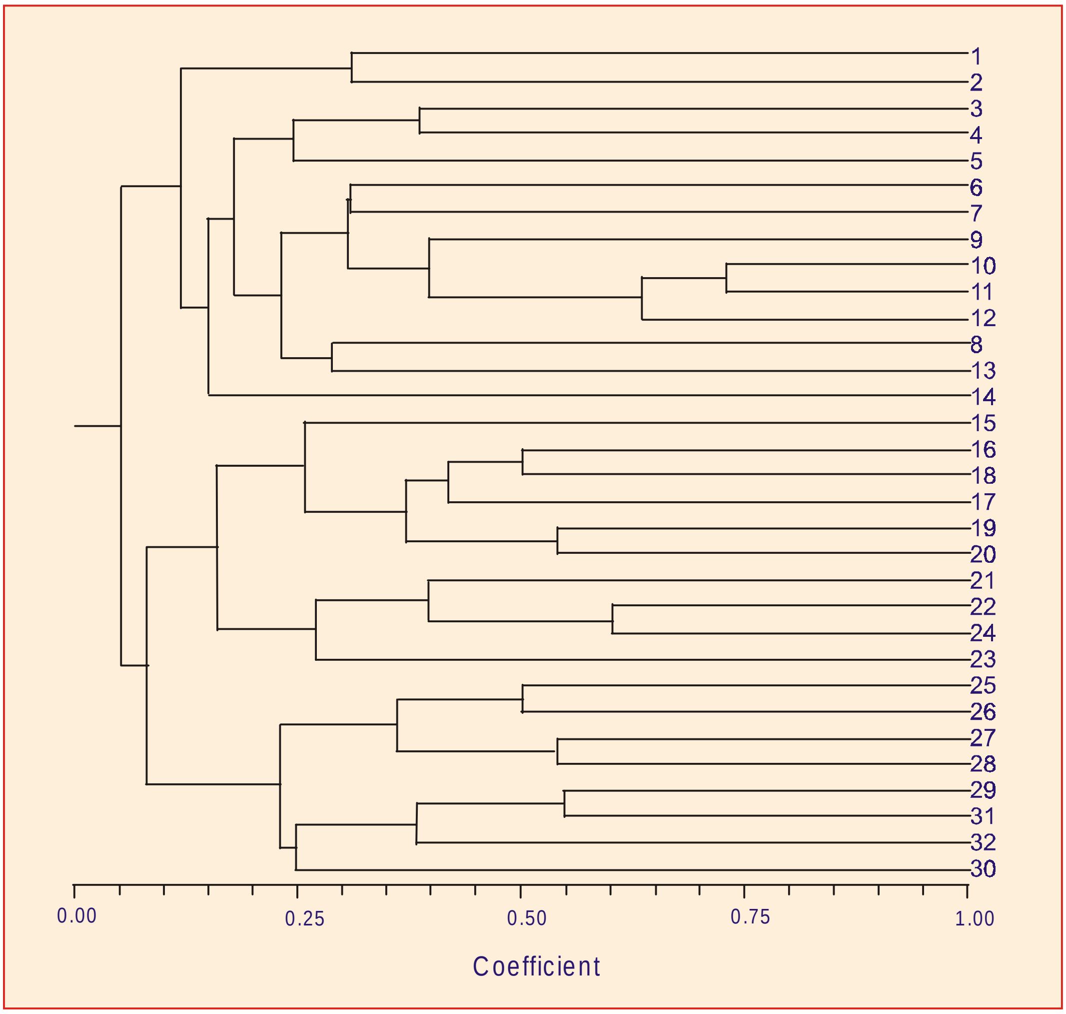
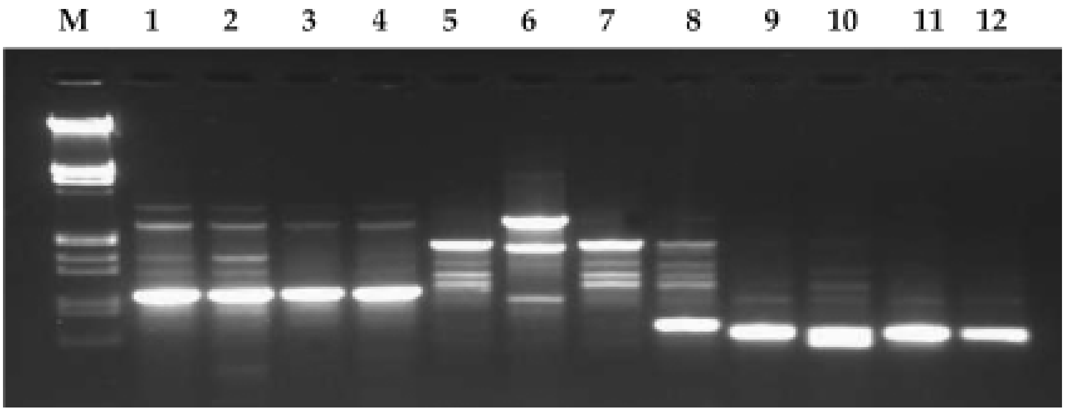


Fig. 4.4. Dendrogram showing relationship among 32 isolates of *F. udum* using SSR 9 primer

Potential markers with specific amplicon size were identified for characterization of *Fusarium* at species and *forma speciales* levels which can be developed as diagnostic marker for identification of *F. udum*, *F. oxysporum* f. sp. *ciceri* and *F. oxysporum* f. sp. *lentis* (Fig. 4.5, 4.6 and Table 4.14).



Lane M-, EcoR1 / HindIII digested l marker Lane 1-4 *Foc*, 5-8 *Fol* and 8-12 *F. udum*

Fig. 4.5. RAPD profile of different *Fusarium* isolates using primer OPI 12

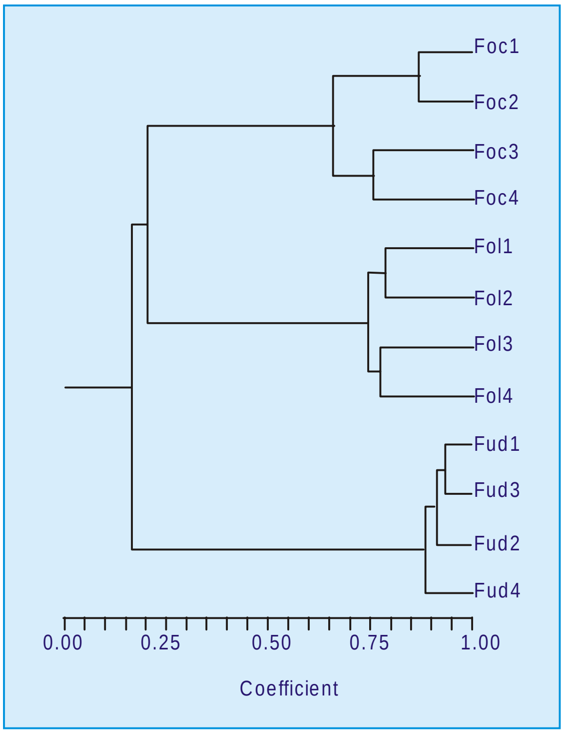


Fig. 4.6. Dendrogram showing relationships among *Foc*, *Fol* and *F. udum* using OPI 12 primer

Table 4.14. Unique amplicons to various *Fusarium* species

Primer	Size of amplicon (kb)
F. oxysporum* f. sp. *ciceri	
OPI 14	0.8
OPI 09	1.3
OPI 17	2.8
OPA 08	1.7
OPA 13	2.1
OPX 07	0.7
F. oxysporum* f. sp. *lentis	
OPA 11	0.6
OPI 08	1.0
OPI 12	2.0
OPX 08	2.2
F. udum	
OPI 09	0.6
OPA 06	0.9
OPI 17	1.3

Another study with 12 isolates of *Fusarium* belonging to different sections (Elegans, Laseola, Mortiella, Discolor, Gibbosum, Lateritium and Sporotrichiolla) using ITS-RFLP indicated that *Fusarium* species are heterogeneous and most of the *forma speciales* have close evolutionary relationships. Pigeonpea wilt pathogen, *F. udum* (Section Lateritium*)* is distinct from all other isolates studied.

Management

Being primarily a soil borne disease, all those practices that reduce *F. udum* population in the soil reduce wilt incidence.

Cultural practices: Several practices like field sanitation, soil solarization through summer ploughing or using polythene sheets, green manuring, *etc*., have been found to reduce the inoculum and wilt incidence. Deep summer ploughing and removal of stubbles reduce the population build-up in the soil and thus help in wilt management (Tables 4.15 and 4.16).

Table 4.15. Population dynamics of *F. udum* in soils with and without stubbles (1998-99)

Month	No stubble	Infected stubbles	Healthy stubbles
January	3.00	5.00	3.67
April	2.67	6.22	5.55
July	4.00	6.67	5.22
October	3.67	4.55	4.33
December	7.67	9.55	9.33
% increase over initial inoculum ($25x10^3$ cfu / g soil)	206.8	282.2	273.3

Table 4.16. Population dynamics of *F. udum* at different soil strata and crop stages

Cropping stage	Cfu (in ‘000/g soil)			Mean
	15 cm depth	15-30 cm depth	30-45 cm depth	
1st crop sowing	2.44	1.86	1.38	1.89
1st crop harvesting	5.88	3.16	2.96	3.99
2nd crop sowing	7.88	5.77	4.63	6.09
2nd crop harvesting	14.05	9.52	6.83	10.13
% increase	475.8	411.8	394.9	-

Crop rotation and mixed cropping are the traditional practices of wilt management. Our studies proved usefulness of intercropping with sorghum (1:1 ratio) in reducing wilt incidence. Leaving sorghum stalks in field after the cob harvest further improves the efficacy. Studies on the root exudates of sorghum revealed its higher fungicidal activity against *F. udum* and other soil borne pathogens. The fungicidal fraction of sorghum root exudates showed its resemblance with carbendazim group of fungicides.

Host plant resistance: Standardization of reliable and less expensive field and pot screening technique has resulted in screening of >4000 accessions at Kanpur and over 11,000 under AICRP and other collaborative programmes. This has led to identification of a large number of resistant sources to key diseases (Table 4.17) which have been utilized in development of wilt resistant varieties. These varieties should form the centre of integrated management of the disease.

Table 4.17. Stable sources of resistance to major diseases in pigeonpea

Disease	Resistance sources
Fusarium wilt	ICP Nos. 4769, 7118, 7182, 8859, 8862, 8863, 9120, 9168, 9174, 9177, 10269, 10958, 11299, 12731, 12745, 12748, 12758, ICPL Nos. 3, 8343, 84008, 88047, 89048, AWR 74/15, BWR 254, BWR, 370, Banda Palera, GPS Nos. 30, 33, 36, 52, Sharan 1-21, Sujata 1-2, DPPA Nos. 85-2, 85-3, 85-13, 85-14
Sterility mosaic (SM)	ICP Nos. 6997, 7035, 7197, 7234, 7867, 7998, 8094, 8362, 8862, 10976, 10977, 10996, 11049, 11204, 11206, 11207, 11231, 11297, BSMR 1, BSMR 2, Bahar, DA 11, Purple 1, KA 32-1, Pusa 14, ICPL Nos. 335, 342, 366, 83024, DPPA Nos. 85-2, 85-13, 85-14, 85-15, PDA 2, BWR 159, PI 397430, PR 5149
Phytophthora blight (PB)	KPBR 80-2-1, KPBR 80-2, KPBR 8-2-2, ICP 8103, 9252, 10958
Multiple disease resistance (Wilt+SM)	ICP 4769, 7035, 7867, 8860, 8862, 9174, 11297, PR 5149, PI 397430, DPPA Nos. 85-11, 85-12, 85-13, 85-14, BWR 159
Multiple disease resistance (SM+PB)	ICP 8103, KPBR 8-2-2, KPBR 80-2
Multiple disease resistance (Wilt+SM+PB)	KPL 43, KPL 44, KPL 45

Among these sources, KPL 43 and KPL 44, selections from open pollinated bulk of 'Bahar' have resistance to wilt and sterility mosaic and tolerance to phytophthora blight. Four selections *viz*., DPPA Nos. 85-2, 85-3, 85-13 and 85-14 have been identified as resistant sources to both wilt and sterility mosaic diseases.

Chemical control: Seed treatment with a combination of carbendazim and thiram (1:3 g/kg seed) has been found very effective in reducing seedling wilt and is recommended as one of the important components of integrated wilt management.

Biological control: Over 25 antagonists are reported effective against *F. udum* in

India. Studies at IIPR have shown that consistency of *Trichoderma harzianum* and *T. viride* although effective is low against pigeonpea wilt. Their sensitivity to high temperature regimes prevalent in the pigeonpea ecosystem necessitates identification of temperature tolerant strains of the antagonist. Preliminary studies initiated at the Institute resulted in identification of few native strains of *Trichoderma* spp. with high temperature tolerance.

Integrated management: Based on studies conducted at IIPR, an integrated module has been developed which is practicable and adaptable by farmers (Table 4.18).

Table 4.18. Integrated management module for pigeonpea wilt

Component	Operations
Field	Wilt free – No pigeonpea for last 3 years
Soil	Solarization – deep summer ploughing
Seed	Treatment with carbendazim + Thiram (1:3 g / kg seed)
Cropping system	Mixed / Intercropping with sorghum
Tolerant varieties	Narendra Arhar 1, Amar
Sowing time	Late sowing

Phytophthora blight (*Phytophthora drechsleri* Tucker f. sp. *cajani*)

Until recently, phytophthora blight (PB) was considered to be a local problem in North East Plain Zone. However, it has become a regular feature under excessive soil moisture conditions in some other parts of the country. In central U.P. (Kanpur and adjoining areas), infection was more at seedling stage (up to 40 DAS). Studies on this disease have mainly been conducted on epidemiology and management.

Epidemiology: Weekly observations on PB incidence revealed that disease appears 25-30 DAS on both short and long duration varieties. Relationship of disease with weather parameters indicates that disease development is mainly influenced by minimum temperature and number of rainy days. A minimum temperature range of 21-25^{0}C and 3-5 rainy days in the preceding week result in disease epiphytotics. Correlation studies also substantiated that minimum temperature, rainfall (RF), number of rainy days (RD) and relative humidity (RH) in current and preceding weeks (lag 1) are positively correlated under two dates of sowing (Table 4.19).

Table 4.19. Significant weather factors influencing phytophthora blight incidence

Date of sowing	Variety	Significant weather factor
19 July	Bahar	Min T_{curr}, RF_{curr}, lag $_1$ lag $_2$, RD_{curr}, RH_{curr}
	Type 7	MinT_{curr}, RF lag $_1$ lag $_2$, RD_{curr}, RH_{curr}
23 August	Bahar	Min T_{curr}, RF lag $_1$ lag $_2$, RF_{curr}, lag $_1$, RH_{curr} lag $_1$ lag $_2$
	Type 7	Min T_{curr} lag $_1$, RF_{curr}, lag $_1$ lag $_2$, RD_{curr}, RH_{curr} lag $_1$

Management

Cultural practices: Since PB infection is highly influenced by excessive soil moisture, avoiding water accumulation in fields has been found to significantly reduce the disease incidence. Sowing of pigeonpea on ridges made in the direction of slope is recommended for its effective management.

Host plant resistance: Unlike wilt and sterility mosaic, resistance to PB could not be identified in the existing germplasm. A significant progress has been made at IIPR in identification of sources with moderate resistance to PB by selection through open pollinated bulk of pigeonpea genotypes. As many as 15 selections consistently showed moderate resistance to PB for the last six years. These are OPA-PB nos. 7-1-1, 7-1-7, 7-2-1, 7-2-2, 7-2-7, 8-1-1, 8-1-5, 8-1-9, 8-1-11, 8-1-14, 8-1-17, 8-1-19, 33-2, 227-1, 55-2 and KPBR 80-2-1 (R-check).

Chemical control: Due to frequent rains at the time of disease epiphytotics, spraying with chemicals like metalaxyl, dithiocarbamates have been found ineffective against the disease at Kanpur. However, seed treatment with metalaxyl @ 3g / kg of seeds reduces seedling blight to some extent. A combination of seed treatment and ridge sowing has been recommended for effective management of PB.

Sterility mosaic (Pigeonpea sterility mosaic virus)

The sterility mosaic (SM) disease caused by pigeonpea sterility mosaic virus and transmitted by eriophyid mite (*Aceria cajani*) is of great economic importance in high endemic areas of U.P., Bihar, Gujarat, Tamil Nadu and Karnataka. The disease was very serious until 2002 at Kanpur and Kanpur Dehat district. In recent years, it has almost become extinct possibly due to wide scale cultivation of resistant varieties like Bahar. However, it is still a serious threat in eastern U.P.

Epidemiology: Survival of the pathogen and its vector during off-season (April to June) is not clearly understood. Our studies confirmed the survival of vector (*A. cajani*) on perennial pigeonpea plants during summer months. The vector predominantly survives in the vegetative buds and growing points by hiding in the relatively cooler space as a result of continued trans-evaporation. Main pigeonpea crop raised during July gets the primary inoculum from such plants. Secondary infection takes place due to repeated cycles of inoculum produced during July to April when the crop remains in field. The vector and disease are further carried in the late sown (September) pre-*rabi* crop for 8-9 months up to April–May which incidentally gets maximum SM infection. Based on this information, a possible disease cycle operating in North India has been suggested.

Weather conditions influence the mite population to a great extent. At Kanpur, high population build-up of the vector is recorded during September to November with consequent build-up of maximum disease. A minimum and maximum temperature of 10-25^{0}C and 25-35^{0}C and relative humidity above 60% have been found congenial for vector build up. These conditions usually prevail during September to November.

Nearly 45% of the total mite population was recorded in the lower one-third portion of the plant followed by 35% in upper and 20% in the middle parts of the plant. More than 90% mite population occurred on lower (ventral) surface with even distribution on the entire leaf blade. Based on these results, a sampling technique for uniform and quick estimation of *A. cajani* population on pigeonpea plants in the field is developed for population studies of the vector. The technique includes sampling of 15 trifoliates (7 from lower stratum and 4 each from middle and upper strata) and counting the mites under 40x in a stereo binocular. For quick observations, counting of mites on smaller squares of disc of 5 mm area is suggested. A very high vector population is invariably noticed in SM diseased plant as compared to healthy ones. Resistance to SM seems to be related with resistance to the vector in our studies with 10 pigeonpea genotypes.

Pathogenic variability: Collaborative studies with ICRISAT have indicated prevalence of five variants of SM pathogen in the country. Isolate from Gwalior has been designated as Variant 1; Badnapur, Patancheru, Varanasi as Variant 2; Coimbatore, Kumarganj, Puddukkotai as Variant 3 and Bangalore, Dholi, Pantnagar as Variant 4. At Kanpur, Variants 3 and 5 have been indicated. Further studies are, however, required to elucidate the extent of variability in SM pathogen.

Management

Host plant resistance: Massive screening of 4000 accessions at IIPR has resulted in identification of 45 resistance and 69 moderately resistance sources to SM. Among these, 37 accessions have exhibited stable resistance over years and locations. Some of these sources like Bahar and ICP 7035 have been widely used as donors for developing resistant varieties.

Chemical control: Limited success has been achieved to reduce SM incidence by controlling the vector. Spraying of metasystox and dimethoate @ 0.1% has been found effective in controlling the vector.

F. Mungbean and Urdbean

Yellow Mosaic disease and Cercospora leaf spot (CLS) were found to be the serious threats to mungbean and urdbean cultivation in early eighties. In spite of concerted efforts during the past 25 years, these two diseases still remain the potential threats to these crops along with emergence of new diseases in certain areas. The past studies at IIPR include standardization of screening techniques, identification of stable sources of resistance, estimation of yield losses, epidemiology, pathogenic variability in MYMV, and other components of integrated disease management (IDM) like cultural practices and chemical control. The research findings emanated during the past 25 years are presented below:

Yellow mosaic disease

Yellow Mosaic disease caused by mungbean yellow mosaic virus (MYMV) is the most destructive disease of mungbean and urdbean and is widely prevalent in the country.

Yield losses: The incidence of yellow mosaic disease in mungbean and urdbean at farmers' fields is estimated to be low to very high in different districts of Uttar Pradesh. Epiphytotics of MYMV in Bundelkhand region during 2000-02 caused 100% loss. The disease is most destructive with above 90% incidence in *kharif* season. Green seeded urdbean appeared to be more prone to MYMV compared to black seeded types.

The extent of losses depends on severity of the disease and genotype. Studies showed that major setback to pod formation and yield in urdbean occurred above 25% disease intensity. The disease also causes delay in pod maturity. In severely infected crop, MYMV caused as high as 52.6% yield loss in mungbean. In highly susceptible genotypes, MYMV infection rendered the crop unproductive. Studies showed that yellow mosaic disease appears within two weeks of sowing and attains maximum severity at 45-60 DAS.

Pathogenic variability: Mungbean varieties when subjected to multilocation testing did not show uniform reaction to MYMV. The varieties found resistant or tolerant at one location were susceptible at other locations and *vice-versa*. This indicated the possibility of existence of strains in MYMV. Keeping this in view, selected mungbean genotypes were screened at Kanpur and Vamban. The results showed varying reaction of mungbean genotypes, T 44, RMG 62, Pratap, LGG 407, CO 6 and Vamban 1 at these two locations, suggesting prevalence of strain variation at Vamban and Kanpur (Table 4.20).

Table 4.20. Reaction of mungbean genotypes against MYMV

Genotype	Disease reaction	
	Kanpur	Vamban
PDM 139	R	R
MUM 2	MR	R
Pusa 9531	MS	MS
T 44	S	R
RMG 62	S	R
Pratap	MS	R
LGG 407	S	R
CO 6	MR	R
Vamban 1	S	MR

Further studies involving mungbean and urdbean genotypes showed that MYMV strains at Kanpur and Dholi (NEPZ) appeared to be similar on mungbean genotypes but differed from the strains prevalent at Pantnagar and Ludhiana (NWPZ), which also differed from each other. In case of urdbean genotypes, Uttara, DPU 88-31, Barabanki Local and AKU 9904 showed differential reaction at Pantnagar and Ludhiana (Table 4.21). Uttara showed different reactions at Pantnagar and Kanpur against MYMV whereas DPU 88-31 showed different reactions at Pantnagar, Ludhiana and Kanpur. Reactions of urdbean lines at Vamban surprisingly resembled with those of Kanpur whereas in case of mungbean, reactions at Kanpur and Vamban varied greatly.

Table 4.21. Reaction of urdbean genotypes against MYMV at different locations

Genotype	Pantnagar	Ludhiana	Kanpur	Dholi	Vamban	Coimbatore
Uttara	5 (MS)	1 (R)	1 (R)	1 (R)	1(R)	2 (R)
DPU 88-31	3 (MR)	7 (S)	1 (R)	1 (R)	1(R)	1 (R)
PDU 1	5 (MS)	4 (MR)	5 (MS)	3 (MR)	3 (MR)	2 (R)
TPU 4	7 (S)	9 (HS)	8 (HS)	9 (HS)	8 (HS)	2 (R)
Barabanki Local	5 (MS)	2 (R)	3 (MR)	2 (R)	1 (R)	1 (R)
AKU 9904	5 (MS)	8 (HS)	8 (HS)	8 (HS)	8 (HS)	2 (R)

It is evident from the reactions of urdbean and mungbean genotypes that MYMV strains have spatial differences. Interestingly, the reactions of genotypes at a particular location also varied over years of testing. This indicates the possibility of existence of spatial and temporal diversity in MYMV strains. Molecular diversity using sequence analysis of the viral genome has recently been initiated at IIPR.

Field screening technique : Infector-row technique for field screening of mungbean and urdbean genotypes against MYMV was standardized. Success of this technique depends on the availability of a susceptible check that can be used as infector cum spreader after every two rows of test genotypes. Urdbean genotype, Barabanki Local was identified as infector cum spreader and used for many years. However, a change in the disease reaction led to identification of mungbean genotype Kopergaon as a better option for infector-cum-spreader. In order to adopt a simple and uniform scoring method, a 1-9 point scale for MYMV reaction has been developed taking both, disease incidence and severity, into account.

Management

Cultural practices: Effect of inter-row spacing on MYMV incidence in susceptible mungbean variety T 44 showed that the wider the spacing the higher is the incidence of MYMV. Crop with inter–row spacing of 40 cm had maximum incidence (75.3%), followed by 66.7% in 35 cm, 53.8% in 30 cm and 47.2% in 25 cm.

Intercropping with sorghum has been found to reduce MYMV severity in mungbean. The MYMV incidence was minimum (20.6%) in mungbean when intercropped with sorghum in 2:2 row ratio as compared to 34.6% in sole mungbean (Table 4.22). Whitefly population was also low under this treatment.

Table 4.22. MYMV incidence and vector population in different row combinations of sorghum (S) and mungbean (M) intercropping (2001-02)

Row ratio	MYMV severity (%)	No. of whiteflies/ plant
1S:2M	27.8	8.2
2S:2M	20.6	5.6
2S:4M	26.1	6.3
2S:6M	27.5	7.6
Mungbean Sole	34.6	9.6

Evaluation of 23 mungbean genotypes along with susceptible check Barabanki local (urdbean) consistantly for three years (1986 to 1988) revealed highest MYMV incidence (80.4%) in summer followed by *kharif* (37.4%) and spring (18.6%) sown crops.

Host plant resistance: Screening of urdbean and mungbean germplasm using infector-cum-spreader row technique against MYMV at IIPR has resulted in identification of stable sources of resistance (Table 4.23). Based on consistent reaction in multi-location testing over years, 12 genotypes of urdbean (NP 16, NP 19, NP 21, PLU 62, PLU 63, PLU 131, PLU 158, PLU 277, K 66-110, K 66-188, 14/5, DPU 88-31) and two of mungbean (DPM 90-1, DPM 90-2) have been identified as stable donors for MYMV resistance. These can be utilized for breeding MYMV resistant varieties.

Table 4.23. Stable resistance sources for MYMV in urdbean and mungbean

Crop	No. of entries tested	Sources of resistance
Urdbean	1412	NP 6, NP 7, NP 14, NP 16, NP 19, NP 20, NP 21, PLU 63, PLU 277, PLU 340, PLU 476, PLU 557, PLU 574, PLU 577, U 9, BR 10, K 66-110, K 66-188, 13/2, 14/5, 15/7, 31/4, 7368/4-B, DPU 88-31, IPU 94-1, IPU 94-2, IPU 2K-1, IPU 2K-7, IPU 2K-13, IPU 2K-14, IPU 2K-15, IPU 2K-21, IPU 2K-37, IPU 99-3, IPU 99-25, IPU 99-62, IPU 99-63, IPU 99-248, TU 99-85, U 797, UK 3
Mungbean	835	DPM 90-1, DPM 90-2, DMG 1045, DMG 1130-2, PDM 139, ML 131, ML 818, HUM 9, Pusa 9672, UPM 58, PSR 11495

Chemical control: Systemic insecticides, aldicarb and disulfoton @ 1 kg a.i./ha have been found effective in reducing the MYMV incidence in mungbean when applied in the soil at the sowing time. Considering the economics of these insecticides, ten and seven- fold advantage was recorded with aldicarb and disulfoton, respectively.

Integrated disease management: Although each component of disease management is efficient in controlling MYMV, but due to plasticity of MYMV, crop phenology and cropping systems, integrated management involving resistant variety, intercropping with non host crops and need based use of insecticides for controlling the vector has been devised for effective control of the disease (Table 4.24).

Table 4.24. Integrated management of MYMV in mungbean and urdbean

Resistant/tolerant varieties	Cultural method	Chemical control
Mungbean: ML 131, ML 267, ML 337, Pant mung 1, PM 2, PM 3, PM 4, PM 5, PDM 54, PDM 139, Meha, PDM 11, BM 4, MUM 2, Narendra Mung 1, HUM 1, Pusa 9072, TARM 1, Pusa 9531, Pusa Bold 1, Ganga 8 **Urdbean:** Uttara, Pant U 19 (PU 19), PU 30, UG 218, PDU 1, Vamban 1, TU 94-2 (*rabi*), Narendra Urd 1, WBU 108, LBG 17 (*rabi*), VB 3, WBG 26, KU 92-1, KU 300	• Inter/mixed cropping of mungbean and urdbean with sorghum, pearl millet and maize. • Destruction of affected plants as soon as noticed in the field. • Adjustment of sowing dates to avoid the disease.	• Application of phorate or disulfoton granules @ 1-2 kg a.i./ha in furrows at sowing • Foliar spray of metasystox, malathion (0.1%), anthio (0.2%), dimethoate (0.02%), monocrotophos (0.05%) at the initiation of disease and subsequently at 10-15 days interval as per disease pressure.

