BREEDING FOR RESISTANCE TO SHOOT AND FRUIT BORER (*Earias vittella* Fab.) IN OKRA (*Abelmoschus esculentus* (L.) Moench)

R. KARUPPAIYAN

THESIS

Submitted in partial fulfilment of the requirement for the degree of

Doctor of Philosophy in Agriculture

Faculty of Agriculture
Kerala Agricultural University, Thrissur

2006

Department of Plant Breeding and Genetics
COLLEGE OF HORTICULTURE
VELLANIKKARA, THRISSUR - 680 656
KERALA, INDIA

DECLARATION

I, R. KARUPPAIYAN hereby declare that the thesis entitled "BREEDING FOR RESISTANCE TO SHOOT AND FRUIT BORER (*Earias vittella* Fab.) IN OKRA (*Abelmoschus esculentus* (L.) Moench)" is a *bonafide* record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other University or society.

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Place: Vellanikkara (R.KARUPPAIYAN)

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Place: Vellanikkara

Date : 02.10.2006

(Dr. K. NANDINI)
Chairman, Advisory Committee
Associate Professor
Dept. of Plant Breeding & Genetics
College of Horticulture
Vellanikkara

CERTIFICATE

We, the undersigned members of the Advisory Committee of Shri. R.KARUPPAIYAN, a candidate for the degree of Doctor of Philosophy in Agriculture with major in Plant Breeding and Genetics, agree that the thesis entitled **"BREEDING FOR RESISTANCE TO SHOOT AND FRUIT BORER (*Earias vittella* Fab.) IN OKRA (*Abelmoschus esculentus* (L.) Moench)"** may be submitted by Shri. R.KARUPPAIYAN, in partial fulfilment of the requirement for the degree.

2/10/06

Dr. K. NANDINI
Chairman, Advisory Committee
Associate Professor (Plant Physiology)
Department of Plant Breeding and Genetics
College of Horticulture, KAU Vellanikkara

2/10/06

Dr. V.V. RADHAKRISHNAN
(Member, Advisory Committee)
Associate Professor and Head
Dept. of Plant Breeding & Genetics
College of Horticulture, KAU
Vellanikkara

2.10.06.

Dr. JIM THOMAS
(Member, Advisory Committee)
Associate Professor and Head
Dept. of Agril. Entomology
College of Horticulture, KAU
Vellanikkara

2/10/06

Dr. R. SUJATHA
(Member, Advisory Committee)
Assistant Professor
Dept. of Plant Breeding & Genetics
College of Horticulture, KAU
Vellanikkara

2.10.06.

Dr. C. NARAYANAN KUTTY
(Member, Advisory Committee)
Assistant Professor
Dept. of Olericulture
Agricultural Research Station, KAU
Mannuthy

02/10/06

EXTERNAL EXAMINER
Dr. V. Muralidharan
Director / TRRI / TNAU
Aduthurai.

ACKNOWLEDGEMENT

This thesis work which took five years since 2001 could not have been completed without the support of my well wishers and God's grace. At this moment of accomplishment, my heart is overwhelmed with gratitude and I take this occasion to thank every one who had helped directly or indirectly to this endeavour. With immense pleasure, I express my heartfelt thanks to Dr (Mrs.) K. Nandini, *Associate Professor, Department of Plant Breeding and Genetics, CoH & chairperson of the research programme advisory committee for her guidance, facilitation for the successful conduct of the thesis work, periodical review of the progress, critical comments at every step of experimentation and thesis writing, encouragement, above all for her patience & motherly affection extended to me throughout the study period. I am proud that I have been guided by her.*

I take this opportunity to extend my profound sense of gratitude to the members of the advisory committee Dr. K. Pushkaran *and* Dr. Achamma Oommen, *former Professor and Heads,* Dr. V. V. Radhakrishnan, *Associate Professor, Department of Plant Breeding and Genetics,* Dr. Jim Thomas, *Associate Professor and Head, Department of Agricultural Entomology,* Dr. C. Narayanan Kutty *Assistant Professor (Horticulture), Agriculture Research Station, Mannuthy,* Dr. R. Sujatha, *Assistant Professor for their constant inspiration with utmost sense of patience, critical analysis and suggestions rendered throughout the course of my study and in the preparation of thesis. My heartfelt thanks are also due to* Dr. Ramesh Singh, *Sr. Scientist at the ICAR Research complex, Sikkim Centre who monitored my thesis work at Sikkim.*

I place on record my indebtedness to Dr. K. M. Bujar Baruah, *Director, ICAR Research Complex for NEH Region for according permission to carry out my thesis work at Sikkim and for granting study leave in time. I also owe my deep sense of gratitude to* Dr. Y. P. Sharma, *Joint Director for his moral support and help. Facilities provided by* Dr. L.S. Srivastava *ex-Joint Director, and* Dr. R.K. Avasthe , *JD i/c, ICAR, Sikkim is also acknowledged with thanks.*

I am ineffable in expressing my deep sense of gratitude to Dr. K.V. Peter, *the then VC, KAU,* Dr. G.S.L.H.V. Prasada Rao, *former Associate Dean, College of Horticulture with whose benevolence I got timely permission from the University to conduct part of my thesis work at the ICAR, Sikkim. I am thankful to them for their valuable advice. I owe my gratitude to* Dr. P.K. Rajeevan, *Associate Dean, College of Horticulture for his help.*

With due respect, I owe my deep sense of gratitude to my teachers in the Dept. of Plant Breeding and Genetics Dr. C. R. Elsy, Dr. Dijee Bastian, Dr. Mareen Abraham, *and to* Dr. T. Girija, *Dept. of Plant Physiology for accommodating me in the Departments with all facilities. Critical suggestions given by them after going through the manuscript are greatly acknowledged.*

I was fortunate to have the association of scientists Sh. K. C. Velayudhan, Dr. K. Joseph John *and* Sh. M. Abdul Nizar *NBPGR Regional Station, Thrissur whose helping hands, love and affection fetched a remarkable place in my days in Kerala. Their constant support, encouragement, warm concern I enjoyed with them all along from the days of my association with them. I am thankful to them for their critical comments after going through the manuscript.*

I place on record my thanks to Dr. U. Jayakumaran, *Associate Professor and Head, ARS, Mannuthy,* Dr. T. R. Gopalakrishnan *Professor and Head, Dept. of Olericulture,* Dr. Babu M. Philip, *in-charge of Central Nursery for providing field and laboratory facilities. I am also thankful to* Dr. E.V. Anoop *and* Dr. S. Gopakumar, *Assistant Professors, College of Forestry,* Dr. Nybe *Professor and Head, Dept. of Plantation Crops and Spices,* Dr. K. Mini *Assistant Professor,*

Dept. of Biochemistry for permitting me to carry out anatomical, histochemical and biochemical studies in their laboratories with all sorts of supports.

I am thankful to Dr. Z. Abraham, *OIC, NBPGR, Thrissur,* Dr. R.V. Singh, *HOD, NBPGR, New Delhi,* Dr. N. Dikshit, *OIC,, NBPGR, Akola,* Dr. M. Prabhakaran, *Principal Scientist, IIHR, Bangalore,* Dr. I. Singh, *Sr. Scientist, IIVR, Varanasi,* Dr. T.S. Raveendran, *Director, CPBG, TNAU,* Dr. D. Veeraraghavathatham, *Dean, COH, TNAU, Coimbatore,* Dr. Kandasamy, *Associate Professor, PAJANCOA, Karaikkal,* Dr. K.V. Suresh Babu, *CoH, for their generous supply of germplasm.*

I extend my gratitude to Dr. V.K.G. Unnithan, Sh. S. Krishnan *and* Dr. C. Laly John, *Department of Agrl. Statistics for their suggestions in processing and interpreting the data. I express my thanks to* Dr. K. Surendiragopal *for his critical suggestions after going through the thesis,* Dr. R. Usha Kumari *Associate Professor, Dept. of Agrl. Entomology for her participation in the advisory committee meetings and* Dr. G. K. Mahapatro *for supply of literature and critical comments. I owe my sincere regards to* Dr. C.T. Abraham, Dr. Augustin, Dr. P.S. John, Dr. P. Sadankumar, Dr. K. Savithri, Dr. Sara T. George, Dr. Nirmaladevi, Dr. V. Indira, Dr. Mani Chellappan, Dr. Maizy Kutty, Dr. Sheela, Dr. P. Ahamed, Dr. Usha, Dr. N. K. Parameshwaran, Dr. Sujatha *and* Dr. Salikutty *for their help. My heart never forget the love and support rendered by colleague friends* Dr. K. Rameash *who had taken photographs for thesis,* Dr. K. Dhinesh Babu *who had supplied seeds and carried out field work in my absence,* Dr. M. Latha *and* Dr. R. Senthil Kumar *who had actively supported my works.*

I can't forget the enjoyable days I had along with my batch-mate and friends Arunachalam, Ganapathi, Ravi Sankar, Manikandan Nagarajan, Chandrahasan, Ponnaiyan, Vezhavendan, Sambasivam, Arul Swaminathan, Mahadev, Jinnappa, Gopinath *and* Jaganathan *who had helped right from field preparation to data recording. I also acknowledge the help rendered by junior friends* Thiyagarajan, Marimuthu, Vishnu, Athani, Cincy, Divya, Manila, Anila, Divya, Gayathri, Sani, Vidhu *and* Smisha.

My thanks to the office staff at the college Mrs. Santhakumari, Mrs. Beena, Mr. Venu, Mrs. Anitha *at Academic Wing,* Mr. Mohanlal *and* Mr. Kunhalkutty *library staff at KAU as well as* Library staff *at TNAU Coimbatore, for their help. The support rendered by Farm supervisors, Technical Assistants /officer* Mrs. Kalyani *and* Mr. Uthaman *(at CoH),* Mrs. Radha, Mr. Joy, Mr. Santhosh *(Olericulture),* Mr. Joseph *(Medicinal Garden),* Mr. Sugudhan, Mr. Easwaran, Mr. Kunjava *(Central Nursery) and* Mr. Manoj Kumar Karkidholy *(ICAR, Sikkim),* Mr. S. Mani & Mr. R. Ashokan Nair *NBPGR, Thrissur,* Mr. Santhosh, *Student computer club,* Mr. Sreekumar, Mr. Nandakumar *and* Mr. Rajith, *COH, Vellanikkara for their help.*

Words can never truly portrait the love, care, warm concern, and valuable advice rendered by my wife Smt. Kokila *which propped up my career all along. She has been always with me right from field work to data processing and computerization of research data. Her help is acknowledged with love. I owe my regards to my father-in-law* Dr. T. N. Ramamoorthy *for his constant inspiration and inculcating inquisitiveness in my thoughts and action.*

The financial support from the ICAR in the form Senior Research Fellowship *and* Salary and research grant *from KAU are acknowledged with thanks.*

(R.KARUPPAIYAN) 2.10.06

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INTRODUCTION

1. INTRODUCTION

Okra (*Abelmoschus esculentus* (L.) Moench), because of its year round cultivation, export potential and high nutritive value has gained a prominent position among the vegetables grown in India. India is a major producer of okra in the world with an annual production of 32 lakh tonnes (NHB, 2005). This crop is attacked by as many as 37 insect pests, of which the shoot and fruit borer (*Earias* species) is considered as the most important (Lal, 1991). Out of the five *Earias* species, *Earias vittella* is more common in India.

At seedling stage, the larvae bore into tender shoots. The shoot apex and leaves above the point of attack soon start drooping and wilt. With the appearance of flower buds, flowers and fruits, the caterpillars move to these parts and inflict damages which result in flower drop. Damaged fruits become stunted or disfigured and show holes plugged with insect excreta, thus making fruits unfit for consumption (Plate 7a). This pest survives uninterruptedly throughout the year and causes yield loss up to 7.33 tonnes / ha (Dhamdhere *et al.*, 1984).

Chemical control measures with contact insecticides were reported ineffective as the larvae bore into shoots and fruits, thus escaping from the toxicity of chemicals. Therefore, application of a thin film of insecticide on the fruits is recommended to kill the larvae before they enter into fruits (Kashyap and Verma, 1983). Though the use of insecticides in crop protection is an established measure, indiscriminate application in okra is often associated with health hazards due to persisting residues on fruits, which are picked green at short interval. Pesticide residues in okra fruits with aldrin, BHC, carbaryl, cypermethrin, DDT, endosulfan, fenvalerate, lindane, monocrotophos and quinalphos were reported (Ahuja *et al.*, 1998; Kole *et al.*, 2002). Continuous use of pesticide will lead to development of resistance in insects, resurgence, environmental pollution, etc. In view of these, an increased emphasis is always being given to develop insect resistant varieties.

A large number of okra germplasm have been screened in the past against this pest to identify resistant genotypes. However, a satisfactory resistant source is yet to be identified. This has prompted to take up the present investigation. Considering the richness of genetic diversity in the genus *Abelmoschus* to which okra belongs, a thorough screening of indigenous and exotic germplasm remains far from satisfaction as inferred from the reports of Rana and Thomas (1991), Hamon *et al.* (1991) and Kirtisingh (1993). Though, breeding for shoot and fruit borer resistance in okra has been identified as one of the priority areas of research (Sidhu, 1998), concerted efforts in this direction are lacking. However, the development of fruit borer resistant okra variety needs no emphasis in India where a sizeable area is always under cultivation with this crop.

Therefore, taking into consideration of the importance of the crop, the severity of the pest, the hazards of extensive use of pesticides and non-availability of resistant varieties it was thought worthy to undertake germplasm screening to identify a resistance source, working out the mechanisms of resistance and to initiate a systematic breeding programme to combine high yield with resistance. The specific objectives of the study are:

1. To screen okra germplasm against shoot and fruit borer (*Earias vittella* Fab) so as to identify a resistance source.
2. To transfer shoot and fruit borer resistant genes to a high yielding variety
3. To elucidate the nature of gene action governing shoot and fruit borer resistance in okra
4. To study the mechanisms of resistance in okra to shoot and fruit borer.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Previous works related to the thesis work entitled "Breeding for resistance in okra to shoot and fruit borer" are reviewed in this section.

2.1 SPECIES AND GENETIC DIVERSITY IN OKRA

Okra belongs to the genus *Abelmoschus* Medik. of Malvaceae. Its systematic classification has undergone several modifications with respect to the name and number of species. The taxonomic study of Waalkes (1966) was the basis for the identification key currently in use. He retained six species (*A. angulosus, A. crinitus, A. esculentus, A. ficulneus, A. manihot and A. moschatus*) out of 13 species proposed by Hochreutiner (1924). However, the IBPGR (1991) has recognized nine species namely,

1. *A. esculentus* (L.) Moench
2. *A. caillei* (A.Chev) Stevels
3. *A. angulosus* Wallich ex. Wight & Arnot
4. *A. crinitus* Wallich
5. *A. ficulneus* (L.) Wight & Arnot ex. Wight
6. *A manihot* (L.) Medikus
7. *A. tetraphyllus* W & L.
    - *A. tetraphyllus* var. *tetraphyllus* (Roxb.ex.Hornem) R. Graham
    - *A. tetraphyllus* var. *pungens* (Roxb.) Hochr.)
8. *A. moschatus* Medikus
    - *A. moschatus* ssp. *moschatus* var. *moschatus*
    - *A. moschatus* ssp. *moschatus* var. *betulifolius* (Mast.) Borss.
    - *A. moschatus* ssp. *biakensis* (Hochr.) Borss.
    - *A. moschatus* ssp. *tuberosus* (Span.) Borss.
9. *A. tuberculatus* Pal & Singh.

The latest classification is that of Hamon and Charrier (2001) who proposed 10 species which is quite similar to that of IBPGR (1991), However, Hamon and Charrier (2001) merged the sub-species of *A. moschatus* and *A. tetraphyllus* with their respective species. *Abelmoschus moschatus* ssp. *tuberosus* was elevated to the status of species and named as *A. tuberosus*. Barring *A. caillei,* all other okra species have originated in the Hindustan Centre (Bates, 1968). *Abelmoschus caillei* is endemic to West Africa (Martin, 1982b). India has been recognized as an important centre of diversity for okra where *A. esculentus* and seven related wild species (*A. angulosus, A. crinitus, A. ficulneus, A. manihot, A. moschatus, A. tetraphyllus,* and *A. tuberculatus*) are distributed. Out of the ten *Abelmoschus* species, *A. esculentus, A. caillei, A. tetraphyllus* and *A. tuberculatus* are more relevant to the present study. Hence a brief review about their genetic diversity is given below.

2.1.1 Variability and genetic diversity in the species *Abelmoschus esculentus*

Chheda and Fatokun (1982) studied the extent of variability for 29 characters in 296 okra accessions collected from 15 countries using numerical taxonomy. The accessions were divided into 10 groups of three major agronomic types. Girenko and Pugachev (1983) studied 300 genotypes from 32 countries for 18 morpho-metric traits. The accessions were grouped into 13 clusters. Morphological differences among Indian and North American varieties were lesser, but the differences were more among genotypes from Africa, suggesting okra originated in that continent. Bisht *et al.* (1995) studied genetic diversity in 260 okra accessions collected from India, Bangladesh, Nepal and Sri Lanka for 18 morphological characters including shoot and fruit borer resistance. The accessions were divided into eight clusters. Characters like days to flowering, plant height and fruit characters were the important components of variability. Deo *et al.* (1996) reported high GCV and PCV for pod yield, number of pods, plant height and number of branches per plant. The authors suggested selection based on number of pods per plant, length of pod and plant height to evolve a high yielding variety.

2.1.2 The species *Abelmoschus caillei* and its genetic diversity

This is a semi-wild or partially-domesticated species, cultivated for its fruits, seeds and leaves in West Africa (Martin, 1982b). The discovery and nomenclature of this species need mention here to avoid confusion. Chevalier (1940) was the first botanist to collect it from the tribal belt of Guinea of West Africa (hence called guinien okra or West African okra). None of the workers drew attention to this species till seventies when Sinnadurai (1977) published a short note mentioning tree like okra with pronounced perennial tendency found in the villages of Ghana (hence treated wrongly as *A. manihot* var. *Ghana*). At the same time, Siemonsma (1978) while observing the variation in okra collections of the Ivory Coast found that they fall into two classes for which he proposed provisional name "type soudanien" corresponding to A. *esculentus* and "type guinien" which consisted of only West African collections corresponding to *A. caillei*. In a later report, Siemonsma (1982) concluded that the two "types" represented entirely different species but did not name it. Singh and Bhatnagar (1975) while observing chromosome number in okra found an unusually high number (2n = 194) in a collection obtained from Ghana which was the highest number reported so far in the whole genus. Although the species was discovered in 1940, it was wrongly quoted till 1988 as *A. manihot* (Animon, 1996), A. *manihot* var. *Ghana* (Nirmaladevi, 1982), *A. manihot* var. *caillei* (Waalkes, 1966) and *A. manihot* ssp *manihot* (Thakur, 1976). This entity was named as *A. caillei* in 1988 (Hamon and Yapo, 1986).

The erstwhile Plant Introduction Division of the ICAR (Now NBPGR) has introduced this species (Accession No EC 31830 or 'Asumtemkoko') into India from Ghana in late seventies. Later this was found to be resistance to yellow vein mosaic virus (YVMV), hence supplied to major okra research centres (Thomas *et al.*, 1990). Using *A. caillei* accessions, studies were conducted on four directions such as, i) assessment and creation of variability for agronomic and quality traits (Thambi and Indira, 2000), ii) improvement through selection as exemplified from

the release of Susthira (Gopalakrishnan, 2004), iii) cytogenetic studies (Sheela, 1994), and iv) gene transfer from *A. caillei* to *A. esculentus* (Arumugam *et al.*, 1975; Kousalya, 2006).

Ariyo (1993) evaluated 30 accessions of *A. caillei* for 25 qualitative and quantitative traits. The extent of variability for pigmentation on various parts, fruit shape, fruit colour, number of pods per plant, pod weight, number of seeds per pod was reported to be high. Velayudhan *et al.* (1996) reported its cultivation in the homesteads of Kerala. Chacko *et al.* (1998) reported high GCV, PCV and heritability for number of fruits and fruit yield per plant. On the basis of D^2 analysis, 22 genotypes of *A. caillei* were grouped into three clusters. Kehinde and Adeniji (2003) pointed out that the response to genetic improvement would be rapid in *A. caillei* as this species exhibited high variability for agronomic traits.

2.1.3 The species *Abelmoschus tuberculatus* and its genetic diversity

This wild species almost resembles *A. esculentus* in morphology except for the presence of strigose pubescence on the stem and shorter fruit with bristly hairs arising from tubercular base and scarlet stigma hence named as *A. tuberculatus* by Pal *et al.* (1952). It is endemic to India (Joshi and Hardas, 1977), distributed across Andhra Pradesh, Gujarat, Madhya Pradesh, Maharashtra, Rajasthan and Uttar Pradesh (Bisht *et al.*, 1997). It's chromosome number (2n=58) and its homology with one genome of *A. esculentus* (2n=130) attest to the validity of *A. tuberculatus* being treated as a species and having role in the origin of *A. esculentus* (Joshi and Hardas, 1977). Bisht *et al.* (1997) studied the genetic diversity in 49 accessions of *A. tuberculatus* collected from North Western India for morphological characters including shoot and fruit borer resistance. They observed that epicalyx shape, size and persistence, petal colour, petal spot, pubescence on stem and fruit, pigmentation on stem and petiole, days to flowering, height and yield per plant had contributed significantly to the total variation.

2.1.4 The species *A. tetraphyllus*

This wild species is commonly found in Kerala, Tamil Nadu and West Bengal (Markose and Peter, 1990). Waalkes (1966) and Charrier (1984) considered *A. tetraphyllus* as a form of *A. manihot* and treated as *A. manihot* ssp. *tetraphyllus* var. *tetraphyllus*. This wild species was reported to be a promising source of resistance to YVMV by Ugale *et al.* (1976). Martinello *et al.* (1996) evaluated 40 accessions of wild and cultivated *Abelmoschus* species for genetic diversity and reported that variability among *A. esculentus* accessions were small, despite its geographical diversity. Principle component analysis has distinguished *A. manihot* ssp. *manihot, A. manihot* ssp. *tetraphyllus* and *A. ficulneus* from *A. esculentus* accessions. *Abelmoschus caillei* was more similar to cultivated species. Characters responsible for the separation of the three wild species into a separate cluster were days to flowering, number of nodes at flowering, plant height and number of internodes.