Cercospora leaf spot

Cercospora leaf spot (CLS) causes severe leaf spots and premature defoliation in mungbean and urdbean under warm and humid climates. The disease is incited by two species of *Cercospora viz*., *Cercospora canescens* Ellis & Martin and *C. cruenta* Sacc. (*Mycosphaerella cruenta* Latham) and is most prevalent during the rainy season. Of the two species, C. *canescens* is more prevalent.

Yield losses: Extensive surveys carried out to study the disease status in mungbean and urdbean in different districts of U.P. during *kharif* seasons showed that CLS severity varied from traces to 70% at different places, highest being at Aliapur block, Ghatampur (Kanpur Dehat). In a CLS susceptible mungbean variety, Narendra Mung 1, yield losses varied from 17.7 to 51.4% depending on the severity of the disease. Studies revealed that the maximum yield loss (51.4%) occurred at 86.1% disease index (PDI).

Epidemiology: Studies showed that the mean temperature of 23.3-33.2^{0}C, relative humidity 73-86%, sunshine hours (> 6 / day), more rainy days and intermittent rains are most conducive for the rapid development and high incidence of CLS disease.

Morphological characterization: Morphological studies of *C. canescens* isolates from Kanpur and Varanasi showed that Kanpur isolate has conidiophores and conidia of varying size (25-172 x 3-6 µm, 54-224 x 3-6.5 µm) and septation (2-7, 3-15) while conidiophores of Varanasi isolate ranged from 20-175 x 3-6.5 µm with 1-7 septa and conidia from 50-225 x 3.5-5 µm with 3-20 septa. Both the isolates were identical in size and septation of conidia and conidiophores.

Standardization of field screening technique: Isolation of the CLS pathogen is not easy since *Cercospora* spp. sporulates with difficulty in natural or semi-synthetic media. Hence, work on disease resistance mainly depended upon field screening. Concerted efforts were made to develop and standardize an efficient field screening technique for mass scale screening of mungbean and urdbean germplasm to identify sources of resistance. Infector row technique was adopted using highly susceptible mungbean variety, Kopergaon as infector–cum-spreader row after every two rows of a test entry grown in 3-5 m row length. For creating high disease pressure, the inoculum is obtained by macerating the CLS infected leaves incubated in moist chamber or on moist blotting paper in Petri dishes at 25^{0}C for 48 hours to allow the pathogen to sporulate profusely. The field is properly irrigated prior to spraying inoculum. To maintain high relative humidity in screening nursery, sprinkler-spray system is used at one hour interval during day time for 2-3 weeks. For recording the reactions of test entries, a 1-9 point rating scale has been devised.

Management

Cultural practices: Studies on the effect of sowing date on the incidence of CLS in a susceptible mungbean cultivar, Narendra Mung 1 revealed that early planting (2nd week of July) contracted high per cent disease index (78.2%) as compared to late sowing (2nd week of August). Another study revealed that closer the spacing in mungbean, the higher was the incidence of CLS. Maximum incidence (80.7%) occurred in crop with intra-row spacing of 5 cm in 30 cm spaced rows followed by 55.5% in 10 cm and 46.7% in 15 cm. Minimum incidence (27.2%) was observed in crop with 20 cm intra-row spacing.

Observations on the effect of hand weeding on CLS incidence in mungbean variety Narendra Mung 1 revealed that percent disease index (PDI) was high (74.8%) with two hand weedings carried out at 25 and 40 DAS as compared to no weeding (55.4 PDI).

Host plant resistance: Sources of resistance to CLS have been identified in mungbean and urdbean under natural and artificial epiphytotic conditions. Screening of 865 genotypes of mungbean and 484 of urdbean using infector-cum- spreader technique resulted in identification of 17 donors in urdbean and 15 in mungbean. Rigorous testing for four years (2004-07) under artificial epiphytotic conditions narrowed down these to five mungbean (ML 515, BM 4, CO 4, CO 5, TM 98-50) and three urdbean (K116-86, NP 6, NP 19) genotypes with stable resistance to CLS. These genotypes can be utilized for development of resistant varieties.

Chemical control: Seed treatment with carbendazim @ 1 g / kg seed has been found effective in reducing the primary inoculum. Studies revealed that four sprays of carbendazim at 10-day interval, beginning at 30 DAS proved most effective with <5% CLS intensity. The highest cost : benefit ratio (1: 5.5) was observed with one spray of carbendazim (0.025%) at 30 DAS which reduced CLS intensity by 60% and increased the yield by 257 kg / ha. Although foliar spray of carbendazim is effective in controlling the disease, but its application increases crop duration by more than a week.

In a recent study in mungbean, mancozeb, carbendazim, metalaxyl + mancozeb, thiophanate – methyl, propiconazole and difenconazole were all found effective in controlling the CLS incited by *C. canescens* and *C. cruenta*. However, minimum disease severity (9.3%) and maximum disease control (87.6%) were recorded in the foliar application of 0.025% thiophanate-methyl followed by carbendazim with 11.2% disease severity and 85.0% disease control.

Integrated disease management: Integrated management of CLS combining host plant resistance, cultural practices, seed treatment with fungicide (carbendazim @ 1g/kg seed) and need based foliar sprays of fungicide (thiophanate-methyl or carbendazim 0.025%) at 30 and 45 DAS has been advocated.

4.2 Insect Pests

A. Chickpea

Chickpea suffers from ravages of about a dozen insect pests, but only a few, namely gram pod borer (*Helicoverpa armigera),* gram semilooper (*Autographa nigrisigna),* gram caterpillar (*Laphygma exigua),* cut worm *(Agrotis ipsilon)* and termites (*Odontotermes* spp.) are of economic importance. Entomological research at IIPR has been confined to these insect pests with major emphasis on damage assessment, biology, ecology and management.

Gram pod borer, *Helicoverpa armigera* Hubner

Gram pod borer is the most important insect-pest of chickpea and extensive work has been carried out on its various aspects. It is polyphagous in nature. Regular surveys carried out in farmers' fields in Uttar Pradesh revealed 15% damage in chickpea due to this pest.

Damage assessment: Information on the extent of losses caused by *H. armigera* on chickpea was assessed in Bundelkhand region during 2003. Pod damage (12-20%) in Jhansi was highest followed by Jalaun (10.7%) and Hamirpur (9.3%). Outbreak of *H. armigera* in different parts of UP during 1995-96 took a heavy toll of chickpea. It was found that larvae damaged leaves, tender shoots, apical tips, flower buds and pods with the larval count ranging from 70-90 per 15 plants and yield losses ranged from 75 to 90%. The economic threshold level (ETL) has been estimated as one larva per meter row of chickpea.

Biology: Detailed works on biology of *H. armigera* at IIPR showed great variation in larvae colour depending on the host. It can be yellow, green, pink, orange, brown, black, *etc*., with light and dark longitudinal strips along the side of the body. Eggs laid singly are yellowish white and glistering at first, which change to dark brown before hatching. The young larvae feed by scrapping green tissues and old larvae bore into locules and consume the developing grains. The incubation, larval and pupal periods last for 3 to 4, 12 to 16 and 6 to 10 days, respectively under normal conditions. The larva passes through 5 to 6 instars. A single larva can eat 8-17 pods in its lifetime. Fully grown-up larvae drop on the ground and enter the soil 2 to 6 cm deep for pupation in earthen chamber, which last for 6 to 10 days. Studies on moth survival and fecundity indicated that *H. armigera* could survive up to 9 days and oviposite 192 eggs during March. Pupal diapause reported probably for the first time has helped in understanding the population influx and abrupt increase in pheromone trap catches during the post winter months. Pupae of *H. armigera* undergo facultative diapause during December to February (winter months) with a maximum of 110 days in comparison to normal pupal period of 6 to 10 days. With the start of warm weather, the diapause is broken and moth emerges out. This diapausing population is most important as it coincides with pod stage of chickpea and causes maximum damage in and around Kanpur.

Population dynamics: In and around Kanpur, *H. armigera* has been found to survive on eight cultivated crops *viz*., chickpea, pigeonpea, tomato, sorghum, sunflower, pearl millet, okra and maize beside some weeds like *Chenopodium album, Croton sparciflorus, etc*. After the harvest of chickpea, the pest survives on tomato, okra and summer sunflower during late April and early May. During August and September, it is found feeding on maize cobs. After the harvest of these crops, the pest migrates to short duration pigeonpea. During these periods, it also infests sorghum and pearl millet. The larvae feed on foliage and pods of chickpea from late October till April. The survival of pest during hot summer months is still not clearly understood.

On chickpea, pod borer larvae are found throughout the crop season *i.e.*, 45th standard week (middle of November to last week of April (17th standard week)). They feed on the foliage during early growth stage and later on damage the pods by inserting half of their body to feed on the developing grains. There have been two major peaks in its population: first during vegetative phase (2.5-6 larvae / m row length) between 47th and 52nd standard week and second during reproductive phase (2.25-3.75 larvae / m row length) between 8th and 11th standard week. Gram semilooper, *Autographa nigrisigna* occurs simultaneously alongwith gram pod borer. A typical relation has been found between the two species. This pest is usually active from 47th to 16th standard week, but its peak is reversed to that of *H. armigera.* The pest disappears from the crop when the pods are hardened. Another pest, *Laphygma exigua* is also found in early growth stage. However, its population remains low throughout the chickpea-growing period.

Studies have been conducted on influence of abiotic factors on relative abundance of *H. armigera* larvae. Observations on larval count in field and its correlation with prevailing weather factors for seven years (1981-88) showed that maximum (r = +0.73) and minimum (r = +0.69) temperatures have positive effect on population build up of the larvae while relative humidity (r = -0.69) adversely affects it.

Monitoring and forecasting: Detailed work on traps (both light and pheromone) to monitor the population of insect pests of chickpea showed that a trap supplied by Ecomax with pheromone lure of NRI (London) was most efficient. Monitoring of pod borer population through sex pheromone trap for more than a decade at IIPR, has clearly revealed that during post winter months, increase in catches of 4-5 male moths per trap per night (usually 9^{th}-10^{th} standard week) as ETL of *H. armigera* larvae within 15-20 days. This finding serves a very good tool for immediate forewarning of this pest. Analysis of 14 years data (1982-83 to 1997-98) on the influence of abiotic factors in relation to weekly pheromone trap catches revealed that minimum and maximum temperatures and winter rainfall have great influence on the pest population at Kanpur.

Management

Cultural practices: Efforts have been made to assess the effect of various agronomic practices on pest incidence. Results indicated that the early sown chickpea crop (October) has minimum pod damage (21.7%) while delay in planting causes a gradual increase in pod damage with as high as 34.8% in December sown crop. Similarly, planting chickpea at close spacing (30 x 5 cm) results in higher incidence (17.1%) of *H. armigera* as compared to wide spacing of 40 x 20 cm and 40 x 10 cm (7.8 and 10.1%).

Intercropping of chickpea with wheat, barley, linseed and mustard has been found to reduce pod damage. The minimum pod damage was recorded with chickpea + linseed (18.18%) and chickpea + wheat + linseed (18.61%) as against the maximum of 28.86% in chickpea alone. Wheat, mustard and linseed offer better protection to chickpea when sown at two rows interval than at three or four rows interval. Two rows of chickpea intercropped with one row of linseed or mustard resulted in least pod damage (2.38, 2.98%) as against 9.25% in chickpea alone.

Studies indicated that phosphorus and potash individually reduce the infestation of *H. armigera* in chickpea. However, the effect of these two nutrients is masked when combined with nitrogen. Application of nitrogen and zinc has been found to enhance the infestation.

Host plant resistance: Although considerable differences in susceptibility of chickpea genotypes have been found, only a few genotypes showed low to moderate tolerance to *H. armigera*. Screening of more than 3000 lines in natural conditions has led to identification of 32 genotypes with tolerance, the important ones being PDE 2, PDE 3-1, BG 261, Parivar 4-1, PDE 5 and PDE 5-1.

Chemical control: Screening of novel and potent insecticides under laboratory condition has led to identification of profenophos, chlorpyriphos, acephate, benfuracarb, ethofenprox, pyraclofos, asymethrin, lambda cyhalothrin and fenvalerate for effective control of pod borer. Lambda cyhalothrin (Karate) at 80 ppm caused >90% mortality (2nd instar) as against >80% and >60% with endosulfan and deltamethrin, respectively. Similarly, Pyraclofos (0.1%) with 98.33% mortality was on par with endosulfan (96.67%).

Two applications of endosulfan (0.07%), quinalphos (0.05%) or carbaryl (0.2%) at pod initiation and full podding stages have proved highly effective against pod borer infestation. Among dust formulations, application of cypermethrin dust @ 25 kg / ha reduced the pod damage (23%) which was on par with chlorpyriphos dust @ 20, 25 and 30 kg / ha. This was followed by fenvalerate (0.4%) dust. Field evaluation of new insecticides for six years (1994-99) revealed effectiveness of Alanycarb (0.1%), acephate (0.04%), lufenuran (.04%), asymethrin (0.04%), benfuracarb 0.04%, radar 0.04%, polytrin C (0.005%) in controlling pod borer damage (8.4 –14.5%). Among 11 insecticides including some new molecules with different mode of action, the best treatment was Match (3.65% pod damage) followed by acephate (4.6%), chlorpyriphos (5.0%) and ethofenprox (5.6%). Chlorpyriphos, acephate and karate resulted in 7-8 times better realization of profit (Table 4.25).

Table 4.25. Evaluation of insecticides against *H. armigera* in chickpea (1998-2001)

Treatment	Pod damage (%)	Yield (kg/ha)	CBR
Chlorpyriphos	5.0	2161	1:8.61
Spark	6.3	1998	1:3.59
Match	3.6	2389	1:6.76
Endosulfan	5.3	2043	1:7.41
Cartaphydrochloride	7.3	1929	1:6.55
Acephate	4.6	2299	1:8.10
Ethofenprox	5.6	1559	1:2.65
Karate	7.6	1880	1:7.84
RH 2485	8.3	1757	1:4.81
Curacron	8.6	1670	1:4.94
Ethion	9.0	1540	1:3.21
Control	16.0	1224	-

Pesticide application technology: In rainfed areas, there is scarcity of water at the time of peak pest activity and it becomes difficult to apply chemicals through traditional high volume sprayers. Keeping this in view, performance of Neem seed kernel extract (NSKE) @ 5% and 10%, endosulfan and acephate as low volume spray (LV) was evaluated with two rounds of treatments at ETL in comparison with high volume spray (HV). Acephate LV has been found most effective (7.3% pod damage), followed by acephate HV and endosulfan LV (Table 4.26).

Table 4.26. Relative efficacy of pesticides against *H. armigera* in chickpea (1999-2001)

Treatment	Pod damage (%)	Yield (kg/ha)	CBR
NSKE 5% HV*	12.9	2000	1:8.87
NSKE 10% HV	11.3	2050	1:6.65
Endosulfan 350 g a.i. HV	9.7	2190	1:7.78
Acephate 400 g a.i. HV	8.3	2465	1:8.57
NSKE 5% LV**	17.5	1835	1:9.56
NSKE 10% LV	14.6	1805	1:5.29
Endosulfan 350 g a.i. LV	8.3	2225	1:10.50
Acephate 400 g LV	7.3	2575	1:11.65
Control	19.9	1335	-

*HV = High volume, **LV=Low volume

Effect of pesticides on non-target organisms: Laboratory screening of commonly used insecticides and biorationals for their toxicity to the parasite, *C. chlorideae* at recommended dose revealed that monocrotophos, chlorpyriphos, endosulfan and Neem EC are 100% safe for parasite emergence. Other relatively safer pesticides are pyrethroids, fenvalerate, deltamethrin, Bt and Neem product 'Repelin' with 50-60% parasite emergence. Among the recently available molecules like Dispel, RH – 2485, Match, Phosmite, Karate, Spark, Match + Profenophos and Ekalux, Match was least toxic to parasite with 100% emergence followed by Spark and Ekalux (80%) and Match + Profenophos (40%). Dispel and Phosmit (20%), Karate (10%) and RH – 2485 (no emergence) were highly toxic to parasite emergence. The toxicity of commonly used insecticides on *C. chlorideae* under field conditions indicated that fenvalerate application is safe to parasite. Quinalphos spray, methyl parathion dust and endosulfan are highly toxic exhibiting with >60% reduction in parasitism.

Biological control: Various aspects of biological control related to this pest have been studied for development of an effective IPM module. Extensive work carried out at IIPR revealed occurrence of insect parasitoids (*Campoletis chlorideae, Apanteles ruficrus, Carcelia illota)*, entomopathogenic nematodes (*Steinernema masoodi, S. seemae, Oschieus amsactae, S. carpocapsae, S. glaseri, S. thermophilum)*, entomogenous fungi (*Beauveria bassiana, Metarhizium anisopliae, Nomuraea rileyi, Aspergillus niger, Aspergillus flavus*), virus (Nuclear polyhedrosis virus), bacteria (*Bacillus thuringiensis)*, predatory spiders (*Araneus nympha, Oxyopes shewta*) and bird predators (Black Drango, Common Myna, House Sparrow, Crow, Cattle egret) in and around Kanpur. These natural enemies of *H. armigera* have been found to parasitize larval stage of the pest.

Integrated pest management: Efficacy of intercropping with bio- and chemo-intensive modules against *H. armigera* for four consecutive years showed that chickpea + mustard (4:2) recorded least pod damage (8.75%) with chickpea equivalent yield of 1672 kg / ha as against 13.60% pod damage and 1402 kg / ha yield in sole crop. Among control modules, bio-intensive IPM proved most effective recording 7.92% pod damage and 1748 kg / ha yield as against 15.34% pod damage and 1260 kg / ha yield in control. Chickpea intercropped with mustard in combination with BIPM resulted in highest CBR (Table 4.27).

Table 4.27. Effect of IPM modules and intercrops on pod damage and yield in chickpea

Treatment	Pod damage (%)	Chickpea equivalent yield (kg/ha)
Chickpea +Mustard 4:2 row ratio	8.75	1672
Chickpea + Linseed 2:1 row ratio	10.35	1573
Chickpea sole	13.60	1402
Bio-intensive IPM (BIPM*)	7.92	1748
Chemo- intensive IPM (CIPM**)	9.42	1684
Untreated control	15.34	1260

*BIPM = Seed treatment with *T. harzianum* + Vitavax (4g+1g / kgseed), first spray 250 LE *Ha*NPV with adjuvant at ETL; Second spray NSKE 5%

**CIPM: Seed treatment with Thiram + Carbendazim (2+1g / kg seed); First spray of Endosulfan 0.07 at ETL followed by second spray with *Ha*NPV @ 250 LE / ha

On-farm demonstrations of IPM: IPM module with more reliance on biocontrol methods were field demonstrated for two consecutive years (1990-92) in Chaubepur block of Kanpur district and compared with chemo-intensive module and / or farmers' practices. Results revealed that application of *Ha*NPV is as effective as endosulfan spray. Demonstrations on HaNPV conducted during 1999-00 to 2002-03 in Kanpur, Kanpur Dehat, Unnao and Hamirpur showed its efficacy against gram pod borer. Under NATP Project, 34 demonstrations on the evaluation of Biointensive (BIPM) and chemointensive (CIPM) modules during 2002-04 in chickpea growing areas in and around Kanpur showed no difference between BIPM and CIPM (about 6% pod damage), but significantly superior over farmers practices (12.8% pod damage). Average yield in BIPM was slightly higher (1717 kg / ha) than CIPM (1550 kg / ha) giving 53.8 and 38.9% yield increase over farmers' practice (1161 kg / ha). The cost benefit ratio was almost similar in both the modules (1:3.42 and 1:3.77). Based on the detailed studies conducted at the Institute, the following IPM schedule has been suggested for pest management in chickpea.

At sowing time	After sowing
Deep summer ploughing	Installation of sex pheromone trap @ 4-5 traps / ha
Timely sowing to exploit host avoidance phenomenon	Regular field scouting
Intercropping with mustard, linseed, wheat, barley, safflower, *etc.*	Erection of bird perches
Use of trap crops *e.g. Vicia sativa* or African giant marigold	Collection and destruction of larvae
Early or timely sowing	ETL 1-2 larvae / 10 plants
Use of tolerant varieties	Application of NSKE or *Ha*NPV as 1st and 2nd spray
Inter cultivation with coriander	Use of REF insecticides e.g. profenophos, dimilin, endosulfan, *etc.*, as 3rd spray, if necessary

B. Pigeonpea

More than 250 species of insects belonging to 8 orders and 61 families have been found to attack pigeonpea. However, only a few of them cause considerable damage to the crop and are economically important as pests. Pod borer, *Helicoverpa (Heliothis) armigera* Hubner; podfly, *Melanagromyza obtusa* Malloch, legume pod borer / spotted pod borer, *Maruca vitrata (testulalis)* Geyer, plume moth, *Exelastis atomosa* Wals, blister beetle, *Mylabris* spp., pod sucking bugs, *Clavigralla* spp. and bruchids, *Callosobruchus* spp. are the most important pests, causing damage to the crop.

Distribution and host range: Pod borer, *Helicoverpa armigera* is distributed throughout the country from tropical Andaman & Nicobar to temperate Jammu & Kashmir. Important host plant families infested by *H.armigera* are leguminosae, compositae, Malvaceae, Graminae, Brassicacae, *etc*. Three plant species *viz*., *Antirrhinums majus* L. (Snap dragon), a winter annual flower, and *Chenopodium album* and *Phalaris minor*, common weeds have been identified as additional weed host suppressing incidence and build up of *Helicoverpa* in and around Kanpur. More recently, appreciable damage to wheat crop in some pockets of Uttar Pradesh has also been observed. Podfly, *Melanagromyza obtusa* is the most predominant insect pest of pigeonpea in North India, causing heavy losses in long duration varieties. This pest alone accounts for 70-80% of total pod damage by pod borer complex. Spotted caterpillar, *Maruca vitrata* is a key pest of short duration pigeonpea. Varieties with determinate growth habit and compact plant types are more prone to lepidopteron borer than the indeterminate and spreading types, which are more susceptible to the podfly damage. The pod weevil, *Apion* spp. is the major problem of pigeonpea in the Tarai region of North East India.

Damage assessment: Surveys in farmers' fields in UP during 2003-04 revealed high pod damage (56.2%) by *H. armigera* in Kanpur Dehat district with as high as 88.89% in Satara block, whereas in Fatehpur district, average pod damage was 30.49% with maximum of 91.8% in Jahanabad block. An extensive survey across ten agro-ecological zones of Uttar Pradesh revealed that podfly accounted for maximum damage to pigeonpea (24%) among the pod borers. Podfly attack resulted in nearly 70% of the total grain damage due to pod borer complex. The avoidable losses due to pod borer complex, mainly pod fly and *H. armigera* were 43.5 and 30.2%. Grain losses due to podfly in different parts of India ranged from 2.5 to 86.8%.

Biology and ecology: *Helicoverpa armigera* larvae that pupated during December after the harvest of short duration pigeonpea were studied for moth emergence. A major population of pod borer underwent diapause in the pupal stage. It lays small white eggs, usually singly on leaves, flowers, pods and tender stems. The young larvae feed by scrapping green tissue and older larvae chew buds, flowers and pods, leaving characteristic holes. The colour of larvae varies from yellow to green, pink, orange, brown or black but all have characteristic light and dark stripes along each side. From the third instars onwards, the larvae start boring the pods. They cut the hole on one to another locule and a single larva can feed 8-17 pods in its lifetime. The pupal period on pigeonpea was recorded to be 18-20 days.

Life table studies: Life table studies of *H. armigera* on short duration pigeonpea cv. UPAS 120 and Manak showed <1.0 trend index, indicating single generation with generation survival of 36% in UPAS 120 and 38% in Manak. Sterility, NPV, fungi, bacteria, pupal-parasitoids and unknown causes were the major mortality factors. The trend index in long duration pigeonpea cv. NDA 1 was 1.26, showing positive trend index in the first generation with generation survival of 47%. In the second generation, mortality was more than 98% with zero trend index and 25% generation survival. In Bahar, the trend index in the first generation was positive (1.13) with 76% survival and in the subsequent generation, there was zero trend index with 16% survival. Therefore, *H. armigera* completes one and two generations in short and long duration pigeonpea.

In the laboratory, survival and developmental times from egg to adult emergence of *H. armigera* were determined at 12 constant and 6 variable (alternating) temperature regimes from 5 to 40°C. The pest developed successfully from egg to adult at constant temperature from 8 to 32°C. The duration of the life history stages decreases as temperature increases from 12 to 32°C. The duration of the egg stage ranged from 14.13± 0.93 days at 12°C to 2.67± 0.47 days at 32°C. Similarly, the duration of the larval stage ranged from 60.29± 2.76 days at 12°C to 11.13±0.33 days at 32°C. Pupal duration ranged from 43.25±1.48 days at 16°C to 9.14±0.35 days at 32°C. Pupae were classified as having entered diapause if adult emergence was delayed beyond 74 days at 12°C, and by the retention of the pigmented eye-spot. Thermal constants of 49.51, 201.35 and 144.01 degree days were estimated as the effective temperature sums for the development of the eggs, larvae and pupae, respectively. Thus, a thermal constant of 51 degree-days above a threshold of 10.5 is required for the development of eggs. The larval stage requires 201.35 degree-days and the pupal stage 144.01 degree-days above 11.3 and 13.8 developmental thresholds, respectively. This information is useful for predicting population phenology of *H. armigera* in Kanpur and adjoining areas in central zone of Uttar Pradesh.

Podfly is estimated to complete two generations in long duration pigeonpea. In both the generations, the key mortality factor was sterility, which caused hatching failure of the eggs. *Euderus lividus*, the prominent larval-pupal parasitoid of *M. obtusa* also caused mortality to the extent of 3.62, 10.91 and 7.14 % in younger, older and pupal stage, respectively, in the first generation. The trend index was positive (1.64) with generation survival of 53% in the first generation and negative (0.85) with 34% survival in the second generation. Growth and development studies of pod fly at 10°C and 28°C with constant RH at 70% showed that the mean incubation period was 8.8±1.17 days at 10°C and 4.0±0.71 days at 28°C. The larval period was 13.2±1.17 and 8.4±0.8 days at these temperatures. The pupal period registered 16.75±1.48 days at 10°C and 11.75 ± 0.43 days at 28°C. Podfly was found thriving on *Rhynchosia minima* in off-season as a collateral / alternate host. During April to September, about 85% pods were found infested. From middle of September onwards, the podfly was found infesting pigeonpea.

Monitoring, modeling and forecasting: The mean annual infestation of gram pod borer in short duration pigeonpea for the period of 1985-86 to 1997-98 (13 years) recorded at Kanpur was computed following the regression equation given below:

$$Y = a_o + a_1 z_1 + a_2 z_2 \ldots\ldots\ldots\ldots\ldots a_6 z_6 + b_{12} z_{12} + \ldots\ldots\ldots\ldots + e$$

Where,

$$Z_1 = \sum_{w=n_1}^{n_1} r_{iw}\, x_{iw} \quad \text{(single weather variable)}$$

$$z_{ij} = \sum_{w=n_1}^{n_2} r_{ijw} x_{iw}\, x_{jw} \quad \text{(combined effect of two independent weather variables)}$$

z_{ijk} = k denotes weighted interaction of i and j

Where, Y is the mean % pod damage, x_{iw} is the value of i^{th} weather parameter in w^{th} week (x_1 = maximum temperature, x_2 = minimum temperature, x_3 = morning relative humidity, x_4 = evening relative humidity, x_5 = rainfall), r_{iw} is value of correlation coefficient between pod borer severity and i^{th} weather parameter in w^{th} week, r_{ijw} is correlation coefficient between y and product of x_{iw} and $x_{jw,}$ p is the number of weather variables, e is error term, and a_o a_{iw} and b_{ijw} are constant, n_1 and n_2 are initial and final weeks for which data were considered e.g., in model using data of lag 1, lag 2, lag 3, lag 4 and lag 5 then in case of 39 standard week, n_1=39 and n_2=34

The weighted interactions between maximum temperature and rainfall were significant in both 38th and 39th standard weeks (Table 4.28). However, it reflected negative response. Minimum relative humidity and rainfall showed significant weighted interaction with positive influence towards extent of damage and prevalence of *H. armigera.*

Table 4.28. Prediction model for pod borer damage in short duration pigeonpea at Kanpur (1985-86 to 1997-98)

Model	R^2	Year	Forecast value	Observed value
$Y=-68.39-0.068Z_{151}+0.034Z_{451}+0.0042Z_{130}$ **(38th std. week)**	0.89%	1998-99	14.36	16.4
		1999-00	9.43	9.8
		2000-01	10.80	14.8
		2001-02	13.65	9.4
		2002-03	13.44	8.8
		2003-04	27.43	31.6
$Y=-76.23+0.01Z_{131}-0.09Z_{151}+0.04Z_{451}-1.33Z_{11}$ **(39th std. week)**	0.91%	1998-99	13.02	16.4
		1999-00	13.84	9.8
		2000-01	14.12	14.8
		2001-02	13.78	9.4
		2002-03	15.88	8.8
		2003-04	18.91	31.6

A simple rule has also been developed to forecast *Helicoverpa armigera* infestation on long duration pigeonpea in North India. According to the rule, "A sudden rise in the minimum temperature (>5°C) around 7-8 standard weeks (A) and rainfall during 1-9 standard weeks (B) along with a considerable adult moth population (above 15 per week) during 5-7 standard weeks (C) trigger a major rise in the pest population during 10-14 standard weeks".

This rule can be successfully used to forecast *H. armigera* moth population and infestation at least 4-5 weeks in advance in long duration pigeonpea ecosystem.

Mechanism of resistance: Ovipositional non-preference and antibiosis are reported as major mechanisms of resistance for *H. armigera* and *M. obtusa*. Abundance of glandular hairs, presence of tannin-like substances beneath outer epidermis and thickness of fibrous cell layer above inner epidermis influenced oviposition preference in pigeonpea as well as in *Atylosia* spp. Studies showed that pigeonpea cultivars having brown small pods with deep constrictions had low podfly oviposition and damage. Resistant selections showed low oviposition (15.3-18.7%) as compared to susceptible types (31-38%). Similarly, small pods (<6 cm) had low seed damage (19.1-20.2%) as compared to 26.5 – 27.35 in large pods (>9 cm). Black or brown mottled seeds showed low podfly damage (4.2-4.3%) in comparison to white and yellow coloured seeds (20.6-23.5%). Sickle shaped pods with deep constrictions exhibited low preference to podfly oviposition and damage.

Biochemical analysis showed that pod wall and seeds of resistant selections had higher content of hydrocarbons like hentriacontane, triacontane and sterols like b-sterol while susceptible selections were rich in alcoholic compounds like hexacosanol, hentriacontanol, *etc*. Resistant selections also showed higher amount of organic acids like P-coumaric acid and caffeic acid and esters like ethyl caffeate while gallic acid was the major constituent in susceptible genotypes.

Management

Cultural practices: Cultural practices have profound influence on the insect survival, their persistence in a particular environment and damage to a crop. Sometimes, even a slight population reduction brought about by these practices delays insect build up. In pigeonpea, limited information has been generated to suppress podfly damage through cultural practices. Podfly is known to thrive during off season (May-August) on perennial pigeonpea and alternative wild hosts *e.g.*, *Rhynchosia minima, Flemingia congesta, Atylosia* spp and *Tephrosia purpurea*, and therefore, removal or destruction of these alternate host plants helps reduce the carry over population of podfly. Multiplication rate of podfly is low during winter (December-February) and, thus, crop maturing in February-March has low podfly damage. Therefore, advancing the sowing of long duration varieties helps reduce podfly damage.

Host plant resistance: Crop phenology greatly influences incidence and intensity of the pest infestation in pigeonpea. Short duration varieties, which mature in November showed only 4% seed damage by podfly and thus, should be preferred for cultivation to avoid its damage. Some of genotypes with less susceptibility to pod fly are SL12-2, SL42-2, ICP7946, ICP7151, GP3-3, ICP8402, PDA 88-2E, PDA 88-1E and PDA 88-3E. Systematic screening of 5067 lines at IIPR has identified 10 selections *viz*., ICRISAT 16, 166-2-1, ICP 7946-1-3-3, ICP 127, SL-3-1, 41-3-3, PDA 88-2E-3-1, ICP3401, ICP7950 and ICP12304 as highly promising against pod fly. Two selections, namely PDA 88-2E and PDA 89-2E have been used as source of resistance against podfly. Screening of promising lines over the years has resulted in identification of six selections *viz*., PDA 88-1E-2, PDA88-2E-2, PDA88-2E-3, PDA88-3E-1, PDA88-3E-3 and PDA88-3E-4 as moderately resistant to podfly.

Chemical control: To date, a management strategy against podfly has been mainly based on the insecticides use. Various insecticides belonging to different groups have been tested and found effective against pod borer complex including podfly in pigeonpea. Among them, endosulfan, monocrotophos, dimethoate, fenvalerate, and cypermethrin are superior. In addition, plant products *viz*., Neem seed kernel extract (NSKE) have also been recommended for application. Usually, two to three applications beginning with pod initiation stage are recommended for effective control.

Pesticides application technique: Application of phosphamidon using ultra low volume spray (5 ml/plot) has been found to reduce pod fly damage substantially while application of endosulfan using high volume spray (20 ml/plot) showed the lowest pod borer (*H. armigera*) damage in pigeonpea variety, Bahar.

Effect of strip treatments of insecticides: Strip application has been found very efficient in controlling pod borer and podfly population, and can be integrated with other practices to control these pests effectively. Studies on pigeonpea cv. Type 7 grown under different strip treatments with one spray of dimethoate (0.3%) revealed superiority of all the treatments over control in suppressing the pod borer damage (Table 4.29). For podfly, nine- and five-row sprayings were superior to other treatments.

Table 4.29. Effect of strip treatments for controlling pod borer in pigeonpea

Treatment	% Pod damage		Yield (kg/ha)
	Pod borer	Podfly	
3 rows spraying (middle rows)	2.52 (9.21)	14.90 (22.72)	1809
5 rows spraying (middle rows)	1.43 (6.72)	11.50 (19.82)	2093
7 rows spraying (middle rows)	1.62 (7.24)	22.90 (21.05)	1988
9 rows spraying (middle rows)	2.00 (8.13)	8.19 (16.64)	1921
Control	10.53 (18.53)	18.57 (25.87)	1541
CD at 5%	3.81	3.58	3.11

IPM module: Five IPM modules evaluated on long duration pigeonpea (Bahar) against lepidopteran borer and podfly showed that monocrotophos (1/2 dose) + *Ha*NPV and monocrotophos (Full dose) gave maximum control (5.8% pod damage) against lepidopteron pod borers, followed by monocrotophos – NSKE and dimethoate (6.6% pod damage). In case of podfly, the plot sprayed with monocrotophos, NSKE and dimethoate provided maximum protection (11.6% pod damage). Half dose each of monocrotophos + NSKE and Endosulfan+ *Ha*NPV-monocrotophos gave maximum grain yield.

C. Mungbean and Urdbean

A wide array of insect-pests has been recorded to attack mungbean and urdbean during both the seasons (*kharif* and spring / summer). Among them, whitefly (*Bemisia tabaci*), leafhopper (*Empoasca* spp.), thrips (*Caliothrips indicus* and *Megalurothrips distallis*), Bihar hairy caterpillar (*Spilarctia obliqua*), semilooper (*Anomis flava*), spotted pod borer (*Maruca vitrata*), pod weevil (*Apion* spp.) and pod bugs (*Nezara viridula* & *Clavigralla gibbosa*) are important. The sucking pest, whitefly (*B. tabaci*) is also a vector for a number of viral diseases, especially MYMV (Mungbean Yellow Mosaic Virus). The yield losses caused by the pest complex of mungbean varied from 19.95% to 29.94% with an average of 23.42% during *kharif* season.

Pest succession : Pest succession on mungbean (Samrat) and urdbean (Uttara) under natural infestation during *kharif* and summer seasons revealed similar pattern on both the crops. During *kharif* season, whitefly (*Bemisia tabaci*) appears at seedling stage (15-21 DAS). Its incidence is noticeable throughout the crop season with peak activity at 50-56 DAS. Incidence of blister beetle (*Myllabris pustulata*) is observed first at flower initiation stage and one week latter, incidence of flower thrips (*Megalurothrips distallis*) is noticeable. Both the pests harbour on these crops till pod maturation. Pod borer (*Maruca vitrata*) and pod bugs (*Nezara viridula*, *Riptortus pedestris* & *Clavigralla* spp.) are observed at pod formation stage and remain active till pod maturation. The broad mite infestation is severe on mungbean and its incidence appears during active vegetative stage (29-35 DAS) and continues throughout the growing season.

During summer season, the crops are mainly infested by two insect-pests *viz*., whitefly and flower thrips. In both the crops, whitefly appears at seedling stage (15-21 DAS) and is noticeable throughout the season. Its population during the season ranged from 0.84 to 3.80 per plant in mungbean and 1.12 to 4.92 per plant in urdbean. In both the crops, its peak activity reached at 43-49 DAS. Incidence of flower thrips starts at flower initiation and remains active till pod maturation. The population ranged from 17 to 57.2 per 100 flowers in mungbean and 6.4 to 15.2 per 100 flowers in urdbean. The population of thrips reached its peak at 57-63 DAS in mungbean and at 64-70 DAS in urdbean.

Management

Host plant resistance: The major thrust in mungbean and urdbean entomology programme has been on identification of sources of resistance for use in breeding programme. The preliminary screening of available germplasm of mungbean and urdbean against major pests has led to identification of resistance sources (Table 4.30).

Table 4.30. Genotypes with low to moderate resistance against major pests in mungbean and urdbean

Sources of resistance	Pest
Mungbean	
TM 97-52, HUM 3, HUM 9, LGG 410, ML 267, Pusa 9531, PDM 84-139, PDM 26, PDM 30, PDM 33, PDM 34	Whitefly
PDM 40	Jassid
LM 40, LM 316, V 3493, LM1533, LM 671, LM 420, V 4501, LM 63, V 4039, PDM 30, PDM 36	Leaf thrips (*C. indicus*) and flower thrips (*M. distallis*)
ML 818, ML 845, Pusa 105, Pusa 9762, PDM 54, HUM 3	Leaf thrips
MSO 11, V 3000, SML 736, HUM 11, TH95-50, LM 667, PDM 84, UPM 99-7, ML 5, MSO 7, MSO 25, HUM 6, HUM 9, PSS 1, ML 881, ML 736, Ganga 14, TM 98-37, IPRM 113, IPRM 115, IPRM 124	Flower thrips
PDM30, PDM38, PDM63, PDM72, PDM 78, PDM79, PDM 94, PDM 99, PDM 107, PDM 117, PDM 118, PDM 127	Spotted pod borer
Pusa 9531, Pusa 9532	Jassid, thrips, semilooper, pod weevil
Urdbean	
RU9801, Barabanki local	Jassid
LBG 623	Thrips and pod weevil
LBG 623, LBG 20, RU 9801	Leaf thrips
MSO 13	Flower thrips
KU 315, LBG 623, Barabanki local	Semilooper

Chemical control: Seed coating with 2% carbosulfan 50 WS and soil application of phorate 10G or carbofuran 3G @ 1 kg ai/ha provide effective protection against sucking pests during seedling and vegetative stages. Foliar application of insecticides *viz.*, dimethoate 0.03% or monocrotophos 0.04% during flowering stage (45 DAS) and pod maturation stage (60 DAS) proved most effective against spotted pod borer. Insecticides *viz.*, RH-2485, Spark, Radar, Traban, Karate, Match + Profenophos, Decis, Ekalux, endosulfan, Bt, Crocron + Phosmit are highly toxic against third instar larvae of Bihar hairy caterpillar.

Botanical control: Commercial neem formulations (Achook, Neemgold, Nimbecidine, Neem liquid and Neemax) exhibited antifeedant property and showed 73.76 to 90.87% leaf area protection against Bihar hairy caterpillar under laboratory conditions.

Biological control: Parasites *viz.*, *Meteorus* spp. and *Gryon* spp. have been recorded at larval stages of Bihar hairy caterpillar and egg stages of pod bugs (*Nezara viridula*

& *Clavigralla gibbosa*), respectively. Entomogenous fungi *Beauveria bassiana* and *Metarhizium anisopliae* have been found to be effective against pod bugs and Bihar hairy caterpillar under laboratory conditions. *B. bassiana* caused 70 - 100% mortality on *N. viridula* and 70 - 90% mortality on *C. gibbosa* within six days. *M. anisopliae* caused 60 - 80% mortality on *C. gibbosa* and 20 - 60% mortality on *N. viridula* within 7 - 9 days. Variation in mortality of pod bugs has been recorded among the different isolates of *B. bassiana*. Isolate from Lucknow (CIHNP) was more effective as compared to other isolates. Dispel, a commercial formulation of *B. bassiana* (4 ml / litre) caused 58.33 % mortality on Bihar hairy caterpillar within 48 hours of treatment.

4.3. Biological Control of Pests in Pulses

Regular surveys of the fields in and around Kanpur were made and insect pests infesting pulses were collected and reared in the laboratory until pupation, adult emergence or emergence of the parasite. The natural enemies recorded are presented in Table 4.31.

Table 4.31. Natural enemies of pests of pulses in and around Kanpur

Crop	Pest	Natural enemy	Stage
Pigeonpea	*Helicoverpa armigera*	*Aspergillus niger*	Larval
		A. falvus	Larval
		Copidosoma floridanum	Larval
	Melanagromyza obtusa	*Euderus agromyzae*	Larval / pupal
		Erytoma spp.	Larval / pupal
		Euderus spp.	Larval / pupal
		Ormyrus orientalis	Larval / pupal
	Eucosma critica	*Apanteles taragamae*	Larval / pupal
	Clavigralla gibbosa	*Gryon* spp.	Egg
	Nezara viridula	*Gryon* spp.	Egg
Chickpea	*Helicoverpa armigera*	*Campoletis chlorideae*	Larval
		Apanteles ruficrus	Larval
		Bracon (Habrobracon) hebetor	Larval
		Carcelia illota	Larval
		Nuclear polyhedrosis virus	
	Autographa nigrisigna	Unidentified tachinid	Larval
		Parasite	Larval
Mungbean & Urdbean	*Diacrisa obliqua*	*Meteorus* spp.	Larval
	Nezera viridula	*Gryon* spp.	Egg
	Clavigralla gibbosa	*Gryon* spp.	Egg
	Spodoptera litura	Unidentified hymenopterous parasite	Larval

A. Natural Enemies of *Helicoverpa armigera*

Helicoverpa armigera is a major pest of chickpea and pigeonpea and causes heavy losses every year. In North India during post winter months (*i.e.* March – April), *H. armigera* moths emerge out from hibernating pupae and breed freely due to absence of almost negligible parasitism and favorable climatic conditions. This coincides with the fruiting stage of chickpea and pigeonpea, causing heavy losses. Recent studies have revealed many new parasites not reported so far. These are discussed below:

Larval parasites: During 2004, 258 larvae of *H. armigera* were collected from IIPR fields. In a single larva, hundreds of undeveloped parasites were present on the surface of body as cylindrical protuberance. After 11 months, small black hymenopteren parasite *Copidosoma floridanum* (Ashmead) emerged. Again after 23 months large number of *C. floridanum* (1058) emerged from the same lot of *H. armigera*. This was the first record of *C. floridanum* from the larvae of *H. armigera* in pulse ecosystem.

In 2008, 24 (9 male and 15 female) parasites emerged from 12 parasitised larvae of *Helicoverpa* collected from IIPR chickpea fields during the first fortnight of April. These parasites have been successfully reared on *H. armigera* larvae in the laboratory. This is identified as *Bracon* (*Habrobracon*) *hebetor,* a gregarious parasite forming 10-16 cocoons per larva.

Entomogenous fungi: During April 2002, two entomogenous fungi, namely *Aspergillus flavus* and *A. niger* were recorded on the larvae (122) of *H. armigera* collected from the fields of IIPR, the latter being more pathogenic.

Entomopathogenic nematodes: Two entomopathogenic nematodes parasitizing on pests of pulses have been isolated and named as *Steinernema masoodi* and *S. seemae.*

B. Population Dynamics of Major Parasitoids

***Apanteles taragamae*:** Studies on *A. taragame,* a larval parasite of pigeonpea leaf tier, *Eucosma critica* was carried out continuously for four years (1984-87). The results showed that it was active from last week of October to December when 18.4 to 23.8% larvae were parasitised. The highest parasitisation level of 29.8% was recorded during the 2nd week of November.

Parasite complex of podfly: Parasite complex of podfly of pigeonpea consists of three parasites *viz*., *Euderus* spp., *Eurytoma* spp. and *Ormyrus orientalis*. Observations on the parasite complex for three years (1984-85 to 1986-87) revealed that parasitisation starts from December end, gradually reaching to its peak (34%) during the first week of March. The pupae collected at the time of crop maturity exhibited 16% parasitisation by three parasitoids *viz*., *Euderus agromyzae, Ormyrus orientalis* and *Eurytoma* spp. during 2002-03.

***Campoletis chlorideae*:** Among various parasitoids, *Campoletis chlorideae* has proved to be a potent parasitoid for gram pod borer in chickpea. It prefers late 1st or early 2nd instar larvae for parasitization. Parasite pupates outside as a cocoon within a week, which lasts for about 5-7 days. Biological studies showed developmental duration of 10.1 days (9-13 days) for immature larva and pupal period of 4.7 days (4-5 days). Females (4.3 days) lived longer than males (3.8 days) and laid 29 eggs during their life span. Sex ratio was in favour of male (1:0.4). The maximum parasitized larvae died (50%) between 6-8 days of parasitization, leading to low recovery of parasites. Under field conditions, the parasite population attains two definite peaks: first during early growth stage of chickpea (pre-winter) *i.e.*, 46-50th standard week and second coinciding with reproductive phase of the crop (post-winter) *i.e.*, 8-15th standard week. The maximum activity of parasitoid is recorded during the 49th standard week with 60% parasitization and second peak during the 10th standard week with 35% parasitization. Low level of parasitization during reproductive phase of the crop indicates that the parasitoid does not keep pace with the pest population and thus, needs manipulation of parasite population through inundative / inoculative release.

C. Control Measures with Biocontrol Agents

Very little success has been achieved so far in the utilization of parasites and predators in managing pest in chickpea ecosystem. The greatest potential for biological control lies in the use of Nuclear Polyhedrosis Virus, entomopathogenic nematode (EPN), *Bacillus thuringiensis* as microbial insecticides for the control of *H. armigera* and other lepidopteran pests.

Virus: The NPV (Nuclear Polyhedrosis Virus) kills the insects when ingested. The institute has perfected isolation, mass multiplication and storage of NPV in the laboratory. Among the major constituents of semi-synthetic diet, *kabuli* gram flour has been found best followed by maize flour, soybean flour and groundnut flour.

The NPV stored at 4^0C remain effective for 18 months without losing its virulence as against only 4-6 months at room temperature. Efforts have been made to standardize the optimum dose required for *Helicoverpa* control on chickpea and pigeonpea. Besides, adjuvants for increasing its efficiency, compatibility with insecticides along with dosage and testing of different strains from different places have also been studied.

Different adjuvants like pH or gut composition changer and phagostimulants have been studied for increasing the efficacy of *Ha*NPV (Table 4.32). Addition of jaggary (0.5%) and charcoal (0.05%) with *Ha*NPV has been found the best, killing 50% larvae 5 days after treatment (DAT) as against 8-10 days with *Ha*NPV alone. Addition of sugarcane juice with sodium carbonate / boric acid or jaggary with tannic acid causes 50% mortality 6 DAT. Addition of surfactant (teepol 0.05%) and UV retardant (tinopal 0.01%) with phagostimulant (jaggary 0.5%) further increases efficiency and stability of NPV.

Table 4.32. Interactive effect of adjuvants on 50% larval mortality of *H. armigera* by *Ha*NPV (2000-2002)

Adjuvant	Jaggary (0.5%)	Sugarcane juice (0.5%)	Cotton seed (0.1%)	Saccharin (0.01%)
Tannic acid 0.01%	6	8	7	7
Charcoal 0.05%	5	14	8	7
Na_2CO_3 0.01%	7	6	8	6
Boric acid 0.01%	7	6	7	6
*Ha*NPV alone	8	8	8	10

The optimum doses of *Ha*NPV have been determined as 250 LE / ha in chickpea and 350 LE / ha in pigeonpea for field application, which are as efficient as endosulfan 0.07% in reducing pod borer damage. Three sprays of *Ha*NPV @ 250 LE / ha with phagostimulant (jaggary 0.5%), surfactant (teepol 0.05%) and UV retardant (tinopal 0.01%) at weekly interval have been found as effective as two sprays of endosulfan (0.07%) followed by *Ha*NPV plus half dose of endosulfan or sequential application of *Ha*NPV followed by endosulfan and *Ha*NPV in reducing pod damage in chickpea. Results of two years' study (1991-93) revealed that addition of gut composition changer, tannic acid (0.01%), boric acid (0.01%) or charcoal (0.05%) with *Ha*NPV enhanced its efficacy in controlling pod borer (Table 4.33).

Table 4.33. Effect of adjuvants on efficacy of *Ha*NPV against *H. armigera* infesting chickpea (1991-93)

Treatment	Pod damage (%)	Yield (kg/ha)
NPV 250 LE + Tannic acid 0.01%	6.5	850
NPV 500 LE + Tannic acid 0.01%	5.4	927
NPV 250 LE + Charcoal 0.05%	5.6	1002
NPV 500 LE + Charcoal 0.05%	4.5	1013
NPV 250 LE + Boric acid 0.01%	6.8	1023
NPV 500 LE + Boric acid 0.01%	6.2	1056
Control	13.4	683

Five-year study revealed that two applications of *Ha*NPV (250LE) with UV retardant (Ranipal 0.01%) and phagostimulant (Jaggery 0.05%) plus half dose of any of the three commonly used insecticides, endosulfan (0.035%), cypermethrin (0.002%) or fenvalerate (0.002%) provide effective control of pod borer in chickpea (Table 4.34). Thus, with the use of *Ha*NPV, the load of insecticide in the ecosystem can be drastically reduced in the present context of environmental concerns.

Table 4.34. Efficacy of *Ha*NPV *vis-à-vis* insecticides for *H. armigera* management in chickpea (1989-93)

Treatment	Pod damage (%)	Mean grain yield (kg/ha)
NPV + Fenvalerate 0.002%	6.6	1961
NPV + Cypermethrin 0.002%	7.3	1886
NPV + Endosulfan 0.035%	8.2	1801
Fenvalerate 0.004%	7.4	1826
Cypermethrin 0.004%	7.6	1906
Endosulfan 0.07%	9.4	1725
NPV alone	6.2	1956
Control	17.7	1463

Bacteria : *Bacillus thuringiensis* (*Bt*) is the only bacterium that has been developed successfully as a commercial insecticide against lepidopteron pests including *Helicoverpa armigera*. Several commercial *Bt* formulations have been evaluated for their efficacy against *H. armigera***.** Three dosages (1,1.5 and 2 kg/ha) of Delfin, a commercial *Bt* formulation, were tested against all the instars of *H. armigera* in the laboratory. The mortality showed decreasing trend with increasing larvae instars at all the doses. Early instar groups (up to 3rd) have been found most susceptible to *Bt*, while the late instars (3rd to 5th) were little affected even at higher dosage. Hundred per cent mortality was recorded in 1st instar larvae at all the dosages after 48 hour as against 55, 65 and 100% mortality of the 2nd instar larvae with increasing dose of

Bt. Evaluation of seven commercial preparations of *Bt* in two dosages (1 & 1.5 kg / ha) against 3rd instar larvae showed that BTK 1 and BTK 2 @ 1 kg / ha proved highly effective with maximum of 80% larval mortality followed by Dipel and Delfin (66.7%), BTK and endosulfan (60%). Almost similar trend was recorded against the 4th instar larvae.

A field cum laboratory experiment showed high toxicity of *Bt* @ 0.5 kg / ha against first instar of *D. obliqa* causing 100% mortality within 48 hours. With the lapse of time, however, the toxicity of Bt gradually slowed down with only 60% mortality in 3-day old treated leaves and 40% in 4-day old treated leaves.

Field evaluation of three *Bt* formulations along with *Ha*NPV and endosulfan against *H. armigera* infesting chickpea showed Delfin @ 2 kg / ha and Dipel @ 1 kg / ha as equally effective exhibiting less damage (1.58-7.3%) as against 7.08 to 16.5% damage in untreated control. These treatments also recorded comparatively higher yield varying from 1927 kg / ha to 1863 kg / ha. Among seven commercial *Bt* formulations evaluated against *H. armigera* infesting chickpea, BTK 1 and BTK 2 @ 1.5 kg / ha have been found highly effective with lower pod damage (9.87 - 11.32%) comparable to endosulfan (13.65%). Next in order of effectiveness were Delfin and Dipel with 17.56 and 18.67%, respectively. The highest yield was recorded with BTK 1 (1666 kg / ha) followed by BTK 2 (1633 kg / ha) and endosulfan (1550 kg / ha).

Fungus: *Beauveria bassiana,* a white muscardine fungus is an important entomofungal pathogen and causes disease in a variety of insects of diverse groups. Laboratory evaluation of four concentrations of *B. bassiana* (2.68 x 10^7, 2.68 x 10^6, 2.68 x 10^5 and 2.68 x 10^4 spores / ml) showed their effectiveness against all the instars of *H. armigera.* Larval mortality increased with increasing spore concentrations. Younger larvae were highly susceptible with comparatively less incubation period for fungal development on the host larvae. In the case of 5th instar, larval mortality ranged from 28 to 40% with corresponding incubation period of 7-15 days. Application of *B. bassiana* at 2.68 x 10^7 spores / ml proved to be the most effective. Field trials for two seasons (1993-1995) further confirmed the effectiveness of this fungus at different concentrations against *H. armigera*, the best concentration being 2.68 x 10^7 spores per ml (Table 4.35).

Table 4.35. Field evaluation of *B. bassiana* against *H. armigera* infesting chickpea during 1993-95

Concent-ration (spores/ml)	Pod damage (%)	Yield (kg/ha)
2.68 x 10^7	6.8	2377
2.68 x 10^6	8.7	2192
2.68 x 10^5	10.5	2135
2.68 x 10^4	11.9	2025
Control	16.3	1844

Entomopathogenic nematodes : The research work on entomopathogenic nematodes (EPN) started in 2003 in this Institute. The work got impetus by sanction of an *ad hoc* project by the Department of Biotechnology and two projects by the Department of Science and Technology. A comprehensive study on different aspects of EPN such as surveys in pulse ecosystem, identification of new species, their biology, taxonomy, pathogenicity, host range, culturing of EPN and insect, *in vivo* and *in vitro* mass production, bio-efficacy in field condition, biopesticide formulation, pesticide application technology, schedule of spray, field demonstrations, *etc.*, were undertaken. The salient achievements are as under:

***Identification of new species*:** Two new heat tolerant EPN species, *Steinernema masoodi* and *S. seemae,* were identified from pigeonpea fields in Bithoor village, Kanpur District and Muskri village, Hamirpur district, U.P. respectively (Fig. 4.7). Another new species, *Oschieus amsactae* was identified from red hairy caterpillar, *Amsactae moorei* in mungbean field. Identification was based on morphometric observations and cross hybridization of new species with *S. abbassi, S. thermophilum* and *S. carpocapsae, S. seemae* and *S. masoodi.*

Fig. 4.7. New species of EPNs: 1. *Steinernema masoodi*, 2. *S. seemae*, 3. *Oschieus amsactae* (SEM photograph)

Molecular characterization of *S. masoodi, S. seemae* and *O. amsactae* was carried out and compared with other EPN species like *S. carpocapsae, S. lami, S. glasseri* and *S. abbassi* which confirmed that these are three distinct new species (Fig. 4.8). These new species are virulent and multiply well on *Helicoverpa armigera* larvae and kill the insect larvae within 72 h under laboratory conditions. Further, Scanning Electron microscopic (SEM) studies were carried out for their ultra-morphological characters in infective juveniles of *S. seemae, S. masoodi, S. carpocapsae* (local strain) and *O. amsactae* (Fig. 4.7) along with other four known species and morphological comparisons were made and it was confirmed that *Steinernema seemae, S. masoodi* and *O. amsactae* are new EPN species.

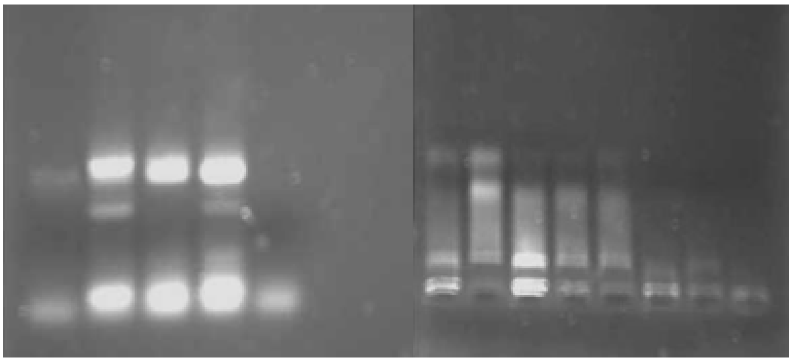


Fig. 4.8. Nematode DNA amplification of *S. seemae* and *S. masoodi*

Two new species of genus *Acerobeloides viz*., *Acerobeloides ishraqi, Acerobeloides* IIPR 02, and two of *Oschieus viz*., *Oschieus* IIPR 04 & *Oschieus* IIPR 05 have been identified.