2. 2 THE SHOOT AND FRUIT BORER OF OKRA

The shoot and fruit borer infesting okra and cotton belongs to the genus *Earias* (Noctuidae: Lepidoptera). Under this genus, five species namely, *E. vittella* Fabricius, *E. insulana* Boisduval, *E. biplaga* Sehans, *E. cupreoviridis* Walker and *E. huegeli* have been described (Reed, 1994). Of these, *E. vittella* and *E. insulana* are predominant species in Asia, while *E. vittella* is more common in India (Lal, 1991). *Earias vittella* moth have pale white forewings with wedge shaped green marking on it whereas, *E. insulana* moth have uniformly greenish forewings (Lefroy, 1909).

2.3 THE EXTENT OF DAMAGE CAUSED BY SHOOT AND FRUIT BORER

The extent of infestation in okra caused by shoot and fruit borers in different parts of India was compiled and presented in Table 2.1. Combined infestation of

sucking pest and fruit borer caused 45.0 to 46.2 per cent reduction in leaf number, 49.8 to 74.1 per cent reduction in plant height, 50.77 to 67.7 per cent reduction in fruit yield, 70.15 per cent reduction in seed yield (Rawat and Sahu, 1973; Suryawanshi *et al.*, 2000). However, Chaudhary and Dadheech (1989) found no reduction in leaf number due to combined infestation of shoot and fruit borer and sucking pests. However, they reported reduction in plant height and fruit number. Dhawan and Sidhu (1984) reported damage of flower buds to the extent of 52.4 per cent. The estimated fruit loss in okra due to *Earias* was 0.76 t/ha in Gwalior (Dhamdhere *et al.*, 1984), 2.66 t/ha in Karnataka (Srinivasan and Krishnakumar, 1983) and 7.33 t/ha in Jabalpur (Rawat and Sahu, 1973).

Table 2.1 Shoot and fruit borer infestation in okra

Distribution	Per cent infestation in		Reference
	Shoot	Fruit	
Andhra Pradesh		58.00	Prasad *et al.*(1986)
Delhi		49.00 – 74.00	Krishnaiah *et al.* (1976)
Karnataka		36.00	Krishnaiah (1980)
Kerala		27.50	Kumar (1989)
Madhya Pradesh	8.5	41.20	Shukla *et al.* (1997)
	5.50(RS) 23.90(SS)	25.93(RS♣) 40.91(SS)	Dhamdhere *et al.* (1984)
	2.00- 5.00	12.00 - 46.70	Kumar and Urs (1988)
Maharashtra		50.77*	Suryawanshi *et al.* (2000)
		88.00- 100.00	Radke and Undirwade (1981)
Punjab		32.06- 40.84*	Singh and Brar (1994)
Rajasthan		52.33 - 70.75	Pareek and Bhargava (2003)
		54.04*	Chaudhary and Dadheech (1989)
Tamil Nadu		30.47	Dhandapani (1985)
West Bengal		44.26	Das *et al.* (2000)
		30.81*	Ghosh *et al.* (1999)

* Estimated yield loss due to combined infestation by sucking pests and fruit borer

♣ RS-Rainy season; SS-Summer season

2.4 RESISTANCE IN OKRA TO SHOOT AND FRUIT BORER

2.4.1 Resistance in germplasm lines

Srinivasan and Narayanaswamy (1961) screened 18 okra genotypes for shoot infestation (SI) and reported that red bhendi lines Red I, Red II, Red wonder I and Red wonder II were less affected by *E. insulana* (SI<3.5 per cent). Nawale and Sonone (1977) tested 14 germplasm against *E. vittella* for fruit infestation (FI). The damage was low in AE 22 (11.41 per cent), AE 52 (11.89 per cent) and Wonderful Pink (15 per cent). Subsequent study by Mote (1978) confirmed the ability of the above genotypes to offer moderate degree of resistance to fruit borer. The percentage of fruit infestation varied from 11 to 18 per cent in AE 22, 11 to 22 per cent in AE 52 and 8.58 to 15.55 per cent in Wonderful pink in *kharif* and summer seasons.

Gupta and Yadav (1978) screened 60 germplasm consecutively for three years. None of them were truly resistant or immune to *E. vittella* or *E. insulana*. However, genotypes like Kalyanpur Bonia, Accession Nos. 5325, 6327, 6701, 6901, 6903, 6904, 6908 and 7117 were moderately resistant (FI <15 per cent). Out of the 21 genotypes screened, AE 71 was fairly resistant to shoot infestation (SI<19.21 per cent) while AE 22, AE 57 and Wonderful pink were fairly resistant to fruit infestation (Raut and Sonone, 1979).

Sixty eight germplasm lines of Indian and exotic origin were screened by Kashyap and Verma (1983). Selection Round showed less than 10 per cent fruit damage. Despite fruit borer damage, genotypes like Bhindi 6 Dhari, All Season 2, Sel 2, Faizabadi Green, IC 6497, IC 12930, IC 12938 and IC 26979 recorded high marketable fruit yield (242 to 407 g/ plant). The reports of Bhalla *et al.*(1989) and Thomas *et al.*(1990) revealed that out of 1000 accessions of okra maintained at NBPGR, 50 showed moderate degree of resistance to fruit borer (FI= 6 to15 per cent) when tested at two locations. Sharma and Dhankhar (1989) reported low

fruit infestation in Long green smooth, All Season I and Sel 2-2 (FI <14.4 per cent). Despite fruit infestation, Sel 2-2 recorded the highest fruit yield (306.5 g/plant). Kumbhar *et al.* (1991) screened 40 lines and found AE 79, AE 69 and AE 22 resistant to shoot infestation (SI=9 to 10 per cent) and AE 79 fairly resistant to fruit infestation (FI=9 per cent).

2.4.2 Resistance in commercial varieties

Shehata (1966) evaluated four commercial varieties against *E. insulana* and reported less damage in early flowering varieties. Madav and Dumbre (1985) reported that resistance varied from season to season. According to their reports, Pusa Sawani, Long Green, Koparwadi Local, White Velvet were tolerant to shoot and fruit infestation when grown during hot weather season. During *rabi* season, not even a single variety was resistant against *E. vittella*.

The available reports revealed that varieties like Kalyanpur Green, Parbhani Kranti, Pusa Makhmali and Pusa Sawani are highly susceptible. Whereas, Arka Anamika, Bhindi 6 Dhari, Gujarat Okra 1, Kamadhenu, P-7 and Wonderful Pink are less susceptible (Mahadevan and Dhandapani, 1985; Gupta, 1988; Sardana and Dutta 1989; Vyas and Patel, 1991; Raj *et al.*, 1993; Khambete and Desai, 1996; Ghosh *et al.*, 1999).

2.4.3 Reaction of F_1 hybrids and advanced breeding lines

Teli and Dalaya (1981) evaluated seven hybrids along with 21 varieties under natural infestation. Genotypes AE 22, 52, 69, 79 and the hybrid Sel 1-1 x AE 79 were reported less susceptible to shoot and fruit borer (SI=9 to 20 per cent; FI =22-31 per cent). None of the hybrids were highly resistant. Marketable fruit yield was high in the cross Sel 1-1 x AE 52 (3.32 t/ha) followed by White Velvet (3.23 t/ha) although they exhibited 36.43 and 45.91 per cent fruit infestation, respectively. They suggested transfer of resistant gene found in AE 79, AE 22 and

AE 52 to White Velvet. Kishore *et al.* (1983) screened 44 lines of okra and reported that HB 22 and HB 53 were relatively more resistant than the other lines.

Shukla *et al.* (1998) evaluated seven F_1 hybrids to shoot and fruit borer. Hybrid AROH 2 and Komal were the least infested hybrids (4 to 5 per cent shoot infestation). Ankur 35 and Parbhani Kranti recorded highest fruit yield but had high incidence of shoot damage (7.5 and 8.0 per cent respectively). Srinivasa and Sugeetha (2001) evaluated seven okra varieties namely, Arka Anamika, Arka Abhay, KS 410, Line 1999, Parbhani Kranti, Pusa Sawani and Varsha Upahar and 21 F_1 hybrids. None were free from fruit damage. Neeraja *et al.* (2004) reported that hybrids were equally damaged by fruit borer (21.7 to 29.2 per cent) as that of varieties. Fruit infestation in the hybrid Vijay was 29.2 per cent while fruit infestation in varieties like Arka Anamika and Arka Abhay were from 23.6 to 25.3 per cent.

2.4.4 Resistance in wild and semi-wild okra

Very few studies have been conducted on the response wild species to shoot and fruit borer. While describing *A. tuberculatus* as new species, Pal *et al.* (1952) mentioned that it was 'almost immune' to *Earias insulana.* Nasr *et al.* (1972) reported that *A. moschatus* was a host for *E. insulana* in Egypt. Gouda *et al.* (1984) and Singh *et al.* (1984) reported that *A. moschatus* was attacked by *Earias vittella.* Joshi *et al.* (1992) reported the occurrence of *E. vittella* in *Abelmoschus crinitus.* Bisht *et al.* (1997) grouped *A. tuberculatus* in 'less susceptible' category based on three point visual score. The extent of shoot or fruit infestation was not quantified by the above workers. Raut and Sonone (1979) estimated 7.5 per cent shoot damage and 51.4 per cent fruit damage in *A. tetraphyllus.* Chelliah and Srinivasan (1983) reported that *A. manihot* was resistant to shoot borer. Kashyap and Verma (1983) reported *A. ficulneus* was susceptible to fruit borer (21 per cent) but *A. caillei* was moderately resistant to fruit borer (11.1 per cent).

2.5 CROSSABILITY AMONG *ABELMOSCHUS* SPECIES

Review of literature (section 2.4) indicates that *A. tetraphyllus*, *A. manihot* are resistant to shoot borer but information on transfer of shoot and fruit borer resistant gene from these wild species to cultivated okra are not available. For effective gene transfer through conventional breeding, prior knowledge on crossability between wild and cultivated okra is become imperative hence these aspects are reviewed hereunder.

2.5.1 Crossability between *A. esculentus* and *A. tetraphyllus* (2n=130 /138)

The available reports indicated that it is possible to obtain the first generation hybrid in either way (Ugale *et al.,* 1976; Prabha, 1986; Cherian, 1986). The F_1 hybrids were intermediate between the parents and produced parthenocarpic fruits. The seeds were empty. Hence, the process of introgression was unattainable (Hamon and Yapo, 1986). Jambhale and Nerkar (1981) isolated a spontaneous amphidiploid in the F_2 generation. Its pollen grains were fertile (88.04 per cent), fruits were short, broad and solid due to seed filling and it bred true in the F_3 and F_4. Jambhale and Nerkar (1982) induced amphidiploids from the F_1 of cross *A. esculentus* var. Pusa Sawani x *A. manihot* ssp. *tetraphyllus*. The induced amphidiploid showed regular meiosis with 134 bivalents (Babu and Dutta, 1994). Arka Anamika and Arka Abhay were the products of *A. esculentus* and *A. tetraphyllus* crossing programme (IIHR, 1991).

2.5.2 Crossability between *A. esculentus* (2n=124/130) and *A. tuberculatus* (2n=58)

Hybridization between the two species was successful in either direction (Pal *et al.,* 1952; Joshi and Hardas, 1977). However, the F_1 was sterile and pollen fertility was 35 to 45 per cent (Pal *et al.,* 1952). Kuwada (1966) obtained an amphidiploid from the F_1 of *A. tuberculatus* x *A. esculentus* cross and named it as *Abelmoschus tubercular-esculentus.*

2.5.3 Crossability between *A. esculentus* and *A. caillei* (2n=194)

Hybridization between *A. esculentus* and *A. caillei* was reported first by Arumugam *et al.* (1975) and subsequently by Thakur (1976), Dhilllon and Sharma (1982), Siemonsma (1982), Martin (1982a), Sharma and Dhillon (1983), Sharma and Sharma (1984), Hamon and Yapo (1986) and Fatokun (1987). In all the above reports, hybridization were effected to transfer YVMV resistant gene from *A. caillei* to *A. esculentus*. The reports revealed that it was easy to obtain F_1 plants. But the F_1 was sterile. Pod set in the F_1 ranged from 0 to 72 per cent while seeds per pod were reduced (0 to 28 seeds / pod). Pollen was much larger than both the parents (0.24 mm) with 35.80 per cent fertility. The seeds produced by F_1 plants were empty. However, backcrossed progenies were reported less sterile and fertility was almost complete in the BC_2. Therefore, gene transfer from *A. caillei* to *A. esculentus*, though difficult, appears to be feasible.

Cytological studies in the F_1 revealed that hybrid sterility was due to differences in chromosome number of the parents which leads to abnormal meiosis. As a result, incorporation of the resistant gene into *A. esculentus* was hindered (Madhusoodanan and Nazeer, 1986; Fatokun, 1987; Hamon and Hamon, 1991).

Jambhale and Nerkar (1982) induced amphidiploid, using 0.1 per cent colchicine. Seed fertility in the amphidiploid was as high as 88 per cent. Dhillon and Sharma (1982) and Jambhale and Nerkar (1983) isolated lines with economically desirable traits and YVMV resistance from the back cross progenies of cross *A. esculentus* x *A. caillei.*

The African variety Winter Bush (Martin, 1982a) and Indian variety Punjab Padmini (Sharma and Sharma, 1984) are the product of *A. esculentus* x *A. caillei* cross.

2.6 COMBINING ABILITY STUDIES

Previous studies on combining ability for shoot and fruit borer resistance in okra are not available. Duhoon *et al.* (1984) made crosses between three different races of *arboreum* cotton and evaluated the hybrids against *Earias vittella* and *Earias insulana*. They reported considerable variation among the hybrids for fruit borer resistance and attributed additive gene action for resistance.

A number of studies on combining ability for yield and yield attributes are available. Brief information on gene action, parents with good *gca* and cross with high *sca* for yield and yield contributing traits are presented in Table 2.2.

Table 2.2 Nature of gene action, parents with good *gca* and hybrids with high *sca* reported by previous workers for yield and yield attributes in okra

No. of parents & mating design	Nature of gene action	Parents with high *gca* effects	Hybrid with high *sca* effects	Reference
1. Days to flowering				
16 x 4 LT[4]	NA	Pusa Makhmali	Dwarf Green x Pusa Sawani	Sharma and Mahajan (1978)
7 x 7 DA	A & NA	IC 6653	IC 12930 x Dwarf Green Smooth	Partap and Dhankhar (1980)
10 x 10 DA	A	Pusa Sawani	Pusa Sawani x Clemson Spineless	Vijay and Manohar (1986a)
15 x 4 LT	NA	Parbhani Kranti	IC 12205 x Parbhani Kranti	Shukla *et al.* (1989)
6 x 6 DA	A	86-40	-	Jawili and Rasco (1990)
5 x 3 LT	NA	Pusa Sawani	Sel 6-2 x Parbhani Kranti	Chaudhary *et al.* (1991)
8 x 8 DA	A & NA	Sel 4	Parbhani Kranti x Sel 10	Mandal and Das (1992)
9 x 9 DA	A	Parbhani Kranti	Parbhani Kranti x TRO	Chavadhal and Malkhandale (1994)
4 x 4 DA	A & NA	AE 129	P 7 x AE 129	Sivakumar *et al.* (1995)
12 x 12 DA	NA	Vaishali Vadhu	IC 12934 x Punjab Padmini	Wankhade *et al.* (1995)
8 x 8 DA	A	IC 9856	P 7 x Arka Abhay	Sood and Kalia (2001)
15 x 15 DA	NA	7310	6305 x 6308	Singh *et al.* (2001)
10 x 10 DA	NA	Ankur 40	Parbhani Kranti x Indam 9821	Mitra and Das (2003)

[4] DA refers to diallel mating while LT refers to Line x Tester A–refers to Additive & NA-Non additive gene action

No. of parents & mating design	Nature of gene action	Parents with high *gca* effects	Hybrid with high *sca* effects	Reference
8 x 8 DA	NA	P 8	HRB 9-2 x VB 9101	Rani and Arora (2003a)
6 x 6 DA	A	Green Velvet	No. 8 x Green Velvet	Saeed *et al.* (2004)
6 x 6 DA	NA	Azad bhindi 1	Azad bhindi 2 x Azad bhindi 1	Kumar *et al.* (2005)
2. Plant height				
6 x 6 DA	NA	AE 107	Sevendhari x Dwarf Green	Kulkarni (1976)
16 x 4 LT	NA	Verma's Jewel	American 7 dhari x Pusa Sawani	Sharma and Mahajan (1978)
10 x 2 LT	NA	6313	7107 x 6313	Singh and Singh (1979)
6 x 6 DA	A	Smooth Green	-	Jawili and Rasco (1990)
5 x 3 LT	NA	Pusa Sawani	Sel 2 x P 7	Chaudhary *et al.* (1991)
8 x 8 DA	A & NA	Parbhani Kranti	Parbhani Kranti x Sel 10	Mandal and Das (1992)
9 x 9 DA	NA	*A. ficulneus* , *A. manihot*	*A ficulneus* x *A. manihot*	Chavadhal and Malkhandale (1994)
4 x 4 DA	A	P 7	P 7 x AE 129	Sivakumar *et al.* (1995)
8 x 8 DA	NA	Punjab Padmini	P 7 x P 5	Singh *et al.* (1996)
20 x 4 LT	NA	MR 15	MR 12 x Raj 12	Dhankhar and Dhankhar (2001)
15 x 15 DA	NA	7310, 6313	6305 x 6308	Singh *et al.* (2001)
10 x 10 DA	A	Ankur 40	Indam 9821 x Ankur 40	Mitra and Das (2003)
8 x 8 DA	NA	P 8	VRO 03 x KS 404	Rani and Arora (2003a)
6 x 6 DA	NA	Parbhani Kranti	Azad bhindi 2 x Parbhani Kranti	Kumar *et al.* (2005)
3. Number of fruits per plant				
16 x 4 LT	NA	Pusa Sawani	Pusa Sawani x Smooth Long Green	Sharma and Mahajan (1978)
7 x 7 HD	A & NA	Sel 2	IC 12930 x Pusa Sawani	Partap and Dhankhar (1980)
7 x 7 DA	A	AE 91	New Selection X AE 91	Poshiya and Shukla (1986)
5 x 3 LT	NA	Pusa Makhmali	Pusa Sawani x P 7	Chaudhary *et al.* (1991)
9 x 9 DA	NA	*A.ficulneus*, *A. tetraphyllus*	Parbhani Kranti x *A. ficulneus*	Chavadhal and Malkhandale (1994)
4 x 4 DA	NA	P 7	P 7 x AE 129	Sivakumar *et al.* (1995)
12 x 12 DA	NA	Local Akola	IC 18960 x Local Akola	Wankhade *et al.* (1995)
20 x 4 LT	NA	MR 15	MR 10-1 x Varsha Upahar	Dhankhar and Dhankhar (2001)
15 x 15 DA	NA	7310	6305 x 6308	Singh *et al.* (2001)
7 x 7 DA	NA	Varsha Upahar	MF 3 x Varsha Upahar	Indurani *et al.* (2002)
8 x 8 DA	NA	P 8, Punjab Padmini	VRO 03 x KS 404	Rani and Arora (2003a)

No. of parents & mating design	Nature of gene action	Parents with high *gca* effects	Hybrid with high *sca* effects	Reference
6 x 6 DA	NA	Azad bhindi 1	Azad bhindi 2 x Azad bhindi 1	Kumar *et al.* (2005)
4. Single fruit weight				
16 x 4 LT	NA	Crimson Spineless	Okra Red x Smooth Long Green	Sharma and Mahajan (1978)
7 x 7 HD	NA	IC 12930 & Narnaul Colln	-	Partap and Dhankhar (1980)
5 x 3 LT	NA	Pusa Makhmali	Sel 6-2 x Parbhani Kranti	Chaudhary *et al.* (1991)
9 x 9 DA	NA	Sel 2-2, Pusa Sawani	Sel 2-2 x *A. ficulneus*	Chavadhal and Malkhandale (1994)
4 x 4 DA	A & NA		EMS 8 x AE 129	Sivakumar *et al.* (1995)
7 x 7 DA	NA	Varsha Upahar	MF 3 x OHD 1	Indurani *et al.* (2002)
8 x 8 DA	NA		Pusa Makhmali x P 8	Rani and Arora (2003a)
5. Fruit yield				
16 x 4 LT	NA	Pusa Sawani	Pusa Sawani x Smooth Long Green	Sharma and Mahajan (1978)
10 x 2 LT	A	KB, 6302	7107 x 6313	Singh and Singh (1979)
7 x 7 HD	A	Sel 2	Dwarf Green Smooth x Sel 2	Partap and Dhankhar (1980)
14 x 4 LT	NA	AE 1068, AE 180	-	Elangovan *et al.* (1981a)
7 x 7 DA	A	New Selection	New Selection X AE 91	Poshiya and Shukla (1986)
10 x 10 DA	A	Pusa Sawani	Pusa Sawani x Clemson Spineless	Vijay and Manohar (1986a)
15 x 4 LT	NA	KS 301 & 310	IC 12205 x Parbhani Kranti	Shukla *et al.* (1989)
6 x 6 DA	A	Smooth Green	Smooth Green x 86-40	Jawili and Rasco (1990)
5 x 3 LT	NA	Punjab Padmini	Pusa Sawani x P 7	Chaudhary *et al.* (1991)
7 x 7 D	NA	AE 974	AE 824 x AE 180	Veeraraghavathatham and Irulappan (1991a)
8 x 8 DA	A & NA	Pusa Sawani	Punjab Padmini x Sel 10	Mandal and Das (1992)
6 x 6 DA	NA	Arka Abhay	Arka Abhay x Arka Anamika	Sivagamasundhari *et al.* (1992a)
10 x 10 DA	A & NA	Foam Barelley	Pusa Sawani x Vaishali Vadhu	Arora (1993)
10 x 5 LT	A & NA	AE 110, AE 118	Pusa Sawani x CO 2	Vasaline and Ganesan (1995)
9 x 9 DA	A	*A. ficulneus*, KO	Pusa Sawani x KO	Chavadhal and Malkhandale (1994)
10 x 10 DA	NA	Gujarat Okra	-	Patel *et al.* (1994)
8 x 8 DA	NA	No. 168, Japan	Japan x Parbhani Tillu	Shinde *et al.* (1995)
4 x 4 DA	A & NA	Punjab 7	P 7 x AE 129	Sivakumar *et al.* (1995)
12 x 12 DA	NA	Vaishali Vadhu	Vaishali Vadhu x Local Akola	Wankhade *et al.* (1995)
8 x 8 DA	NA	Punjab Padmini	Punjab Padmini x P 7	Singh *et al.* (1996)
6 x 3 LT	NA	Arka Abhay	IC 9275 x HB 55	Pathak *et al.* (1998)
15 x 15 DA	NA	7310 & 6313	6305 x 6308	Singh *et al.* (2001)

No. of parents & mating design	Nature of gene action	Parents with high *gca* effects	Hybrid with high *sca* effects	Reference
8 x 8 DA	A	Parbhani Kranti	P 7 x Arka Abhay	Sood and Kalia (2001)
7 x 7 DA	NA	Varsha Upahar	MF 3 x Varsha Upahar Varsha Upahar x Arka Anamika	Indurani *et al.* (2002)
7 x 3 LT	NA	Pusa Makhmali	Punjab Padmini x Pusa Makhmali	Prakash *et al.* (2002)
10 x 10 DA	A	Ankur 40	Parbhani Kranti x Indam 9821	Mitra and Das (2003)
8 x 8 DA	NA	P 8, HRB 9-2	Pusa Makhmali x P 8 VRO 03 x KS 404	Rani and Arora (2003a)
6 x 6 DA	A	Parbhani Kranti Green Velvet	No. 8 x Green Velvet	Saeed *et al.* (2004)
6 x 6 DA	NA	Azad bhindi 1	Azad bhindi 2 x Azad bhindi 1	Kumar *et al.* (2005)

2.7 STUDIES ON HETEROSIS

In okra, hybrid vigour over mid parent was reported first by Vijayaraghavan and Warrier (1946), later by Venkatramani (1952), Joshi *et al.* (1959), Raman and Ramu (1963) and Jalani and Graham (1973). The hybrids synthesized by the above workers (*e.g.* H 398 x Pusa Sawani, H 398 x Pusa Makhmali, Malaysian Local 5 x Emerald, Local 7 x Gold Coast) manifested earliness, tallness, high fruit weight, high fruit number and high yield (Peter, 1998). However, hybrids developed by Isaak (1965), Singh *et al.* (1975), Sharma and Mahajan (1978), Elangovan *et al.* (1981b) and Sood (1999) didn't manifest hybrid vigour in desirable direction over OPVs or over better parent. Jawili and Rasco (1990) reported that F_1 hybrids flowered earlier than the parents. But hybrid did not differ significantly from check variety for fruit yield.