The survival of *S. seemae*, *S. masoodi* and *S. carpocapsae* was assessed under seven controlled temperature regime of 15, 20, 25, 30, 35, 40 and 45°C. Infective juveniles of indigenous populations of *S. seemae, S. masoodi* and *S. carpocapsae* were able to survive at all the tested temperatures. Temperature regime of 20-35°C was found better suited for survival of EPN studied, as it ranged from 60 to 80 per cent.

Out of six substrates (field soil, FYM, sand, vermicompost, talc and cowdung), the EPN population showed increasing trend from the base population of post inoculation in FYM, vermicompost and cow dung. The population was multiplied and the density increased. But all the three substrates had different pattern of increase. The EPN population increased gradually in FYM and vermicompost but declined after 8 months of post inoculation. In cow dung, there was abrupt increase of population up to 8 months thereafter the population started declining, however, the EPN density was still higher.

Host range : Pathogenicity of *Steinernema masoodi* and *S. seemae*, the two newly described species have been tested against various insect pests. It was noticed that these EPN were infective to 14 insect species, of diverse group *viz*., *Corcyra cephalonica* (rice moth), *Diacrisia obliqua* (Bihar hairy caterpillar), *Galleria mellonella* (greater wax moth), *Helicoverpa armigera* (gram pod borer), *Lampides boeticus* (blue butterfly), *Maruca vitrata* (spotted borer), *Mylabris pustulata* (blister beetle), *Myllocerus* spp.

(grey weevil), *Poecilocerus pictus* (aak grasshopper), *Rhizopertha dominica* (lesser grain borer), *Tribolium castaneum* (rust red flour beetle), *Callosobruchus chinensis* (gram dhora) and *Callosobruchus* spp. (bruchid). *O. amsactae* has been tested against *Myllocerus* spp., *Mylabris pustulata, Aulacophora foveicollis* and *Epilachna* spp. These were found as a good host and the mortality of these insects were observed within 42 – 96 hrs.

Entomopathogenic nematodes *viz., Steinernema carpocapsae, S. masoodi, S. seemae, S. glaseri* and *S. thermophilum* and *O. amsactae* were tested for their bioefficacy against larvae of *Helicoverpa armigera, Galleria mellonella* and *Corcyra cephalonica* under laboratory conditions. LC_{50} of EPN against above insects were in decreasing order, *C. cephalonica, G. mellonella* and *H. armigera. S. seemae* was found most virulent to *C. cephalonica* followed by *S. masoodi.*

Technique for mass production: Mass multiplication of entomopathogenic nematode was done in different artificial media. Out of 6 media, no multiplication was observed in dog biscuit, wheat flour and nutrient agar media others were moderate. A new *kabuli* gram based medium (IIPR medium) was developed and perfected which was found economical and gave 20% more IJs yield than other media (Table 4.36).

Table 4.36. *In vitro* mass production of EPN in three different media

Medium	Production	*S. seemae*		*S. masoodi*	
	Cost per flask (Rs)	Yield of IJs per flask	Cost for 1 ha treatment (Rs)	Yield of IJs per flask	Cost for 1 ha treatment (Rs)
IIPR medium	2.20	61.1×10^9	900	52.7×10^9	1,043
Egg yolk-based	13.90	49.6×10^9	7,006	39.2×10^9	8,864
Wout's Medium	4.92	36.6×10^9	3,360	28.7×10^9	4,285

* The approximate requirement to treat one hectare area is 2.5 Í 109 IJs

EPN based biopesticide formulation: *S. masoodi, S. seemae* and *O. amsactae* are used for making the biopesticide formulation for the management of insect-pests of pulses. Efforts were made to formulate the EPN so produced in laboratory. The entomopathogenic nematodes were formulated into spray, soil, cadavers, dust, water dispersible granules (WDG) (Fig. 4.9) and soaked sponge cubes to improve the activity, absorption, uniform application, delivery and ease in application and shelf life. Formulated products were stored at room temperature and infectivity of formulated EPN was worked out periodically through petriplate bioassay in case of sponge, cadaver and dust formulation (Fig. 4.9) or baiting technique in case of soil formulation (Fig. 4.9). The results showed that liquid formulation was best followed by soil (Table 4.37).

Fig. 4.9. *In vivo* production and EPN based biopesticide formulations

Table 4.37. Viability of different EPN formulations under storage

Formulation	Viability duration (in weeks)	Bioassay technique
Sponge @ 500-1000 IJs/cm^2	12 – 15	Petri plates
Soil (Polythene)	15 – 18	Baiting
Soil (Earthen pot)	36	Baiting
Cadavers	4 – 12	Petri plates
Liquid formulation	24-30	Petri plates
Dust (talc and bentonite based)	8-10	Polybags
Water dispersible granules	8	Polybags

A new Water Dispersible Granule formulation (WDG) has been developed in which IJs were enclosed in 10-20 mm diameter granular matrix. This allows access of oxygen to nematodes, which enters into partial anhydrobiotic static due to the slow removal of body water by substrate.

Delivery techniques: Experiment was conducted to evaluate the performance of different types of nozzles on the shredding and extent of deposition of live EPN (*O. amsactae*) on pigeonpea leaves when applied through hand compression sprayer. Five different nozzles were studied *viz*., flood jet , flat fan, broad cone, hollow cone (plastic type) and hollow cone (brass type) nozzles. Spray of *O. amsactae* @ 50,000 IJs/lit. of water was done on 6 pigeonpea leaves kept on a plastic tray. Maximum EPN was deposited in case of Flood jet nozzle (750/leaf) showing its superiority over others. This type of nozzle gave rise to least shredding of EPN. Hence Flood jet nozzle is recommended for spray of EPN biopesticide liquid formulation.

EPN can be applied using most conventional liquid application system designed to deliver along with pesticides. Experiment conducted on spraying schedule indicated that the spraying during evening hours was found superior with respect to EPN survival over the morning spray schedule.Addition of adjuvant, phagostimulant, antidesiccant, UV protectant in EPN based liquid formulation had given best results.

Efficacy against Lepidopteran pests : Field trials were conducted during 2005-2008 to test the efficacy of EPN against Lepidopteran borer complex of chickpea and pigeonpea under field conditions. Liquid and dust formulation based on *S. masoodi* and *S. seemae* in different concentrations along with UV retardant, antidesiccant and phagostimulant were evaluated. Out of the two formulations, dust formulation was found better than the liquid formulation.

Field studies during 2005-2008 showed that application of *S. seemae* @ 1.5 x 10^9 IJs / ha in early pigeonpea cv UPAS 120 recorded 83% larval mortality of *H. armigera* with an increase of 53.9% yield over control.

In case of chickpea, application of EPN @ 3x10^9 IJs / ha was highly effective against *H. armigera* as pod damage was 12.4% as against 34.8% in untreated control. The increase in yield over control was 68.6% (Table 4.38).

Table 4. 38. Performance of EPN against *H. armigera* in chickpea under protected (Net) condition

Treatment	Pod damage (%)	Yield (kg/ha)	Increase in yield over control	
			(kg/ha)	(%)
Application of EPN @ 3 × 10^9 IJs / ha	12.4	1475	600	68.6
Untreated control	34.8	875	-	-

Efficacy against stored grain pests : The most important insects damaging legumes in field and storage are bruchids or pulse beetles. Some other insect-pests also damage pulses in storage. Studies have clearly indicated that EPN are effective against various pests of stored grains to a varying degree. The comparative infectivity of 3 EPN species based on adult mortality has shown differential reaction. *S. masoodi* brought about mortality of *R. dominica*, *C. cephalonica* and *Callosobruchus chinesis* within 48-72 h of inoculation. *O. amsactae* brought mortality of pulse beetles *viz.*, *C. chienensis* and *C. maculatus* within 24 hours of post inoculation.

D. Biocontrol Agents *vs* Biorationals

Four commercial neem formulations *viz.*, Repelin 1.0%, Neem Guard 0.4%, Neem EC 0.15% and Neem WDP 0.15% were evaluated in laboratory for their antifeedant properties against *H. armigera*. Neem 25 EC was the best antifeedant with maximum protection of leaf area (89.54%) from larval feeding followed by Neem 25 WDP and Repelin (83.46%) as against only 44.59% protected leaf area in untreated control. Field evaluation of three commercially available neem formulations in two dosages for four consecutive years (1993-1997) showed that Achook 1%, Repelin 1% and Nimbecidine 0.4% gave better results with pod damage (as low as 7.7, 8 .6 and 10.3%, respectively) and were as effective as endosulfan (Table 4.39).

Table 4.39. Field efficacy of neem formulations against *H. armigera* in chickpea (1993-97)

Treatment	Pod damage (%)
Repelin 0.5%	11.7
Repelin 1.0%	8.6
Nimbecidine 0.2%	14.7
Nimbecidine 0.4%	10.3
Achook 1.0%	7.7
Endosulfan 0.07%	8.1
Control	26.1

Among different oils (pine, cedar wood, castor, mineral, turpentine, linseed, arachis and eucalyptus, each 0.5%), garlic extract 2% and multineem 0.5% tested against the 2nd instar larvae of pod borer, multineem exhibited better antifeedant property with 81.6% grain weight remaining unconsumed compared to 71.6% in control. Mineral oil was found least effective. Avoidable feeding was maximum (35.3%) with Multineem followed by castor oil (33.1%), linseed oil (32.4%) and arachis oil (31.7%).

E. Comparative Evaluation of Biorationals

Besides evaluating the efficacy of various fungi, bacteria and viruses individually against *H. armigera*, their comparative performance was also assessed under laboratory and field conditions. Laboratory evaluation of four biorationals, *viz.*, *Bt*. (Biolep 1 kg / ha), *B. bassiana* (Dispel 2 ml / litre), four strains of *Ha*NPV 250 LE / ha collected from different sources and three neem formulations along with endosulfan (0.07%) were evaluated against the 2nd instar larvae. Application of *Bt*, *B. bassiana* and Gulbarga strain of *Ha*NPV has been found as good as endosulfan in controlling *H. armigera*. Biopesticides like NPV and *Bt* formulations as well as insect growth regulators like Jadoo (Diflubenzuron +Alphamethrin) and Rimon (Novaluron) were tested against early instar larvae. Rimon 0.01% was most effective causing 85% mortality followed by *Bt (*80%) and NPV (60%). Insect growth regulator (Jadoo 0.01%) though caused only 30% mortality, it induced heavy deformity in the emerged adults. Rimon and *Bt* was as effective as good as Endosulfan (80% mortality). Jadoo offers advantage to reduce next generation population build-up by causing heavy deformities in adults .

Field evaluation of three biorationals *viz*., *Bt* (biolep), *Ha*NPV and Neem (Nimbecidine, Neemgold and NSKE) along with Radar and endosulfan against *H. armigera* in chickpea (1999-2000) showed that two applications of NSKE (315%), Nimbecidine (3.19%), NPV (4.16%) and Biolep (6.76%) are as effective as endosulfan (5.55%) and Radar (7.76%). Similarly in pigeonpea, evaluation of different *Bt* formulations, strains of *Ha*NPV, neem products and fungal formulations for three consecutive years showed that fungal formulation (Dispel 2 ml/l) was most effective followed *Bt* (BARC) and Delfin which are as effective as endosulfan and monocrotophos. Among neem products, neem gold shows better results. Both *Ha*NPV performed equally.

F. Screening of Insecticides against Biocontrol Agents

Laboratory screening of commonly used insecticides and biorationals for their toxicity to parasite, *C. chlorideae* at recommended dose revealed that monocrotophos, chlorpyriphos, endosulfan and Neem EC are safe for the parasite. Similarly, pyrethroids, fenvalerate, deltamethrin, *Bt* and Repelin are also relatively safer with 50-60% parasite emergence.

Field evaluation showed that fenvalerate 0.04% dust and 0.004% spray are safer to *C. chloridae* in comparison to endosulfan 0.07% spray and methylparathion 2% dust. In another study, three sprays of different insecticides, NSKE, profenophos and dimethoate have been found safer to the parasitoids of podfly recording 18.0, 17.2 and 15.4% parasitisation. Acephate ranked next with 12.5% parasitisation.

4.4. Stored Grain Pests

Bruchid or pulse beetle, *Callosobruchus* spp. (Coleoptera: Bruchidae), is a serious stored grain pest of pulses. The attack of these beetles starts in the field and the infestation is carried over to storage. Two species of bruchids, *Callosobruchus chinensis* (L.) and *C. maculatus* (F.) have been found most serious pests of pigeonpea, chickpea, mungbean, urdbean and lentil.

A. Field and Storage Losses

The pulse beetle, *C. chinensis* caused field infestation to the extent of 0.32 to 10.83, 0.0 to 0.96 and 0.0 to 8.72% grain damage on pigeonpea, mungbean and lentil, respectively. In chickpea, the field infestation was to the tune of 2.04 % on pod basis. This is the first record of bruchid infestation under field condition in chickpea crop. In a study on field infestation of bruchid (*C. chinensis*) in farmers' fields, grain infestation ranged from 0.0 to 8.94% in pigeonpea. The storage losses were found to the tune of 14.4, 10.0, 8.4 and 3.5% infestation in pigeonpea, mungbean, chickpea and urdbean, respectively.

B. Bio-ecology

Chickpea has been found as the most suitable host for *C. chinensis* followed by pigeonpea and mungbean. The bruchid recorded short developmental duration (49.91 days), higher growth index (1.52) and minimum mortality (25%) on chickpea. Chickpea exhibited a maximum of 75.5 eggs in an oviposition period of 6 days, followed by 72.60 eggs in 7 days in pigeonpea. The maximum egg hatchability was observed on chickpea (91.59%) and minimum in mungbean (85.60%). The number of eggs laid per grain was higher in chickpea (1–7 eggs) than pigeonpea (1-5 eggs) and mungbean (1-4 eggs). The developmental period and growth index of *C. chinensis* on chickpea during April–October ranged from 21.3 to 28.3 days and 2.69 to 3.65, respectively. The highest developmental period (42.25 days) and lowest growth index (2.26) were recorded during cold months (November to February). During cold months (November-February), 5-9% of the pupae had extraordinarily longer duration, which extended from 73 to 105 days, indicating the possibilities of occurrence of pupal diapause.

In pigeonpea, *C. chinensis* caused maximum infestation compared to *C. maculatus* under field condition. Both the species laid eggs on the side of the pods, which were not affected by direct sunlight. The oviposition behaviour of bruchids in short duration variety UPAS 120 revealed that the oviposition on pods initiated in the last week of October and went on increasing 12 days before the crop harvest in the last week of December and the pest infestation registered as high as 10% in the last week of November. In long duration variety NDA 1, oviposition was observed daily in April, indicating that maximum of 35% pods with eggs (1-4 eggs / pod) was found in the first week of April. Thereafter, it fluctuated to a great deal intermittently varying from 6-18 % and up to 34 % before the crop harvest with an average infestation of 17% during the period.

C. Management

Host plant resistance: Screening of germplasm against bruchid (*C. chinensis*) shows large variation in damage under open field and storage conditions. The germplasm lines reported to be promising are listed in Table 4.40.

Table 4.40. Resistance donors for bruchid tolerance in different pulse crops under field conditons

Crop	Sources of resistance
Chickpea (storage condition)	NIC 18852, NIC 18865, NIC 18878, ICC 6282, ICC 16438, ICC 8465, ICC 16443, ICC 10052, ICC 16429, ICC 16516, ICC 16462, ICC 16557, W5675, DGM 16577, ICP 16473, IC 1237, MRP 98, MRP 14, ICCC 10234-3, T1, ICCL 7811, GL 11587, FC 88-80, DN 66, FXIV flower, HY 10-3
Pigeonpea	KP 8139, ICP 3940, ICP 7946, SL 12/2, Bahar, SL 42-11, ICP 7946-2, SL 42-3, PDA 84-2
Mungbean	PDM 84-176, PDM 84-177, PDM 85-197, PDM 86-198, PDM 86-204, PDM 86-205
Urdbean	DPU 154, DPU 10-16, DPU 14-225

Physical and botanical control: Admixture of grains with plant products, edible / non-edible oils and inert materials showed promise in preventing bruchid damage under storage. It reduces oviposition, adult emergence, grain weight loss and prolonged the developmental period of bruchids. Among the plant products, seed treatment (20 g / kg of seed) with *dhatura* leaf powder, custard apple (*Annona* spp.) seed powder, *sadabahar* (*Vinca rosea*) leaf powder, *kaner* (*Neerium* spp.) leaf powder, neem (*Azadirachta indica*) leaf powder, Eucalyptus leaf powder, asgan leaf powder and orange peel powder are effective in providing protection against bruchids in pigeonpea and mungbean. Among the oils, mustard oil, neem oil and mahua oil (3-12 ml / kg of seed) act as surface protectants against *C. chinensis*. Inert materials showed promise in preventing bruchid damage. Lime, pond clay, *morang* (fine sand), fly ash, paddy straw ash and Ipomea ash (20 g/kg of seed) were quite effective in reducing *C. chinensis* population and its damage in pigeonpea and mungbean.

4.5. Nematodes

A. Major Nematodes

Surveys were carried out in different parts of the country to find out the predominant nematodes in the rhizosphere of different pulse crops.

Survey of chickpea for nematode pests in Kanpur area revealed *Hoplolaimus indicus* as predominant nematode along with *R. reniformis, M. javanica, H. dihystera, T. mashoodi, Pratylenchus thornei* and *Pratylenchus* sp. Under ICAR-ICRISAT collaborative programme, a survey was undertaken in the 11 chickpea growing districts of Rajasthan *viz*., Ajmer, Alwar, Bikaner, Churu, Sri Ganganagar, Jaipur, Jhunjhunu, Nagore, Sawaimadhopur, Sikar and Tonk. Lesion nematode, *Pratylenchus thornei*, root knot nematode, *Meloidogyne incognita* and *M. javanica* and cyst nematode were prevalent throughout the state. A new species of cyst nematode, *Heterodera swarupi* has been identified from Ajmer district.

Helicotylenchus dihystera was predominant among the nematodes associated with fieldpea. *Meloidogyne javanica* and *R. reniformis* infested the root system. Other nematodes such as *T. mashoodi, H. indicus, Basiria* sp. and *Pratylenchus* sp. were also recorded in good numbers in majority of the soil samples drawn from the pea crop.

Hoplolaimus indicus and *Rotylenchulus reniformis* were major nematodes associated with lentil.Concomitant population of *M. javanica, R. reniformis* and *H. indicus* were found associated with *rajmash.*

Surveys were conducted in Uttar Pradesh, Rajasthan and Gujarat in collaboration with ICRISAT to find out nematodes associated with pigeonpea. In Kanpur area, major nematodes encountered in pigeonpea fields are *Meloidogyne javanica, Rotylenchulus reniformis* and *Hoplolaimus indicus.* Survey in Banda, Ghazipur and Pratapgarh districts of UP revealed that pigeonpea crop was infested with eight nematodes, which included economically important nematode *Meloidogyne* spp. and *Hoplolaimus* sp. *Heterodera cajani* was recorded from Fatehpur, Kanpur and Lucknow. Survey conducted in Gujarat revealed presence of *H. cajani* in 69% of the locations in Bharuch, Kheda, Surat and Vadodera districts. The average densities of *H. cajani* were 8 times greater in Bharuch and Vadodera districts than in Kheda. *Rotylenchulus reniformis* was present in 70% of the locations. The population densities of *R. reniformis* were 2-3 times more in Bharuch and Surat districts than Vadodara and Kheda.

In mungbean, highest population of *R. reniformis* followed by *M. javanica* was recovered from root samples of mungbean. Other nematodes recorded were *Helicotylenchus abunaamai* and *Pratylenchus thornei*. *Telotylenchus* sp. and *Boleodorus* sp. were new records in mungbean. *Heterodera cajani* was recorded first time on mungbean at Kanpur. In urdbean, *Telotylenchus* sp. was recorded first time. Concomitant population of *Meloidogyne* sp. *Heterodera cajani, R. reniformis* and *Hoplolaimus* sp. were recorded in urdbean. Studies on yield losses in various pulse crops due to different nematodes are given in Table 4.41.

Table. 4.41. Loss in yield of pulses due to nematodes

Crop	% Yield loss
Pigeonpea	15.3
Chickpea	25.6
Lentil	15.4
Mungbean	12.3
Urdbean	15-30
Fieldpea	15-18
Rajmash	37.0

B. Population Dynamics

***Heterodera cajani* in pigeonpea**: Population dynamics of *H. cajani* was studied on cv. Bahar. In monthly sampling, it was observed that the cysts and egg masses increased in the month of October and November. Thereafter, cyst population started declining and was minimum in the month of March. During April, there was an increase again probably due to regeneration of fresh roots (Fig. 4.10). The egg masses to cysts ratio was more during initial growth period of the crop as compared to later stages.

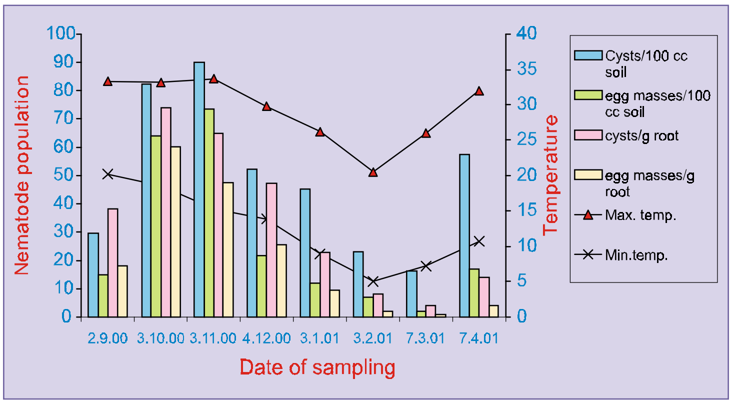


Fig 4.10. Population trend of cyst nematode in pigeonpea

***Hoplolaimus* in pigeonpea:** Population dynamics studies were carried out on early maturing UPAS 120, medium maturing PDA 86-1 and late maturing T 7. In UPAS 120, maximum population was recorded during the month of October. In PDA 86-1 two peaks of population were recorded during the month of October and January and then there was sharp decline of population. In T 7, maximum population was recorded during February, while minimum was recorded in the month of November.

Interaction studies : Studies on the interaction of *Meloidogyne javanica* and *Fusarium* wilt in chickpea showed that when *M. javanica* preceded *F. oxysporum* by 21 days, the mortality was recorded higher as compared to simultaneous inoculation of fungus and nematode and fungus preceding nematodes. *M. javanica* predisposed chickpea seedlings to wilt caused by *F. oxysporum* f. sp. *ciceri*. Plants were killed when both pathogens were present but not by either nematodes or fungus alone.

Out of 13 chickpea wilt resistant varieties screened against wilt in presence of root knot nematode, Avrodhi, KPG 59, H 86-72, Phule G 5, IPC 97-7, IPCK 96-3, ICCV 10, KWR 108, JG 315, ICCV 2, H 82-2, BG 372 and GCP 105 had shown enhanced wilt incidence in presence of nematodes.

In pigeonpea variety MAL 13, *H. cajani* + F. *udum* caused maximum wilting followed by *H. cajani* + *F. udum* + *Rhizobium* compared to fungus alone or fungus in combination with *Rhizobium*. In Bahar variety, wilting was not affected by *Rhizobium* and it was almost same in *H. cajani* + *F. udum* and *H. cajani* + *F. udum* + *Rhizobium* treatments. *Fusarium udum* in combination with root knot nematode caused more wilting in Bahar than *F. udum* alone.

Ten pigeonpea genotypes resistant to wilt namely, KPL 43, GPS 33, KPL 44, AWR 74/15, ICP 8859, ICPL 89048, PI 397430, BWR 370, ICPL 89049, ICP 12745 were evaluated against *Fusarium udum* in presence of root knot nematode, *Meloidogyne javanica*. Five genotypes *viz*., AWR 74/15, ICP 8859, ICPL 89049, ICP 12745 and KPL 44 recorded 30 to 60% wilting in presence of *M. javanica* (Fig. 4.11).

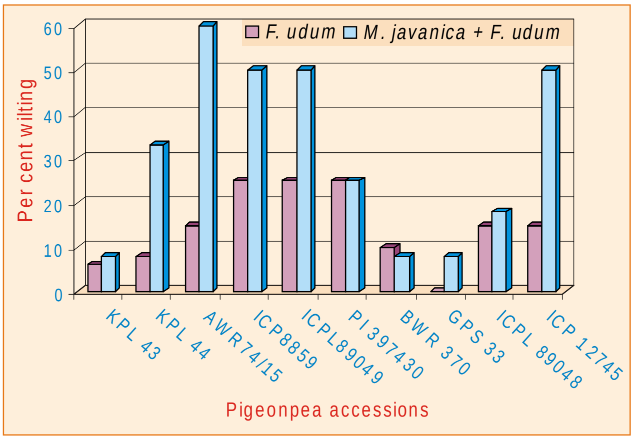


Fig. 4.11. Wilting of pigeonpea accessions in presence of *Fusarium udum* and *Meloidogyne javanica*

In an interactive study of root knot nematode and *H. cajani* in urdbean, the effect of *Meloidogyne javanica* and *Heterodera cajani* was studied on each other and on urdbean plant. The combination of *M. javanica* and *H. cajani* taken was 100+100, 100+200, 100+400, 200+100 and 400+100 on the urdbean plants grown in earthen pots. *Meloidogyne javanica* when present alone reduced more plant height, shoot and root fresh and dry weights compared to *H. cajani*. Minimum plant growth characters were recorded when 400 *M. javanica* was combined with 100 *H. cajani*. Data on population of juveniles present in the soil showed that multiplication rate of *H. cajani* was more compared to *M. javanica*. When both the nematodes were combined in different combinations, the per cent reduction was more in *H. cajani* compared to *M. javanica*. When 100 juveniles of both nematodes were combined, reduction in *M. javanica* was 23.3% compared to 58.9% in *H. cajani*. With the increase of *M. javanica*, the population of *H. cajani* decreased with maximum reduction of 86.4% by combining 400 juveniles of *M. javanica* and with 100 juveniles of *H. cajani*. Similarly population of *M. javanica* decreased with increase in the inoculum of *H. cajani*. The maximum reduction in population of *M. javanica* was 40.1% by combining 400 juveniles of *H. cajani* with 100 juveniles of *M. javanica*.

C. Management

Cultural practices: Among different crop rotations, sorghum - chickpea + mustard sequence recorded highest chickpea equivalent yield of 1918 kg/ha followed by maize-based system. Lowest root knot nematode population was recorded in maize – chickpea sequence whereas maximum population was recorded in mungbean - chickpea / mustard system. As regards the lesion nematodes, the trend was reverse. It thrived well in cereal – chickpea system and populations were low in legume – chickpea + mustard system. In urdbean based cropping systems, it was observed that the urdbean + sorghum – wheat and urdbean – wheat + mustard cropping systems were best in decreasing the nematode population up to 83.3 and 75.6% in a year.

Host plant resistance: A total of 1860, 510, 350, 526, 410 and 360 accessions of chickpea, pigeonpea, mungbean, urdbean, fieldpea and lentil, respectively were screened against root knot nematode, *Meloidogyne javanica*. The resistant accessions of different pulse crops are given in Table 4.42.

Seventeen accessions of different wild relatives of pigeonpea were evaluated for resistance against *M. javanica* and *Heterodera cajani*. Four accessions, ICWP 016

Table 4.42. Genotypes/accessions found promising against nematodes

Crop	Nematode	Resistant donors
Chickpea	*Meloidogyne javanica*	BG 369, BGM 481, 483, GL 88341, GMS 815
	M. javanica & *M. incognita*	BGM 481, 483, GL 88341, GMS 815
Pea	*M. javanica*	DDR 16, HFP 4, HFP 9510, LFP 227
Lentil	*M. javanica*	DPL 14, IPL 100, KLS 214, L 4628, PL 406
Pigeonpea	*M. javanica*	MTH 9, T 9, UB 218, MA 7, TT 10, H 84-5, Pant A 169, MA 4, KPL 43, GPS 33, BWR 376, Pusa 991, Pusa 992, AL 1430, AF 345, AL 1381
	H. cajani	MAL 9, MAL 14
Mungbean	*M. javanica*	GM 85-2, 85-68, ML 323,HUM 7, MH 98-1, PMB 34, LGG 460, Ganga 4, ML 5, Pusa 105
Urdbean	*M. javanica*	TPU 3, TPU 4, WBU 105, PLU 648, AKU 7, UG 218, UG 562, KU 304

(*C. albicans*), ICWP 062 (*C. platycarpus*), ICWP 086 and ICWP 097 (*C. scarabaeoides*) were identified as resistant against *M. javanica* and resistance was confirmed in two accessions of *Cajanus platycarpus* namely, ICWP 062 and ICWP 069 against *H. cajani*.

Chemical control

Chickpea : Seed treatment with Posse 3% and Bavistin 0.2% were effective in reducing *M. javanica* infection in chickpea. Similarly, Nimbecidine @ 0.2% was superior to other neem products in managing the nematode population in chickpea. In a trial conducted at farmers fields, seed treatment with neem seed powder @ 5% and latex 1% were found effective for the control of nematode population and higher yield in chickpea.