Nevertheless, the ease in emasculation, high fruit set and high number of seeds per pollination had prompted many breeders to exploit hybrid vigour commercially. At present, few private seed companies, ICAR institutes and State Agricultural Universities have their own proprietary F_1 hybrids. An appraisal on relative heterosis reported so far for fruit yield revealed that the range was from 0.03 to 68.03 per cent. However, this wide range of heterosis may not be of practical use unless heterosis is expressed in comparison with better parent (*i.e.*

heterobeltiosis) or with check variety (*i.e.* standard heterosis). Therefore, heterobeltiosis and standard heterosis reported by the previous workers for yield and yield attributes are summarized in Table 2.3.

Table 2.3 Promising F_1 hybrids reported in okra for yield and yield attributes

Outstanding heterotic crosses	Mean	d_i %*	d_{iii} %	Reference
1. Days to 50 per cent flowering				
7107 x KB	48.83	-1.02		Singh *et al.* (1975)
Dwarf green x AE 107	43.64	-4.37	-3.46	Kulkarni and Virupakshappa (1977)
6319 x KT1	51.33	-9.95		Singh and Singh (1979)
AE 711 x AE106	49.65		-5.31	Elangovan *et al.* (1981b)
Pusa Sawani x Sel 6-1	46.30	-13.06		Vijay and Manohar (1986b)
AE 100 x Pusa Sawani	41.30		-8.70	Shukla and Gautam (1990)
EMS 8 x Punjab Padmini		-		Mandal and Dana (1993)
Sel 4 x Parbhani Kranti		-9.63		Singh *et al.* (2004)
TCR 2056 x Mohanur local			67.10	Surendirakumar *et al.* (2004)
2. Plant height (cm)				
Sevandhari x AE 107	83.67	19.19	19.19	Kulkarni and Virupakshappa (1977)
7106 x 6313	99.33	28.16		Singh and Singh (1979)
AE 800 x AE 142	116.68		20.35	Elangovan *et al.* (1981b)
Balady x Gold Coast	112.5	43.87		Maksoud *et al.* (1984)
Sel 10 x Punjab Padmini		-		Mandal and Dana (1993)
VRO 04 x VRO 05		59.69		Singh *et al.* (2004)
3. Number of fruits per plant				
6302 x FC	27.96		13.52	Singh *et al.* (1975)
Sevendhari x AE 107	13.50	4.65	4.65	Kulkarni and Virupakshappa (1977)
7114 x 6313	29.61	71.46		Singh and Singh (1979)
AE 1068 x AE 100	24.12		19.90	Elangovan *et al.* (1981b)
KS 310 x Pusa Sawani	25.20		31.20	Shukla and Gautam (1990)
Arka Abhay x Arka Anamika			11.75	Sivagamasundhari *et al.* (1992b)
Sel 10 x Punjab Padmini		-		Mandal and Dana (1993)
F_1-1A (Ankur seeds)	21.30		83.60	Babu *et al.* (1994)
Vaishali Vadhu x AE 1	-	24.33		More and Patil (1997)

* d_i-heterosis over better parent d_{iii}-heterosis over standard variety / hybrid

Outstanding heterotic crosses	Mean	d_i %	d_{iii} %	Reference
P7 x Arka Abhay	16.20	1.84	59.8	Sood (1999)
No 315 x IIVR 10	19.60	81.23		Singh *et al.* (2004)
TCR 2056 x Mohanur local	-	67.00	8.67	Surendirakumar *et al.* (2004)
4 Fruit yield per plant (g)				
7170 x FC	321.16		32.71	Singh *et al.* (1975)
7114 x Pusa Sawani	304.72	70.28	-	Singh and Singh (1979)
AE 1068 x AE 180	-	31.42	-	Elangovan *et al.* (1981b)
Pusa Sawani x Clemson Spineless	365.20	64.93		Vijay and Manohar (1986b)
KS 310 x Pusa Sawani	491.60		44.1	Shukla and Gautam (1990)
AE 974 x AE 180	317 .00			Veeraragavathatham and Irulappan (1991b)
Arka Abhay x Arka Anamika		24.51	-	Sivagamasundhari *et al.* (1992b)
Padra 18-6 x KS 312	341.00			Kumbhani *et al.* (1993)
Sel 7 x KS 312	360.00	48.00		Singh and Mandal (1993)
F_1-1A (Ankur seeds)	573.90	134.6		Babu *et al.* (1994)
New Selection X AE 91	420.62	27.77		Poshiya and Vashi (1995)
Pusa Makhmali x Parbhani Kranti			103.20	Singh *et al.* (1996)
Vaishali vadhu x Sel 6-2	321.05	28.94		More and Patil (1997)
Vaishali Vadhu x Local Akola	386.52			Wankhade *et al.* (1997)
P7 x Arka Abhay	293.00	68.00	80.00	Sood and Sharma (2001)
Pusa Makhmali x VRO 03	162.49	276.76		Rani and Arora (2003b)
No 315 x IIVR 10		67.57		Singh *et al.* (2004)

Note: d_i=heterosis over better parent d_{iii}=heterosis over standard variety / hybrid

2.8 GENERATION MEAN ANALYSIS

2.8.1 Gene action for fruit borer resistance

Ghai *et al.* (1990) after analyzing percentage fruit damage (by *Heliothis armigera*) in two parents (Punjab Padmini and Pusa Sawani) and their F_1 advanced to 21 generations reported that resistance was not an outcome of simple additive dominance or digenic interactions but of more complexities and higher order gene interactions like trigenic might be involved.

2.8.2 Gene action for fruit yield in inter varietal crosses of *A. esculentus*

Randhawa (1989) and Jawili and Rasco (1990) reported that additive gene effects were higher in relation to dominance for fruit weight, fruits per plant, plant height and yield per plant. According to Randhawa (1989), three parameter model was adequate to explain the variation for days to first flowering, plant height and fruit weight but inadequate for number of fruits and fruit yield. He suggested simple selection during early generation to develop high yielding varieties. Other workers have reported non-additive gene action for yield and yield contributing traits in okra (Partap and Dhankhar, 1980; Veeraragavathatham and Irulappan, 1991b; Indurani *et al.* 2002).

Panda and Singh (2001) attributed additive gene effects for pod number, dominance effect and additive x additive effects for pod yield. Korla and Sharma (1987) reported the prevalence of epistasis for fruit yield in Vaishali Vadhu x EC 68475, Sel 6-2 x EC 68475 and Pusa Sawani x EC 68475. Rajani and Manju (1999) reported over dominance for fruit yield. Tripathi *et al.* (2002) reported the prevalence of duplicate type of epistasis for all economic traits in AG-26 x Pb-8.

Senthilkumar *et al.* (2005) reported that days to first flowering, number of nodes, plant height, single fruit weight, fruit length and fruit weight in the cross Arka Anamika x Punjab Padmini were predominantly controlled by dominance x dominance interaction. However, fruit yield per plant in the cross Punjab Padmini x Parbhani Kranti was predominantly determined by additive gene action.

2.8.3 Gene action for fruit yield in *A. esculentus* x *A. caillei* crosses

Arumugam and Muthukrishnan (1979) estimated gene effects through five parameter model in the cross Co-1 x *A. caillei* and Pusa Sawani x *A. caillei* (African & Japanese source). Complementary gene action for plant height and duplicate gene action for days to flowering were reported. In an another study involving parents, F_1, F_2, BC_1 and BC_2 generations of cross Pusa Sawani x *A.*

caillei var. Ghana, Reshmi x *A. caillei* var. *Ghana*, Dhillon and Sharma (1982) observed dominance for days to flowering, internode length and resistance to the YVMV. Kehinde and Adeniji (2003) reported that in *A. caillei sca* variance was greater than the *gca* variance for pod yield due to non-additive gene action.

2.9 MECHANISMS OF RESISTANCE

2.9.1 Non-preference or antixenosis

The shoot and fruit borer exhibited marked preference for various host plants and are reported to attack as many as 38 plant species (Hiremath, 1984). Comparative evaluation of *E. vittella* on different Malvaceae hosts such as *Abelmoschus, Gossypium, Hibiscus, Sida* and *Urena* species for parameters like larval survival, larval growth, adult reproductive potential, mean generation time and population doubling time revealed that okra was the most preferred host followed by cotton (Satpute *et al.*, 2002; Sumathi and Balasubramanian, 2002).

Studies on oviposition preference among three okra varieties *viz.*, Sagar-1, Sagar-2, Sagar-2 revealed that Sagar-1 attracted fewer moths (Patil *et al.*, 1986). Vyas and Patel (1990) found that Parbhani Kranti, Gujarat okra 1, Padra18-6, Sel-2, Punjab Padmini and Pusa Sawani did not show differences for oviposition preference. But showed difference for the number of larvae entered in fruits. Low percentage (9.4 per cent) of *E. vittella* larvae had entered into fruits of Sel-2 but this value was high in other varieties.

2.9.2 Adverse effect on survival and longevity (Antibiosis factors)

Presence of gossypol (>0.50 %) and tannin (>0.20 %) in cotton lines inhibited larval growth of *E. vittella* and *E. insulana* (Sharma and Agarwal, 1984). High phenol and low sugar in cotton variety JK 260 was attributed for its resistance to *E. vittella* (Ilango and Uthamasamy, 1989).

2.10 BASIS OF RESISTANCE IN OKRA TO SHOOT AND FRUIT BORER

2.10.1 Biophysical basis of resistance

Mehta and Saxena (1970) and Kishore *et al.* (1983) opined that colour differences among host plants may not be involved in host plant resistance as the pests oviposit in darkness. Singh (1987) reported that moisture content in the fruits had positive correlation (r=0.74) with larval survival. Mehta and Saxena (1970) found that okra fruit and cotton leaves were preferred by *E. vittella* for oviposition for which they attributed dense hairs present on these parts and certain chemical stimulants. Density and length of trichomes on fruits were also important in deciding ovipositional preference as per Singh and Chaudhary (1989), Singh and Taneja (1991) and Saini and Singh (1999). Mote (1982) studied egg laying preference of *E. vittella* on different okra varieties. The level of oviposition and larval entry into okra fruits were low in varieties with high hair density and long fruit hairs.

Kumbhar *et al.* (1991) reported positive correlation with hair density and fruit infestation in Ankur 35, Lam Hybrid, Pusa Sawani, Sel 1-1, Sel 2-2, Sel 6-2 and Vaishali Vadu. Gupta and Yadav (1978) reported that late flowering germplasm were highly susceptible to fruit borer irrespective of the fruit texture (smooth or hairy). At the same time, they opined that the texture of fruit surface and time of flowering cannot be taken as the sole factor for determining resistance or susceptibility. Teli and Dalaya (1981) reported that larval entry was easier in soft skinned, smooth surfaced and dense haired varieties like Early Long Green, AC 3375, Glossy Green and Pusa Sawani and *vice versa* in hard skinned, tough and sparsely haired genotypes like AE 52, 69, 79 and Sel 1-1 x AE 79.

2.10.2 Biochemical basis of resistance

Mehta and Saxena (1970) found that the juice extracted from okra fruit elicited higher oviposition response in *E. vittella*. The chemical constituents of the

juice contain essential oils, diterpenoids, terpenoids, triterpenes, aglycons and steroids. Reducing sugar, aldehyde, and amino acid could not be detected in the juice extract of okra by spot test. The residues of plant parts after extraction with petroleum ether did not attract *E. vittella.*

Biochemical constituents in different parts of okra fruits namely epicarp, fruit axil, seeds and whole fruit was found to affect the development behaviour and reproductive potential of this pest (Vishwapremi and Krishna, 1974; Singh, 1987). The reproductive potential of *E. vittella* on the epicarp and fruit axil was found to be poor due to less number of free amino acids and lower concentration of soluble protein as compared to seeds (Mani *et al.,* 1986). Singh (1987) reported that primary phytochemicals like protein, free amino acids, total sugars, and non-reducing sugars were positively correlated with survival of *E. vittella* but expressed optimism that these chemicals could not be definitely attributed to host resistance due to non-significant correlation. However, tannin content in okra fruits was reported to have negative correlation (r= -0.46 to- 0.81) with larval survival.

2.10.3 Anatomical and histochemical basis of resistance

Previous studies on this aspect are not found in okra. Resistant cultivars to brinjal shoot and fruit borer (*Leucinodes orbanalis*) had compact vascular bundles in thick layers with lignified cells and low pith area while the susceptible varieties had poorly lignified hypodermis and loosely packed vascular bundles and larger pith area (Panda *et al.,* 1971). Histochemical examination in the leaf tissues of sorghum variety resistant to shoot fly revealed highly lignified cell wall (Blum, 1968).

Thus, the above review unfolds the severity and damage caused by the shoot and fruit borer in okra on one side and non-availability of resistant varieties for cultivation on another side and the existing research gap between the two ends.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The research work for the thesis entitled 'Breeding for resistance in okra to shoot and fruit borer' was conducted at the College of Horticulture, Kerala Agricultural University, Vellanikkara from 2002 to 2006.

3.1 MATERIALS

The materials for the present study consisted of 144 accessions of okra germplasm representing two cultivated and eight wild species. The details are given below.

3.1.1 Cultivated species: *Abelmoschus esculentus* (L.) Moench

Fourteen released varieties, five landraces (Plate 1), 84 indigenous germplasm lines assembled from different parts of India and 21 exotic germplasm lines from South Asian countries (total 122 accessions) constituted this group (Table 3.1). The materials were obtained from National Bureau of Plant Genetic Resources, Indian Institute of Horticultural Research, Indian Institute of Vegetable Research, Tamil Nadu Agricultural University, University of Agricultural Sciences, Indian Agricultural Research Institute, Kerala Agricultural University and through germplasm exploration and collection trips carried out by the author.

Table 3.1 List of *A. esculentus* accessions used in the study

I	List of released varieties
1	Arka Abhay
2	Arka Anamika
3	Aruna
4	Bio 2
5	CO 1
6	EMS 8-1
7	MDU -1
8	Parbhani Kranti
9	Punjab Padmini
10	Pusa Makhmali
11	Salkeerthy
12	Sel 2
13	Varsha Upahar
14	VRO 06
II	**Landraces/Traditional cultivars**
1	Aarumasavendai
2	Anakomban
3	Anjilaivendai
4	Maravendai
5	Palvenda

(Table contd...)

Anjilai vendai

Maravendai

Palvenda

Anakomban

Aarumasavendai

EC 2

i) *Abelmoschus esculentus* genotypes (landraces & exotic collection)

AC 10

Thamaravenda

AC 5

ii) *Abelmoschus caillei* genotypes

Plate 1 Cultivated and semi-wild okra screened against *Earias vittella*

Table 3.1 continuation.....List of *A. esculentus* accessions used in the study

III List of indigenous germplasm					
S No	Code number used in this study	Accession number assigned by NBPGR	S No	Code number used in this study	Accession number assigned by NBPGR
I Andhra Pradesh collections			29	KL-14	IC 69302
1	AP-1	IC 282243	30	KL-15	IC 85585
2	AP-2	IC 218887	31	KL-16	IC 113904
3	AP-3	IC 128095	32	KL-17	IC 208870
4	AP-4	IC 33071-I	33	KL-18	IC 282235
5	AP-5	IC 33087	34	KL-19	IC 218879
II Bihar collections			35	KL-20	IC 282252
6	BH-1	IC 33182	36	KL-21	IC 282257
7	BH-2	IC 33255	37	KL-22	IC 282260
8	BH-3	IC 33255 S	38	KL-23	IC 282294
III Gujarat collections			39	KL-24	IC 282294-I
9	GU-1	IC 90177	40	KL-25	IC 140902
10	GU 2	IC 33302 P	41	KL-26	IC 140907
11	GU 3	IC 33315	42	KL-27	IC 140933
12	GU-4	IC 33318	43	KL-28	IC 140934
IV Haryana collections			VI Karnataka collections		
13	HA-1	IC 111472	44	KA-1	IC 1111324
14	HA-2	IC 33329	45	KA-1	IC 282277
15	HA-3	IC 33340	46	KA-3	IC 282285
V Kerala collections			47	KA-4	IC 282287
16	KL-1	IC 43299	48	KA-5	IC 282289
17	KL-2	IC 43720	49	KA-6	IC 282293
18	KL-3	IC 43736	VII Madhya Pradesh collections		
19	KL-4	IC 43745	50	MP-1	IC 33350 A
20	KL-5	IC 43750	51	MP-2	IC 9856 C
21	KL-6	IC 45792	52	MP-3	IC 13917 A
22	KL-7	IC 45805	53	MP-4	IC 18537 A
23	KL-8	IC 45806	VIII Maharashtra collections		
24	KL-9	IC 45818	54	MH-1	IC 140872
25	KL-10	IC 69194	55	MH-2	IC 128883
26	KL-11	IC 69248 I	56	MH-3	IC 128888
27	KL-12	IC 69254	57	MH-4	IC 128890
28	KL-13	IC 69286	58	MH-5	IC 128892

(Table contd...)

Table 3.1 continuation..... List of *A. esculentus* accessions used in the study

III Indigenous germplasm		
59	MH-6	IC 112445
IX New Delhi collections		
60	ND-1	IC 33854
61	ND-2	IC 39134
X North East Collections		
62	NER-1	IC 140897
63	NER-2	IC 140898
64	NER-3	IC 90004
65	NER-4	IC 90049
66	NER-5	IC 90168
67	NER-6	IC 90133
68	NER-7	Personal collections
69	NER-8	made at Sikkim
XI Orissa collections		
70	OR-1	IC 99729
71	OR-2	IC 99746
XII Rajasthan collections		
72	RA-1	IC 90171
73	RA-2	IC 90262
XIII Tamil Nadu collections		
74	TN-1	Personal collection
75	TN-2	IC 218881
76	TN-3	IC 282263
77	TN-4	IC 111443
XIV Uttar Pradesh collections		
78	UP-1	IC 282268
79	UP-2	IC 218904
80	UP-3	IC 45857
81	UP-4	IC 45955

XV West Bengal collections		
82	WB 1	IC 52305 B
83	WB 2	IC 52310
84	WB 3	IC 117182
IV	Exotic germplasm	
1	EC-1	EC 305746
2	EC-2	EC 329365
3	EC-3	EC 329398
4	EC-4	EC 305609
5	EC-5	EC 305617
6	EC-6	EC 305619
7	EC-7	EC 305620
8	EC -8	EC 169335
9	EC-9	EC 169381
10	EC-10	EC 169393
11	EC-11	EC 169408
12	EC-12	EC 169416
13	EC-13	EC 169419
14	EC-14	EC 169423
15	EC-15	EC 169467
16	EC-16	EC 169500
17	EC-17	EC 169948
18	EC-18	EC 305623
19	EC-19	EC 305645
20	EC-20	EC 305725
21	EC-21	EC 306742 P
IC refers to indigenous collection EC refers to exotic collections accessioned by NBPGR		

3.1.2 Semi-domesticated species: *Abelmoschus caillei* (A.Chev) Stevels

Eight accessions from West Africa (AC1 to AC 8) obtained from NBPGR and two accessions from Sikkim (AC 9 and 10), a traditional cultivar from Kerala (Thamaravenda) and a released variety Susthira from KAU constituted this group. The details are shown in Table 3.2 and in Plate 1.