Pigeonpea : Seed treatment with neem seed powder 5% was found effective in reducing the nematode infection and increasing the biomass and yield in pigeonpea cv. Narendra Arhar 1 followed by Neemarin (2%).

Mungbean : Among various organic amendments (neem cake, castor cake and poultry manure), lowest root knot counts and highest yield were recorded in poultry manure @ 10 q / ha treated soil followed by neem cake.

Urdbean : In a nematode management trial in urdbean, 12.5 NSP + 1 tonne FYM / ha in combination with seed treatment with carbosulfan @ 3% w / w was found best and recorded highest biomass (16.32 q / ha), yield (3.83 q / ha), minimum gall index and soil population of root knot and cyst nematode.

Biological control: Two endoparasitic fungi belonging to *Catenaria* sp. were isolated from the root knot nematode juveniles collected from chickpea fields. Similarly, one endoparasitic fungus was isolated from *H. cajani*. One nematode trapping fungi identified as *Pestolosia* spp. was isolated from the soil.

Out of eight fungi isolated from the egg masses of root knot nematode and cysts of *H. cajani*, two fungi *Fusarium solani* and *Aspergillus niger* were found most effective in reducing the number of galls, egg masses and soil population of root knot nematode in chickpea. Number of galls was 10 and 30 in *F. solani* and *A. niger* treated soil as compared to 64 galls per root system in plants with out fungus treatment.

Trichoderma viride and *T. harzianum* applied as seed treatment @ 10 g / kg seed or soil application @ 10 g / kg soil were found effective in reducing the galling in chickpea and increasing the plant growth. The egg infection was observed slightly more (65%) with *T. harzianum* than *T. viride* where egg infection was observed 57%.

Integrated nematode management: Integration of three components *viz.*, cropping system, cultural methods and seed treatment in chickpea showed that summer deep ploughing combined with seed treatment with latex of *Calotropis* and carbofuran and intercropping mustard considerably reduced nematode population and recorded highest yield.

5. Crop Physiology, Biochemistry & Microbiology

5.1. Crop Physiology

A. Chickpea

Stress physiology : The research work on drought in chickpea was initiated in 1983. About 30 genotypes adapted to different rainfed agro-ecological zones of India were evaluated in dug out plot with varying moisture gradients. The field screening showed large genotypic variation in growth and grain yield under different moisture regimes. This enabled identification of putative genotypes with drought tolerance, primarily based upon the grain yield and biomass. These genotypes were further evaluated under different soil moisture regimes such as irrigated, rainfed and rainout shelter.

Assessment for morpho-physiological traits : In successive years of experiments, about 12 genotypes having different degrees of drought tolerance as identified from the experiment conducted in dug out plots, were planted under three distinct moisture regimes such as irrigated, rainfed and rainout shelter representing no stress, moderate stress and severe stress respectively. A number of morpho-physiological traits (Table 5.1) were considered for evaluation under three moisture regimes in order to identify traits associated with drought tolerance. The data were analyzed to work out the association of each trait with grain yield, and the traits

Table 5.1. Correlations (r) of different traits with grain yield in chickpea

Trait	Correlation (r)						
Phenological	**(r)**	**Morphological**	**(r)**	**Morphological**	**(r)**	**Physiological**	**(r)**
1st branch	-0.36	Plant height	0.30	Root dry weight	0.78**	Pod fill rate	0.42*
1st flower	-0.28	Root length	0.36	Leaf dry weight	0.64**	Harvest index	0.73**
1st pod	-0.46	Leaf number	0.50*	Shoot biomass	0.75**	Water potential	0.21
Flower duration	0.32	Canopy spread	0.53*	Flower number	0.22	Osmotic adjustment	0.45*
Pod duration	0.60*	Branch number	0.58**	Pod number	0.83**	Turgor potential	0.45*
Maturity	0.10	Nodule number	0.47*	Seed wt/plant	0.81**	RWC	0. 6**
		Leaf area	0.56**	Hundred seed wt.	-0.34	SLW	0.37
		Stem dry weight	0.77*				

RWC=Relative water content; SLW = Specific leaf weight which could explain the maximum variability influencing grain yield under water-limiting environments. The correlation of morpho-physiological traits with grain yield was determined. Traits like biomass, pod number, harvest index, root dry matter, osmotic adjustment and relative water content showed high correlation with grain yield.

Stress tolerance index : Several chickpea genotypes have been identified as drought tolerant based on their yield performance and flowering under irrigated and rainfed conditions as per method described by Fisher and Maurer (1977). The genotypes showing low yield relative to its rainfed counterparts, had higher drought susceptibility index (DSI). The lower the DSI, the greater was the drought tolerance of the line. Some of the genotypes identified having lower DSI are RSG 143-1, RSG 888, Phule G 5, Vijay, and ICC 4958.

Root traits for drought tolerance : During 1996 to 2001, concerted efforts were made to investigate genotypic variation in root morphology, depth, dynamics and function. Initially, limited success was made in extracting roots with minimum damage at 2-3 weeks seedling stage, thereafter with declining soil moisture followed by hardening of soil crust, it was practically impossible to uproot the plants with intact roots. Keeping this in view, a system was developed to screen genotypes with higher root profile using 18 cm diameter PVC tubes (Fig. 5.1). Another innovative technique was developed for root studies which involve a wooden structure with front window fixed with glass slot for direct viewing of roots *in vivo*.

Fig. 5.1. Screening root traits for drought tolerance using PVC tubes

Genetic variation for root traits : Observations on roots in PVC tubes revealed that root system of chickpea is diverse in nature, particularly in terms of root length density (RLD), biomass and branching pattern (Figs. 5.2 and 5.3). Some of the genotypes such as ICCV 92944, ICC 4958, BG 256, Phule G 5, ICCV 94916 and RSG 143-1 showed vigorous root system with high RLD and extensive branching at the uppermost region during initial growth. These genotypes belong to early flowering group and have drought avoidance characteristics. Some genotypes such as Vijay and Katila showed deep root system with less RLD and branching at the top. They are best adapted to the dry environments where roots need to penetrate very deep in search of water. On the other hand, medium maturity genotypes had lesser root biomass compared to early maturity group, for example, ICCV 10, Annegiri, DCP 92-3, *etc*. The root system in late maturity group like C 235 and C 214 showed very poor root growth establishment during initial growth phase and their early vigour was also very poor. The methodologies used at field level for genotypic comparison under three conditions *e.g.*, irrigated *vs* rainfed and rainout shelter representing maximum to minimum moisture levels showed that irrespective of the genotype, root biomass increased under moisture stress.

Fig. 5.2. Genotypic differences in rooting behaviour of chickpea at seedling stage (3 weeks)

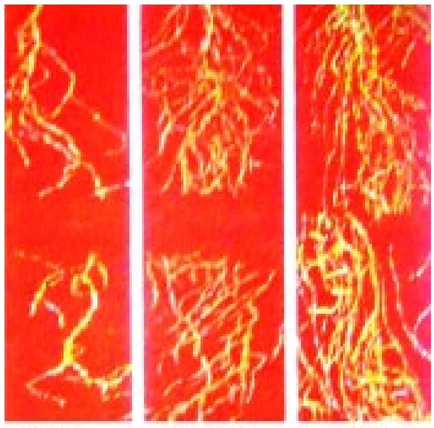


Fig. 5.3. Root profile of different chickpea genotypes at 15 cm depth

Phenological adaptation : A wide genotypic variation for flowering time was observed among chickpea genotypes. The flower initiation was as early as 20 days after sowing in ICCV 2 and as late as 100 days in C 214, C 235, *etc*. The flowering pattern has been found to be the crucial factor for determining grain yield under a given environment. Therefore, flowering is an important physiological event and is related with location specific adaptation. For example, in South and central zones, genotypes such as ICC 4958, Annegiri, ICCV 2, Phule G 5, Vijay, *etc.*, are most successful because of quick biomass production, early canopy coverage, early root proliferation for efficient soil moisture utilization, particularly when the terminal drought is more severe as a result of high temperature combined with increased water loss through evapotranspiration. This condition does not favour long pod duration and actually needs short crop duration. Limited number of genotypes evaluated under three moisture regimes indicated an advancement of flower initiation even under moderate water stress, suggesting that drought accelerates earliness and reduces reproductive period in order to avoid terminal drought.

Phenological development and grain yield : Based on the limited number of contrasting genotypes tested under three soil moisture regimes, chickpea were broadly grouped into early, medium and late maturity groups based on the phenological traits such as initiation of 1st branch, appearance of 1st flower, days to 50% flowering and first pod, length of reproductive phase. Genotype C 214 being late flowering type had the shortest reproductive phase but higher yield under rainfed conditions. Early maturing genotypes, ICCV 92944 and ICCV 96030, could not yield as much as recorded by medium and late groups such as K 850, BG 256, DCP 92-3 and C 214. In general, drought caused early flower induction in all genotypes whereas well-watered conditions delayed the maturity. Correlation studies revealed inverse relationship between flowering time and grain yield. Pod number showed highly significant positive association with days to flowering. The results indicated that early genotypes did not yield better under northern plains where crop season extends till March / April and terminal drought is not as harsh as in central India. This suggests that the genotypes with medium to late maturity types are best adapted to North plain zone while early group is best adapted to South and central zones. Early genotypes had poor harvest index than the late genotypes. Therefore, early induction of flowering greatly penalizes the final grain yield in chickpea in northern plains as the crop faced a lag period of growth due to prevailing low temperature during December-January. On the contrary, early genotypes have adequate time to gain biomass in South or central zones because they did not encounter low temperature during December-January. Therefore, extended period of crop growth could be the desired character for chickpea for higher yield under northern plains.

Source-sink relationship : A large number of genotypes were evaluated under two different soil moisture regimes (irrigated and rainfed) for almost five years. Vegetative biomass was most sensitive to water stress. Leaf expansion was affected even under mild water stress with the leaf water potential declining to 1.2 MPa. Biomass showed a linear relationship with yield under rainfed conditions, indicating source (leaves & stems) as the major limiting factor for higher yield. Contrary to this, increasing biomass beyond a certain limit did not increase grain yield further under irrigated conditions suggesting sink as the limiting factor (Fig 5.4).

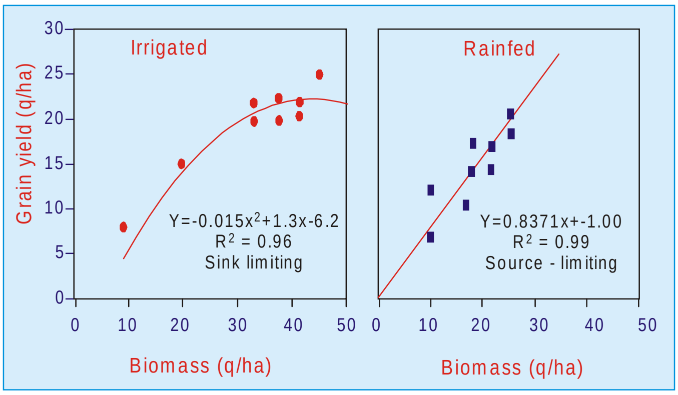


Fig 5.4. Biomass-yield relationship under rainfed (stress) and irrigated (non-stress) conditions

Yield and yield attributing traits under drought conditions : Number of primary and secondary branches had positive influence on grain yield. Biomass had significant positive correlation (r=0.75) with yield followed by harvest index (r=0.73), pod number (r=0.83), phenology (1st pod) (r=-0.46) and pod fill rate (r=0.42). The results showed that pod number played an important role in determining the yield under drought. The pod number invariably decreased under water stress. Suitable traits such as high branch number should be identified to increase pod number under water stress.

Water relation parameters : The soil moisture profile estimated gravimetrically or by using neutron moisture probe revealed that in sandy loam soil (Inceptisol), the moisture declined to 4% on the top 15 cm soil at crop maturity as compared to the field capacity of 20% soil moisture at the beginning. The relative water content (RWC) decreased very slowly except under high atmospheric vapour pressure deficit. Similarly, Leaf water potential measured by Pressure Chamber declined slowly and fell below –2.0 MPa at terminal water stress with a corresponding decrease in the RWC by 70-75%. The canopy temperature determined by infrared thermometry was 1-2^{0}C higher in chickpea grown under rainfed or rainout shelter during podding stage. The canopy microclimate significantly influenced the root biomass and water relation characteristics. The RWC had highly significant correlation with canopy temperature, specific leaf weight, root dry weight, and water and turgor potentials. This indicated that maintenance of higher RWC could be a factor contributing towards increasing root biomass and at the same time RWC also regulates the leaf water and turgor potential. There were large differences in the water relation characteristics such RWC, leaf water potential and osmotic potential among the genotypes grown under rainfed conditions. It indicated that several mechanisms are involved in maintaining the leaf water status of chickpea such as deep root systems, ability to adjust osmotically and high stomatal resistance to reduce transpiration. Hence the measurement of RWC may prove a viable method to assess the water status of genotypes under rainfed conditions.

Mechanisms of drought tolerance : Out of many physiological parameters tested, few of them such as osmotic adjustment, rooting efficiency, photosynthesis, water use efficiency and sucrose synthase activity in grains appeared to be promising in defining the drought tolerance.

(i) Osmotic adjustment : Under a collaborative Indo-Australian project (1998-2005), about 20 genotypes of chickpea were evaluated for various physiological traits related to drought tolerance. A significant genotypic variation in osmotic adjustment was observed among chickpea genotypes with a maximum value of about 1.3 MPa in Tyson, moderate values of about 0.5-0.7 MPa in Annegiri, K 850, IPC 94-132 and ICCV 14880, and low in ICC 4958. The study at IIPR showed that osmotic adjustment prevents lowering of RWC below a critical level by efficient water uptake, restore photosynthesis and maintains positive carbon balance for longer period under water stress conditions. However, evaluation of ABL lines at IIPR and Australia, a significant difference was observed suggesting that osmotic adjustment is not a stable physiological character and does change with the environment, physiological status and stress level (Table 5.2). Poor heritability, less stability and contradictory reports regarding relationship of OA with grain yield are some of the

Table 5.2. Osmotic adjustment in chickpea genotypes

Genotype/ ABL	Osmotic adjustment	
	India (2005)	Australia (2003)
CTS	0.53	0.38
60453	0.70	0.56
Tyson	0.54	0.54
Kaniva	0.78	0.67
M 39	0.70	0.77
M 51	1.27	0.45
M 55	0.88	0.63
M 75	0.88	1.05
M 86	0.64	0.79
M 93	0.73	0.61
M 110	0.72	0.47
M 129	0.76	0.62
Mean	0.38	0.38
LSD (P=0.05)		

facts describing its inconsistency towards its influence on yield. Therefore, the osmotic adjustment could not prove as a potential tool to screen chickpea germplasm for drought tolerance.

(ii) Water use efficiency : The water use efficiency (WUE) of 17 chickpea lines determined by using ^{13}**C** carbon isotope discrimination technique showed significant genetic variation in WUE. RSG 143-1 and Vijay showed higher water-use efficiency.

Sucrose synthase activity : One of the key enzymes called sucrose synthase (SuSy) controlling the seed size has been identified in chickpea. It was observed that the activity of this enzyme (SuSy) dramatically increased in response to mild water stress. Most of the large seeded genotypes like ICC 4958, Phule G 5, K 850 showed higher SuSy activity as compared to small seeded genotypes such as C 214, ICCV 10, C 235, ICCV 14880 and Pant G 114 irrespective of soil moisture status. Higher sucrose synthase activity, though beneficial for productivity, did not show advantage because of biomass or source limitation.

GE interaction : In order to investigate specific and general adaptation of chickpea in India, a wide range of sub-continental, Australian and Mediterranean genotypes were grown across seven sites characterizing the major chickpea growing areas over 3 years, and extensive data on plant stand, early vigour, phenology, productivity and yield components were collected. High and low yielding sites were clearly separated by a range of physical and biological characters, low yield being associated with low latitude and pre-season rainfall, high temperature, early phenology, short crop duration, low biomass and fecundity. Genotype x environment interaction for yield was highly significant and accounted for more variance than the genotypes. The study has identified both specific and wide adaptation to low and high yielding environments of southern and northern India, and demonstrated the central role of phenology, biomass and harvest index in adaptation of chickpea. Drought escape through early phenology and high harvest index are critical traits for yield in southern and central India. In the North, late flowering is necessary to maximize biomass accumulation, and delay pod set until temperatures rise sufficiently to prevent abortion. Germplasm specifically adapted to the North is able to delay flowering significantly more at later sites than unadapted material.

Plant ideotype : Based on the studies conducted during the last five years (2002-07), a minicore from ICRISAT combining of 216 lines and 50 released varieties including advanced breeding lines were categorized into four different groups. These groups represent the genotype's adaptive potential to a particular environment.

Based on the morphological and physiological characters, these were easily distinguishable. Genotypes belonging to the Group I have the features with dominating main stem with reduced growth of primary branches at the base, erect, bold seeds, early flowering, high root biomass, large leaflet size and low to medium yield (Fig. 5.5a). These genotypes are well adapted to Central and Southern zones under rainfed condition. Genotypes of Group II were characterized by synchronous growth of main and primary branches at the base, high yield, medium flowering, semi-spreading, medium seed and leaflet size and relatively less root biomass (Fig. 5.5b). The Group II genotypes are adapted predominantly under northern plains where extended crop seasons are available. The genotypes belonging to Group III have the features with small leaflet size, small seed, highly spreading, possess heliotropism and invariably show very deep root system with moderate osmotic adjustment (Fig. 5.5c). Few prominent genotypes belonging to this category are Vijay and RSG 143-1. Both the genotypes are reported to be most suitable for drought condition. Group IV genotypes are represented by very small leaflet size, medium height with bushy habit, late flowering and high osmotic adjustment (Fig. 5.5d). The classical example of the genotype falling in this category is Tyson having very high osmotic adjustment and good adaption to drought condition.

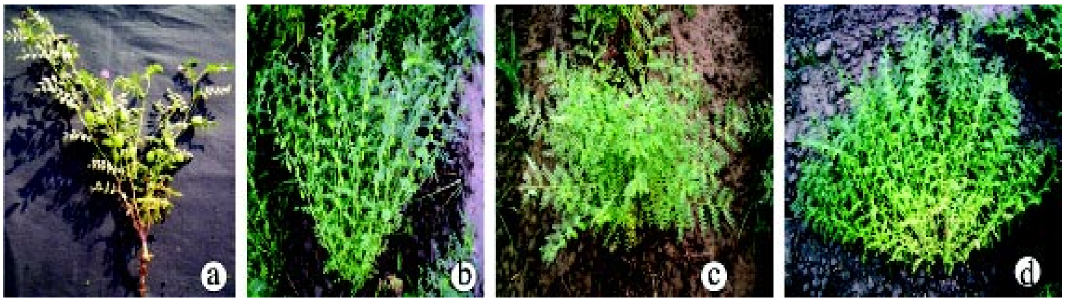


Fig. 5.5 : Four groups of plant types in chickpea

Group I plant has invariably large leaflets, large seed size, profuse nodulation and vigorous root system and are early flowering type. It appears that these characters are linked and expressed simultaneously. Therefore, seed size influences leaf size, root vigour and nodulation. As the seed size decreases, the flowering time delays with decrease in root biomass and leaf size.

Influence of climatic changes on crop yield : Meteorological record for two decades at Kanpur revealed that minimum temperature is increasing consistently while maximum temperature remained almost constant. The trend indicated that difference between maximum and minimum temperatures has been decreasing as a result of lesser atmospheric heat dissipation. The present weather pattern indicated larger atmospheric vapour pressure deficit with unusually warmer winter during night and almost negligible dew precipitation. As a result, the chickpea crop is pushing more towards severe terminal drought and high temperature during reproductive phase in the North India.

A collection of 330 chickpea germplasm lines including 160 ICRISAT minicore, advanced breeding lines and released varieties were assessed for heat tolerance during 2007-08. About 80% failure of pod setting was observed when temperature suddenly increased to 41^0C during March. Few of them could set pods, however, majority of them showed reduced, shriveled or deformed grains except some lines having normal seeds. Based on the pod setting, seed size, biomass, foliar resistance and grain yield, genotypes were tentatively screened as highly tolerant to heat, moderately resistant or sensitive ones.

The critical temperature range for damage of reproductive organs was somewhere in between $35\text{-}40^0$C. The reproductive parts may damage irreversibly depending upon the sensitivity of the genotypes. Foliar resistance measured by chlorophyll fluorescence showed remarkable resilience against high temperatures, though photosynthetic rates decreased but reduction is fully reversible within temperature limit of $35\text{-}40^0$C. Another limit was coinciding with 47^0C where photosynthetic system is itself irreversibly damaged.

Thermo-tolerance : A wide genotypic variation in thermotolerance was observed among chickpea germplasm involving ICRISAT minicore, released varieties and advanced breeding lines when subjected to daytime temperature exceeding 35^0C. Genotypes *viz.*, ICC 3512, 7819, 4958, Vaibhav, JG 74 and ICCV 92944 showed higher yield under late sown conditions and also tolerance to high temperatures ($35\text{-}41^0$C) based on the series of preliminary screening tests comprising of ability of pod set, flower abortion, seed size, membrane injury and chlorophyll fluorescence conducted.

B. Lentil

In general, lentil is grown under stored soil moisture from preceding monsoon season and faces moisture stress during the reproductive phase. Studies showed that under such conditions, yielding ability depends mainly on seed filling period as increase in other physiological traits leads to higher vegetative growth and less reproductive growth. However, under non-stress conditions, yielding ability is mainly dependent on dry matter partitioning during seed filling period as well as leaf dry matter accumulation. Drought tolerance index (DTI) in lentil is largely controlled by leaf area and its duration, leaf dry matter accumulation and relative leaf growth rate. It was further observed that higher magnitude of DTI can be achieved through manipulating leaf area and its duration for known quantity of soil moisture over a given period (Fig. 5.6).

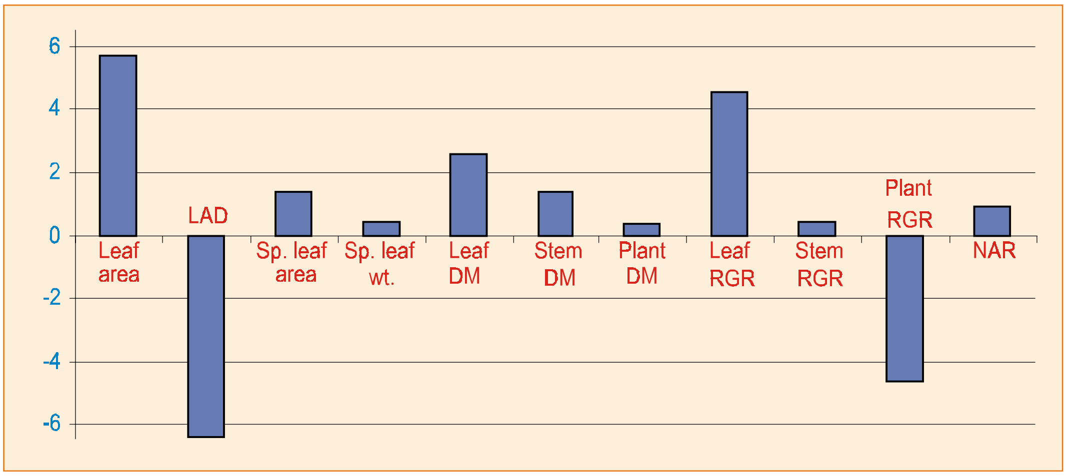


Fig. 5.6. Direct effect of physiological traits on drought tolerance index in lentil

While evaluating the yield structure of lentil genotypes, it was revealed that under irrigated condition, lentil yield is mainly influenced by pod and seed number per plant followed by total dry matter yield and harvest index (Fig. 5.7). But, under non irrigated condition, maximum association was observed for 100-seed weight followed by harvest index, total dry matter yield and seed number per plant.

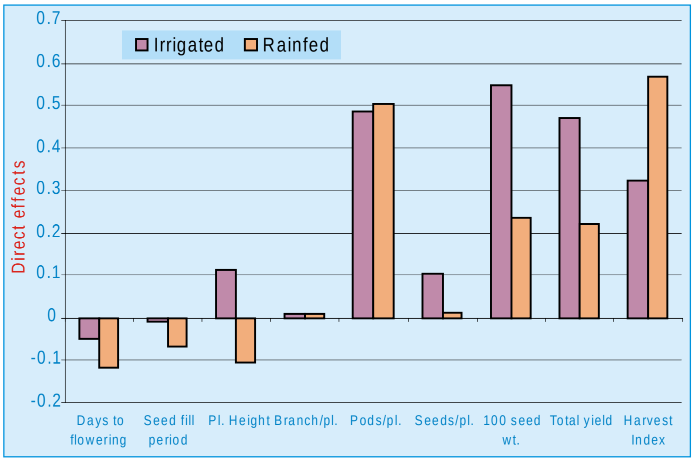


Fig. 5.7. Direct effects of traits on lentil seed yield under irrigated and rainfed conditions

Moreover, plant height, number of seeds per plant and harvest index had differential mode of association with yield under irrigated and non-irrigated conditions. Multiple correlations of traits having significant contribution for yield were 0.536 and 0.611 under rainfed and irrigated conditions, respectively. Under irrigated condition, lentil seed yield is determined positively by days to podding, plant dry matter at maturity, per day dry matter production, harvest index and negatively by plant dry matter at vegetative stage and by total degree days during flowering to podding.

Other study showed that lentil yield under non-irrigated condition was lower than that in irrigated condition and was determined positively by days to podding, plant dry matter at podding, relative total plant growth rate during podding to maturity, per day dry matter production and harvest index. Under non-irrigated condition, yield is determined by total dry matter yield, per day dry matter production and partitioning, mean temperature as well as total degree days during podding to maturity whereas under irrigated condition, it is determined by root dry matter at vegetative stage, total dry matter yield, per day dry matter production its partitioning during seed filling period and total degree-days during flowering to podding.

The per cent association of lentil seed yield under irrigated condition was worked out to be 1.42, 2.86, 25.7, 0.94, 44.4, 42.25, 0.76, 41.6 and 21.4 with days to flowering, seed filling period, plant height, branches / plant, seeds / plant, 100-seed weight, biomass and harvest index, respectively. However, the same association percentages under non-irrigated condition were 6.55, 6.55, 3.2, 12.9, 17.2, 21.4, 64.6, 43.3 and 45.43, respectively.

C. Pigeonpea

Flower Drop : In pigeonpea, flower drop and pod abortion are of higher magnitude. Pigeonpea genotypes examined for the extent of flower drop showed significant genotypic differences with respect to physiological traits and flower drop at different dates of sowing. Physiological analysis revealed that during early flowering, leaf area and specific leaf weight restricted the flower drop under normal sown crop while leaf and stem dry matter in the late sown crop. During the peak flowering period, leaf area and total dry matter are the major traits restricting flower drop under normal while under late sown condition, they were root dry matter, leaf area, total plant dry matter and specific leaf weight. While examining the physiological basis of yield structure in pigeonpea genotypes under normal and late seeding conditions, it was observed that pigeonpea yield under normal seeding was greatly affected by total plant dry matter and relative plant growth rate at flowering, relative pod growth rate, total plant dry matter at podding and relative plant growth rate at podding. Pigeonpea seed yield under late seeding was affected mainly by stem and plant dry matter at flowering, relative plant growth rate and stem and leaf dry matter at podding and by stem and pod dry matter and relative pod growth at maturity.

Trait association with yield : Correlation study involving short duration genotypes of pigeonpea showed that high yielding genotypes (>1500 kg / ha) had higher growth in terms of dry matter build up and leaf area at all crop growth stages as compared to poor yielding genotypes (<1000 kg / ha). High yielding (>1500 kg / ha) genotypes had open plant type as compared to poor yielding (<1000 kg/ha) genotypes in terms of leaf and branch angles at flowering. Soluble sugar content (m moles / g dry weight) in leaves was initially lower at flowering in high yielding than poor yielding genotypes. But the trend was reversed during subsequent growth stages and finally at maturity, high yielding genotypes had higher soluble sugar in leaves as compared to poor yielding genotypes. Total amino acid content (m moles/g dry weight) in leaves was initially lower at flowering in poor yielding genotypes as compared to high yielding genotypes. But the trend was reversed during subsequent growth stages and finally at maturity, higher yielding genotypes had lower amino acid as compared to poor yielding genotypes. In high yielding genotypes, ratio of total sugar in leaves and total amino acid was initially lower at flowering but increased at subsequent growth stages. The reverse was true for poor yielding genotypes from flowering to maturity.