1. *A. angulosus*
(Resistant to YVMV)

2. *A. ficulneus*

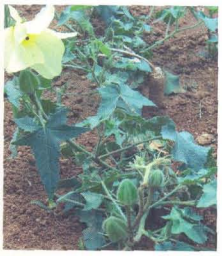
3. *A. moschatus*

4 *A. moschatus* var. *multiformis*
(ornamental & YVMV resistant)

5. *A. tetraphyllus*
(Resistant to shoot borer)

6. *A. tetraphyllus* var. *pungens*
(Resistant to YVMV)

A. tuberculatus (Resistant to fruit borer)



A. tuberosus

Plate 2 Wild okra screened against *Earias vittella*

Table 3.2 List of *A. caillei* accessions used in the study

S.No.	Code no. followed in the study	Accession no. assigned by NBPGR
1	AC-1	EC 305672
2	AC-2	EC 305741 A
3	AC-3	EC 305745
4	AC-4	EC 305749
5	AC-5	EC 305760
6	AC-6	EC 305771
7	AC-7	EC 306706
8	AC-8	EC 306722 B
9	AC-9	Personal collections from North Eastern India
10	AC-10	
11	Thamaravenda	Traditional cultivar from Kerala
12	Susthira	Released variety from KAU

3.1.3 Wild *Abelmoschus* species

Eight wild *Abelmoschus* taxa (species / sub-species / varieties) collected by the author through germplasm collection trips constituted this group (Table 3.3 and Plate 2).

Table 3.3 List of wild *Abelmoschus* species used in the study

#	Species Name followed in the study*	Synonym in Waalkes (1966) classification
1	*A. angulosus*	*A. angulosus* Wall ex. W. & A.
2	*A. ficulneus*	*A. ficulneus* (L.) W. & A. ex Wight
3	*A. tetraphyllus*	*A. tetraphyllus* var. *tetraphyllus* (Roxb) Hochr.
4	*A. tetraphyllus* var. *pungens*	*A. tetraphyllus* var. *pungens* (Roxb.) Hochr.
5	*A. moschatus*	*A. moschatus* ssp. *moschatus* var. *moschatus*
6	*A. moschatus* var. *multiformis* Wall. ex Mast.	*A. moschatus* ssp. *moschatus* var. *sagittiformis* Kurz
7	*A. tuberosus*	*A. moschatus* ssp. *tuberosus* (Span.) Borss
8	*A. tuberculatus*	*A. tuberculatus* Pal & Singh

* Species name is according to recent taxonomic revisions (IBPGR, 1991; Hamon and Charrier, 2001)

3.2 METHODOLOGY FOR FIELD STUDIES

Five field experiments were carried out successively from 2002 to 2006 at College of Horticulture, Vellanikkara. These experiments were conducted: i) to identify resistance sources to shoot and fruit borer, ii) to confirm resistance, (iii) to effect crosses between resistant and high yielding parent, (iv) to evaluate F_1s against shoot and fruit borer and to develop F_2 and back cross progenies (B_1 and B_2) and (v) to evaluate six generation materials (Parents, F_1, F_2, BC_1) against shoot and fruit borer. Details of individual experiments are given below.

3.2.1 Experiment 1: Field screening of germplasm to identify resistance source for *E. vittella*

This experiment was conducted during November 2002 to March 2003 at the Vegetable Farm under Dept. of Olericulture where okra is grown every year. This was a hot spot for *E. vittella*. Five separate but simultaneous field trials (Table 3.4) were laid out for the 144 germplasm mentioned in Table 3.1 in randomized block design (RBD) replicated thrice. In each replication a pair of three metres long row (spaced 60 cm apart) was maintained for each genotype and seeds were dibbled 30 cm apart within a row. Recommended package of practices of KAU was followed to grow a successful crop of okra. No pesticides were sprayed. The crop was left for natural infestation by shoot and fruit borer.

Table 3.4 Germplasm screened against shoot and fruit borer in field experiment I

Trial No	Germplasm category	No. of genotype	Name of the genotype
1a	Commercial varieties and traditional cultivars	19	Same as given in Table 3.1
1b	Indigenous germplasm	84	
1c	Exotic germplasm	21	
1d	*A. caillei* accessions	12	As in Table 3.2
1e	Wild species	8	As in Table 3.3
	Total	144	

To ensure build up of pest population infector row technique was followed. Ten days before sowing, a susceptible cotton variety MCU 5 was raised all around the experiment plots. Natural insect population of *E. vittella* was supplemented with artificial release of moth reared in the laboratory.

The minimal descriptor of okra published by the NBPGR for cultivated okra (Mahajan *et al.*, 2001) was modified to accommodate variation in wild and semi-wild species. Using the modified descriptor (Pl. see section 3.4.1), data on 21 qualitative traits namely, growth habit, stem pubescence, stem colour, leaf shape, leaf colour, petiole colour, epicalyx number, epicalyx shape, epicalyx persistence, petal colour, petal spot, fruit position, fruit colour, fruit shape, fruit tip, fruit ridges, fruit pubescence, pod quality, seed shape, hairiness and corrugations on seed surface were recorded from the 144 accessions. Five plants per genotype in a replication were tagged for observation on yield attributes. Fruit number, fruit yield and shoot and fruit infestation was recorded from all the plants.

3.2.2 Experiment 2: Confirmation of field resistance

Ten genotypes namely, *A. tetraphyllus, A. tetraphyllus* var. *pungens, A. tuberculatus, A. caillei* accessions AC 1, AC 5, AC 10, Susthira and Thamaravenda and *A. esculentus* cv. KL 9 and EC 2 which showed less than 20 per cent shoot or fruit damage in the preliminary screening were selected for second year trial to confirm their resistance.

A field experiment was laid out during March 2003 in RBD replicated thrice. Shoot and fruit borer susceptible variety Salkeerthy was raised as check. For each genotype, 10 to 15 plants per replication were maintained. In the confirmation trial, fruits were left on the plant till maturity to allow prolonged exposure to fruit borer. Natural population of *E. vittella* was supplemented with laboratory reared moths. Data on shoots and fruit infestation was recorded from each entry.

3.2.3 Experiment 3: Development of hybrids

The experiment was conducted at the ICAR Research Complex for NEH Region, Gangtok, Sikkim and at College of Horticulture, KAU during 2004-05. Shoot and fruit borer resistant genotypes identified in experiments 1 and 2 were crossed with high yielding varieties. The crossing programme was divided into two sets as shown below.

SET I: Crosses between wild and cultivated species

Wild species resistant to shoot borer (*i.e. A. tetraphyllus*) and fruit borer (*i.e. A. tuberculatus*) were crossed with high yielding genotypes *A. esculentus* cv. KL 28 and Arka Anamika as shown below.

1. Direct and reciprocal crosses of KL 28 x *A. tetraphyllus*
2. Direct and reciprocal crosses of Arka Anamika x *A. tuberculatus*

SET II: Crosses between cultivated species (*A. caillei* x *A. esculentus*)

This was a 6 x 6 full diallel mating involving four genotypes in the species *A. esculentus* (Sl. No 1 to 4) and two genotypes in *A. caillei* (Sl. No. 5 and 6) as detailed below.

Parent 1. Arka Anamika - high yielding but susceptible to borer
2. KL 28 -high yielding but susceptible to borer
3. KL 9 - moderately resistant (MR) to shoot borer
4. EC 2 - moderately resistant to fruit borer
5. AC 5 - high yielding and MR to shoot and fruit borer
6. Susthira- MR to shoot borer and acceptable fruit quality

3.2.4 Experiment 4: Evaluation of F_1 hybrids and generation of F_2 and BC_1

The materials included in this trial was set I and set II hybrids. Set I hybrids (4 F_1s) were raised along with their parents following 75 x 30 cm spacing. Set II

crosses (30 F_1s) were raised following 60 x 30 cm spacing along with their parents and a check hybrid (Texico No. 46). The materials were raised at the Vegetable Farm under Dept. of Olericulture during October 2005 to January 2006 in RBD with three replications. In each replication, a pair of three metre long rows was allotted to each genotype. Pesticides were not sprayed and natural population of *E. vittella* was augmented from laboratory reared insects. Fruit borer susceptible variety Salkeerthy was raised in border rows.

Data on yield attributes were recorded from five randomly selected plants from each replication. Fruit number, fruit yield and shoot and fruit infestation were recorded form entire population in each entry. Heterotic crosses that were resistant to *E. vittella* were selfed as well as back crossed to their female parents (referred as B_1) and male parents (B_2) to generate F_2 and backcross generations, respectively.

3.2.5 Experiment 5: Evaluation of F_1, F_2, B_1, B_2 and Parents (Generation mean analysis)

Since F_1's of set I cross *i.e. A. esculentus* x *A. tetraphyllus* and *A. esculentus* x *A. tuberculatus* did not set seeds on selfing as well as on backcross, the F_1s could not be advanced to next generation.

However, P_1, P_2, F_1, F_2, B_1 and B_2 of inter-varietal cross (of *A. esculentus*) Arka Anamika x KL 9 and *A. esculentus* x *A. caillei* inter-specific cross KL 9 x AC 5 were raised along with check during February-May 2006 in a compact family block design, replicating each generation materials thrice within a block. Salkeerthy was grown along the borders. In each replication, two rows (3 m long each) were allotted for parents and F_1s, four rows for B_1 and B_2 and six rows for F_2s. Pesticides were not sprayed in the trial plot. The crop was left for natural infestation and was supplemented with artificial release of *E. vittella* moths reared in the laboratory.

Data on yield and yield contributing traits, shoot infestation and fruit infestation were recorded from five randomly selected plants in a replication in parents and F_1, from 10 plants in B_1 and B_2 and from 20 plants in F_2.

3.3 METHODLOGY FOR LABORATORY AND SCREEN-HOUSE STUDIES

3.3.1 Mass rearing of *E. vittella* on natural diet and method of field release

Mass multiplication of shoot and fruit borer was done to supplement natural field population so as to create high selection pressure. Larvae collected from infested okra plants were kept in plastic containers and fed with cut pieces of fresh okra fruits (Plate 3). The feed was changed on alternate days. Rearing was carried at room temperature. The pupae formed were sorted out according to their sex. They were kept in two separate plastic containers. When moths emerge, a pair of female and male moth was released to an amber colour plastic container. The mouth of container was covered by a wet cotton cloth and kept in a mating chamber for oviposition. Adults were fed on 1 per cent sugar solution. After three days, eggs containing cloth were taken out for further multiplication.

When the crop was two to three weeks old, gravid female moths reared in laboratory were taken to field and released at dusk. Second batch of field release was carried out during flowering stage of crop. The number of moths released in the field are given in appendix I. Whenever the necessity for further release for a specific entry was felt (*e.g.* for 'escaped' entries), eggs collected on a piece of cotton cloth (each piece having 5 to 10 eggs) was taken to field and placed on shoots or buds or fruits of test genotype (Plate 3).

3.3.2 Multiple choice test for antixenosis

To assess oviposition preference of *E. vittella* for shoots, buds and fruits of wild and cultivated okra namely, *A. angulosus, A. caillei* cv. AC 5, *A. esculentus* cv. Salkeerthy, *A. ficulneus, A. tetraphyllus, A. tetraphyllus* var. *pungens, A. moschatus, A. moschatus* var. *multiformis, A. tuberosus* and *A. tuberculatus* a

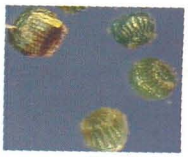
1. Larvae collected from infested okra field were fed with cut pieces of okra. Rearing was carried out in room temperature

♂ ♀

2. Pupae were sorted according to their sex and placed in two separate containers

♂ ♀

3. As soon as moths emerge, a pair of male and female was released inside a plastic container and kept in a mating chamber. *Earias* prefer laying eggs in darkness.



4. Eggs were collected in muslin cloths

a) Rearing technique for *E. vittella* in natural diet

To augment natural field infestation, gravid female moths multiplied in the laboratory were released in the experimental field.

To test the resistance of specific entry, *E. vittella* eggs collected on muslin cloth pinned on the shoots and fruits.

b) Supplementing natural field infestation with *E. vittella* reared in laboratory

c) Multiple choice test to assess oviposition preference of *E. vittella* for wild and cultivated okra

Plate 3 Technique of mass rearing for *E. vittella*, augmenting natural field infestation with artificial release and method for multiple choice test

potted plant from each species (pre-flowering stage) was kept inside a nylon net of size 2 m x 2 m x 2 m. Five gravid female from laboratory rearing were released inside the cage in dusk for oviposition. The moths were fed with one per cent sugar solution and left in the cage. The number of eggs laid on each species *i.e.* on the top 15 cm shoot apex was counted using a hand lens, during fourth and seventh day of release. The number of larva entered into shoot was recorded on the tenth day of release. The study was repeated at flowering stage. During fruiting stage, excess flower buds and old fruits were removed retaining three flower buds and fruits per plant to facilitate counting of eggs. The number of eggs that were laid on buds and fruits were counted. The number of larvae that entered into three flower buds and fruits were counted by splitting the infested buds and fruits

3.3.3 Single choice test

This test was conducted to assess adverse effects of feeding on resistant shoots and fruits on the growth and development of *E. vittella.* The test materials or substrate for rearing were, i) fruits of *A. tuberculatus* (highly resistant to fruit borer), ii) shoots of *A. tetraphyllus* (highly resistant to shoot borer) and iii) shoots and fruits of *A. esculentus* cv Salkeerthy (highly susceptible to fruit borer). *Earias vittella* eggs collected from laboratory reared insects were placed inside a jar containing cut pieces fruits or shoots of above test species. Rearing was carried out at room temperature (28±2°C and 65 ± 5 % RH) and continued till pupation on the above test species. Shoot and fruit remnants left in the rearing trays were changed in alternative days and fresh shoots or fruits were provided. Data on larval mortality, larval and pupal period, percent pupation, adult emergence and fecundity were recorded.

3.3.4 Characterization of trichome present on shoots and fruits

To ascertain the relationship, if any, of trichomes present on shoots and fruits of wild and cultivated okra with oviposition by *E. vittella*, plant samples from field grown okra of 10 *Abelmoschus* species were drawn from apical stem

(of 4 weeks old plants), flower buds and tender fruits (10 days after pollination). The samples were examined for trichome length and density (in 5 mm^2) in research microscopes fitted with an image analyser. Three samples in a species were studied and each one was treated as one replication. Ten measurements were recorded in each sample.

3.3.5 Biochemical analysis in resistant and susceptible *Abelmoschus* species

To understand the biochemical basis of resistance in okra to *E. vittella*, shoot samples of *A. tetraphyllus* (HR to shoot borer), *A. caillei* (MR to shoot borer) and Salkeerthy (Susceptible variety) and fruit samples of fruit borer *A. tuberculatus* (HR to fruit borer), *A. caillei* (MR to fruit borer) and Salkeerthy (Susceptible variety) were analysed for pH, phenol, tannin, gossypol, moisture and mucilage content. Moisture content was estimated as per AOAC (1980), total phenol as per Bray and Thorpe (1954), tannin by Folin-Denis method (Burns, 1971), mucilage as per Mahdy and Sebaiy (1984) and gossypol as per Sadasivam and Manickam (1996). The content was expressed on dry weight basis. For determination of pH about 2 g plant sample (fresh shoots and fruits) from each species was crushed in a mortar and homogenized with 40 ml of distilled water. The pH of the juice mixture was measured using a hand pH meter.

3.3.6 Anatomical and histochemical studies

This study was carried out to understand the anatomical and histo-chemical basis of resistance in okra to *E. vittella*. Thirty days old shoots of *A. tetraphyllus* (resistant to shoot borer) and seven days old fruit of *A. tuberculatus* (resistant to fruit borer) were used in the study along with shoots and fruits of susceptible species *A. esculentus* cv. Salkeerthy. Fairly thin, fresh hand sections were made. The sections were treated with selective stains (see Table 3.5) as per Malik and Singh (1980) and Dwivedi and Singh (1990).

The stained sections were observed for location and degree of staining (*i.e.* score 0 for no staining, 1 for faintly staining and 3 for deeply staining). Selected tissue portion showing differences for location and intensity of staining were micro-photographed using a microscope attached with image analyser.

Table 3.5 Staining procedures adopted for histo-localisation of cutin, lignin, mucilage, pectic acid, phenol, reducing substances, suberin and tannin.

Chemical substances localised	**Adopted staining procedure**	**End result / indication**
Starch, cellulose and cutin	Zn-Chloral-Iodine reaction	Blue purple indicate starch Brown indicate Lignin Violet purple indicate Cellulose Yellow indicate Cutin Yellowish indicate Suberin
Cellulosic substances	Methylene blue staining	Deep blue indicates Pure cellulose Greenish blue indicate cellulose mixed with other chemicals
Phenolic substances	Toluidine blue staining in acetate buffer	Greenish blue to green colour indicates phenolic substances
Pectic acid, Lignin and Tannin	Toluidine blue staining*	Pinkish purple indicate pectic acid Green / greenish blue / bright blue indicate lignin or tannin
Lignin	Phloroglucinol-HCl staining *	Red colour indicate lignin
Reducing substances	Fehling's reagent test	Brown deposit of metallic copper indicates reducing substances

* Hand cut sections were first cleared in dilute chloral hydrate before staining

3.4 OBSERVATIONS RECORDED FROM FIELD EXPERIMENTS

3.4.1 Recording qualitative data

The modified descriptor presented below was used for recording 21 qualitative characters in nominal and ordinal scale.

1 Vegetative character

1. Growth habit: 1-Erect, 2-Medium, 3-Procumbent
2. Stem pubescence (1-Glabrous, 2-Slight, 3-Conspicuous)
3. Stem colour : 1-Green (Non pigmented), 2-Green with red patches, 3-Purple, 4-Light rose, 5-Red
4. Leaf shape : See Figure 1
5. Leaf colour :1-Green, 2- Dark green, 3-Green leaf with light red veins (dot like), 4-Green leaf with deep red veins, 5-Purple blotched
6. Petiole colour : 1-Green, 2-Green with purple, 3-Purple, 4-Rose
7. Internode length:1-Congested (<5cm),2-Short(5-10cm), 3-Medium(10-15cm), 4-Long(>15cm)

2 Floral and fruit characters

1. No. of epicalyx segment: 1- Four to five, 2-Six to seven, 3- Eight to ten, 4-Above eleven
2. Shape of epicalyx segment: 1- Linear, 2-Lanceolate, 3-Triangular with straight margin, 4. Triangular with wavy margin, 5-Triangular, margin of adjacent epicalyx fused at base
3. Persistence of epicalyx segment:1-Non-persistent seven days after flowering, 2- Partially persistent (after 7 days), 3-Persistent (till maturity)
4. Petal colour : 1-Cream yellow, 2-Sulphur yellow, 3-Yellowish white, 4-Pale white, 5-White, 6-Yellowish with red veins, 7-Red
5. Petal spot :1-Inside only, 2-Both sides
6. Position of fruit:1-Erect, 2-Horizontal, 3-Pendent, 4-Aligned on one side
7. Fruit colour :1-Pale white, 2-Light green, 3- Dark green, 4-Yellowish green, 5-Red, 6- Green with purple striation, 7-Beige pink or Rose
8. Fruit shape : See Figure 2
9. Fruit tip :1-Acute, 2–Obtuse
10. Fruit ridges :1–Non-ridged, 2– Five ridges, 3- Six to ten ridges
11. Fruit pubescence :1-Downy, 2-Slightly rough, 3–Prickly

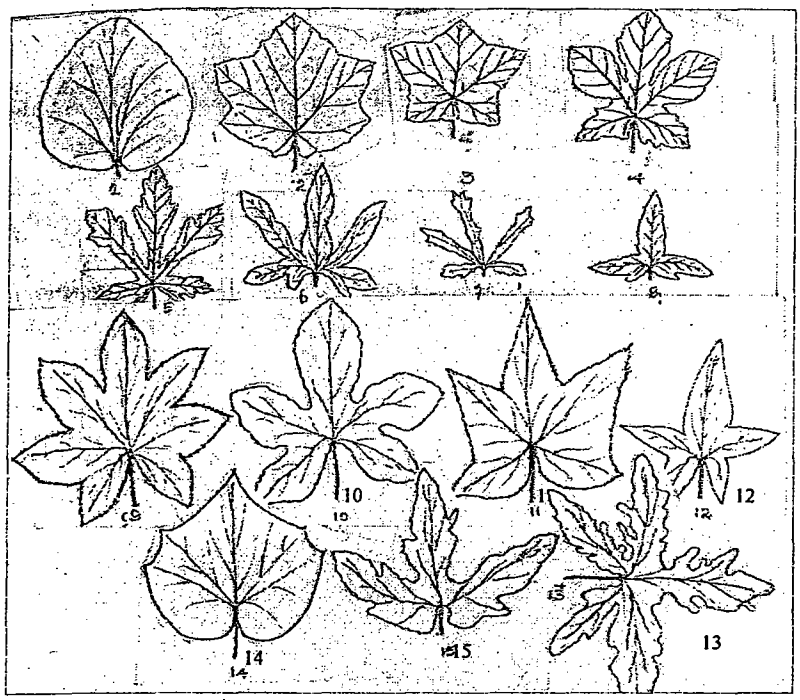


Fig. 1 Code for leaf shape

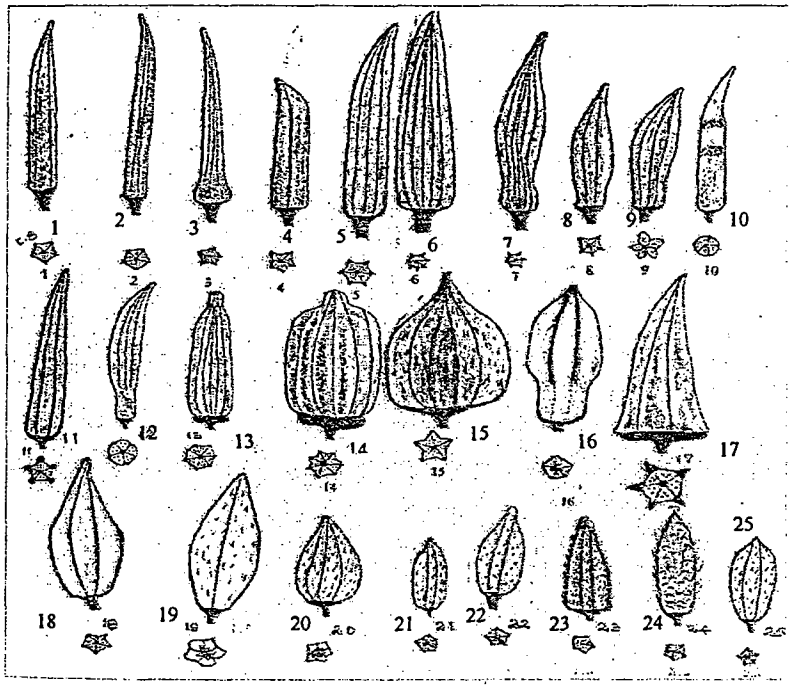


Fig. 2 Code for fruit shape

12. Fruit quality score (0 to 9): Score 1 to 3: Non consumable, Score 3-5: Consumable but low quality, Score 6-7: Medium, Score 8-9: Good quality

3 Seed and seedling characters

1. Seed Shape : 1-Globular, 2-Reniform, 3-Oblong
2. Seed surface : 1-Glabrous, 2-Slightly downy, 3-Downy
3. Concentric rings on testa : 1-Visible, 2-Invisible

3.4.2 Recording quantitative data

3.4.2.1 Yield and yield contributing characters

1. **Days to first flowering:** Duration between sowing and first flower opening was expressed in days.
2. **Effective flowering period:** Number of days from first flowering to end of flowering was calculated and expressed in days.
3. **Plant height:** Measured from soil level to the tip of the plant at the time of final harvest and expressed in centimeter.
4. **Number of leaves:** Number of well formed leaves remaining in the plant between 65 and 75 days after sowing was counted.
5. **Number of internode:** Total internode in the main stem was counted.
6. **Internode length:** Three measurements at top, middle and bottom of a plant at final harvest were made and the average was expressed in centimeter.
7. **Fruit yield:** Tender pods were harvested at seven days intervals from all the plants in a replication leaving only one border plant for seed purpose; pods were sorted into healthy and infested; counted and weighed. To derive fruit yield per plant, cumulative fruit weight (healthy + damaged fruits) from all harvest were divided by the number of plants in a replication and expressed in gram

8. **Number of fruits:** The cumulative figure from all harvests was divided by the number of plants and expressed in per plant basis.
9. **Average fruit weight:** Arrived from total fruit weights and fruit number.
10. **Fruit length:** Measured at the time of harvest and expressed in centimeter.
11. **Fruit girth:** Measured at the time of harvest and at the point of maximum bulging using an electronic caliper and expressed in millimeter.

3.4.2.2 Quantitative assessment of shoot and fruit damage

1. **Shoot damage:** Number of shoots damaged by *Earias* spp. was counted from all the plants in a replication and the percent shoot infestation (SI) was calculated as given below.

$$\text{Shoot infestation (\%)} = \frac{\text{Number of damaged shoots per genotype}}{\text{Total number of shoots per genotype}} \times 100$$

2. **Fruit damage:** Percent fruit infestation (FI) on number and weight basis was calculated based on infestation data recorded at each harvest.

$$\text{Fruit infestation (\%)} = \frac{\text{Number of damaged fruits per genotype}}{\text{Total number of fruits per genotype}} \times 100$$

3. **Marketable fruit yield (MFY):** Weight of healthy fruit divided by total fruit (healthy + damaged) weight and expressed in grams as well as in percentage.

$$\text{Marketable fruit yield (g)} = \frac{\text{Weight of healthy fruits per plant}}{\text{Weight of healthy + damaged fruits per plant}}$$

3.4.2.3 Rating shoot and fruit infestation in resistance scale

The relative degree of resistance to shoot and fruit borer infestation was judged on the basis of percentage shoot and fruit infestation in each genotype. The classification suggested by Kumbhar *et al.* (1991) was adopted in the present study.

Table 3.6 Resistance scale based on intensity of infestation

S.No	Resistance category	Shoot infestation	Fruit infestation (number basis)
1	Immune	0 %	0 %
2	Highly resistant	1-10.99 %	1-10.99 %
3	Moderately resistant	11-20.99 %	11-20.99 %
4	Susceptible	21-30.99 %	21-30.99 %
5	Highly susceptible	>31 %	>31 %

3.4.2.4. Incidence of Yellow Vein Mosaic Virus (YVMV)

The number of plants infected by YVMV was counted and the percent disease index (PDI) was worked out as shown below.

$$\text{Per cent Disease Index} = \frac{\text{Number of infected plants}}{\text{Total number of plants observed}} \times 100$$

The disease severity in the infested leaf of each genotype was recorded in five point scale as per Mayee and Datar (1986).

YVMV score	Leaf area infected
0	No infection
1	25 % leaf area infected
2	25-50 %
3	51-70 %
4	75-90 %
5	90 % and above

Then, the per cent disease severity (PDS) was worked out as shown below.

$$PDS = \frac{\text{Sum of all numerical ratings}}{\text{Total number of leaves observed}} \times \frac{100}{\text{Maximum disease grade}}$$

The values of PDS and PDI were multiplied to arrive at co-efficient of infection (CI)

$$CI = (PDS \times PDI) / 100$$

Based on CI, the genotypes were classified into different resistant classes as suggested by Mayee and Datar (1986).

Co-efficient of infection (%)	Resistance category
0-4	: Highly resistant
4.1 to 9	: Resistant
9.1 to 19	: Moderately resistant
19.1 to 39	: Moderately susceptible
39.1 to 69	: Susceptible
69.1 to 100	: Highly susceptible

3.5 STATISTICAL ANALYSIS OF DATA

3.5.1 Analysis of variance and estimation of co-efficient of variation

Data on quantitative characters were analyzed for variances and significance of treatments. The genotypic co-efficient of variation (GCV) and phenotypic co-efficient of variation (PCV) were estimated as per Singh and Chaudhary (1985).

3.5.2 Combining ability

The data recorded from 6 x 6 diallel crosses was analysed for *gca* and *sca* effects and variance following Method I and Model I of Griffing (1956). Variance components such as additive variance (σ^2A), dominance variance (σ^2D) and environmental variance (σ^2e) were estimated as per Sharma (1998).

3.5.3 Heterosis and inbreeding depression

Standard heterosis over check hybrid (Texico hybrid No 46) and inbreeding depression were computed and their significance were tested using standard error.

3.5.4 Generation mean analysis

The means of six generation *viz.*, P_1, P_2, F_1, F_2 and B_1 and B_2 were used in this analysis. A scaling test of Hayman and Mather (1955) was applied to detect the presence of epistasis. If epistasis was absent then, the estimates of mean (m), additive gene effects (d) and dominant gene effects (h) were calculated through three parameter model (additive dominance model) of Jinks and Jones (1958). If epistasis was present then, digenic non-allelic interaction model was resorted and six parameters namely, m, d, h, i, j and l were estimated as per Hayman (1958). A joint scaling test was also carried out to test the adequacy of three or six parameter model.

3.5.5 Genotypic correlation and clustering

To assess the association between shoot and fruit borer resistance with other quantitative traits genotypic correlation was worked out as per Singh and Chaudhary (1985).

The extent of genetic divergence in the 144 germplasm was assessed through Mahalnobis D^2 statistics using 14 quantitative traits namely, days to first flowering, flowering period, plant height, number of leaves per plant, number of internode, internode length , fruits per plant, average fruit weight, fruit length, fruit girth, fruit yield per plant, shoot and fruit infestation and marketable fruit yield. Grouping of genotypes was done using Euclidean squared distance (Mahalnobis, 1936).

RESULTS

4. RESULTS

Okra shoot and fruit borer (*Earias vittella*) is a cosmopolitan pest and it causes losses over 30 per cent. The development of resistant varieties either by selection from germplasm or through recombination breeding is an economical way to reduce the fruit loss in okra. Hence, the screening of available germplasm to locate the resistance source, the study of variability in the germplasm with reference to shoot and fruit borer resistance and identification of factors determining resistance will be the basic steps for a successful breeding programme. Therefore, the present study was undertaken and the results are presented under the following headings.

1. Variability in the germplasm for qualitative and quantitative traits
2. Identification of resistance source against shoot and fruit borer
3. Transfer of shoot and fruit borer resistant genes to a high yielding variety
4. Generation mean analysis to understand inheritance of resistance
5. Mechanism of resistance in okra against shoot and fruit borer

4.1 CHARACTERIZATION OF GERMPLASM AND EXTENT OF VARIABILITY FOR QUALITATIVE TRAITS

Twenty one qualitative data namely, growth habit, stem pubescence, stem colour, leaf shape, leaf colour, petiole colour, epicalyx number, epicalyx shape, epicalyx persistence, petal colour, petal spot, fruit position, fruit colour, fruit shape, fruit tip, fruit ridges, fruit pubescence, fruit quality, seed shape, seed surface and corrugations on testa recorded from 144 accessions are given in Appendix II.

4.1.1 Variability for growth habit

The study materials exhibited three growth habits namely, erect, procumbent and intermediate (Table 4.1). One accession *i.e. A. ficulneus* was

procumbent, 142 accessions (99 per cent) were erect and the remaining one *i.e. A. tetraphyllus* was intermediate (main stem was erect while branches procumbent).

Table 4.1 Number of accessions in each descriptor state for growth habit

Code	Descriptor states	*A. esculentus*	*A. caillei*	Wild spp.	Total
1	Erect	124	12	6	142 (99 %)
2	Medium			1	1 (0.5 %)
3	Procumbent			1	1(0.5 %)

4.1.2 Variability for leaf shape

Fifteen different leaf types ((Plate 4) ranging from non-lobed to highly lobed leaves were observed from 144 accessions (Table 4.2). About 64 accessions resembled leaf shape code 4 (see Fig.1), 42 accessions resembled leaf shape 5 and 6 accessions resembled leaf shape code 7. These three shapes, together represent 78 per cent of the germplasm studied.

Table 4.2 Number of accessions in each descriptor state for leaf shape

Code	Descriptor states	*A. esculentus*	*A. caillei*	Wild spp.	Total
1	For leaf type see Figure 3.1 given in section 3.4.1	4	1		5 (3.5 %)
2		6			6 (4.0 %)
3			8		8 (6.0 %)
4		64	1		65 (45.0 %)
5		42			42 (29.0 %)
6		1	1		2 (1.4 %)
7		6			6 (4.0 %)
8		1	1		2 (1.4%)
9				1	1 (0.7 %)
10				1	1 (0.7%)
11				1	1 (0.7 %)
12				2	2 (1.4%)
13				1	1 (0.7 %)
14				1	1 (0.7 %)
15				1	1 (0.7 %)

i) Variability for leaf shape

ii) Variability for petal colour

iii) Variability for fruit position on main stem

iv) Obtuse and acute fruit tip

v) Variability for epicalyx shape

Plate 4 Variability for vegetative and floral characters in 144 okra genotypes

4.1.3 Variability for pigmentation on stem, leaf, petiole, flower and fruit

Stem colour varied from green to red through purple and light rose (Plate 5). Forty three accessions showed green stem, 65 accessions showed green stem with red patches, 11 accessions showed purple stem, 18 accessions light rose stem and 7 accessions red stem (Table 4.3). Petiole colour ranged from green to purple (Table 4.3). Green petiole was found in 24 accessions (17 per cent), green with purple markings in 86 accessions (59 per cent), purple petiole in 10 accessions and rose petiole in 24 accessions. Leaf lamina colour varied from green to red via various grades of green and red mix such as green lamina with feeble red veins and green lamina with deep red veins (Table 4.3). Two accessions *viz.*, *A. tetraphyllus* and *A. tetraphyllus* var. *pungens* had dark green leaves while the remaining accessions had light green leaves. Fourteen accessions such as *A. moschatus,* Aruna, Co-1 and *A. caillei* lines AC Nos 2 to AC 12 exhibited deep red veins whereas 116 accessions (81 per cent) exhibited green leaf with light red veins.

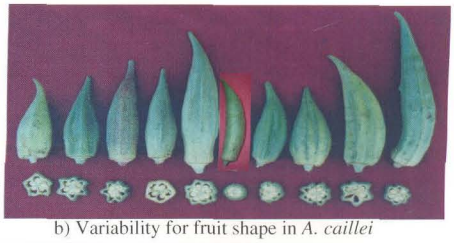
The study materials exhibited seven different petal colour ranging from white to red with various grades of yellow such as cream yellow, sulphur yellow, yellowish white, yellowish with red veins and pale white (Plate 4). The number of entries in each category is shown species-wise in Table 4.3 . Regarding petal spot, 100 accessions (69 per cent) exhibited purple spots on both sides of petals, whereas accessions belonging to semi-wild and wild species and 24 accessions of *A. esculentus* had purple spot only on the inner side of petals (Fig 4).

Fruit colour of 144 accessions ranged from pale white to red (Plate 5). Pale white fruits were recorded in 26 accessions (18 per cent), light green fruits in 55 accessions (38 per cent), yellowish green in 11 accessions (8 per cent), dark green fruits in 30 accessions (21 per cent), green and purple striation in 14 accessions (10 per cent), rose fruits in five accessions (3 per cent) and red fruits in three accessions (Table 4.3).

Table 4.3 Number of accessions across descriptor state for pigmentation on stem, petiole, leaf, flower and fruit

Code	Descriptor states	*A. esculentus*	*A. caillei*	Wild spp.	Total
Stem colour					
1	Green	35	5	3	43 (30 %)
2	Green + Red mix	60	3	2	65 (45 %)
3	Purple	10		1	11(8 %)
4	Light rose	13	3	2	18 (12 %)
5	Red	6	1		7 (5 %)
Leaf colour					
1	Green	7		5	12 (8 %)
2	Dark green			2	2 (1 %)
3	Green leaf with light red veins (dot like)	115	1		116 (81 %)
4	Green leaf with deep red veins		10	1	11 (8 %)
5	Purple blotched	2	1		3 (2 %)
Petiole colour					
1	Green	22	1	1	24 (17 %)
2	Green and purple	73	6	7	86 (59 %)
3	Purple	9	1		10 (7 %)
4	Red	20	4		24 (17 %)
Petal colour					
1	Cream yellow		12		12 (8 %)
2	Sulphur yellow			4	4 (3 %)
3	Yellowish white	120			120 (83 %)
4	Pale white			2	2 (1 %)
5	White			1	1 (1%)
6	Yellowish with red veins	4			4 (3 %)
7	Red			1	1 (1%)
Fruit colour					
1	Pale white	22		4	26 (18 %)
2	Light green	48	4	3	55 (38 %)
3	Dark green	27	3		30 (21 %)
4	Yellowish green	11			11 (8 %)
5	Red	3			3 (2 %)
6	Green and purple striation	8	5	1	14 (10 %)
7	Beige pink or rose	5			5 (3 %)

a) Variability for fruit shape in *A. esculentus*



b) Variability for fruit shape in *A. caillei*

c)

Fruit shape in wild okra

d) Variability for fruit colour

e) Variability for stem colour

A. esculentus fruits

A. caillei fruits

f) Variability for fruit length

Plate 5 Variability for stem colour, fruit colour, fruit shape and fruit length in 144 okra genotypes

4.1.4 Variability for epicalyx shape and persistence

Shape of epicalyx segment varied from linear to triangular (Plate 4). Linear epicalyx was observed in 128 accessions (88 per cent) whereas triangular epicalyx (including its minor variations) was found in 15 accessions (11 per cent). One accession namely *A. ficulneus* had lanceolate epicalyx (Table 4.4). Epicalyx was persistent till maturity in two accessions *viz., A. angulosus* and *A. tetraphyllus* var. *pungens* whereas non-persistent in 122 accessions (85 per cent). Epicalyx segment was caducous (falling off at early stages) in *A. ficulneus* while partially persistent (up to 10 days after pollination) in 20 accessions *viz., A. moschatus, A. moschatus* var. *multiformis, A. tuberosus, A. esculentus* accessions EC 10, EC 11, EC16, GU 3, KL 4 and WB 1and all *caillei* accessions except AC 10.

Table 4.4 Number of accessions across descriptor state for epicalyx shape and persistence

Code	Descriptor states	*A. esculentus*	*A. caillei*	Wild spp.	Total
Shape of epicalyx segment					
1	Linear	124		4	128 (88 %)
2	Lanceolate			1	1 (1%)
3	Triangular, free		12	1	13 (9 %)
4	Triangular, free, wavy margin			1	1 (1 %)
5	Triangular, adnate at base			1	1(1%)
Persistence of epicalyx segment					
1	Non-persistent	118	1	3	122 (85 %)
2	Partially persistent	6	11	3	20 (14 %)
3	Persistent			2	2 (1%)

4.1.5 Variability for pubescence on stem and fruit

Stem pubescence was conspicuous in 10 accessions such as A. *moschatus, A. moschatus* var. *multiformis, A. tetraphyllus* var. *pungens, A. tuberculatus, A.*

tuberosus, *A. caillei* cv. AC3 and AC 7, *A. esculentus* cv. KL 4, MH 1 and EC 12. However, 160 accessions bears glabrous stem (Table 4.5 and Plate 9).

Trichomes present on fruit were classified into i) downy (soft), ii) slightly rough and iii) prickly (Table 4.5 and Plate 10). Downy fruits were found in 115 accessions, slightly rough fruits in 13 accessions and prickly fruits in 16 accessions namely, eight wild species, five *A. caillei* accessions (AC Nos. 3, 4, 6, 7, 9) and three *A. esculentus* accessions (EC 12, KL 4 and MH 1).

Table 4.5 Number of accessions across descriptor state for pubescence on stem and fruit

Code	Descriptor states	*A. esculentus*	*A. caillei*	Wild spp.	Total
Stem pubescence					
1	Glabrous	97	8	1	106 (73 %)
2	Slight	24	2	2	28 (20 %)
3	Conspicuous	3	2	5	10 (7 %)
4. Fruit pubescence					
1	Downy	110	5		115 (80 %)
2	Slightly rough	11	2		13 (9 %)
3	Prickly	3	5	8	16 (11 %)

4.1.6 Variability for fruit shape, fruit tip, fruit ridges and fruit quality

The germplasm exhibited high variation for fruit shape (Table 4.6 and Plate 5). Twenty five different fruit shapes ranging from non-ridged smooth fruits to multi-ridged hairy fruits were recognised (Fig 3.2). Fruit shape code number- 1, 2, 4, 5, 6 and 7 were more common, constituting 80 per cent of total germplasm (115 accessions). Two types of fruit tip namely, acute and obtuse was observed in the germplasm (Table 4.7and Plate 4). Acute tip was recorded in 115 accessions (80 per cent) whereas obtuse tip in 29 accessions (20 per cent).

Table 4.6 Number of accessions across descriptor state for fruit shape

Code	Fruit shape description	*A. esculentus*	*A. caillei*	Wild spp.	Total
1	Five ridged fruits; furrows between ridges appears concave in cross section (C.S)	35	1		36
2	Five ridged and thin	43			43
3	Five ridged and bulged base	1			1
4	Five ridged, short, tapering apex	5			5
5	Six ridged; C.S. concave furrows	7	1		8
6	Multi-ridged; C.S. concave furrow	16	2		17
7	Multi-ridged, lower middle of fruit is constricted	9			9
8	Five to six ridged, short, bulged middle and tapering ends		1		1
9	Five to six ridged, bulged upper middle and deep furrows		1		1
10	Non-ridged, pencil type fruits		1		1
11	Five ridged, ridges are thick	1			1
12	Non-ridged base and ridged apex	1	1		2
13	Multiridged fruits with obtuse tip	1			1
14	Multi-ridged, extra-short bold	2			2
15	Extra-short, bold with acute fruit tip		1	1	2
16	Non-ridged base, five ridged apex, obtuse fruit tip	2	2		4
17	Five ridged, cone shaped, short, curved apex	2			2
18	Five ridged fruits, tapering begin from middle to tip		1		1
19	Ovoid, broad middle with long tapering rostrum			1	1
20	Ovoid, spiny, deeply furrowed			2	2
21	Oblong, spiny, short rostrum			1	1
22	Ovoid, obtuse tip, hirsute hairs			1	1
23	Oblong, prickly hairy, short rostrum			1	1
24	Five ridged, studded with bristle bearing tubercles			1	1
25	Narrow and truncate at base, broader and obtuse apex			1	1

Table 4.7 Number of accessions across descriptor state for fruit position on main stem, fruit tip, fruit ridges, fruit quality and seed characters

Code	Descriptor states	*A. esculentus*	*A. caillei*	Wild spp.	Total
Position of fruit on main stem					
1	Erect	124	10	5	139 (97 %)
2	Horizontal		1	1	2 (1 %)
3	Pendent		1		1 (1 %)
4	Aligned on one side			1	2 (1 %)
Fruit tip					
1	Acute	107	7	1	115 (80 %)
2	Obtuse	17	5	7	29 (20 %)
Fruit ridges					
1	Non- ridged	1	1		2 (1 %)
2	Five ridged	94	6	8	108 (75 %)
3	Six to ten ridged	29	5		34 (24 %)
Fruit quality score					
1	Non consumable (score 0-3)	4	2	4	10 (7 %)
2	Consumable but low quality (score 4-5)	11	8	4	23 (16 %)
3	Medium quality (Score 6-7)	98	2		100 (69 %)
4	Good quality (score 8-9)	11			11 (8 %)
Seed shape					
1	Globular	2	10	3	15 (10 %)
2	Reniform			5	5 (4 %)
3	Oblong	122	2		124 (86 %)
Seed surface					
1	Glabrous		10	3	13 (9 %)
2	Slightly downy	124	2	1	127 (88 %)
3	Downy			4	4 (3 %)

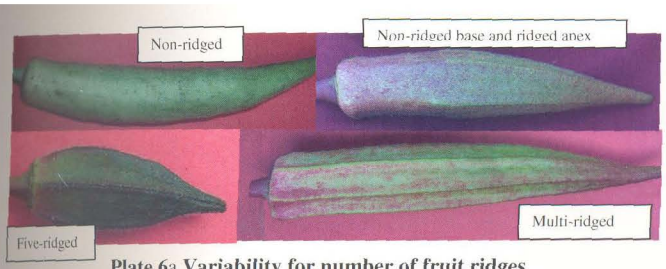


Plate 6a Variability for number of fruit ridges

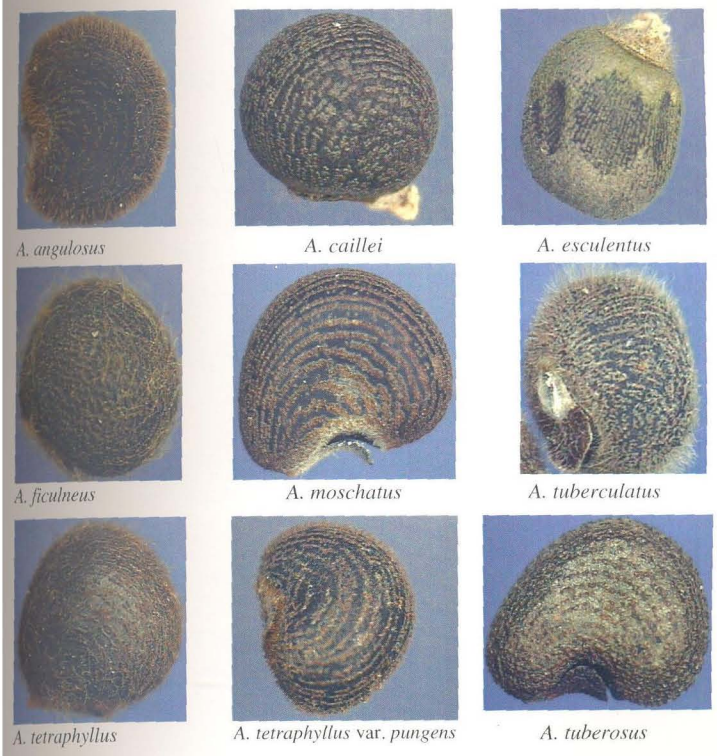


Plate 6b Inter-specific variation for seed shape and seed surface in okra

Fruits were aligned in four different ways on the main stem *i.e.* erect, horizontal, pendent, and aligned radially in a row (Plate 4). Fruit position was erect in 139 accessions (97 per cent). Number of ridges in fruits varied from zero to ten (Table 4.7). Five ridged fruits were predominant in the materials studied (108 accessions or 75 per cent) followed by multi-ridged fruits (34 accessions or 24 per cent). Two genotypes namely, AC 2 and UP 2 produced non-ridged fruits (Plate 6a). With regard to fruit quality, 10 accessions produced non-edible (palatable) spiny fruits, 23 accessions produced low quality fruits, 100 accessions bear medium quality fruits and 11 accessions namely, OR 2, WB 1, EC 5, Bio 2, Salkeerthy, KL 2, KL 26, KL 28, MP 1, MP 3 and NER 7 produced better quality fruits (Table 4.7).