D. Mungbean

Study on application of nitrogen (20 kg N / ha) showed that split application (10 kg N as basal and 10 kg N as top dressing at flowering) gave higher grain yield as compared to basal application. The nitrogen so applied was fractioned in different plant parts. The grain yield was negatively influenced by root nitrogen concentration, total nitrogen partitioned in root, and leaf nitrate nitrogen content during vegetative stage. However, yield showed positive association with leaf nitrate reductase activity during crop ontogeny.

Evaluation of twenty mungbean genotypes for physiological traits revealed significant genotypic variation for relative growth rates of different plant parts, net assimilation rate, leaf area duration, and specific leaf weight at various crop growth stages. The mungbean yield was positively correlated with relative shoot growth rate and negatively with dry matter partitioning in leaf and stem during 20 days after podding and maturity.

Evaluation of mungbean genotypes for relative importance of different physiological traits during pre and post-flowering periods in realization of yield revealed that during pre flowering, dry matter accumulation in plant and its partitioning into leaf and stem and relative leaf growth rate had major influence on the harvest index. During post flowering period, stem and total plant dry matter had their definite role in influencing the harvest index. Amongst the various physiological traits, yield structure was largely governed by leaf area duration, relative leaf and total plant growth rates and days to flowering during pre flowering period. During post flowering period, dry matter allocation in pods and total plant, days to podding and leaf area duration had their definite roles in influencing the seed yield. Dry matter partitioned during pre-flowering period has very little effect on yield, but during post flowering period, higher magnitude of dry matter partitioned in leaves and stem reduced the yield. During pre flowering phase, leaf as well as total plant dry matter and their rates of accumulation had major influence on seed yield. During pre flowering period, higher order of association existed between mungbean seed yield and relative shoot, leaf and plant growth rate, leaf area duration and net assimilation rate. However during post flowering period, root, shoot and total plant dry matter, leaf area and relative root growth has better association than other physiological traits under study.

In order to assess physiological diversity, mungbean genotypes were grouped as late (>70 days) and early (<70 days) maturity groups. It was observed that leaf, stem and total dry matter were more in late than in early maturity group. Leaf area and specific leaf weight were higher amongst the late group as compared to early group. Photosynthetic rate during flowering and podding were higher for late maturity group. Photosynthetic efficiency was almost same for late and early maturity group. Early maturity group had high total yield as well as seed yield as compared to early maturity group. Higher seed yield in early maturity group was mainly due to higher per day dry matter partitioning during seed filling period.

Pre-harvest sprouting : Screening of 28 mungbean genotypes under field as well as under laboratory conditions resulted in identification of five promising genotypes *viz.*, TARM 1, TARM 18, Ganga Mung 1, Pusa Vishal and Pusa 9072 for tolerance to pre-harvest sprout.

E. Urdbean

Field experiment involving 15 genotypes revealed that grain yield was positively associated with total dry matter and negatively with stem dry matter at vegetative stage, and positively with total plant dry matter and negatively with stem and leaf dry matter during flowering and maturity. The maximum positive effect was from per day dry matter partitioning. Variation in yield could be explained by root dry matter at maturity and relative leaf growth rate at flowering.

5.2 Biochemistry

A. Chickpea

Nutritional and anti-nutritional properties: Important genotypes of chickpea *viz*., BG 256, BG 224, BG 364, BGD 86, GPF 2, GL 769, GL 88341, K 850, KPG 59, RSG 143-1, ICC 4958, ICCV 10, PDG 84-16, Pant G 114, Pusa 362, Phule G 5, Avrodhi, Annigeri, Radhey, KWR 108, DCP 92-3, JG 74, JG 315, Haryana chana, BG 1053, KAK 2, JKG 1, L 550, Sadabahar and BGD 112 were evaluated for their nutritional parameters. The results showed that protein in different genotypes ranged from 20.88 to 27.44% with an average of 23.13%. Some of the genotypes *viz*., GL 88341, Pusa 362, GL 769 and GPF 2 had high protein as compared to other genotypes. The starch in seed ranged from 35.80 to 51.14% with an average of 41.86%. Avrodhi, GL 769, BGD 86, PDG 84-16, and ICCV 10 possessed relatively higher starch. Soluble sugar was present in the range of 3.31 to 5.02% with an average of 4.18%. BG 364, RSG 143-1, BG 224, GPF 2, GL 769 had low soluble sugars as compared to other genotypes. A part of these sugars was oligosaccharides, which consisted of raffinose, stachyose and verbascose, which cause flatulence effect on its consumption. Polyphenol, an anti-nutritional component of pulses was present in low quantity in chickpea; however, the range was found in between 0.07 and 0.11% with an average of 0.09%. Avrodhi, Pusa 362, Pant G 114, BGD 86, PDG 84-16, Annigeri, Radhey and ICC 4958 had low polyphenols in their seed. Polyphenols can be removed partially by soaking and discarding the water after soaking or discarding the broth after boiling the dehulled split seed or *dhal*.

Chickpea is relatively high in lipid content as compared to other pulses. The fat content of chickpea ranged from 2.78 to 4.57% with an average of 3.75%. BG 256, KPG 59, Avrodhi, Pusa 362, BGD 86 and PDG 84-16 had relatively higher fat. The fat of chickpea is a ‘good fat’ as it contains major quantity of unsaturated fatty acids, which help in lowering the cholesterol levels in blood serum. The most predominant fatty acid of chickpea is linoleic acid (C18:2), which constituted about $2/5^{th}$ of total fatty acids. Oleic (C18:1) and linolenic (C18:3) acids are other unsaturated fatty acids. Avrodhi, GL 88341, Pusa 362, GL769, BG 364, K 850, Pant G 114, PDG 84-16 and Radhey relatively have higher linoleic acid. The presence of higher unsaturated fatty acid especially linoleic and linolenic acids (PUFA) is one of the main reasons for hypocholesterolemic effect of chickpea. It helps in reducing low density lipids.

The dietary fibre of chickpea consisted of insoluble as well as soluble fibres. Among insoluble dietary fibres, cellulose and hemicellulose were the major fibres whereas the lignin was present in lower proportion. The pectin, a soluble dietary fibre was also present in chickpea, which was in higher proportion in *kabuli* types than *desi* types. The total dietary fibre in chickpea genotypes varied between 10.3 and 19.6%. The *kabuli* type chickpea differs from *desi* type in their chemical composition and the variation in important parameters responsible to lower cholesterol in blood serum.

The chickpea contained adequate quantity of calcium, potassium, zinc and iron. High potassium in chickpea advocated its use for hypertensive people as it helps in maintaining Na - K equilibrium in the body.

The presence of saponin in chickpea genotypes was also established. It was present in the range of 108.9 to 158.3 mg/100 g seed. The chickpea saponin has been reported to reduce cholesterol as well as prevent colon cancer in human beings, hence useful from health point of view.

Processing effect on protein, fatty acids, minerals, vitamins and saponins was also studied in different genotypes of chickpea. Soaking and germination reduced starch and soluble sugars, but increased the protein content of seed. There was manifold increase in vitamin C content of seed during germination. Therefore, sprouts are useful from health point of view due to high antioxidant effect of vitamin C. In addition, soaking and germination reduced polyphenols and enhanced the digestibility of chickpea. Cooking and pressure cooking help in removing protease inhibitors and lectins. Polyphenols and flatulence causing sugars can be minimized, if the broth after boiling the grain/*dhal* is discarded.

Biochemical basis of resistance to wilt: Wilt is an important disease of chickpea, which is caused by *Fusarium oxysporum* f.sp. *ciceri*. There are certain secondary plant metabolites synthesized in the plant, which impart resistance against the disease.

Wilt resistant genotypes such as DCP 92-3, JG 74, JG 315, KWR 108, Radhey, Haryana Chana 1, Avrodhi, GPF 2, Vijay, SAKI 9516, NNW 16, NNW 19 were compared with susceptible genotypes such as JG 62, JKG 1, L 550, Pusa 256. It was revealed that certain phenolic acids such as chlorogenic, coumaric, caffeic, ferulic and protocathuic acids were present in plant, which play an important role in imparting wilt resistance in chickpea. The presence of chlorogenic acid, coumaric, caffeic and ferulic acids was prominent in roots of the plant. The chlorogenic acid in roots of resistant varieties was 400 to 1500 mg / kg as against 150 to 200 mg / kg in susceptible varieties. The leaf of the wilt resistant plant also had high chlorogenic and coumaric or ferulic acids as compared to susceptible plants.

The mechanism of formation of chlorogenic acid was from p-coumaric to ferulic or caffeic acid, which combine with quinic acid and produces chlorogenic acid in the plant.

B. Lentil

Lentil is an important pulse crop and and is quite nutritious from quality point of view. The soluble protein content in different genotypes was varying between 20.62-23.84%. The soluble sugar was found in the range of 3.52-5.33%. Starch is the major carbohydrate of lentil and constituted 46.49-52.72% of the seed. Polyphenols in lentil was low *i.e.*, below 0.31%. The fat content of the lentil grain is very low *i.e.*, almost 1%. Linoleic acid is the main unsaturated fatty acid and palmitic acid is the main saturated fatty acid. Oleic and Linolenic acids were the other fatty acids. The total unsaturated fatty acids were in between 70-75% of the total fatty acids. The mono-unsaturated (MUFA) and poly-unsaturated fatty acids (PUFA) are useful from health point of view as they help in lowering the blood cholesterol. The varieties studied were DPL 58, Priya (DPL 15), Sheri (DPL 62), Pant L 4, Pant L 406, Pant L 639, VL 1, JL 1, K 75 and Ranjan.

C. Fieldpea

Genotypes of fieldpea *viz*., JP 885, HFP 4, HUP 2, KPMR 144, KFP 103, Rachna, IPF 14, IPF 17, IPF 27, IPFD 98-1, IPFD 98-7 and IPFD 98-9 differed in their nutritional quality parameters. The soluble protein content of these genotypes was in the range of 16.3 to 22.9%. Genotypes like JP 885, KFP 103 and Rachna had high protein content as compared to other genotypes. The starch of seed ranged between 41.3 and 51.2%. HUP 2, KPMR 144, KFP 103 and IPF 14 possessed relatively higher starch as compared to other genotypes. Soluble sugar was found in the range of 6.1 to 7.8%. All the genotypes were at par in respect of soluble sugar except KPMR 144, IPF 14 and IPFD 98-9, which had high sugar in their seeds. The crude fibre of seed was in the range of 3.4 to 4.7%. HUF 2, Rachna, IPF 17, IPFD 98-7 had relatively high crude fibre in their seed. The seed lipid was in the range of 1.1 to 1.5%. The most predominant fatty acid of seed was linoleic acid (C 18:2). The palmitic (C 16:0), oleic (C18:1) and linolenic (C 18:3) acids were other fatty acids of fieldpea.

D. *Rajmash*

Popular genotypes of *rajmash viz*., HUR 15, HUR 137, Udai, Amber, GPR 257, GPR 358, BDJ 338, EC 406071, EC 406072, 96-2-2 and 62-1-P-1 differ in their nutritional quality parameters. The soluble protein of rajmash beans was found in the range of 16.13 to 21.83%. GPR 358, BDJ 338 and 96-2-2 had high protein as compared to other genotypes. The starch was present in the range of 46.39 to 51.65%, soluble sugar in the range of 3.24 to 4.51% and crude fiber in the range of 3.88 to 5.68% in seed of different genotypes. The fat content of seed of different genotypes of *rajmash* was found in the range of 2.20 to 5.03%. The genotype Amber, GPR 358, HUR 15 and GPR 257 had relatively high fat in their seed. The linoleic acid was the main unsaturated fatty acid of *rajmash* and constituted about 1/3rd of total fatty acids. The oleic is the main mono-unsaturated fatty acid of *rajmash* and linolenic is another unsaturated fatty acid. Palmitic acid is the main saturated fatty acid. Stearic acid is also found but in very low quantity. The genotypes HUR 137, EC 406072, Amber, 96-2-2 and 62-1-P-1 had high linoleic acid in their seed as compared to other genotypes.

E. Lathyrus

Lathyrus contains a neurotoxic compound, known as BOAA or ODAP. This compound causes neurolathyrism, a disease characterized by lower limb paralysis. The safer tolerance limit of BOAA for human being is below 0.1%. Pusa 24, Pusa 28, Pusa 90-2. Pusa 94-3 were having high BOAA in the range of 0.15 to 0.35 % but the varieties recently developed at IARI like Bio L 212, Bio L 231, Bio L 208, Bio R 202 are having very low BOAA *i.e.*, in the range of 0.04 to 0.08%, which is very much within safer limits (Table 5.3).

Table 5.3. BOAA in seed of lathyrus genotypes

Variety	BOAA (%)
Ratan	0.06
Bio L 208	0.06
Bio L 202	0.05
Bio L 231	0.08
Pusa 24	0.275
Pusa 28	0.21
LSD 3	0.17

The BOAA can be further minimized by roasting or soaking the *dal* in water and discarding the water. More than half of the BOAA can be removed by these techniques.

The fatty acid profile of lathyrus is more or less similar to chickpea and contain higher quantity of unsaturated fatty acids *i.e.*, linoleic and linolenic acids. Palmitic acid is the main saturated fatty acid. More than 2/3rd fatty acids are unsaturated fatty acids.

F. Pigeonpea

The important genotypes/lines of pigeonpea *viz*., Bahar, Pusa 991, Pusa 992, AL 201, UPAS 120, AL 1430, ML 12, ML 15, NDA 98-1, Manak, C 11, MA 3, PDA 3, PDA 9, PDA 10, PDA 85-3, PDA 85-4, PDA 86-1, PDA 87-1, PDA 87-4, and Type 7 were evaluated for nutritional quality parameters. The protein content was found in the range of 18.36 to 22.08%. The genotype AL 1430, AL 201 and Manak had high protein as compared to other genotypes. The starch constituted 51.55 to 58.92% of seed depending on the genotype. The soluble sugars constituted 4.32 to 5.17% of seed weight. The polyphenol of seed was found in the range of 0.32 to 0.62%. The genotypes Bahar, Pusa 992 and AL 1430 had low polyphenols. Most of the polyphenols are present in seed coat and the cotyledons have negligible amount of polyphenols, hence dehulling of seed removes majority of polyphenols. The pigeonpea is generally consumed as *dhal*, hence polyphenol does not adversely affect the digestibility of protein of pigeonpea. Phosphorus of seed was in the range of 0.26 to 0.33%. Manak, UPAS 120, ML 12 and C11 had higher phosphorus in their seed.

The fat content of seed was in the range of 1.25 to 2.45 % with an average of 1.72%. The genotypes AL 1430, NDA 98-1, MA 3 and C 11 had higher fat than other genotypes. The palmitic acid is the main saturated fatty acid in seeds of pigeonpea, whereas linoleic, oleic and linolenic acids are the most important unsaturated fatty acids (Table 5.4). High linoleic and linolenic acids in pigeonpea are beneficial from the health point of view, as these possess hypocholesterolemic property and lower down LDL levels of lipoprotein in human beings, hence protect cardio-vascular system. High monounsaturated and polyunsaturated fatty acids are beneficial from health point of view.

Table 5.4. Palmitic and lineleic acid in seed of different pulses

Fatty acids	Total fatty acids (%)					
	Chickpea	**Pigeonpea**	**Lentil**	**Fieldpea**	***Rajmash***	**Lathyrus**
Palmitic acid	17.2	21.4	15.0	14.5	15.5	17.5
Linoleic acid	52.8	41.2	38.5	42.1	30.5	45.0

The dietary fiber consists of cellulose, hemicellulose, lignin and pectin. Cellulose and hemicellulose were relatively higher than lignin.

G. Urdbean

Variation in different genotypes occurs in terms of their chemical composition. Improved lines of urdbean *viz.*, PDU 3, PDU 6, PDU 7, PDU8, PDU 10, PDU 30, NP 16, NP 21, and released varieties T 9, UG 218, Pant U 19, PS 1 and PDU 1 were compared for their nutritional quality. The soluble protein was ranging between 17.25 to 19.69%. ND 21, Pant 419, PDU 3 and PDU 7 had high protein. The soluble sugar was ranging between 2.60 to 3.53%. The total polyphenols in urdbean were found in the range of 0.08 to 0.21%. Polyphenols decreases the digestibility of food legume and are not reduced by cooking unless the cooking broth is discarded, hence the genotypes with low polyphenols are considered superior from digestibility point of view. PDU 7, PDU 8, PDU 10 and PDU 30 were superior, being the low polyphenol genotypes. Pre-cooking soaking for 4-6 hours partially removes polyphenols in urdbean. Crude fibre varied between 3.84 to 4.95 % and considered as quality attribute responsible to enhance cholesterol lowering properties of food legumes. The crude fibre consists of majority of cellulose and lignin. The phosphorus content of urdbean was found in the range of 0.29 to 0.44%. Urdbean has good amount of phosphorus than other food legumes.

5.3 Microbiology

A. Compatibility of *Rhizobium* with Fungicides and Bioinoculants

Seed treatment with fungicides and *Rhizobium* are normal recommended practice to protect seedlings from soil borne pathogens and improve nitrogen fixation in pulses. In addition, pulses are also inoculated with other microorganisms like phosphate solubilizing microorganisms and bio-control agents such as *Trichoderma harzianum*. All these bio-inoculants have to establish and colonize the rhizosphere soil. An understanding of their interactions on seed surface is important to utilize and increase effectiveness of microbial inoculants in fields.

Chickpea and urdbean *Rhizobium* strains were found to be compatible with thiram and carbendazim up to 2000 ppm (a.i based). *Trichoderma harzianum*, a biocontrol agent was also compatible with *Rhizobium*. Metabolites produced by *T. harzianum* also showed no inhibition of R*hizobium* growth.

Population of *Rhizobium* on fungicides (Carbendazim and thiram) treated seeds and stored for different period after inoculation showed a gradual decline in population size with increase in period of storage from 0 hr to 48 hr. (Fig. 5.8). Within 8 hrs of storage, *Rhizobium* population declined from 10^7CFU g^{-1} seed to 10^5CFUg^{-1} seed and after 24 hr of storage this level was reduced to just half of the initial values. This fall in population size was more in presence than absence of the fungicides.

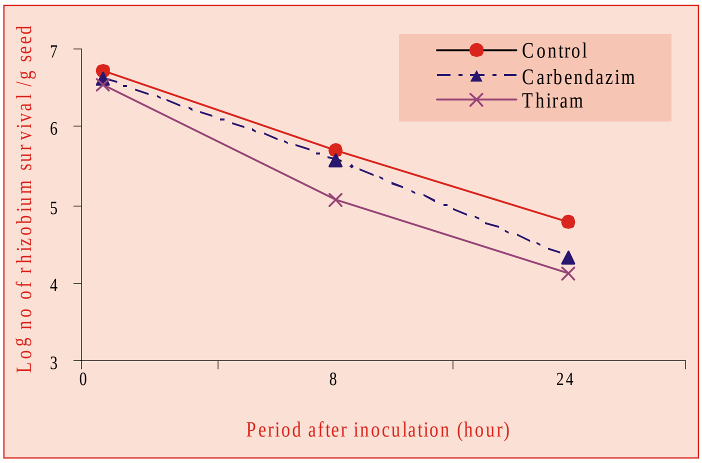


Fig 5.8. Survival of *Rhizobium* on seeds treated with carbendazim and thiram

Increase in storage period of inoculated seeds also adversely influenced on nodulation of chickpea and urdbean in field. Chickpea seeds, treated with recommended rate of fungicide (1000 ppm of carbendazim and thiram), followed with *Rhizobium* inoculation showed that increase in storage period from 3 hr to 24 hr significantly reduced specific nodule weight and shoot weight where as nodule number per plant showed a slight decline but the differences were not significant. This decline in nodule numbers is attributed to the reduction in population size of *Rhizobium* cells on seed surface with increase in period of storage. Seeds sown 3 hr after inoculation accumulated significantly greater biomass in shoots compared to seeds sown after 24 hr of storage period. This study clearly showed that to improve the effectiveness of inoculation, seeds should be sown within 3 hrs of their treatment with *Rhizobium*.

B. PGPR for Chickpea and Pigeonpea

PGPRs are microorganisms that colonize rhizosphere / rhizoplane and increase nutrient uptake and growth of plants through production of bioactive molecules such as antibiotics, antifungal compounds, siderophores, growth hormones, *etc.* Number of microorganisms were isolated and screened for their ability to promote growth and nutrient uptake in chickpea and pigeonpea. These isolates were characterized for production of various bioactive molecules such as HCN, siderophore and ammonia. Nine out of 16 *Azotobacter* strains were HCN positive, 11 showed siderophore production and all *Azotobacter* strains were positive for ammonia production. Similarly, out of 18 *Pseudomonas* strains, 14 were positive for ammonia production and 13 showed siderophore production.

Among the *Azotobacter* strains, five strains improved chickpea growth with maximum increase of 52% produced with strain A4 within 4 weeks of plant growth (Fig. 5.9).

Out of 15 strains of phosphate solubilizing bacteria (PSB), plant inoculated with strain 24 and 27 produced significantly greater biomass compared to the uninoculated control. Some of the isolated strains showed inhibition to wilt fungus *Fusarium oxysporum f. sp. ciceri* (Fig. 5.10). Based on plant bioassay and biochemical

Fig. 5.9. Response of *Azotobacter* strains on chickpea root growth

Fig. 5.10. Inhibition of fungal growth

attributes 23 elite strains of *Azotobacter*, *Pseudomonas* and PSB were selected for the further studies in chickpea.

Interaction of PGPRs with pigeonpea genotypes : Five PGPR strains were tested for their growth promoting activity in different pigeonpea varieties *viz.*, UPAS 120, NA1, Bahar and Kudrat. All the strains showed positive growth promoting effect with UPAS 120 but with other varieties' growth response was highly variable (Fig. 5.11). This demonstrated the host genotype dependent interactions of PGPR strains.

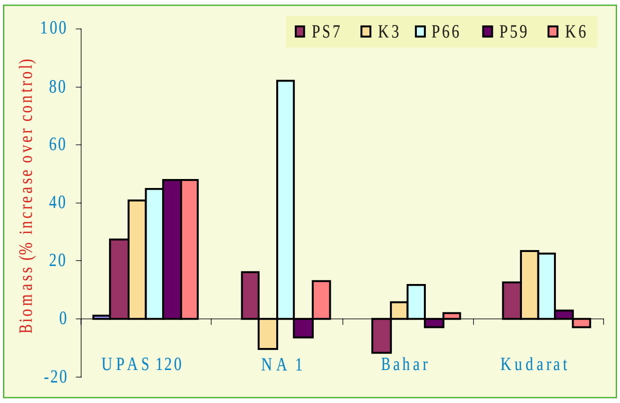


Fig. 5.11. Interaction of PGPRs with different varieties of pigeonpea

Soil fertility status also influenced upon the performance of PGPRs. Soil with high carbon content produced 85-137 % increase in plant biomass due to inoculation with different strains of PGPRs over control (Fig.5.12). Growth response to inoculation was relatively low in soils with less carbon level.

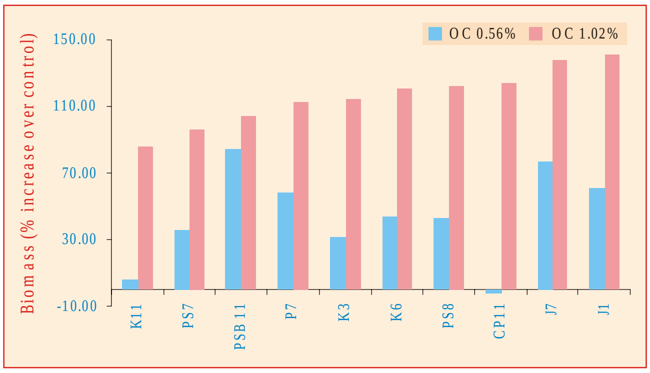


Fig. 5.12. Evaluation of PGPRs at different soil fertility status in pigeonpea

C. Organic Production of Pulses

Studies on organic production of lentil and chickpea were initiated in year 2006. Organic crop production system was compared with chemical and integrated systems of crop management for their relative effects on soil quality and crops yield. The system performance was evaluated in a two year crop rotation involving crops of sorghum for fodder, followed by chickpea / lentil -mungbean and mustard.

Soil quality parameters determined after harvest of mustard crop showed distinct improvement in organic carbon, mineralizable-C, available-N and P as well as microbial activity of soil under organic management compared to integrated and chemical based management systems (Table 5.5). Soil organic carbon content increased from initial level of 0.24% to 0.42% and 0.35% under organic and integrated production systems, respectively. Similarly, available nitrogen content in soil increased from initial level of 225 kg/ha to 317 and 254 kg/ha under organic and integrated production systems. Organic production system sequestered highest amount of organic carbon compared to integrated system while in chemical production system there was depletion of soil carbon by 8% from its initial value (Fig. 5.13). Mineralizable carbon in soil under organic production increased from initial level of 310 kg/ha to 1122 kg/ha an increase of about 250% compared to only 924 and 836 kg/ha under chemical and integrated production systems.

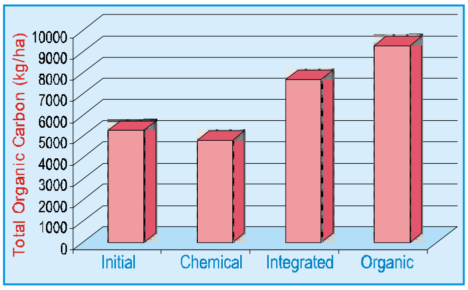


Fig. 5.13. Organic carbon in soil under different crop management systems

Table 5.5. Soil properties after harvest of mustard crop under different crop management systems

Properties	Management system		
	Chemical	Integrated	Organic
Chemical			
pH	7.94	8.2	7.93
EC (ds/m[2])	0.563	0.554	0.634
Organic carbon (%)	0.220	0.350	0.424
Mineralizable carbon (mg C/g soil)	0.380	0.420	0.510
Total-N (mg N/g soil)	0.520	0.533	0.840
Available-N (kg N/ha)	201.0	254.0	317.0
Total-P (µg P /g soil)	420.8	418.0	434.0
Olsen's P (µg P /g soil)	19.2	22.9	28.4
Microbial activity			
Soil respiration rate (mg CO_2-C/100 g soil/10 days)	3.22	3.85	6.50
Dehydrogenase (µg formazone/g soil/h)	3.80	8.50	12.45
Acid phosphatase (mg p-nitrophenol/g soil/h)	2.84	3.15	4.65
Alkaline phosphatase (mg p-nitrophenol/g soil/h)	3.12	3.62	4.85

Yields of fodder sorghum, chickpea, mungbean, and mustard were low in organic compared to integrated production systems but it compared well with chemical based production systems. Mustard yield with organic and chemical fertilizers was 28.15 and 28.07 q/ha, respectively.

D. Effect of Flooding on Soil Properties

Flooding soil for 90 days resulted in almost two folds increase in electrical conductivity and a significant increase in soluble carbohydrate content. Soil respiration rate, an indicator of soil biological activity was also higher in flooded compared to un-flooded control soil.

Native population of chickpea *Rhizobium* in soil was low and ranged from 10 to 282 cells/g soil. Chickpea *Rhizobium* population in soil after harvest of paddy and sorghum crops ranged between 100-200 cells/g soil. Though these differences in population of *Rhizobium* due to a preceding crop of paddy and sorghum were not significant statistically, yet there were significant differences in the nodulation of the chickpea grown after these crops. Nodule numbers per plant were higher in chickpea grown after paddy compared to sorghum (Fig. 5.14).

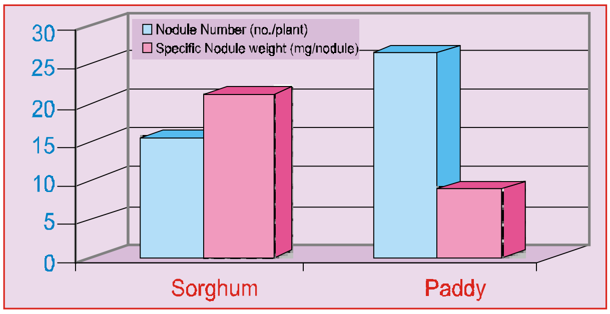


Fig. 5.14. Effect of preceding crops of paddy and sorghum on nodulation in chickpea

The specific nodule weight was, however, significantly higher in chickpea grown after sorghum compared to paddy. Inoculation with a mixture of efficient strains of *Rhizobium ciceri* improved nodulation. This beneficial effect of inoculation was more pronounced in chickpea grown after sorghum compared to paddy.

Inoculation with *Rhizobium* and application of recommended doses of fertilizers significantly increased shoot weight and nitrogen content compared with control or inoculation alone. The observed effects of preceding crops on nodulation characteristics clearly showed that the root exudates of sorghum alter *Rhizobium* population diversity much more prominently compared to anaerobic conditions developed during the paddy growth.

6. Post-Harvest Management

In the post-harvest chain of pulses, it has been observed that losses are around 25% but in extreme conditions it may be as high as 50%. Out of the total losses, milling (15-20%) and storage (5-10%) contribute the maximum. Therefore, importance of post-harvest handling and processing has been given due importance at the Institute. Concerted efforts were made during the last 25 years on various aspects such as storage, handling and processing. The salient achievements are as follows:

6.1 Processes and Methodologies

A. Determination of Grain Characteristics and Milling Behaviour

Important engineering properties *viz*., moisture content, 1000-grain weight, bulk density, true density, husk content, germ content, theoretical *dal* yield, angle of repose and internal friction, coefficient of friction, sphericity and specific heat were determined for different pulses and its cultivars. Milling behaviour of some released cultivars of pigeonpea, chickpea, lentil, mungbean, urdbean, fieldpeas, *rajmash* and lathyrus were also determined. Dehusking efficiency, finished product recovery, hulling efficiency and *dal* yield were recorded to evaluate milling performance of these cultivars. Amongst pigeonpea cultivars, Pusa 9 yielded the highest finished product recovery of 75.31% (Fig.6.1). For chickpea, lentil, urdbean, mungbean and field pea, BG 372 (58.82%), JL 2 (84.84%), IPU 94-1 (63.93 %), Samrat (74.14%) and IPF 27 (68.24%) gave the maximum finished product recovery. Information about husk, germ, cotyledon contents and milling recoveries are

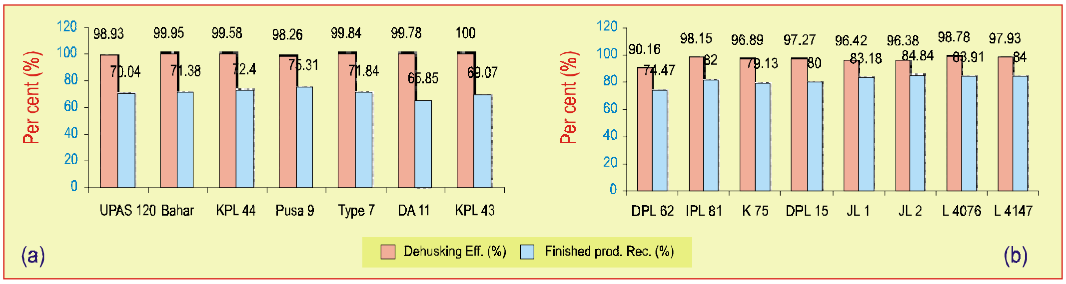


Fig. 6.1. Milling behaviour of pigeonpea (a) and lentil (b) cultivars

important characteristics, which indicate *dal* yield potential and can be utilized by pulse breeders for developing easy-to-mill varieties with less energy input and higher milling recoveries.

B. Standardization of Milling Procedure

Pulse milling procedures have been developed for small or lab scale mills, which can facilitate millers to assess *dal* recovery at the time of procurement of raw grains. The milling parameters *viz*., rotor rpm, sample weight and residence time were standardized for pigeonpea and urdbean on Grain Testing Mill.

C. Evaluation and Optimization of Pre-milling Treatments

Pigeonpea is considered as the toughest-to-mill pulse. Therefore, various pre-milling treatments were developed and tested for pigeonpea. Oil and water treatment process is commonly adopted in commercial milling of pigeonpea. Sodium bi-carbonate pre-treatment process developed at Pantnagar and thermal treatment developed by CFTRI were evaluated along with untreated grains and water soaking treatment, commonly adopted at village scale milling. In oil and water treatment, pitted grains were mixed with 0.7% mustard oil and then water was applied to grain in 1:33 ratio. Treated grains were tempered for 14 hours and sun dried to the milling moisture content. In sodium bi-carbonate treatment process, grains were pitted and then mixed with 5.5% concentration of the solution, in 1:26 grain to solution ratio, tempered for 5.5 hours, dried to 10% moisture content prior to milling. The same experiment was conducted with unpitted grains. Optimized thermal treatment was given to pigeonpea grains at 166^{0}C air temperature and heating time was 7 minutes. Among various pre-milling treatments, oil and water treatment gave highest recovery (79.8%) followed by sodium bi-carbonate (75.9%).

Pre-milling Treatment	Recovery (%)
Untreated	70.90
Water soaking	74.66
Oil and water	79.80
Sodium bi-carbonate	75.90
Thermal	72.42

6.2 . Machineries

A. IIPR *Dal Chakki*

A low capacity *dal* mill, popularly known as IIPR *dal Chakki*, has been designed and developed at the Institute. Commercial *dal* mills use rough surface of emery

rollers for husk removal after pre-milling treatment. Rough emery surface not only removes husk but also scratches outer surface of precious cotyledons, which is lost in the form of powder. In IIPR *dal chakki*, rubber and steel discs are used instead of abrasive roller for dehusking. Treated pulse grains are fed between the stationary rubber and rotating steel discs to remove husk. Use of rubber disc facilitate smooth removal of husk from pretreated grains, reduces scouring losses and increases *dal* recovery. *Chunni* and *bhunsi* are separated with the help of cyclone separator. Dehusking, splitting and cleaning operations are carried out simultaneously in this unit. This *chakki* can be used for milling all kind of pulses using 1.5 hp single phase motor. Its capacity ranges from 75-125 kg / h and gives recovery of 74-79 % in case of pigeonpea and 78-84% in case of chickpea with suitable pre-milling treatment.

This *chakki* basically comprises feeding unit, milling unit and cleaning unit. Feeding unit consists of a feed hopper and auger type feeding mechanism, which maintains uniform flow of treated grains to the milling unit. Milling unit is a vertical attrition unit, comprising of stationary rubber and rotating corrugated steel discs. Gap between the two discs can be adjusted depending upon pulse and size of the grains. The milled product is exposed to air suction with the help of blower. Husk and powder is separated by means of cyclone separator. Due to use of rubber disc, this *dal* mill yields 5-10% higher *dal* recovery as compared to emery roller mills. This machine can also be used for making *dalia* and grits for animal feed using corrugated steel disc in place of rubber disc to crush the material.

B. IIPR Mini *Dal* Mill

An upgraded model of IIPR *Dal Chakki*, namely, IIPR Mini *Dal* Mill, has been developed. This model has additional provision of grading the raw grains as well as finished product. In the old model, a separate grader was used for grading raw grains and milled fractions. Apart from this, an emery roller attachment has also been incorporated, which makes the pitting process easier. With the help of emery roller, scratching of whole grains is done to ease pre-milling treatment. This roller also enables the production of dehusked whole *i.e.*, *gota* like *malka masoor*, which was difficult to produce in earlier model as most of the grains passed through the unit get splitted in vertical attrition mills. Incorporation of grader and pitting units has made this model a complete mini *dal* mill, wherein grading of raw grains, pitting (scratching of seed coat), milling of all types of pulses like dehusked splits (pigeonpea, chickpea, pea, lathyrus, *etc.*), unhusked splits (mungbean and urdbean), and dehusked *gota* (*malka masoor*), cleaning and separation of husks, *etc.*, and grading of finished products (*dal*) are done in the same machine and operations can be done simultaneously.

It was observed that dehusking for tough-to-mill kind of pulses needs proper pretreatment with rubber-steel disc mechanism used in IIPR *Dal Chakki*. To improve absorption of oil or water applied for pretreatment, pitting is quite helpful. For scratching purpose, an emery roll of size of 3810 x 1524 mm has been added to the original IIPR *Dal Chakki*. Pitting facilitates fast pre-milling treatment and reduces residence time significantly. All pitting, milling, cleaning and grading operations can be done simultaneously in the model with the help of two horse power single phase motor. By replacing rubber disc with corrugated steel disc, this mill can also be used for making *dalia* and grits for animal feed.

C. IIPR Multipurpose Pulse Grinding Mill

This grinder comprises of swinging beater type rotor to crush the fed material inside the chamber in which outlet is provided at the lower end through perforated sieve. Sieves of different size can be placed to increase or decrease the particle size of crushed material. The fed material is beaten by swinging rotating beaters till the powder size reduces to equal or less than the sieve perforations. This grinder was primarily developed for *besan* or *sattu*, but the machine worked successfully for grinding of spices like turmeric, coriander, red chilly, black pepper, *etc.* Therefore, the unit has been named as multi-purpose grinder. Capacity of the grinder is 40-45 kg / h for *besan* and rice flour. The unit can grind 3-4 kg of coriander and black pepper, 2-3 kg of red chillies, 9-10 kg of turmeric powder per hour. Due to beating action by hammers and air circulation within the grinding chamber, the product temperature does not rise much during milling. The unit is powered by a 1 hp single phase motor and, thus, has the potential to be adopted as cottage industry for grinding of different products.

D. *Dal*-cum-*Besan* Making Machine

This machine has been developed to use single motor for pulse milling as well as grinding. Arrangements have been made to mount *dal chakki* and multipurpose grinder on the same frame. Necessary modifications have been made for providing drive to different moving pulleys from the motor. A 2 hp single phase motor has been used to perform milling and grinding operations simultaneously. This unit can be installed by rural entrepreneurs for round the year income generation, as rainy and winter seasons are considered as lean seasons so far as pulse milling is concerned due to weather dependence of milling process. Pulse milling and grinding operations can be performed simultaneously in this unit.

E. Swinging Beater Type Plant Thresher

This machine has been especially designed and developed to thresh crop harvested from experimental plots. This plot thresher can be utilized by crop scientists as well as plant breeders to determine single plant yield. It is very effective for pulse crops apart from cereal crops.

6.3. Storage Methods

A. Controlled Atmospheric Storage

To reduce losses during storage in pulses, controlled atmosphere storage methods were evaluated. The controlled atmosphere storage of pigeonpea at CO_2 level above 4% effectively checked the growth of insect infestation. Insect growth was reduced from 5.6% to 1.6% in >4% CO_2 level during the ten months of storage period. This indicates inhibited respiration rate of grain and insects due to presence of CO_2. Loss in dry matter and increase in grain moisture were low in CO_2 induced containers when compared with control.

B. Evaluation of Storage Structures for Safe Commercial Storage

Different storage structures, namely metallic bins, earthen pots, plastic containers, pp woven bags, jute bags, polythene bags, and cotton bags were evaluated for suitability of storage of dehusked splits, *i.e.*, *dal* and whole grains of pigeonpea. Dehusked splits of pigeonpea were prepared using standard milling technique. *Dal* and whole grains of pulses were stored in above mentioned structures for a period of one year. Samples were drawn on monthly basis and were analyzed for moisture content and insect infestation.

Infestation due to bruchid was observed in the very first month of storage in case of whole grains, which was subsequently controlled by fumigation (Fig. 6.2). No visible insect activity was recorded in case of dehusked splits in all the evaluated storage structures during the storage period. Whole grains are prone to internal infestation irrespective of storage method and, hence, require fumigation whenever any insect activity is observed. For whole grains in metal bins, two fumigations were given one during the month of June and other in February to control the insect activity.

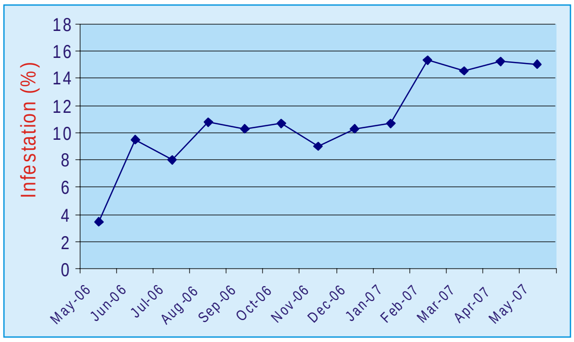


Fig. 6.2. Infestation in storage of whole pigeonpea

7. Statistics and Computer Application

The Statistics and Computer Application Section attained its present status in 1993. In 1996, the Section got a major boost with the initiation of a computer-based network, Agricultural Research Information System (ARIS) by the Indian Council of Agricultural Research (ICAR) with a goal to strengthen information management system using modern information technology tools within the Indian NARS. The Statistics and Computer Application Section is a service unit to provide data analysis facilities to all the divisions/sections of the institute and AICRPs on pulses. In addition, the ARIS cell also provided a variety of services such as PERMISnet and IRS (Intelligent Reporting System) at headquarters and in NARS. The Institute website on new domain server (www.iipr.res.in) is regularly updated and maintained. An up-to-date database on different varieties of pulses, pulses production, diseases and insect-pests, *etc*. are maintained and used for development of user-friendly information system.

7.1 Variety Research Information System (VRIS)

Variety Research Information System (VRIS) – A comprehensive relational database has been created at the Indian Institute of Pulses Research (IIPR), Kanpur to facilitate easy data entry and retrieval of information on varieties of major pulse crops *viz*., chickpea, pigeonpea, mungbean and urdbean. This relational database provides an efficient and powerful way to store, retrieve, manipulate query and report data in a multi-user environment. Data entry is performed through a series of self-explanatory forms. Information can be retrieved and queried through a Local Area Network (LAN). This System is combined with modern statistical analysis and graphical presentation tools for storing, retrieving, summarizing, and presenting acquired data.

The programme code written in MS ACCESS 2000 and is network accessible. All queries, forms, and reports were generated using *wizards*, a very useful option in the MS-ACCESS 2000 software package that eliminates most of the need of tedious code writing. Structural Query Language (SQL) and Visual Basic Command (VBA) were used for generation of additional forms and reports enhance the functionality of the new database.

The VRIS for pulse possesses information on various aspects of 120 released varieties of chickpea, 95 of pigeonpea, 74 of mungbean, 64 of urdbean, 21 of lentil, 25 of fieldpea, 3 of lathyrus and 14 of *rajmash* in database. Entering data and generating reports are the main activities in VRIS. Each activity is selected from the VRIS main menu. The system was designed in various stages (*i.e.*, Table design - Form design - Output design - Queries report). Major output and query reports have been developed in addition to a complete report on a particular variety such as numbers and list of varieties released during a given period, information regarding the parents / pedigree of varieties, morphological information, plant protection and other related information on varieties.

7.2 District-wise Database and Information System

District-wise time series data of area, production and yield on chickpea and pigeonpea were collected for U.P. (1980-81 to 2004-05), M.P. (1980-81 to 2002-03), Maharashtra (1980-81 to 2003-04), Rajasthan (1980-81 to 2003-04), Karnataka (1980-81 to 2004-05), A.P. (1980-81 to 2002-03), Orissa (1980-81 to 2003-04), Bihar (1995-96 to 2003-04), Gujarat (1980-81 to 2004-05), Tamilnadu (1980-81 to 2002-03), Chhatisgarh (2000-01 to 2003-04), Meghalaya (1980-81 to 2002-03) and Arunachal Pradesh (1985-86 to 2000-01). District-wise data for these states were analysed on the basis of five yearly means, trends, compound growth rates and instability. District-wise Database has been designed in MS-ACCESS 2000 for safe storage and retrieval of desired information. Information system is being developed using Relational Database Management System (RDBMS) in various stages.

Compound growth rates of area, production and yield of chickpea and pigeonpea for all districts and the targeted states as a whole for the period mentioned above were calculated by fitting an exponential function ($Y=Ab^t$). By taking the combination of both area and yield, the pulses production in district(s) was classified into four categories (*i.e.*, small area-low yield; large area- high yield; small area-high yield; and large area- low yield). This approach enables the development of district or region specific strategies rather than old blanket strategy for state as a whole.

7.3 GE Interaction

Multi-environment trials (MET) are conducted every year for pulse crops throughout the India by All India Coordinated Research Project with the purpose to identifying superior cultivars for the target region. The yield of each cultivar in a test environment is the combined effect of environment main effect (E), genotype main effect (G), and genotype x environment interaction (GE). Typically, the E explains most of the total yield variation, and G and GE are usually small. Generally, it is observed that most of the variations in multilocation yield trials was environmental with moderate GE interaction and smaller due to genotypes. However, it is G and GE that are relevant to cultivar evaluation.

So taking into consideration of the above point, the data of AICRP has been collected and analyzed by the GGE biplot techniques which allow visual examination of the GE interaction pattern of MET data and ranking of genotypes based on means and stability and ranking of location based on discriminating ability and representativeness of environments has been done.

To know the stability status of the released cultivars, a programme has been initiated in which more than 20 varieties of chickpea released during 45 years (1960-2004), were evaluated for assessing Genotype and Environment (GE) interaction at 22 different locations of the country, falling in different zones, in association with AICRP on Chickpea. Data have been analyzed based on Eberhart & Russel model and varieties were classified on stability and performance environment. The result did vary due to change in climatic condition at different locations over the years but over all about half of the varieties are highly stable.

8. Agricultural Extension

With the inception of National Training and Communication Centre (NTCC) in the year 1984, a systematic programme on transfer of pulses production technology was initiated. This centre was primarily mandated for organizing training to the extension personnel and farmers besides arranging farmers' visit, organizing exhibitions, and bringing out extension publications and their distribution among the farmers. Subsequently, in 1991, the centre was assigned major responsibility of organizing Frontline Demonstrations of improved pulses production and protection technology under Technology Mission on Oilseeds and Pulses (TMOP), which gave opportunity to the research and extension scientists to have first hand assessment of the developed technologies on farmers' fields in close collaboration with farmers and also to offer appropriate feedback to the research system. During 1997-2001, an UNDP sponsored project on "Increasing Pulses Production through Demonstration and Training" was also implemented across twelve districts of Uttar Pradesh.

During 2000-2005, farmer participatory research and extension project on Technology Assessment and Refinement (TAR) through Institution Village Linkage Programme (IVLP) was implemented in a holistic manner in the Vidokhar village in Hamirpur district of Bundelkhand region under the aegis of National Agricultural Technology Project. Another farmer participatory project on improvement of grain legumes in rainfed Asia (IFAD TAG-532, ICRISAT) was implemented in three villages namely Helapur, Amirta and Kaluali Tir of Hamirpur district during 2002-06. The response of the above two projects was extraordinary at farmers' fields and a number of location specific appropriate pulse production technologies were identified and popularized with active participation of pulse growers. Presently, a large number of projects such as participatory project on "Model Seed System (s)", Impact assessment of farmer participatory programme, documentation of various indigenous knowledge being followed by the farmers, inclusion of pulse crop in the prevailing cropping system to ensure sustainability, stakeholder analysis in pulses research and development and consumption pattern of pulses and pulse-based products among the rural households are being implemented by the section. Besides this, the section is also delivering the services like information exchange and communication services to farmers, farm women, rural youths, extension professionals and development workers by organizing farmers' day, field days, on-campus and off-campus training, in-service training as well as organizing and participating in the *kisan mela* of inter-state level.

8.1 Transfer of Technology

A. Frontline Demonstration (FLD)

During the period of 1991-2007, the institute organized 6453 FLDs on improved and new pulses technologies covering improved varieties, nutrient management, pest management and application of *Rhizobium* culture across the state of Uttar Pradesh. The salient results were as follows.

Improved varieties : During the period, total of 3269 demonstrations on varietal performance were conducted. The overall yield advantage due to improved varieties was 29.49% (Table 8.1). The maximum impact of improved variety was noted in case of *kharif* urdbean (39%) followed by pigeonpea (38%) and fieldpea (33%). The important varieties of *desi* type chickpea emerged were Avrodhi, KWR 108, DCP 92-3, JG 322, JG 315, JG 16, *etc*., (1300-1800 kg / ha). *Kabuli* type varieties BG 256, KAK 2 and JGK 1 were also found more remunerative. Similarly, UPAS 120 was found suitable as short duration and NA 1, Bahar, MAL 13, as long duration varieties of pigeonpea (1200-2200 kg / ha). Similarly, for mungbean, Samrat and Meha emerged as the potential varieties yielding 530-800 kg / ha and, for urdbean, Uttara, Azad Urd 2 and Shekhar 1 were the most promising varieties giving average yield of 640-750 kg / ha.

Nutrient management : A total of 1560 FLDs were laid out on application of sulphur @ 20 kg / ha in pulses. In all pulses, there was average yield advantage of 26.78% due to sulphure use (Table 8.1). Highest advantage was noticed in case of fieldpea (34.58%) followed by summer mungbean (32.50%), *kharif* urdbean (30.27%) and pigeonpea (25.71%).

Insect-pest management: A total of 1209 FLDs were conducted on insect-pest management. It was found that pod borer / pod fly was the major insect pest affecting pigeonpea and chickpea. Appropriate insect-pest management (two sprays of 0.07% endosulfan) gave yield advantage of 24.61% over the farmers' practice. In case of chickpea and summer mungbean, maximum yield advantages of 30.0% and 28.3%, respectively were obtained because of improved insect-pest management.

Application of *Rhizobium* culture: This component was also demonstrated at 415 farmers' fields during the above period (Table 8.1). The results indicated yield advantages of 25.17% over uninoculated seed. The effect was more pronounced in case of fieldpea (36.02%) followed by chickpea (22.76%) and lentil (22.73%).

Table 8.1. Impact of high yielding varieties and technology management on pulse production (Frontline Demonstration: 1990-91 to 2007-08)

Component	Crop	Season	Number of FLDs conducted	Yield (kg/ha)		Yield advantage (%)
				Improved	Local	
Improved variety	Pigeonpea	*Kharif*	374	1410	1020	38.23
	Urdbean	*Kharif*	300	0750	0540	38.88
		Spring	125	0640	0465	37.63
	Mungbean	*Kharif*	225	0530	0438	21.00
		Summer	600	0805	0610	32.78
	Chickpea	*Rabi*	750	1460	1180	23.73
	Lentil	*Rabi*	370	1410	1160	21.55
	Fieldpea	*Rabi*	525	1690	1275	32.55
Fertilizer management (20 kg S/ha)	Pigeonpea	*Kharif*	125	1276	1015	25.71
	Urdbean	*Kharif*	200	0680	0522	30.27
		Spring	75	0515	0440	17.04
	Mungbean	*Kharif*	125	0512	0422	21.32
		Summer	375	0795	0600	32.50
	Chickpea	*Rabi*	300	1390	1122	23.89
	Lentil	*Rabi*	150	1345	1090	23.39
	Fieldpea	*Rabi*	210	1615	1200	34.58
Insect-pest management (Two spray of 0.07% endosulfan)	Pigeonpea	*Kharif*	174	1175	0995	18.09
	Urdbean	*Kharif*	99	0640	0505	26.73
		Spring	50	0515	0412	25.00
	Mungbean	*Kharif*	85	0490	0405	20.98
		Summer	197	0725	0565	28.31
	Chickpea	*Rabi*	320	1250	0961	30.01
	Lentil	*Rabi*	109	1310	1125	08.88
	Fieldpea	*Rabi*	175	1600	1215	08.23
Seed inoculation with *Rhizobium* culture	Pigeonpea	*Kharif*	75	1190	1010	17.82
	Chickpea	*Rabi*	100	1375	1120	22.76
	Lentil	*Rabi*	150	1350	1100	22.73
	Fieldpea	*Rabi*	90	1605	1180	36.02

8.2 Human Resource Development

A. Short-term Training

Short term training for enhancing the awareness about pulses in sustainable agriculture and also imparting knowledge and improving farmers' skills to raise pulse production was arranged. Large number of on-campus and on-farm trainings of 1-3 days duration were organized on different aspects of pulses production, protection and post-harvest handling. This training was also supported with organizing the related activities like field days, farmers' day, field visit, *etc*. During the period of 1985-2008, total of 138 specialized farmers' trainings were organized. In all these trainings, 14,383 participants including 12,271 males and 2,112 female farmers participated (Table 8.2). In addition, total of 49 trainings of short duration were organized for 1200 extension personnel including 23 women.

B. Field-days

Important extension activities like field days, farmers' days, *etc*., were also organized for human resource development. During the period, 560 field days and 775 farmers' days were organized. In these field activities, total of about 15,000 farmers, farm women and rural youths participated and benefited about the improved production technologies. Altogether, 22,000 farmers visited the institute during last twenty five years (Table 8.2).

Table 8.2. Details of the training and other activities conducted during 1985-2008

Particulars	Number of activities	Total participants		
		Male	Female	Total
Specialized farmers' training	138	12,271	2,112	14,383
Training for the extension personnel				
National level training	19	570	-	570
State level training	30	846	23	869
On-farm farmer' training	960	8,800	300	9,100
Field day	560	7,125	200	7,325
Farmers' day	800	6,080	025	6,105
Farmers' visit	450	11,425	575	22,000
Total	**2,503**	**35,453**	**2,660**	**38,113**

8.3 On-Farm Participatory Research

Several on-farm research projects supported by the Institute as well as external agencies were implemented to increase pulses production. The salient achievements are discussed below:

Technology assessment and refinement through IVLP: This project was implemented in the Village Vidokhar under Hamirpur district of Bundelkhand region in 787 farm families during 2000-05. The project was holistic in nature comprising crops (cereals, pulses, oilseeds, horticultural and fodder crops), livestock and income generating propositions. The details of activities carried out under project have been shown in Table 8.3.

Table 8.3. Performance indicators of NATP funded Project TAR through IVLP

Particulars	2000-2001	2001-2002	2002-2003	2003-2004
Number of farmers covered	268	535	601	787
Number of technological intervention actually implemented	27	38	32	33
Number of technologies assessed	18	22	20	19
Number of technologies refined	9	16	12	14
Number of skill oriented training organized	04	06	05	08
Number of farmer-scientist interaction	08	16	20	23
Newspaper coverage	20	38	42	44
Exposure visit of the farmers at IIPR and CSAUA&T Kanpur	01	--	01	02
Scientist visit to trial plot	10	24	29	31

Appropriate varieties: On-farm evaluation and farmers' perception revealed that Narendra Arhar 1 variety of pigeonpea was wilt resistant, frost tolerant and moderately tolerant to water logging condition. IPU 94-1 variety of urdbean was found most productive (grain yield:13.4 q/ha) and remunerative (net return: Rs. 18,810/ha) over the local variety. During *kharif* season on clay loam and loam soils, PDM 139 (Samrat) variety of mungbean proved superior and high yielder having resistance to YMV. TKG 22 variety of sesamum gave higher yield and has been rated short duration as well as most productive at farmers' fields.

Similarly, Lok 1 variety of wheat gave 45-50 q/ha under limited availability of irrigation. Farmers preferred this variety due to shining grains, better cooking quality and taste and adequate wheat straw palatable to milch animal. One hundred and fifty budded *Aonla* plant varieties such as Narendra 7, Narendra 10 and Chakaiya were transplanted in 10 farmers field. HUDP 15 variety of fieldpea performed better on clay and clay loam soils. This variety gave 42 quintals/ha yields when 60 kg urea/ha was top dressed after irrigation at 50-55 days of sowing. This variety is rated more remunerative and resistant to powdery mildew. Three improved chickpea varieties were assessed at the farmers' fields in existing resources under two different micro-farming situations in village Vidokhar of Hamirpur district. JG 315 performed well in rainfed mono-cropping (clay type of soil) situation and found to be wilt resistant. JG 322 was assessed as wilt resistant and performed better in double cropping system (clay loam and loam type of soil). DPL 62 variety of lentil was found most productive having moderate wilt resistance and bold grains.

Other assessed technologies: The performance of other technologies assessed and their impact on productivity and profitability enhancement is given in Table 8.4.

Table 8.4. Assessment of location specific technologies

List of technologies assessed	Productivity (% increase over FP)	Profitability (% increase over FP)	Micro-farming situation
Assessment of productivity of chickpea and linseed through improved variety and row ratio	30.8	19.26	Rainfed Mono cropping, clay soil
Control of pest attack in lentil	98.5	78.40	Rainfed Mono cropping, clay soil
Effect of timely sowing on wheat yield	44.6	42.30	Partial irrigated double cropping situation, clay loam and loam soil
Management of white rust and A*lternaria* leaf spot through early sowing	25.5	22.00	Partial irrigated double cropping situation, clay loam and loam soil
Evaluation of Oat variety for green fodder	84.0	179.00	Partial irrigated, clay loam and loam soil

Under rainfed mono-cropping clay soil situation, pest management in lentil crop gave 98% productivity advantages and 78% additional profitability over the farmers' practice. Similarly, other pulse-based and crop-based interventions revealed considerable productivity and profitability enhancement over farmers' practice.

Usable technologies: The experiences of on-farm trials and farmers' reflection of the assessed and refined technologies helped in identification of a set of usable technologies that could be spread in the similar production domain (Table 8.5).

Farmer participatory improvement of pulses in rainfed area : This project was executed in three villages namely, Helapur, Amirta and Kalauli Tir in district Hamirpur of Uttar Pradesh during October 2002 to June 2006. The main objectives of the projects were to create or enhance capacity at the field level for farmer-participatory research and extension (FPRE) programme on grain legumes and using this enhanced capacity, generate better adapted grain legume varieties so as to expand the role of grain legumes in crop intensification of rainfed agriculture on sustainable basis.