4.1.7 Variability for seed shape and seed surface

The materials studied were exhibiting three seed shapes *viz.*, globular, reniform and oblong (Plate 6b) and the number of accessions in each category was 15, 5 and 124 respectively (Table 4.7). Seed surface was glabrous in 13 accessions, slightly downy (hairy) in 127 accessions and downy in four accessions namely *A. angulosus, A. ficulneus, A. tetraphyllus* and *A. tuberculatus.*

4.2 VARIABILITY AND PERFORMANCE FOR YIELD AND YIELD ATTRIBUTES

Quantitative data recorded from field experiment 1 (Table 4.8 to 4.10) were analyzed for significance of treatment mean square. The ANOVA showed significant differences among genotypes for days to first flowering, flowering period, plant height, internode number, internodal length, fruits per plant, average fruit weight, fruit length, fruit girth, fruit yield per plant, per cent shoot and fruit infestation, marketable fruit yield and co-efficient of infection for yellow vein mosaic (Appendix 2). The range, mean performance and co-efficient of variation

for the 144 accessions are given in Table 4.11. The salient results alone from field experiment-I are presented below.

4.2.1 Days to first flowering

The range for days to first flowering in 144 germplasm varied from 31.00 to 61.67 days (Table 4.11). Among 122 accessions in *A. esculentus,* AP 5 flowered early (31.67 days) followed by EC 16 (32 days), NER 8 and UP 2 (35 days) whereas Maravendai, EC 21 and Aarumasavendai flowered late (52 days, 53.67 days, 57 days respectively) (Table 4.8). The mean for 12 accessions in *A. caillei* was 47.33 days (Table 4.9) and AC 6 recorded the minimum value (50 days). In wild species, days to first flowering ranged from 39.33 to 61.67 days (Table 4.10). The minimum value was recorded in *A. tuberculatus* and the maximum in *A. angulosus*.

4.2.2 Flowering period

Flowering period extended from 25.50 to 56 days and the mean was 38.57 days (Table 4.11). In *A. esculentus,* the minimum value was (14 days) recorded in TN 3 whereas the maximum value in traditional cultivars, Aarumasavendai and Maravendai (45.66 and 40 days). The latter two were on par (Table 4.8). In *A. caillei,* the maximum value (34.67 days) was recorded in AC 8 and the minimum value (25.53 days) in AC 4 (Table 4.11). In wild species, flowering period lasted between 23.33 days in *A. tuberculatus* to 41.33 days in *A. moschatus* var. *multiformis* (Table 4.10).

4.2.3 Plant height

The mean value for plant height ranged from 47.33 to 194.00 cm (Table 4.11). Among the accessions of *A. esculentus,* KL 7 recorded the minimum value for plant height (47.43 cm) whereas Maravendai recorded the maximum value

(170.32 cm) for this trait. Maravendai was on par with Bio-2 (152.50) and Arka Abhay (157.26 cm) (Table 4.8). *A. caillei* accession AC 6 was taller (165.71 cm) while Susthira was shorter (125.33 cm) (Table 4.9). Among wild species, the maximum value for plant height (194.33 cm) was registered by *A. tuberculatus* and it was on par with *A. tetraphyllus* var. *pungens* (190.00 cm) and *A. tetraphyllus* (172 cm). The minimum value (69.67 cm) for plant height was registered by *A. moschatus* var. *multiformis* (Table 4.10).

4.2.4 Number of leaves per plant

The mean for number of leaves per plant varied between 7.67 (in EC 5) and 43.67 (in *A. ficulneus*) and the mean was14.78 (Table 4.11).

4.2.5 Internode number

Number of internodes in main stem ranged between 8.00 and 40.67 (Table 4.11). The mean for 124 accessions of *A. esculentus* was 11.77 whereas the mean for *A. caillei* and wild species were 19.75 and 28.4 respectively (Tables 4.11 to 4. 13). The accessions registered high value for this character were Aarumasavendai (19.33 internode), Maravendai (18.33 internode), AC 4, AC 5, AC 6 (23 internode) and *A. tetraphyllus* var. *pungens* (40.70 internode).

4.2.6 Length of internode

Length of internode varied between 2.83 cm and 18.50 cm in 144 accessions (Table 4.11). The lowest value (3.63 cm) among the accessions of *A. esculentus* was registered by KL 21, followed by UP 4 and WB 2 (3.75 cm) (Table 4.8). Among *A. caillei*, Susthira and AC 1 recorded the lowest value *i.e.* 4.97 and 5.88 cm respectively (Table 4.9). *A. moschatus* var. *multiformis* showed the shortest internodal length (2.83 cm) followed by *A. tetraphyllus* var. *pungens* (3.47 cm) (Table 4.10).

4.2.7 Number of fruits per plant

The data on number of fruits per plant ranged from 4.00 to 59.00 in the materials studied (Table 4.11). The mean for *A. esculentus* was 9.43 fruits per plant while it was 12.10 fruits per plant in *A. caillei* and 33.50 fruits per plant in wild species (Tables 4.8 to 4 10).

4.2.8 Fruit length

Fruit length varied between 4.00 cm and 23.75 cm (Table 4.11 and Plate 5). *Abelmoschus esculentus* accessions EC 6, KL 3 and NER 2 produced short fruits (8.12 to 8.88 cm long), whereas Anakomban (23.75 cm), KL 26 (22.97 cm), NER 7 (22.50 cm) and Salkeerthy (22.10 cm) produced lengthy fruits and were on par (Table 4.9). In *A. caillei* fruit length was short in AC 2 (7.48 cm) and long (18.95) in Susthira (Table 4.9). In wild species (Table 4.10), fruit length ranged between 3.33 cm (*A. tuberosus*) and 6.93 cm (*A. moschatus*).

4.2.9 Fruit girth

Fruit girth varied from 13.33 mm to 31.81 mm in the germplasm under study (Table 4.11). The mean value for fruit girth in *A. esculentus* was 20.48 mm. The minimum girth (13.33 mm) was recorded in EC 17 and the maximum value (27.60 mm) in EC 20 (Table 4.8). In *A. caillei*, the lowest value (16.70 mm) was observed in Susthira whereas the highest value (31.81 mm) in AC 7 (Table 4.9). In wild species the range for fruit girth was 14.50 mm (*A. angulosus*) to 22.66 mm (*A. moschatus*) (Table 4.10).

4.2.10 Average fruit weight

The minimum value for average fruit weight was recorded by *A. moschatus* var. *multiformis* (2.80 g / fruit) whereas the maximum value was recorded by Salkeerthy (20.64 g / fruit) (Table 4.11). The mean value was 16.11 g.

4.2.11 Fruit yield per plant

Fruit yield per plant varied from 47.00 to 247.56 g among the germplasm (Table 4.11). The genotype KL 28 registered high fruit yield (247.50 g / plant) (Table 4.8). It was on par with Anakomban (219 g / plant), Aarumasavendai 215.30 g), Arka Anamika (212.63 g), MP 1 (212.18 g), MP 3 (210.79 g) and EC 4 (210 g). Among *A. caillei*, AC 5 registered high yield (228.62 g / plant) followed by Thamaravenda (214.77 g), AC 6 (214.77 g) and Susthira (209.94 g) (Table 4.9). Among wild species, *A. moschatus* registered the maximum value (268.33 g fruits / plant) followed by *A. tetraphyllus* (225.07 g fruits / plant) (Table 4.10).

4.2.12 Yellow vein mosaic virus (YVMV)

The co-efficient of infection (CI) for yellow vein mosaic virus varied from 0 to 77.50 per cent (Table 4.11). *A. esculentus* accessions Arka Anamika, KL 28 and KL 9 and *A. caillei* accessions AC 2, AC 5, AC 8, AC 9 and Thamaravenda and wild species *A. angulosus*, *A. moschatus* var. *multiformis* and *A. tetraphyllus* var. *pungens* showed field resistance to YVMV (co-efficient of infection=0 %) whereas Salkeerthy and Anakomban were highly susceptible to YVMV (CI was 77.50 and 64.50 per cent respectively). The CI was 4 to 10 per cent in 29 accessions of *A. esculentus* namely, KL 6, KA 4, KL 2, KL 17, WB 3, EC 18, WB 2, KL 8, KA 5, GU 1, AP 2, KL 5, KL 7, KL 20, Parbhani Kranti, Varsha Upahar, RA 1, Pusa Makhmali, KL 14, KL 25, WB 1, KL 19, AP 1, EC 19, KA 2, AP 5, EC 16 and UP 4.

Table 4.8a Performance of 14 commercial varieties and five traditional cultivars for yield and yield attributes

SNo	Variety	Dff	Flp	Pht	LNo	IN	IL	FN	FW	FL	FG	FY	YMV
1	Arka Abhay	36.67	**20.33**	157.26	13.33	17.00	**12.50**	8.67	14.33	14.07	17.85	124.27	16.60
2	Arka Anamika	36.67	30.66	132.54	18.10	13.33	12.36	13.50	15.75	18.50	19.69	212.63	0.00
3	Aruna	42.00	30.66	151.67	10.66	13.00	9.57	**7.33**	15.83	15.17	18.23	116.06	29.18
4	Bio-2	40.33	33.66	157.50	10.33	12.33	8.67	12.00	14.50	14.65	22.37	174.00	24.45
5	CO-1	41.67	31.66	91.76	14.67	10.55	9.38	11.00	15.42	16.80	21.99	169.62	28.65
6	EMS 8-1	37.33	23.67	132.55	10.50	12.00	10.50	8.67	13.70	12.48	19.38	118.78	42.00
7	MDU-1	39.00	27.00	126.33	11.22	12.00	9.50	8.54	**13.00**	14.12	18.15	**111.02**	29.41
8	Parbhani Kranti	**36.33**	31.66	106.22	10.72	16.17	9.02	10.67	14.90	15.50	17.53	158.97	**7.54**
9	Punjab Padmini	41.55	26.66	146.50	14.67	15.40	10.75	8.50	15.60	17.00	20.64	132.60	28.05
10	Pusa Makhmali	40.00	31.33	86.67	10.33	10.33	7.80	9.82	14.67	**10.63**	16.18	144.03	8.36
11	Salkeerthy	41.33	32.33	117.24	11.33	15.67	**6.61**	8.25	**20.64**	22.10	20.04	170.28	**77.50**
12	Sel-2	41.00	28.00	142.33	13.50	13.00	12.05	8.00	16.50	18.25	21.30	132.00	35.16
13	Varsha Upahar	40.33	26.33	134.67	12.67	12.33	6.52	9.67	15.83	13.80	**15.65**	153.06	7.54
14	VRO-06	37.33	24.00	129.00	10.33	13.50	10.75	10.12	14.25	16.25	22.00	144.21	29.52
15	Aarumasavendai	**57.67**	**45.66**	151.50	**20.66**	**19.33**	9.57	**13.67**	15.75	13.62	20.50	215.30	34.00
16	Anakomban	42.33	33.00	111.32	**9.77**	14.55	6.50	12.00	18.29	**23.75**	20.57	**219.48**	64.50
17	Anjilaivendai	39.00	33.11	90.41	8.67	**9.67**	9.67	11.17	15.57	12.58	20.48	173.88	19.60
18	Maravendai	52.33	40.00	**170.32**	18.22	18.33	8.76	11.50	16.90	12.25	**23.62**	194.35	33.00
19	Palvenda	41.00	35.33	**64.56**	9.33	16.26	8.80	11.67	14.93	13.50	22.99	174.22	44.35
	Mean	*43.35*	*33.22*	*126.64*	*12.68*	*14.40*	*8.89*	*10.70*	*16.29*	*16.25*	*20.36*	*173.18*	*34.23*
	CD 5 %	*3.56*	*4.21*	*24.93*	*4.54*	*2.90*	*2.60*	*2.25*	*3.08*	*2.19*	*2.05*	*40.19*	*15.36*

Abbreviation: Dff-Days to first flowering, Flp-Flowering period, Pht-Plant height (cm), LNo-Number of leaves/plant, IN-Number of internode on main stem, IL-Internode length, FN-Fruit number / plant, FW-Average fruit weight (g), FL-Fruit length (cm), FG-Fruit girth (mm), FY-Fruit yield (g)/ plant, YMV-Co efficient of infection for yellow vein mosaic (%) .

Table 4.8b. Performance of 84 indigenous okra germplasm of *A. esculentus* for yield and yield attributes

SNo	AccessionNo	Dff	Flp	Pht	LNo	IN	IL	FN	FW	FL	FG	FY	YMV
1	AP 1	38.00	32.33	58.67	11.33	8.00	7.36	10.67	10.42	10.73	17.55	111.15	8.87
2	AP 2	**58.00**	19.11	48.00	8.67	9.67	4.37	9.12	15.30	12.75	16.38	139.54	7.15
3	AP 3	41.33	31.66	138.67	9.33	12.33	6.60	7.00	10.75	11.15	16.00	75.25	15.50
4	AP 4	35.67	34.33	141.06	13.00	16.78	11.78	11.52	15.00	12.92	21.08	172.80	12.20
5	AP 5	**31.67**	**38.55**	125.67	11.67	14.67	11.58	**14.33**	13.83	12.55	18.15	198.23	9.41
6	BH 1	38.11	29.33	124.00	14.00	16.67	10.45	12.63	16.50	13.90	20.64	208.40	35.05
7	BH 2	39.00	30.00	127.65	10.33	16.00	10.70	8.50	13.98	10.17	22.37	118.82	29.52
8	BH 3	43.33	23.67	99.52	17.00	10.67	8.38	8.00	15.50	14.23	19.38	124.00	42.00
9	GU 1	40.00	34.00	65.37	10.62	9.00	4.78	6.89	13.00	11.65	16.84	89.57	6.83
10	GU 2	42.00	30.67	110.24	17.67	9.33	7.93	13.00	15.25	11.88	21.58	198.25	38.73
11	GU 3	41.33	25.67	141.00	16.33	**18.11**	8.90	11.33	15.60	13.32	21.89	176.80	26.16
12	GU 4	46.00	26.33	103.62	13.00	16.75	6.60	11.84	12.83	13.73	19.62	151.95	33.52
13	HA 1	47.33	26.55	57.81	13.33	8.00	4.68	7.00	11.26	11.77	16.59	78.82	21.50
14	HA 2	47.55	26.00	97.67	17.00	9.00	6.80	8.50	19.00	12.75	21.09	161.50	22.81
15	HA 3	42.33	29.33	54.26	12.33	9.33	4.87	8.50	17.24	13.50	23.30	146.54	38.05
16	KA 1	41.67	25.33	133.25	12.67	12.83	6.62	12.35	13.67	12.64	16.43	168.78	27.75
17	KA 2	40.00	32.33	78.50	15.00	9.67	8.37	10.00	12.13	10.34	17.47	121.33	9.04
18	KA 3	42.00	31.00	96.41	12.00	10.55	8.52	9.87	15.40	15.85	18.39	152.00	13.56
19	KA 4	42.67	29.67	76.67	**8.33**	10.44	7.85	8.67	18.54	14.33	18.90	160.76	4.01
20	KA 5	43.00	26.33	83.50	10.33	10.00	7.40	10.33	16.32	17.60	23.77	168.59	6.81
21	KA 6	41.00	28.00	113.33	11.55	15.83	9.55	12.74	13.69	19.93	21.61	174.41	27.49

(Table contd..)

Values in bold and bold underlined faces refer to the minimum and maximum values, respectively

Table 4.8b continuation.... Performance of indigenous okra germplasm for yield and yield attributes

SNo	Accession No	Dff	Flp	Pht	LNo	IN	IL	FN	FW	FL	FG	FY	YMV
22	KL 1	48.33	25.67	79.28	13.50	9.00	9.55	4.68	17.50	13.00	15.16	81.90	10.40
23	KL 2	42.33	29.00	56.00	10.33	8.78	7.03	7.67	**10.25**	10.07	15.60	78.58	4.22
24	KL 3	41.00	28.33	47.81	13.00	7.00	4.73	4.92	11.17	**8.18**	20.98	**54.94**	14.34
25	KL 4	39.67	27.33	47.67	14.00	7.00	8.18	7.33	11.00	10.08	16.89	80.67	14.75
26	KL 5	39.33	27.33	56.84	11.50	9.33	5.38	7.12	14.58	18.90	**15.07**	103.83	7.24
27	KL 6	41.67	25.67	62.50	14.33	9.00	8.33	10.50	13.94	13.33	19.06	146.34	4.00
28	KL 7	42.67	29.00	**47.42**	11.00	7.67	6.55	4.67	15.50	11.83	20.18	72.39	7.33
29	KL 8	38.00	35.33	53.00	10.33	8.78	6.40	9.00	19.43	9.63	21.69	174.91	6.40
30	KL 9	43.11	24.55	90.67	12.00	12.33	9.53	6.67	16.95	11.07	22.06	113.06	0.00
31	KL 10	42.33	30.33	88.42	13.16	10.00	6.02	9.33	17.29	13.53	19.68	161.39	22.50
32	KL 11	43.67	26.00	108.06	14.00	16.50	8.58	14.00	14.31	13.89	17.95	200.28	30.45
33	KL 12	43.00	23.33	88.61	13.50	11.00	5.12	8.34	18.84	13.03	20.62	157.13	27.75
34	KL 13	44.67	30.67	81.56	17.33	11.00	4.23	7.50	19.50	12.03	20.64	146.25	12.40
35	KL 14	39.33	26.00	64.00	12.25	8.33	4.83	6.67	18.45	15.23	18.33	123.06	8.70
36	KL 15	52.00	19.11	73.53	12.00	8.00	4.30	5.67	19.00	16.80	22.47	107.73	48.38
37	KL 16	41.00	29.00	69.57	11.33	8.33	6.17	5.00	17.75	13.28	19.73	88.75	10.70
38	KL 17	42.33	30.33	127.50	15.00	7.50	7.75	13.11	15.71	15.43	17.14	205.99	4.48
39	KL 18	57.33	22.00	90.10	13.51	**6.67**	8.32	7.50	16.50	10.85	**22.62**	123.75	16.80
40	KL 19	47.33	26.67	92.51	14.00	9.55	11.33	8.00	16.00	9.28	25.36	128.00	8.85
41	KL 20	48.00	21.00	91.50	12.00	9.00	11.00	7.00	18.50	15.30	20.29	129.50	7.47
42	KL 21	46.67	23.33	60.24	10.33	8.33	**3.63**	6.33	18.50	19.75	21.66	117.11	40.20

(Table contd...)