Farmer participatory varietal selection : Total of 75, 42, 125 and 58 farmers actively participated in the on-farm varietal selection trials (OFVST) for pigeonpea, urdbean, chickpea and lentil, respectively during three years (2002-05) in rainy and post-rainy seasons. JG 315 and DCP 92-3 was found most suitable chickpea varieties appropriate for clay (*Mar*) and clay loam (*Kabar*) soils in rainfed mono-cropping situation and, clay loam (*Kabar*) and loam (*Parwa*) soils in double cropping situations respectively. Similarly, lentil variety DPL 62 and urdbean variety IPU 94-1 were found suitable under rainfed mono-cropping situation. Inclusion of short duration YMV free variety (IPU 94-1) of urdbean helped to shift 20 per cent monocropped area in the village into double cropped area. In case of pigeonpea, Narendra Arhar 1 (NA 1)was found to be the best variety. The increase in productivity and profitability of above varieties is given in Table 8.6.

Integrated pest management (IPM) : Total 35 trials on pigeonpea and 50 trials on chickpea were laid out in three consecutive seasons (2003-2005). In case of pigeonpea, two sprays of endosulphan were more effective and farmers recorded 1616 kg / ha yield with about 26 per cent productivity enhancement and thereby giving the net return of Rs. 19083 / ha (Table 8.7). Further, it was observed that one spray of 5% NSKE + one spray of endosulfan (0.07%) reduced the damage of pod borer by 20-25 per cent in pigeonpea. In case of chickpea, one spray of NSKE followed by one spray of endosulfan recorded highest yield (1350 kg / ha) and net return (Rs. 7759 / ha).

Table 8.5: Usable technologies for wide spread dissemination

Production problem with micro farming situation	Existing/ Farmers' practice	Recommended technology	Assessed/ Refined technology	Remarks
Low yield of chickpea due to initial poor germination and periodical plant mortality due to root rot/wilt in (a) clay (Mar) & clay loam (Kabar) soil – Rainfed, after fallow, and (b) Loam (Parwa) soil – Irrigated (one irrigation at 45-50 DAS) sown after urd, moong, sesamum and soybean	Local variety	KWR 108 JG 315 JG 322	(a) In clay (Mar) & clay loam (Kabar) soil – Rainfed, after fallow, JG 315 variety performing well and (b) Loam (Parwa) soil – one irrigation at 45-50 DAS sown after *kharif* crops, JG 322 variety was found to be wilt resistant as well as more remunerative	Assessed technology
Low yield of chickpea due to non-application of bio-fertilizer in (a) clay (Mar) & clay loam (Kabar) soil – Rainfed, after fallow and (b) clay loam (Kabar) & Loam (Parwa) soil – irrigated, after fallow	5 kg N/ha + 12 kg P_2O_5/ha	20 kg N/ha + 45 kg P_2O_5/ha + *Rhizobium* culture	10 Kg N/ha + 25 kg P_2O_5/ha + *Rhizobium* culture	Refined technology
Poor yield of chickpea due to incidence/infestation of pod borer in (a) mono cropping in clay (Mar) & clay loam (Kabar) soil – Rainfed, after fallow and (b) loam (Parwa) soil – Irrigated (one irrigation at 45-50 DAS) sown after urd/moong/sesamum. Farmers do not adopt plant protection measures due to unavailability of effective means & measures and unawareness	No protection measures against pod borer.	Spray of NPV @ 250 LE/ha + ½ dose of Endosulphan 35 EC @ 0.04 % followed by NSKE @ 5% at one week interval.	Spray of NSKE @ 5% and 2nd spray of Endosulphan 35 EC @ 0.04 % at one week interval	Refined technology
Low yield of lentil due to diseases susceptible seed in clay (Mar) and clay loam (Kabar) soil – Rainfed, mono-cropping situation	Local variety	DPL 62 JL 1 IPL 81	DPL 62	Assessed technology
Low yield of lentil due to no application of biofertiliser and less amount of chemical fertilizers in clay (Mar) and Clay loam (Kabar) soil – Rainfed, mono-cropping situation	5 kg N + 12.5 kg P_2O_5/ha	20 kg N/ha + 45 kg P_2O_5/ha + *Rhizobium* culture	10 kg N/ha + 30 kg P_2O_5/ha + *Rhizobium* culture	Refined technology

Table 8.6. Farmer participatory assessment of various *kharif* and *rabi* pulse varieties under different farming situations

Variety	Average yield (kg/ha)	Increase over control (%)	Net Return (Rs. /ha)	B:C ratio
Farming Situation I: Clay (Mar) and clay loam (*Kabar*) soils – rainfed mono-cropping				
Chickpea				
Local variety	1002	-	6800	2.1
DCP 92 -3	1386	38.3	11269	2.4
JG 315	1462	45.9	11965	2.5
BG 256	1174	17.1	7719.0	2.0
Farming Situation II: Clay loam (*Kabar*) and Loam (*Parwa*) soils – sown with pre-sowing irrigation, double cropping				
Chickpea				
Local variety	991	-	6448	2.0
DCP 92 -3	1504	51.7	12259	2.5
JG 315	1429	44.1	11580	2.4
BG 256	1239	25.0	8310	2.0
Farming Situation III: Clay (*Mar*) and clay loam (*Kabar*) soils – rainfed mono-cropping				
Lentil				
Local variety	1060	-	8673	2.4
DPL 62	1495	41.0	15216	3.1
DPL 15	1290	21.7	12133	2.7
JL 1	1505	42.0	13258	2.8
Pigeonpea				
Local variety	980	-	12618	4.1
NA 1	1250	27.6	16648	4.6
Bahar	1100	12.2	14089	4.1
Amar	1160	18.4	15101	4.3
MAL 13	1070	9.2	13545	4.0
Urdbean				
Local variety	240	-	196	1.1
IPU 94-1	507	111.3	1048	1.2
Shekhar	482	100.8	773	1.2
Azad	455	89.6	476	1.1

Table 8.7. Integrated pest management in pigeonpea and chickpea

Treatment	Average yield (kg/ha)	Increase over control (%)	Net return (Rs./ha)	B:C ratio
Pigeonpea				
Local practice (No control measures)	1284	-	15127	3.3
Two spray of endosulfan 35 EC @ 1.5 l/ha	1616	25.7	19083	3.3
One spray of 5% NSKE solution followed by one spray of endosulphan 35 EC @ 1.5 l/ha	1572	22.4	18298	3.2
Chickpea				
Local practice (No control measures)	1090	-	5858	1.6
Two sprays of endosulfan 35 EC @ 1.5 l/ha	1220	11.9	6056	1.6
One spray 5 % NSKE solution followed by one spray of endosulfan 35 EC @ 1.5 l/ha	1350	23.9	7759	1.7

NSKE=Neem seed kernel extract

Adoption of improved technologies : The follow-up study and participatory surveys were held to assess the extent of adoption of improved technologies in the project and nearby villages. All categories of farmers were involved under participatory survey. Component wise extent of adoption was measured as the level of adoption of proven technology (for instance, area planted with improved seed or the amount of fertilizer applied per hectare, *etc.*).

It was observed that 310 farmers in project villages used improved chickpea varieties (DCP 92-3 and JG 315) in 280 hectare area (Table 8.8). In case of pigeonpea, 80 per cent area (190 ha) was covered with improved variety NA 1. Total 218 farmers of project villages grew this variety during rainy season 2005. In adjoining areas (about 24 villages) more than 200 farmers adopted Narendra Arhar 1 in 25 per cent pigeonpea area. JG 315 and DCP 92-3 varieties of chickpea were adopted in 65 per cent area (280 ha) in project villages and 45 per cent in nearby villages during post rainy season 2005-06 by 265 farmers. In lentil 72 per cent area (210 ha) was covered under DPL 62 variety during 2005-06 by 348 farmers in project villages. More than 185 farmers procured seed of DPL 62 and planted in 40 per cent area of 16 villages of Hamirpur district.

Since the implementation of the project, improved varieties of chickpea, lentil and pigeonpea have replaced almost 75 per cent of local seed and are expected to

Table 8.8: Adoption of improved technologies in Hamirpur

Crop	Adoption by partner farmers		Adoption by non-partner farmers in project villages		Adoption in nearby villages	
	No. of farmers	Area (ha)	No. of farmers	Area (ha)	No. of farmers	Area (ha)
Chickpea	170	180	140	100	265	130
Lentil	242	168	106	42	185	170
Pigeonpea	170	138	48	52	200	136

cover 90 per cent area in a couple of years. Pulse production has gone up to two and half-fold by adopting integrated crop management (ICM) or full package technology in project and nearby villages. It was impressive to note that over 3-4 years period (2003-06), farmers increased the adoption level from 8-12% to 60-80%.

Model seed system for quality seed production: In order to ensure the availability of quality seed and to establish the sustainable seed production and delivery system at village level for economic empowerment and nutritional security, the institute is implementing ISOPOM sponsored project 'Model Seed System(s)' in two districts *viz*., Fatehpur and Kanpur Dehat since 2006. The basic aim of the project is knowledge empowerment among the farmers about quality seed production at village level. The approaches adopted in the project are farmer participatory varietal selection trials (FPVST) followed by on-farm seed production of farmers' preferred pulses varieties.

Pigeonpea: Farmer participatory varietal selection trials were conducted to ascertain farmers' preferences along with the suitability of long duration pigeonpea varieties under the situation of loam soil and partially irrigated condition. Among five (5) varieties of pigeonpea, NA 1 was the highest yielder (2208 kg / ha) followed by Bahar (2020 kg / ha), Amar (1979 kg / ha), MAL 13 (1812 kg / ha) and Azad (1804 kg / ha). These improved varieties yielded almost 1000 kg / ha more than the local variety.

Seed production of short duration and long duration pigeonpea was also initiated in Fatehpur and Kanpur Dehat during rainy season 2007. Seed production of early pigeonpea involving variety UPAS 120 was undertaken in 16 ha area at 80 farmers field in Pahur village of Fatehpur district. Total 9250 kg seed of early pigeonpea was produced and out of which 3976 kg was procured by National Seed Corporation.

Seed production of long duration pigeonpea varieties (NA 1 and Bahar) was undertaken in two compact blocks in 12 ha by 46 farmers in Fatehpur and 17 hectare area at 44 farmers in Kanpur *Dehat* district during *kharif* 2007. Total 228 q seeds were produced in Kanpur *Dehat* district. Some of the farmers preferred Bahar whereas others preferred NA 1. The net return was more in NA 1 (Rs 52,630 / ha) compared to Bahar (Rs. 44,860 / ha) and local (Rs 22,610 / ha).

Chickpea: Farmer participatory on-farm varietal selection trials on chickpea involving six improved varieties *viz.*, DCP 92-3, JG 16, KWR 108, PG 186, KGD 1168 and JGK 1 and two local large and small seeded varieties were carried out in 10 and 5 farmers field in Kanpur Dehat and Fatehpur district, respectively. Among these varieties, farmers preferred JG 16 and DCP 92-3 for their high yield (25-28 q / ha) and PG 186 for its suitability in late sown condition.

Total 368.95 quintals seed of chickpea was produced as foundation category at five villages in Fatehpur district, of which, 205.90 quintals was procured by National Seed Corporation as foundation seed. Majority of farmers kept seed of DCP 92-3, JG 16 and PG 186 for next year sowing, distribution and sale to other farmers in the same village or the neighbouring villages within the district and the farmers of the adjacent districts. As regards economics of seed production, highest return was obtained with DCP 92-3 (Rs. 65,005 / ha) followed by JG 16 (Rs. 49,910 / ha) and PG 186 (Rs. 40,820 / ha) as against Rs. 21,702 / ha for local variety.

With the active involvement of farmers, one Farmer Association named as "**Chaudgra Kisan Seva Samiti"** was formed and got registered in Fatehpur which is actively discharging its responsibility.

D. Success Story

On-farm quality seed production of pulses: In participatory appraisal, it was observed that farmers of the Bundelkhand region primarily resorted to local and old seed thereby getting poor yield of pulse crops. In view of this, the institute started farmer participatory seed production in Hamirpur district in the year 2002 with main aim to make farmers self sufficient in quality seed production and availability at the village level. The programme included DCP 92-3 and JG 315 varieties of chickpea; DPL 62 of lentil and NA 1 of pigeonpea in four villages Vidokhar, Helapur, Amirta and Kalauli Tir. In each of four villages, farmers' group was formed and each group comprised ten numbers of active and enterprising farmers. Thus, total of 40 partner farmers started on-farm quality seed production under the technical supervision of scientist of the institute. These group members were also trained on-farm and on-campus on different aspects of quality seed production and post harvest handling to improve and enhance group capacity.

As a result, in the year 2003-04, 180 q of quality seed of chickpea (var: DCP 92-3 and JG 315), 58 q of lentil (var: DPL 62) and 36 q of pigeonpea (var: NA 1) were produced in these villages under the project. Farmers sold 65 q of chickpea seed, 32 q of lentil (DPL 62) and 46 q of pigeonpea (NA 1) seed and earned an extra income of Rs. 600-700/q thereby enhancing the profitability from pulses cultivation. Besides, the availability of quality seed at the village level itself led to coverage of 100%, 80% and 65% of the area under lentil, chickpea and pigeonpea respectively under high yielding varieties. Similarly, in the year 2005-06, farmers produced 610 q of chickpea seed, 440 q of lentil and 94 q of pigeonpea seeds of above varieties.

The primary consequences of seed production at the village level helped to augment farmers' income which they utilized for purchase and application of production inputs for other crops for productivity enhancement. The secondary impact of this initiative was witnessed as replacement of *desi* buffaloes by the high yielding *murrah* buffaloes due to the additional income. In totality, farmers' socio-economic condition was elevated.

Rural entrepreneurship through value-addition: A self-help group comprising ten rural youths was formed to promote rural entrepreneurship through improved post-harvest management technology in the village Helapur under Hamirpur district of Bundelkhand region. Members of the group were trained on the aspects like primary processing *viz*., cleaning, grading of pulses, *etc*., and the secondary processing *i.e. dal* making at the village level. The group members were facilitated to purchase IIPR *mini dal mill* on cost sharing basis. The 20% of the cost of the mill was shared by the group members and the remaining 80% of the cost was borne by ICRISAT.

After proper training and demonstrations, members of the group started *dal* making of the major pulses like chickpea, pigeonpea and lentil. On an average, the group produced 300 kg, 210 kg, 150 kg and 150 kg of chickpea, pigeonpea, lentil and mungbean *dal*, respectively every month. The group also levied a nominal amount of Rs 2.00 per kg from the local farmers as the milling charge. The economics of this enterprise was quite encouraging. It was found that group members earned an extra income of Rs. 6000-7000 per month. This was possible as the group sold the processed *dal* at the rate of Rs 17 / kg higher than the pulse grains which were usually sold at the rate of Rs 30-35 per kg in the nearby market.

This initiative not only ensured the employment of the rural youths at the village level, but the local pulse growers also found the appropriate alternative market for their produce. The by-products like *bhusi* and *chunni* were used as nutritive cattle feed especially for the milch animals for increasing milk production.

Contributors

Introduction	Shiv Kumar
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Chickpea	S.K. Chaturvedi
Lentil	Shiv Kumar and R.K. Solanki
Fieldpea	G.P. Dixit
Rajmash	Sanjeev Gupta
Lathyrus	G.P. Dixit
Pigeonpea	I.P. Singh
Mungbean	Shiv Kumar and B.B. Singh
Urdbean	Sanjeev Gupta
Biotechnological Interventions	Subhojit Datta and Nandeesha P.
Crop Management	
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Nutrient management	M. S. Venkatesh
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Irrigation management	K.K. Singh
Allelopathy	Lalit Kumar
Crop Protection	
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Post-harvest Management	Prasoon Verma
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Annexure - I

List of Scientists

A. In position as on 31st December, 2008

1.	Dr. Masood Ali		Director

Crop Improvement

2.	Dr. Shiv Kumar	Plant Breeding	Principal Scientist & Head
3.	Dr. S.K. Chaturvedi	Plant Breeding	Principal Scientist
4.	Dr. Sanjeev Gupta	Plant Breeding	Principal Scientist
5.	Dr. I.P. Singh	Plant Breeding	Senior Scientist
6.	Dr. A.K. Choudhary	Plant Breeding	Senior Scientist
7.	Dr. S. Datta	Biotechnology	Senior Scientist
8.	Dr. Aditya Pratap	Plant Breeding	Senior Scientist
9.	Dr. Jitendra Kumar	Plant Breeding	Senior Scientist
10.	Mr. P. Nandeesha	Biotechnology	Scientist
11.	Dr. Ramesh Kr. Solanki	Plant Breeding	Scientist
12.	Mr. Prakash G. Patil	Biotechnology	Scientist
13.	Dr. Khela Ram Soren	Biotechnology	Scientist

Crop Production

14	Dr. N.B. Singh	Agronomy	Head
15.	Dr. B.L. Kushwaha	Agronomy	Principal Scientist
16.	Dr. Ravi Kumar	Agronomy	Principal Scientist
17.	Dr. S.C. Pramanik	Agronomy	Principal Scientist
18.	Dr. K.K. Singh	Agronomy	Senior Scientist
19.	Dr. M.S. Venkatesh	Soil Science	Senior Scientist
20.	Dr. Narendra Kumar	Agronomy	Senior Scientist

Crop Protection

21.	Dr. Vishwa Dhar	Plant Pathology	Principal Scientist & Head
22.	Dr. R.A. Singh	Plant Pathology	Principal Scientist
23.	Dr. R.G. Chaudhary	Plant Pathology	Principal Scientist
24.	Dr. R. Ahmad	Entomology	Principal Scientist
25.	Dr. (Mrs.) Hem Saxena	Entomology	Principal Scientist
26.	Dr. Bansa Singh	Nematology	Principal Scientist
27.	Dr. Shiva Kant Singh	Entomology	Senior Scientist
28.	Dr. S.D. Mohapatra	Entomology	Senior Scientist
29.	Dr. Mohd. Akram	Plant Pathology	Senior Scientist
30.	Mr. Naimuddin	Plant Pathology	Scientist (SG)
31.	Dr. P. Durai Murugan	Entomology	Scientist

Physiology, Biochemistry & Microbiology

32.	Dr. Mohan Singh	Microbiology	Principal Scientist & Head
33.	Dr. R.P. Srivastava	Biochemistry	Principal Scientist
34.	Dr. A. Bhattacharya	Plant Physiology	Principal Scientist
35.	Dr. P.S. Basu	Plant Physiology	Principal Scientist
36.	Dr. (Mrs.) Vijay Lakshmi	Plant Physiology	Senior Scientist
37.	Dr. Lalit Kumar	Agril. Chemistry	Scientist (Sr. Scale)
38.	Dr. K. Swarnalakshmi	Microbiology	Scientist
39.	Mr. S. Paul Raj	Microbiology	Scientist

Agricultural Extension

40.	Dr. S.K. Singh	Agril. Extension	Principal Scientist
41.	Dr. Shantanu Kr. Dubey	Agril. Extension	Scientist (Sr. Scale)
42.	Dr. (Mrs.) Uma Sah	Agril. Extension	Scientist (Sr. Scale)
43.	Dr. Purushottam	Agril. Extension	Scientist (Sr. Scale)

Agricultural Statistics and Computer Application

44.	Mr. Devraj	Computer Application	Scientist (Sr. Scale)
45.	Dr. (Mrs.) Sarika	Agril. Statistics	Scientist

Agricultural Engineering

46.	Mr. Prasoon Verma	Agril. Engineering	Scientist (SG)

AICRP on Pigeonpea

47.	Dr. N.D. Majumder		Project Coordinator
48.	Dr. Farindra Singh		Senior Scientist

AICRP on Chickpea

49.	Dr. N.P. Singh		Project Coordinator
50.	Dr. Shiv Sewak		Senior Scientist
51.	Dr. Meer Asif Iquebal		Scientist

AICRP on MULLaRP

52.	Dr. B.B. Singh		Project Coordinator
53.	Dr. G.P. Dixit		Senior Scientist
54.	Dr. P.K. Katiyar		Senior Scientist
55.	Sh. Hemant Kumar		Scientist

II. Scientists retired/transferred during 1984-2008

Crop Improvement

Dr. Satish Chandra	Project Director
Dr. S. Lal	Project Director
Late Dr. A.N. Asthana	Director
Dr. S.R. Gupta	Principal Scientist
Dr. R.P. Dua	Principal Scientist
Dr. S.S. Singh	Principal Scientist
Dr. Jawahar Lal	Principal Scientist
Dr. S.P. Mishra	Principal Scientist
Dr. D.P. Srivastava	Principal Scientist
Dr. D.P. Tripathi	Principal Scientist
Dr. P.K. Agarwal	Senior Scientist
Dr. B.B. Mandal	Senior Scientist
Dr. S.D. Dubey	Senior Scientist
Dr. Narendra Singh	Senior Scientist
Dr. D.K. Pandey	Senior Scientist
Dr. N.P. Singh	Senior Scientist
Dr. (Mrs) Jyoti Kaul	Senior Scientist
Sh. Suresh Chandra	Scientist (SG)
Dr. K.B.R.S. Visharda	Scientist
Dr. H.K. Dikshit	Scientist
Dr. S. Rakshit	Scientist
Dr. P.R. Choudhary	Scientist
Dr. (Mrs) Jyoti Kumari	Scientist
Dr. Nirupma Singh	Scientist

Crop Production

Dr. A.N. Ganeshamurty	Head
Dr. J.G. Varshney	Principal Scientist
Dr. B.N. Singh	Principal Scientist
Dr. K.L. Kinra	Principal Scientist
Dr. Ghanshyam Singh	Principal Scientist
Dr. S.B. Singh	Principal Scientist
Dr. N.L. Meena	Senior Scientist
Dr. S.N. Singh	Senior Scientist
Dr. Ch. Srinivasarao	Senior Scientist
Dr. R.L. Arya	Senior Scientist
Dr. J.P. Mishra	Scientist
Dr. Sunil Kumar	Scientist

Crop Protection

Dr. J.N. Sachan	Head
Dr. K.S. Amin	Principal Scientist
Dr. S.S. Lal	Principal Scientist
Dr. C.P. Yadav	Principal Scientist
Dr. Y.S. Rathore	Principal Scientist

Dr. Atin Ghosh	Principal Scientist
Dr. S.N. Gurha	Principal Scientist
Dr. R.K. De	Senior Scientist
Late Dr. C.A.R. Dias	Senior Scientist
Dr. G. Katti	Senior Scientist
Dr. Pratibha Shukla	Senior Scientist
Dr. O.P. Sharma	Scientist
Dr. P. Sridhar	Scientist

Physiology, Biochemistry & Microbiology

Dr. J.D.S. Panwar	Head
Dr. R.K. Gupta	Principal Scientist
Dr. D.N. Singh	Principal Scientist
Dr. V.S. Bhatia	Senior Scientist
Sh. Anand Tripathi	Senior Scientist
Sh. R. Banerjee	Scientist

Agricultural Extension

Dr. R.K. Nigam	Principal Scientist
Dr. R.R. Burman	Scientist

Agricultural Statistics and Computer Application

Dr. R.A. Singhal	Principal Scientist
Dr. K.V.S. Rao	Senior Scientist
Dr. P.S. Pandey	Scientist (Sr. Scale)

Agricultural Engineering

Dr. R.R. Lal	Principal Scientist

Agricultural Economics

Dr. I.P.S. Yadav	Principal Scientist
Dr. V.P. Tyagi	Senior Scientist
Sh. L.K.Gangal	Senior Scientist
Dr. A. Amrendra Reddy	Scientist

AICRP on Chickpea

Dr. Masood Ali	Project Coordinator
Dr. R.P. Dua	Project Coordinator
Dr. S.P. Mishra	Project Coordinator

AICRP on Pigeonpea

Dr. A.K. Singh	Project Coordinator

AICRP on MULLaRP

Dr. J.L. Tickoo	Project Coordinator
Dr. D.P. Tripathi	Project Coordinator
Dr. G.K. Jha	Scientist

Annexure - II

List of Externally Funded Projects Implemented during 1984-2009

S.No.	Name of the project	Funded by	Period
1.	Development of cultivars and production system for early maturing pigeonpea	ACIAR	1986-1989
2.	Promotion of R & D of hybrids in selected crops - Pigeonpea	ICAR	1989-1997
3.	Development of genotypes of pigeonpea and chickpea resistant to biotic stresses through biotechnological research	DBT	1992-1997
4.	Nutsedge management in field crops with particular emphasis on pulses	AP Cess	1995-1998
5.	Development, production and demonstration of biocontrol agents under IPM	DBT	1995-1998
6.	Regional promotion of mungbean research and development	AVRDC	1997-2000
7.	Increasing pulses production through on-farm demonstration and training	UNDP	1997-2001
8.	Promotion of research and development efforts on hybrids in pigeonpea	AP Cess	1997-1999
9.	Development of genotypes of chickpea tolerant to salinity through *in vitro* cellular approaches	AP Cess	1998-2001
10.	Physiological approaches to genetic enhancement of drought resistance in chickpea	AP Cess	1998-2001
11.	Traits for yield improvement of chickpea in drought prone environments of India and Australia	ACIAR	1998-2005
12.	Biological control of gram pod borer (*H. armigera*) in chickpea, pigeonpea and sunflower	DBT	1999-2003
13.	Development of IPM packages under selective crop conditions against *Helicoverpa armigera* (Hubner) in pulses	AP Cess	1999-2003
14.	Integrated management of plant nematodes/soil pathogens in pulse based cropping systems	NATP	1999-2003

15.	Integrated management of viral diseases problems of mungbean (*Vigna radiata*) and urdbean (*Vigna mungo*)	NATP	1999-2003
16.	Upgradation and evaluation of mini *dal* mills	NATP	1999-2003
17.	Low cost technology for safe storage of pulses	NATP	1999-2003
18.	Improvement of components of agro-technologies for management of intercrops	NATP	1999-2003
19.	Development of bio-intensive IPM modules in chickpea against *Helicoverpa armigera*, wilt and dry root rot	NATP	1999-2003
20.	Development of bio-intensive IPM module(s) against pest complex, wilt and phytophthora blight in pigeonpea intercropping systems	NATP	1999-2003
21.	Agro-economic characterization, constraint analysis and delineation of efficient eco-zones using soil type and rainfall data in chickpea and pigeonpea based cropping systems	NATP	1999-2003
22.	Integrated nutrient management in major pulse based sequential cropping systems and identification of the most productive and remunerative system	NATP	1999-2003
23.	Resource management for rice-wheat cropping system through inclusion of legumes, Indian mustard and potato	NATP	1999-2003
24.	Technology assessment and refinement of pulse based rainfed agro-ecosystem through institute village linkage programme for Bundelkhand region (U.P.)	NATP	1999-2003
25.	Sustainable management of plant biodiversity	NATP	1999-2003
26.	Development of hybrid crop : Pigeonpea	NATP	1999-2003
27.	Development of weather based forewarning systems for crop pests and diseases	NATP	1999-2003
28.	Influence of host plant resistance on interactions among podfly *Melanagromyza obtusa* Malloch and its parasitoids in pigeonpea	AP Cess	2000-2002
29.	Development of genotypes of pigeonpea resistant to pod borer through biotechnological tools	UPCAR	2000-2002

30.	Identification and genetic characterization of photo-thermoinsensitive sources in urdbean	NATP	2002-2005
31.	Farmers participatory improvement of grain legumes in rainfed Asia	IFAD	2002-2006
32.	Use of entomopathogenic nematodes as a tool of biological control for lepidopteran borer complex infesting early pigeonpea	DBT	2004-2007
33.	Enhancing yield and stability of pigeonpea through heterosis breeding	ISOPOM	2005-2010
34.	Transgenic crops-Chickpea and pigeonpea (Genomics and Transgenics components)	ICAR Network	2005- 2012
35.	Molecular mapping and tagging of *Fusarium* wilt resistance in pigeonpea	AP Cess	2005-2007
36.	Gene pyramiding for resistance to *Fusarium* wilt in chickpea	AP Cess	2005-2008
37.	Wilt of crops with special reference to cultural, morphological, molecular characterization and pathogenic variability of isolates in India-Chickpea, pigeonpea and lentil	AP Cess	2005-2008
38.	Development of extra-large seeded *kabuli* chickpea varieties for crop diversification	ISOPOM	2006-2009
39.	Development and popularization of model seed systems for quality seed production of major legumes to ensure seed sufficiency at the village level	ISOPOM	2006-2009
40.	Application of microorganisms in agriculture and allied sector	AMAAS	2006-2009
41.	Network project on functional genomics in chickpea	ICAR	2007-2009
42.	Tagging genes for resistance to wilt in lentil	DBT	2007-2009
43.	Improving tropical legume productivity for marginal environments in Sub Saharan Africa and South Asia	Bills & Melinda Gates Foundation	2008-2010
44.	Shuttle breeding for development and identification of high yielding varieties of pulses for South Asia	SAARC Division, MEA	2008-2011
45.	Mapping and tagging of genes imparting resistance to MYMV and CLS in urdbean	DBT	2008-2011
46.	Understanding plant nematode interactions using RNAi	NAIP	2008-2012

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