Table 4.8b continuation... Performance of indigenous okra germplasm for yield and yield attributes

SNo	Accession No	Dff	Flp	Pht	LNo	IN	IL	FN	FW	FL	FG	FY	YMV
43	KL 22	52.00	21.67	75.42	11.62	8.00	8.95	9.50	16.25	14.20	20.10	154.38	19.00
44	KL 23	45.67	24.33	91.57	13.00	9.00	6.35	8.16	18.67	10.47	23.12	152.32	27.80
45	KL 24	50.67	26.67	105.12	13.33	12.11	**18.50**	12.00	13.50	12.67	16.23	162.00	45.70
46	KL 25	46.33	26.33	80.95	14.00	9.00	12.85	9.33	14.00	9.05	24.52	130.67	8.73
47	KL 26	41.33	25.00	78.45	14.67	8.11	5.90	11.00	16.57	**22.97**	19.11	182.27	18.51
48	KL 27	47.00	22.92	74.00	11.00	12.75	6.55	7.12	15.00	21.07	19.59	106.80	10.67
49	KL 28	43.33	23.00	151.04	16.11	8.50	5.00	13.67	18.11	17.00	18.50	**247.56**	0.00
50	MP 1	49.67	22.00	73.10	15.33	7.67	4.10	11.50	18.45	10.25	21.74	212.18	23.80
51	MP 2	44.00	31.67	59.50	9.67	12.50	4.52	8.67	19.50	12.75	20.88	169.07	22.30
52	MP 3	40.33	30.55	105.33	14.30	14.00	8.45	11.82	17.83	17.47	22.37	210.79	13.23
53	MP 4	44.00	30.33	60.15	13.00	8.50	3.97	8.00	17.63	12.06	22.58	141.00	37.11
54	MH 1	42.00	32.33	83.13	11.33	13.00	7.48	9.67	17.35	13.17	18.10	167.72	32.75
55	MH 2	41.00	24.67	**151.34**	16.00	16.75	9.48	12.50	11.71	12.67	15.87	146.43	21.25
56	MH 3	46.33	26.67	113.00	12.00	9.00	11.17	10.00	13.50	10.98	18.05	135.00	41.64
57	MH 4	44.00	25.00	106.57	13.00	10.17	13.60	8.61	14.00	14.09	21.44	120.54	45.05
58	MH 5	41.23	31.33	120.33	15.67	13.50	11.98	8.33	19.50	14.35	25.17	162.44	37.05
59	MH 6	42.67	30.83	88.74	16.00	10.00	4.82	10.30	16.00	13.97	23.85	164.80	14.92
60	ND 1	38.67	33.67	69.10	13.00	9.25	8.15	9.10	17.06	10.00	21.44	155.25	41.45
61	ND 2	48.33	24.11	88.14	13.33	8.00	8.72	8.67	17.67	11.63	19.16	153.17	17.73
62	NER 1	40.52	27.33	126.87	13.00	16.17	8.00	13.00	15.10	11.93	19.47	196.30	32.15
63	NER 2	35.33	33.55	117.20	11.00	13.75	7.07	13.62	12.50	8.88	16.82	170.25	22.55
64	NER 3	38.50	28.33	60.42	10.33	7.67	6.74	10.00	15.17	11.67	16.62	151.67	14.20
65	NER 4	39.00	28.00	96.50	11.00	11.00	8.78	7.67	**19.75**	13.03	17.51	151.42	32.25

Table 4.8b continuation..... Performance of indigenous okra germplasm for yield and yield attributes

SNo	Accession No	Dff	Flp	Pht	LNo	IN	IL	FN	FW	FL	FG	FY	YMV
66	NER 5	39.33	27.33	75.14	15.00	8.44	7.28	9.00	19.24	15.72	24.07	173.16	26.55
67	NER 6	39.50	32.83	128.44	10.00	14.83	10.97	12.67	13.40	12.23	19.33	169.78	43.07
68	NER 7	42.33	35.11	136.72	16.33	17.00	11.25	13.00	18.75	22.50	21.01	243.75	36.00
69	NER 8	35.00	19.83	132.00	16.33	17.00	12.75	13.00	14.00	14.75	18.24	182.00	11.85
70	OR 1	39.33	33.33	100.25	13.00	12.50	10.57	10.52	17.61	10.58	24.33	185.27	13.50
71	OR 2	40.50	29.33	84.00	14.12	9.78	7.07	11.27	18.37	14.28	16.82	206.99	10.08
72	RA 1	43.33	26.33	76.33	9.00	8.44	6.97	7.00	16.50	11.40	20.39	115.50	8.18
73	RA 2	42.33	24.11	106.50	13.33	12.75	11.57	6.50	15.25	12.80	22.50	99.13	30.05
74	TN 1	36.67	36.00	121.33	12.33	13.67	10.51	9.67	13.85	12.73	19.11	133.88	11.50
75	TN 2	46.29	26.67	92.16	14.00	9.00	7.28	9.50	18.74	16.17	21.07	178.03	45.15
76	TN 3	51.33	14.00	87.00	17.67	9.67	6.33	8.00	14.25	12.18	23.49	114.00	48.80
77	TN 4	43.00	26.33	85.33	18.00	9.00	7.48	8.17	17.25	16.00	21.45	140.88	40.80
78	UP 1	43.33	23.00	109.00	16.67	14.00	7.77	8.33	19.63	13.75	20.63	163.48	41.78
79	UP 2	35.00	32.33	83.33	17.00	9.50	7.02	9.00	18.85	15.20	17.88	169.67	31.65
80	UP 3	48.55	25.33	70.25	8.67	8.00	7.35	8.67	17.50	11.50	19.20	151.73	24.75
81	UP 4	45.11	26.33	77.67	10.11	8.33	3.75	6.67	18.25	16.50	19.58	121.73	9.86
82	WB 1	41.00	27.00	69.36	10.00	8.11	7.43	7.50	13.71	15.70	16.26	102.81	8.78
83	WB 2	39.22	28.67	60.84	12.33	8.00	3.75	4.67	17.17	13.55	16.82	80.17	6.28
84	WB 3	38.00	29.55	58.50	9.67	7.67	5.47	6.25	13.82	9.70	17.92	86.40	5.32
	Mean	*42.82*	*27.67*	*90.26*	*12.97*	*10.72*	*7.79*	*9.23*	*15.91*	*13.40*	*19.82*	*145.90*	*21.27*
	CD 5 %	*3.74*	*3.66*	*15.46*	*3.61*	*2.39*	*1.78*	*3.33*	*4.76*	*2.33*	*2.57*	*68.05*	*14.29*

(Table contd...)

Table 4.8c Performance of 21 exotic germplasm (*A. esculentus*) for yield and yield attributes

SNo	Accession No	Dff	Flp	Pht	LNo	IN	IL	FN	FW	FL	FG	FY	YMV
1	EC 1	37.67	29.33	67.17	13.46	7.55	4.13	11.50	15.78	12.73	26.56	181.44	28.10
2	EC 2	39.00	32.67	118.53	19.33	13.00	11.18	7.94	17.94	15.49	21.93	142.44	33.85
3	EC 3	37.67	33.00	80.36	16.15	9.33	5.98	7.67	18.00	11.85	22.92	138.06	17.55
4	EC 4	45.33	23.33	118.68	17.33	15.00	9.33	**12.00**	17.50	10.18	21.98	**210.00**	32.75
5	EC 5	36.00	33.67	92.65	**7.67**	9.11	9.17	8.50	16.00	14.57	21.19	136.00	16.18
6	EC 6	49.00	18.00	79.81	13.33	8.67	6.33	9.12	18.00	**8.12**	26.30	164.16	15.56
7	EC 7	35.33	31.44	125.33	**19.50**	**15.83**	8.42	8.46	16.59	12.73	21.18	140.37	19.35
8	EC 8	43.00	26.17	71.50	17.67	8.78	4.65	5.50	**18.33**	11.62	19.09	100.83	**41.71**
9	EC 9	42.00	**34.33**	101.36	14.00	12.42	9.08	10.42	16.67	11.88	21.02	173.67	33.85
10	EC 10	39.00	33.67	70.12	9.25	8.33	8.62	7.50	17.76	12.95	18.63	133.23	25.44
11	EC 11	41.67	25.34	86.50	12.67	9.17	11.88	9.33	13.75	16.44	14.23	128.29	35.20
12	EC 12	41.33	27.33	81.64	10.00	9.00	7.72	8.00	13.96	12.78	18.70	111.67	25.65
13	EC 13	38.00	28.50	90.50	10.30	9.00	8.85	8.00	17.15	10.90	22.90	137.20	18.40
14	EC 14	42.00	24.67	60.95	17.00	7.78	4.00	6.67	**11.00**	13.05	18.93	**73.37**	35.60
15	EC 15	38.33	27.61	**128.00**	15.80	13.75	**14.50**	11.29	15.21	12.13	19.46	171.70	37.20
16	EC 16	**32.00**	33.00	101.69	11.67	13.00	7.83	9.14	15.43	13.33	19.97	141.06	9.42
17	EC 17	43.00	29.33	85.63	9.33	8.67	6.28	7.25	18.21	**21.83**	**13.33**	132.01	32.80
18	EC 18	42.00	29.67	68.33	11.52	7.78	4.33	5.67	14.54	10.65	21.70	82.45	**5.76**
19	EC 19	36.67	32.67	**56.50**	10.33	**7.00**	**3.87**	**4.78**	17.50	10.97	19.82	83.65	8.96
20	EC 20	51.00	18.67	97.67	13.67	9.00	9.88	5.96	12.75	15.98	**27.60**	75.99	31.20
21	EC 21	**53.67**	17.67	104.51	15.45	12.00	6.80	9.00	14.38	13.75	27.23	129.38	20.40
	Mean	*41.13*	*28.10*	*89.88*	*13.59*	*10.20*	*7.75*	*8.27*	*16.02*	*13.04*	*21.17*	*132.71*	*25.00*
	CD 5%	*2.87*	*4.41*	*15.16*	*4.63*	*2.34*	*1.72*	*3.11*	*5.23*	*1.90*	*3.07*	*67.73*	*13.78*
Mean for 124 accns		**42.20**	**28.31**	**95.65**	**12.99**	**11.12**	**8.05**	**9.23**	**15.90**	**13.67**	**20.01**	**145.95**	**23.24**
CD for pooled analysis		**3.42**	**3.67**	**16.88**	**3.94**	**2.43**	**1.90**	**3.16**	**4.51**	**2.22**	**2.56**	**66.17**	**19.64**

Table 4.9 Performance of 12 *Abelmoschus caillei* genotypes for yield and yield attributes

SNo	Genotype No	Dff	Flp	Pht	LNo	IN	IL	FY	FN	FW	FL	FG	YMV
1	AC 1	57.67	32.33	96.54	22.15	**15.33**	5.88	180.16	11.00	16.38	11.11	26.79	**18.00**
2	AC 2	54.67	32.00	119.38	19.00	16.17	7.63	**108.40**	**9.56**	**11.33**	**7.48**	23.05	0.00
3	AC 3	50.00	34.76	118.54	18.83	20.11	7.57	186.67	12.00	15.56	13.90	25.43	12.40
4	AC 4	**60.33**	**25.53**	147.82	18.67	23.00	7.38	195.20	12.87	15.17	10.62	27.63	10.33
5	AC 5	56.33	28.86	123.65	18.17	**23.50**	6.40	**228.62**	**16.33**	14.00	12.10	25.40	0.00
6	AC 6	**50.00**	30.00	**165.71**	20.33	23.33	7.27	214.54	12.62	17.00	11.13	28.22	10.67
7	AC 7	57.67	30.33	140.43	19.33	21.67	6.67	191.79	11.30	16.97	11.87	**31.81**	10.33
8	AC 8	55.33	**34.76**	110.94	18.50	18.00	8.25	177.22	11.43	15.51	9.06	26.31	0.00
9	AC 9	58.00	31.76	144.15	**24.83**	21.50	6.42	167.58	9.67	17.33	11.37	28.22	0.00
10	AC 10	55.33	32.50	123.46	14.67	15.66	7.52	188.30	13.45	14.00	11.40	29.88	11.33
11	Thamaravenda	57.33	25.76	125.71	24.33	21.44	**8.47**	214.77	13.56	15.83	12.17	22.68	0.00
12	Susthira	51.00	27.33	**89.46**	**11.00**	17.33	**4.97**	209.94	11.45	**18.33**	**18.97**	**16.70**	**18.73**
	Mean	*55.31*	*30.49*	*125.48*	*19.15*	*19.75*	*7.04*	*188.60*	*12.10*	*15.62*	*11.77*	*26.01*	*9.37*
	CD 5%	*6.18*	*3.61*	*12.90*	*4.77*	*3.75*	*1.74*	*80.21*	*3.34*	*2.57*	*2.49*	*4.83*	*NS*

Values in bold and bold underlined faces refer to the minimum and maximum values, respectively

Table 4.10 Performance of eight wild *Abelmoschus* species for yield and yield attributes

SNo	Species	Dff	Flp	Pht	LNo	IN	IL	FN	FW	FL	FG	FY	YMV
1	*A. angulosus*	**61.67**	29.00	159.67	33.33	24.33	5	23.67	4.23	3.68	**14.15**	100.40	0.00
2	*A. ficulneus*	48.33	31.11	149.67	33.67	33.33	3.93	25.00	3.80	3.59	16.38	94.90	12.80
3	*A. moschatus*	44.33	30.00	162.00	36.33	29.00	4.10	45.00	**5.93**	6.93	**22.66**	**268.33**	5.07
4	*A. moschatus* var.*multiformis*	40.67	**41.33**	**69.67**	**23.7**	24.33	**2.83**	**22.00**	**2.80**	3.63	17.62	**61.60**	0.00
5	*A. tetraphyllus*	44.67	33.33	172.00	32.67	27.67	8.53	**59.00**	3.80	4.07	14.87	225.07	7.73
6	*A. tetraphyllus* var. *pungens*	53.67	30.00	190.00	**41.2**	**40.7**	3.47	32.00	4.90	4.27	17.37	156.60	0.00
7	*A. tuberculatus*	**39.33**	27.67	**194.33**	25.33	**22.7**	**8.54**	24.33	5.00	5.33	14.96	121.57	**21.33**
8	*A. tuberosus*	46.00	**26.33**	147.67	40.67	25.00	5.53	37.00	3.50	**3.33**	18.34	128.90	4.27
	Mean	*47.33*	*31.9*	*155.63*	*34.5*	*28.4*	*5.24*	*33.5*	*4.25*	*4.36*	*17.04*	*144.7*	*68.52*
	CD 5%	*4.53*	*2.23*	*20.06*	*4.55*	*4.03*	*1.57*	*8.41*	*0.39*	*0.39*	*0.32*	*45.62*	*6.87*

Values in bold and bold underlined faces refer to the minimum and maximum values, respectively

Table 4.11 Range, mean, standard deviation and coefficient of variation in 144 okra germplasm for different quantitative traits

Characters	Range	Mean	SD	GCV %	PCV %
Days to first flowering	31.00-61.67	43.63	6.14	13.85	14.84
Flowering period	25.50-56.00	38.57	4.99	15.84	17.66
Plant height (cm)	47.00-194.33	99.52	32.35	34.33	45.77
No. of leaves /plant	7.67-43.67	14.78	6.10	33.87	42.41
Internode number	8.00-40.67	15.15	4.75	25.28	27.31
Internodal length (cm)	2.83-18.50	8.39	3.43	32.53	36.72
No. of fruits / plant	4.00-59.00	11.33	6.66	56.49	59.63
Average fruit weight (g)	2.80-20.64	16.11	4.19	24.77	29.76
Fruit length (mm)	3.33-29.10	13.11	4.00	29.93	31.66
Fruit girth (mm)	13.33-31.81	20.40	3.39	15.85	17.96
Fruit yield / plant (g)	47.00-247.50	169.82	59.80	33.87	41.36
Co-efficient of infection for YVMV (%)	0.00-77.50	20.37	14.84	58.76	86.14
Shoot infestation (%)	0.00-93.33	50.82	21.41	39.36	46.95
Fruit infestation (%)	5.09-75.15	38.63	15.18	36.62	46.11
Marketable fruit yield / plant (%)	30.92-96.42	69.23	14.51	18.79	23.87

4.2.1 Genotypic and phenotypic co-efficient of variations (GCV and PCV)

The co-efficient of variations at genotypic (GCV %) and phenotypic level (PCV %) calculated for 15 quantitative characters observed in 144 accessions are presented in Table 4.11. In general, the PCV was higher than the corresponding GCV for all the traits under study. The percentage of GCV was less than 20 per cent (low variability) for days to first flowering, flowering period and fruit girth; 20 to 30 per cent (medium variability) for internode number, average fruit weight and fruit length; above 30 per cent (high variability) for plant height, number of leaves per plant, internodal length, number of fruits per plant, fruit yield and incidence of YVMV.

4.3 SCREENING GENOTYPES FOR RESISTANCE TO SHOOT AND FRUIT BORER (*EARIAS VITTELLA*)

Data on percentage shoot infestation, fruit infestation and marketable fruit yield recorded from 144 accessions in field experiment I are presented in Tables 4.12-4.14. Salient results are presented below.

4.3.1 Screening cultivated okra (*A. esculentus*) accessions

4. 3.1.1 Shoot infestation (SI)

Shoot borer infestation in 124 accessions of *A. esculentus* ranged between 16.67 and 90.00 per cent and the mean was 56.58 per cent (Table 4.12). The minimum shoot infestation (16.67 per cent) was observed in KL 9. It was on par with EC 20 (20 per cent) and NER 7 and MH 3 (23.33 per cent).

4. 3.1.2 Fruit infestation (FI)

Fruit borer infestation varied from 12.93 to 75.15 per cent and the grand mean was 36.58 per cent (Table 4.11). Accessions EC 2 (12.92 per cent) and Punjab Padmini (18.96 per cent) registered low fruit infestation.

4.3.1.3 Marketable fruit yield

It was observed that fruit borer damaged 38.85 per cent of the total harvested fruits. Hence, the remaining 61.15 per cent were marketable (Table 4.12). Marketable fruit yield ranged from 24.69 to 187.36 g per plant. The highest marketable fruit yield was recorded by KL 28 (187.36 g / plant) followed by NER 7 (171.87 g / plant) and Anakomban (162.72 g / plant). They were on par.

4.3.2 Screening semi-domesticated okra (*A. caillei*) accessions

4. 3.2.1 Shoot infestation (SI)

The range for shoot borer infestation was 3.33 to 16.67 per cent and the grand mean was 11.11 per cent (Table 4.13). Accession AC 5 was the least infested (3.33 per cent) followed by Thamaravenda (6.67 per cent) and AC 1 (6.67 per cent). AC 1 and Thamaravenda were on par.

4. 3.2.2 Fruit infestation (FI)

The mean fruit infestation recorded was 23.49 per cent and the range was between 12.53 per cent in AC 1 and 31.11 per cent in AC 2 (Table 4.13). Next to AC 1, genotype such as AC 4, AC 5, AC 7, AC 9, Thamaravenda and Susthira showed low fruit infestation (18.12 to 22.00 per cent).

4.3.2.3 Marketable fruit yield

On an average 77.39 per cent fruits were marketable (Table 4.13). On weight basis, marketable fruit yield per plant ranged from 74.53 to 190.28 g per plant. Among 12 accessions of *A. caillei*, AC 5 ranked first for marketable fruit yield (190.28 g / plant).

Table 4.12 Percentage shoot infestation (SI), fruit infestation (FI) and marketable fruit yield (MFY) in 124 accessions of *A. esculentus*

SNo	Accession No	% SI *	TSI	% FI	TFI	MFY (g)	MFY (%)
I	**Varieties**						
1	Arka Abhay	40.00	39.21	39.00	38.62	79.28	63.80
2	Arka Anamika	60.00	50.83	36.81	37.30	138.46	65.12
3	Aruna	63.33	52.84	36.67	37.24	71.81	61.87
4	Bio-2	46.67	43.06	26.87	30.90	137.74	79.16
5	CO-1	43.33	41.14	21.23	27.18	134.92	79.54
6	EMS 8-1	26.67	30.98	23.83	29.21	93.84	79.00
7	MDU-1	53.33	46.99	27.56	31.35	83.20	74.94
8	Parbhani Kranti	63.33	53.04	36.36	25.73	103.64	65.19
9	Punjab Padmini	29.76	33.02	**18.96**	23.73	108.85	**82.09**
10	Pusa Makhmali	**73.33**	58.98	53.90	47.32	**57.98**	**40.26**
11	Salkeerthy	70.00	56.76	22.73	28.47	122.16	71.74
12	Sel-2	**26.67**	30.98	26.04	30.52	107.66	81.56
13	Varsha Upahar	43.33	41.14	**58.33**	49.82	63.77	41.67
14	VRO-06	33.33	35.20	25.42	27.98	113.12	78.44
II	**Landraces**						
15	Aarumasavendai	70.00	56.97	46.26	42.83	126.17	58.60
16	Anakomban	63.33	52.75	21.48	23.88	**162.72**	74.14
17	Anjilaivendai	60.00	54.03	47.78	43.70	95.05	54.66
18	Maravendai	60.00	50.75	22.64	28.40	155.13	79.82
19	Palvenda	46.67	43.06	49.40	44.64	90.88	52.16
Mean		*53.61*		*35.49*		*113.21*	*65.08*
CD 5 %			*8.49*		*9.13*	*22.14*	*14.89*
III	**Indigenous germplasm**						
1	AP 1	63.33	52.84	28.64	32.17	85.44	76.87
2	AP 2	50.00	44.98	64.17	53.41	48.75	34.94
3	AP 3	46.67	42.97	47.50	43.52	42.44	56.40
4	AP 4	30.00	32.99	39.17	38.71	118.23	68.42
5	AP 5	70.00	56.97	37.56	37.65	128.73	64.94
6	BH 1	56.67	48.91	26.23	30.79	150.78	72.35
7	BH 2	30.00	32.99	28.75	31.46	81.24	68.37
8	BH 3	26.67	30.98	30.83	33.40	93.49	75.40
9	GU 1	63.33	52.84	53.75	47.14	41.66	46.51

* TSI and TFI-Angular transformed value for per cent shoot and fruit infestation respectively

Table 4.12 continuation..... Shoot and fruit infestation in *A. esculentus* accessions

SNo	Genotype	% SI	TSI	% FI	TFI	MFY (g)	MFY (%)
10	GU 2	50.00	44.98	60.61	51.11	85.15	42.95
11	GU 3	70.00	56.97	35.89	36.62	117.83	66.65
12	GU 4	76.67	61.19	37.27	37.61	105.44	69.39
13	HA 1	66.67	55.05	45.71	42.51	42.99	54.55
14	HA 2	73.33	58.98	75.15	60.08	41.02	25.40
15	HA 3	63.33	53.34	33.38	35.23	99.27	67.74
16	KA 1	53.33	46.99	47.78	43.66	94.44	55.95
17	KA 2	80.00	68.04	35.00	36.20	82.73	68.18
18	KA 3	70.00	57.32	67.27	55.09	60.01	39.48
19	KA 4	73.33	59.19	32.48	34.73	114.38	71.15
20	KA 5	70.00	56.97	49.23	44.54	91.94	54.53
21	KA 6	60.00	50.83	52.66	46.53	82.84	47.50
22	KL 1	40.00	39.13	53.33	47.06	39.03	47.65
23	KL 2	76.67	61.89	50.00	44.98	39.15	49.83
24	KL 3	60.67	54.97	35.00	35.14	37.15	67.62
25	KL 4	80.00	68.04	46.67	43.07	39.46	48.91
26	KL 5	50.67	48.82	52.50	46.48	47.17	45.43
27	KL 6	60.67	54.97	65.56	54.22	53.74	36.72
28	KL 7	76.67	61.89	56.67	48.91	25.37	35.05
29	KL 8	60.33	53.04	42.50	40.63	110.70	63.29
30	KL 9	16.67	23.84	24.65	29.75	85.92	76.00
31	KL 10	30.67	30.98	32.22	34.35	110.60	68.53
32	KL 11	50.67	48.91	24.68	29.77	151.55	75.67
33	KL 12	30.33	34.91	39.55	38.53	102.92	65.50
34	KL 13	66.67	54.76	29.09	32.62	104.09	71.17
35	KL 14	40.00	38.84	40.29	39.34	75.36	61.24
36	KL 15	30.33	35.20	36.67	37.20	73.70	68.41
37	KL 16	63.33	53.04	65.00	53.74	24.69	27.82
38	KL 17	50.00	44.98	37.98	37.82	121.52	58.99
39	KL 18	50.33	46.90	40.00	38.13	74.89	60.51
40	KL 19	50.33	46.99	57.73	49.59	59.01	46.10
41	KL 20	63.33	57.97	48.75	44.26	70.14	54.16
42	KL 21	60.00	51.12	65.00	53.74	41.29	35.26
43	KL 22	46.67	43.06	48.75	44.26	81.68	52.91
44	KL 23	73.33	58.98	70.32	57.69	38.18	25.07
45	KL 24	67.50	55.31	62.22	52.11	73.32	45.26
46	KL 25	60.00	53.83	41.82	39.26	79.47	60.82

Table 4.12 continuation..... Shoot and fruit infestation in *A. esculentus* accessions

47	KL 26	70.00	56.97	58.72	50.25	74.59	40.92
48	KL 27	63.33	53.04	49.58	44.71	54.12	50.68
49	KL 28	66.67	59.97	23.54	29.01	**187.36**	75.68
50	MP 1	**90.00**	71.97	45.83	42.55	115.53	54.45
51	MP 2	66.67	55.05	34.29	35.80	110.33	65.26
52	MP 3	60.33	52.75	32.73	34.85	157.41	74.68
53	MP 4	70.00	58.98	40.95	39.77	92.51	65.61
54	MH 1	60.00	50.83	28.45	31.98	129.14	77.00
55	MH 2	63.33	52.84	45.90	42.63	88.61	60.51
56	MH 3	23.33	28.77	63.57	52.87	57.97	42.94
57	MH 4	40.00	41.14	61.67	52.09	46.52	38.59
58	MH 5	56.67	48.91	40.95	39.77	105.75	65.10
59	MH 6	66.67	54.76	38.57	37.27	101.66	61.69
60	ND 1	70.00	56.97	30.83	33.68	112.70	72.60
61	ND 2	40.00	38.13	29.64	32.91	106.94	69.82
62	NER 1	50.00	44.98	47.27	43.35	111.51	56.81
63	NER 2	73.33	59.68	50.61	45.34	78.79	46.28
64	NER 3	65.00	53.74	57.74	49.45	70.38	46.41
65	NER 4	70.00	56.97	64.17	54.82	61.00	40.28
66	NER 5	43.33	41.05	39.02	38.64	108.10	62.43
67	NER 6	40.00	38.84	48.69	44.23	83.54	49.21
68	NER 7	23.33	28.77	27.25	31.45	171.87	70.51
69	NER 8	66.67	54.76	50.50	45.27	75.64	41.56
70	OR 1	70.00	58.98	39.67	39.02	109.05	58.86
71	OR 2	36.67	37.21	42.05	40.41	119.22	57.60
72	RA 1	60.00	54.03	66.82	54.88	38.63	33.44
73	RA 2	73.33	58.98	44.72	41.91	56.40	56.90
74	TN 1	70.00	57.76	52.22	46.25	73.02	54.54
75	TN 2	50.00	49.62	**21.11**	27.34	142.67	**80.14**
76	TN 3	63.33	53.04	35.00	36.25	74.40	65.26
77	TN 4	46.67	42.97	40.95	39.77	83.55	59.31
78	UP 1	50.00	44.98	39.58	38.69	102.14	62.48
79	UP 2	50.00	49.06	25.00	29.91	132.41	78.04
80	UP 3	60.67	54.82	57.92	49.68	69.90	46.07
81	UP 4	80.00	63.90	69.72	57.10	37.17	30.54
82	WB 1	40.67	42.02	39.23	38.69	68.74	66.86
83	WB 2	70.00	58.98	51.67	46.03	39.41	49.16
84	WB 3	80.00	66.61	42.50	40.63	54.10	62.62
Mean		*58.64*		*44.94*		*84.19*	*56.74*
CD 5 %			*16.88*		*12.33*	*26.15*	*14.23*

Table 4.12 continuation..... Shoot and fruit infestation in *A. esculentus* accessions

S.No	Accession No.	% SI	TSI	% FI	TFI	MFY (g)	MFY (%)
IV	**Exotic germplasm**						
1	EC 1	70.00	56.12	30.54	33.53	123.45	68.04
2	EC 2	50.00	44.98	12.92	20.59	125.19	**87.89**
3	EC 3	70.00	56.97	**21.52**	26.91	112.99	81.84
4	EC 4	60.00	51.12	31.52	34.09	**149.77**	71.32
5	EC 5	53.33	44.90	37.09	37.50	88.09	64.77
6	EC 6	50.00	46.90	27.50	31.61	120.49	73.40
7	EC 7	70.00	56.97	25.40	30.22	109.06	77.69
8	EC 8	60.00	51.82	**39.29**	38.69	78.45	77.81
9	EC 9	43.33	41.05	33.17	34.34	117.80	67.83
10	EC 10	50.00	44.98	28.33	31.81	94.02	70.57
11	EC 11	**73.33**	58.88	35.71	36.41	82.47	**64.29**
12	EC 12	63.33	52.75	29.09	32.63	80.18	71.80
13	EC 13	70.00	56.97	23.33	28.72	106.05	77.30
14	EC 14	50.00	44.98	23.39	28.91	**55.98**	76.30
15	EC 15	50.00	44.98	25.00	29.99	136.35	79.41
16	EC 16	50.00	44.98	38.75	38.48	95.93	68.00
17	EC 17	40.00	39.21	29.64	32.97	94.10	71.28
18	EC 18	40.00	38.84	30.00	33.20	59.82	72.55
19	EC 19	26.67	30.77	29.76	32.67	62.07	74.21
20	EC 20	**20.00**	26.06	26.00	30.64	56.49	74.33
21	EC 21	36.67	36.92	27.86	31.69	89.39	69.10
	Mean	*53.81*		*29.32*		*96.38*	*72.84*
	CD 5%		*13.44*		*8.73*	*19.65*	*9.01*
Pooled mean for 124 accessions		**56.58**		**40.60**		**89.87**	**61.15**
CD at % for pooled analysis			**15.41**		**11.19**	**29.62**	**22.14**

Note: In a column values in bold and bold underlined faces refers to the minimum and maximum value, respectively.

Table 4.13 Percentage shoot infestation (SI), fruit infestation (FI) and marketable fruit yield (MFY) in 12 accessions of *A. caillei*

SNo	Genotype No	% SI	TSI	% FI	TFI	MFY (g)	MFY (%)
1	AC 1	6.67	12.28	**12.53**	20.72	158.10	**87.76**
2	AC 2	13.33	21.14	**31.11**	33.61	**74.53**	68.76
3	AC 3	**16.67**	23.84	26.62	31.05	138.54	74.22
4	AC 4	13.33	21.14	22.11	28.04	152.62	78.19
5	AC 5	**3.33**	10.47	18.12	25.18	**190.28**	83.23
6	AC 6	13.33	21.14	26.28	30.83	164.06	76.47
7	AC 7	13.33	21.14	21.65	27.72	155.90	81.29
8	AC 8	13.33	21.14	30.06	33.23	120.60	**68.05**
9	AC 9	13.33	21.14	21.10	27.33	132.32	78.96
10	AC 10	10.00	18.43	30.66	33.89	134.88	71.63
11	Thamaravenda	6.67	12.28	20.43	26.86	171.88	80.03
12	Susthira	10.00	18.43	21.26	27.45	168.18	80.11
	Mean	*11.11*		*23.49*		*146.83*	*77.39*
	CD 5%		*2.15*		*3.89*	*32.14*	*12.06*

Table 4.14 Percentage shoot infestation (SI), fruit infestation (FI) and marketable fruit yield (MFY) in eight wild *Abelmoschus* species

SNo	Species	% SI	TSI	% FI	TFI	MFY (g)	MFY (%)
1	*A. angulosus*	16.67	19.06	37.26	37.60	200.80	75.77
2	*A. ficulneus*	13.67	10.51	29.63	32.96	87.76	68.60
3	*A. moschatus*	**28.22**	27.04	48.83	44.31	204.00	53.29
4	*A. moschatus* var. *multiformis*	20.69	27.04	35.00	36.25	172.70	67.49
5	*A. tetraphyllus*	**0.00**	-	**55.60**	48.18	201.10	**42.40**
6	*A. tetraphyllus* var. *pungens*	3.33	10.51	16.56	24.00	224.10	84.76
7	*A. tuberculatus*	3.33	10.51	**0.00**	-	205.20	**100.00**
8	*A. tuberosus*	24.67	29.77	46.93	43.21	141.70	55.85
	Mean	*10.83*		*33.70*		*179.00*	*68.52*
	CD 5%		*4.79*		*4.87*	*22.84*	*16.87*

Note: In a column values in bold and bold underlined faces refers to the minimum and maximum value, respectively.

4.3.3 Screening wild *Abelmoschus* species

4.3.3.1 Shoot infestation (SI)

The maximum shoot borer infestation (28.22 per cent) was recorded in *A. moschatus,* whereas the minimum (0.00 per cent) was recorded in *A. tetraphyllus* (Table 4.14). Shoot infestation was low (3.33 per cent) in *A. tetraphyllus* var. *pungens* and *A. tuberculatus* as well.

4.3.3.2 Fruit infestation (FI)

Observation on fruit infestation showed a range from 0.00 to 55.60 per cent. The minimum value was recorded by *A. tuberculatus* (0.00 per cent) and the maximum value by *A. tetraphyllus* (Table 4.14). Next to *A. tuberculatus,* fruit infestation was the lowest (16.56 per cent) in *A. tetraphyllus* var. *pungens.*

4.3.3.3 Marketable fruit yield

On an average 33.70 per cent fruits were affected by fruit borer (Table 4.14). Marketable fruit yield per plant ranged from 87.76 g per plant in *A. ficulneus* to 224 g per plant in *A. tetraphyllus* var. *pungens.* Fruits of *A. tuberculatus* were unaffected by fruit borer and hence recorded 100 per cent marketable fruit yield.

4.3.4 CONFIRMATION OF RESISTANCE

Shoot and fruit borer infestation data recorded in the confirmation trial (field experiment II) are given in Table 4.15. In the case of wild species, shoot infestation in *A. tetraphyllus* was 6.67 per cent in the confirmation trial as against zero per cent in the preliminary screening. This species recorded 62.45 per cent mean fruit infestation over two seasons. Shoot infestation in *A. ficulneus, A. tetraphyllus* var. *pungens* and *A. tuberculatus* ranged between 12.67 and 18.57 per

Table 4.15 Shoot and fruit infestation in selected accessions in the confirmation trial (Mar to Jun 2003)

S. No	Entries tested	Shoot infestation (%)			Fruit infestation (%)		
		Preliminary screening	Confirmation trial	Average	Preliminary screening	Confirmation trial	Average
A	**Wild species**						
1	*A. tetraphyllus* var. *pungens*	3.33	18.57	10.28	6.56	9.62	8.04
2	*A. tetraphyllus*	0.00	6.67	3.50	55.59	69.32	62.45
3	*A. tuberculatus*	3.33	12.67	7.12	0.00	7.53	3.77
B	***A. caillei***						
1	AC 1	6.67	25.33	16.15	12.53	20.60	16.57
2	AC 5	3.33	16.27	8.42	18.12	19.83	18.98
3	AC 10	10.00	23.27	16.63	30.66	28.20	29.43
4	Susthira	10.00	18.67	14.33	21.26	26.00	23.63
5	Thamaravenda	6.67	18.00	12.33	20.43	24.83	22.63
C	***A. esculentus***						
1	KL 9	16.67	20.67	18.67	24.67	38.43	31.55
2	EC 2	50.00	39.78	44.92	12.92	20.68	16.80
3	Check: Salkeerthy	70.00	63.67	66.83	22.73	55.67	39.20
Mean		*14.08*	*22.06*	18.07	*28.25*	*35.98*	32.35
CD at 5 %		*15.41*	*6.61*		*11.19*	*9.74*	

Note: For comparison, values of shoot and fruit infestation recorded in preliminary evaluation trial (Nov.2002 -Mar. 2003) are also presented in the table.

cent as against 3.33 per cent shoot damage in the preliminary screening. Percentage of fruit borer infestation was low (7.53 per cent) in *A. tuberculatus* and *A. tetraphyllus* var. *pungens* (8.09 per cent).

Among the accessions of *A. caillei,* shoot borer infestation in AC 5, Thamaravenda and Susthira were 16.27 per cent, 18 per cent and 18.67 per cent respectively in the confirmation trial while it was 3.33 per cent, 6.67 per cent and 10 per cent in the preliminary screening (Table 4.15). Fruit infestation in AC 1 and AC 5 was between 19 and 21 per cent whereas it was 24.83 and 26 per cent fruit infestation respectively in Thamaravenda and Susthira.

Out of the two *A. esculentus* accessions retested during second season (Table 4.15), KL 9 showed 20.67 per cent shoot infestation and 38.43 per cent fruit infestation. On the other hand, EC 2 recorded 39.78 per cent fruit infestation and 20.68 per cent fruit infestation.

4.3.5 CLASSIFICATION OF GENOTYPES BASED ON THEIR RELATIVE DEGREE OF RESISTANCE

The rating scale suggested by Kumbhar *et al.* (1991) was followed to classify the germplasm based on their shoot and fruit infestation into five resistance classes namely, i) immune (0 per cent infestation), ii) highly resistant (1-10 per cent shoot or fruit infestation), iii) moderately resistant (11-20 per cent infestation), iv) susceptible (21-30 per cent infestation) and v) highly susceptible (>31 per cent infestation). The mean infestation data from trial I (Preliminary screening) and trial II (confirmation trial) were used for the classification. The genotypes grouped according to their resistance reactions are shown in Table 4.16.

4.3.5.1 Genotypes resistant to shoot borer (E. vittella)

Out of the 144 accessions tested, none was immune to shoot borer (Table 4.16). Only one entry *i.e. A. tetraphyllus* was highly resistant. Fifteen accessions were moderately resistant which included three wild species such as *A. angulosus,*

Table 4.16 Classification of germplasm based on their relative degree of resistance to shoot and fruit borer

Based on shoot infestation	Based on fruit infestation
Group 1: Immune (0 % infestation) - Nil	
Group 2: Highly Resistant (1 to 10.99 % infestation)	
Wild species: *A. tetraphyllus*	**Wild species:** *A. tuberculatus* and *A. tetraphyllus* var. *pungens*
Group 3: Moderately Resistant (11 to 20.99 % infestation)	
Wild species: *A. angulosus, A. tetraphyllus* var. *pungens A. ficulneus* and *A. tuberculatus* **Semi-wild species:** AC -2, 3, 4, 5, 6, 7, 8, and 9, Susthira and Thamaravenda **Cultivated species:** Two genotypes of *A. esculentus viz.*, KL 9 and EC 20.	**Semi-wild species:** AC-1, AC- 5 and Thamaravenda of *A. caillei* **Cultivated species:** EC 2 and Punjab Padmini
Group 4: Susceptible (21 to 30.99 % infestation)	
Wild species: *A. moschatus, A. moschatus* var. *multiformis* and *A. tuberosus* ***A. caillei*** **:** AC 1 and AC 10 ***A. esculentus*****:** AP 4, BH-2 & 3, EC 19, EMS 8-1, KL 10, MH 3, NER 7 Punjab Padmini, and Sel-2.	**Wild species:** *A. ficulneus* ***A. caillei*** **:** AC-3, 4, 6, 7, 9 & 10 and Susthira ***A. esculentus*** **:** Anakomban, AP 1, BH 1, 2 & 3, Bio-2, EC 3, 7, 10, 13, 15, 19, 21, CO-1, EC Nos-1, 6, 12, 14, 17, 18 & 20, EMS 8-1, GU 2, KL-11, 13 & 28, Maravendai, MDU-1, MH 1, ND 1 & 2, NER 7, Sel-2, TN 1, UP 2 and VRO-06
Group 5: Highly Susceptible (>31 % infestation)	
A. esculentus**:** Aarumasavendai, Anakomban, Anjilaivendai, AP-1, 2, 3 & 5, Arka Abhay, Arka Anamika, Aruna, BH 1, Bio-2, CO-1, exotic germplasm such as EC-1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18 & 21, GU 1, 2, 3 & 4, HA-1, 2 & 3, KA-1, 2, 3, 4, 5 & 6, MDU-1, KL-1, 2, 3, 4, 5, 6, 7, 8, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27 & 28, Maravendai, MH-1, 2, 4, 5 & 6, MP-1, 2, 3 & 4, ND-1 & 2, NER-1, 2, 3, 4, 5, 6 & 8, OR-1 & 2, Palvenda, Parbhani Kranti, Pusa Makhmali, RA-1 & 2, Salkeerthy, TN-1, 2, 3 & 4, UP-1, 2, 3 & 4, Varsha Upahar, VRO-06, WB-1, 2 and 3	**Wild species:** *A. angulosus, A. moschatus, A. moschatus* var. *multiformis,* A. *tetraphyllus* and *A. tuberosus* ***A. caillei*** **:** AC 2 and AC 8 ***A. esculentus*****:** Aarumasavendai, Anjilaivendai, AP-2, 3, 4 & 5, Arka Abhay, Arka Anamika, Aruna, EC- 4, 5, 8, 9, 11, 16, GU-1, 3 & 4, HA-1, 2 & 3, KA-1, 2, 3, 4, 5 & 6, KL-1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26 & 27, MH-2, 3, 4, 5 & 6, MP-1, 2, 3 & 4, NER 1, 2, 3, 4, 5, 6 & 8, OR-1 & 2, Palvenda, Parbhani Kranti, Pusa Makhmali, RA-1 & 2, Salkeerthy, TN-2, 3 & 4,UP-1, 3 & 4,Varsha Upahar, WB-1, 2 and 3.

A. ficulneus, *A. tetraphyllus* var. *pungens*, 10 accessions of *A. caillei* such as AC 2, 3, 4, 5, 6, 7, 8, 9, Susthira and Thamaravenda and two accessions of *A. esculentus* such as KL 9 and EC 20. The remaining 127 accessions (88 per cent) were either susceptible or highly susceptible to shoot borer.

4.3.5.2 Genotypes resistant to fruit borer (E. vittella)

No genotype was immune to fruit borer (Table 4.16). *A. tuberculatus* and *A. tetraphyllus* var. *pungens* showed less than 10 per cent fruit infestation consistently over two seasons and hence treated as highly resistant to fruit borer. Therefore, these two could be considered as potential resistant donors for fruit borer as well as shoot borer. Two accessions of *A. caillei* (AC 1 and AC 5) and Punjab Padmini and EC 2 of *A. esculentus* were moderately resistant to fruit borer. The remaining 138 accessions (*i.e.*96 per cent) were susceptible to fruit borer.

4.4 CORRELATION BETWEEN SHOOT AND FRUIT BORER RESISTANCE WITH OTHER TRAITS

To ascertain the inter-relationship, if any, between shoot and fruit borer resistance with yield and yield attributes, data recorded from 144 accessions in field experiment I were subjected to correlation analysis. The genotypic correlation co-efficients among 14 traits are presented in Table 4.17. Characters like internode number (r=-0.59) followed by leaf number (r=-0.58) and number of fruits per plant (r=0.50) had significant but negative correlation with shoot infestation. On the other hand, days to first flowering, fruit weight and fruit length showed significant positive correlation with shoot borer infestation. Plant height, leaf number and marketable fruit yield showed significance but negative correlation with fruit infestation. Both shoot borer infestation and fruit borer infestation were positively inter-related (r=0.41). In the present study, fruit yield per plant was positively correlated with number of fruits per plant (r=0.32), fruit weight (r=0.51) and fruit girth (r=0.36).

Table 4.17 Genotypic correlation coefficients among 14 quantitative traits in 144 accessions of okra

Traits	Dff	Flp	Pht	LNo	IN	IL	FN	FW	FL	FG	FY	SI	FI	MFY
Dff	1.00													
Flp	0.25	1.00												
Pht	0.13	0.20	1.00											
LNo	0.39**	0.09	0.55**	1.00										
IN	0.35**	0.07	0.49**	0.82**	1.00									
IL	0.20	0.01	0.34**	-0.17	-0.16	1.00								
FN	0.14	0.22	0.46**	0.75**	0.72**	-0.08	1.00							
FW	0.02	-0.09	-0.32**	-0.50**	-0.46**	-0.02	-0.52**	1.00						
FL	0.20	-0.12	-0.06	-0.47**	-0.43**	0.15	-0.43**	0.59**	1.00					
FG	0.40**	-0.04	0.07	0.06	0.11	0.02	-0.11	0.39**	-0.02	1.00				
FY	0.13	0.16	0.18	0.10	0.19	0.04	**0.32****	**0.51****	0.22	**0.36****	1.00			
YMV	0.13	-0.11	0.03	-0.22	-0.29**	0.25	-0.32**	0.33**	0.48**	0.04	0.04			
SI	**0.46****	0.00	**-0.47****	**-0.58****	**-0.59****	0.02	**-0.50****	0.30**	0.28**	-0.22	0.17	1.00		
FI	0.11	-0.11	**-0.30****	**-0.30****	-0.24	0.05	-0.08	-0.10	-0.03	**-0.33****	0.26	**0.41****	1.00	
MFY	0.05	0.01	0.13	0.16	0.13	-0.04	-0.06	0.18	0.04	0.26	0.19	-0.31**	**-0.88****	1.00

Abbreviation: Dff-Days to first flowering, Flp-Flowering period, Pht-Plant height (cm), LNo-Number of leaves/plant, IN-Number of internode, IL-Internode length (cm), FN-Fruit number / plant, FW-Average fruit weight (g), FL-Fruit length (cm), FG-Fruit girth (mm), FY-Fruit yield (g)/ plant, YMV-Coefficient of infection for Yellow Vein Mosaic virus, SI-Shoot infestation (%), FI-Fruit infestation (%), MFY-Marketable fruit yield (%).

4.5 GENETIC DIVERGENCE AMONG GENOTYPES

To assess the extent of genetic diversity among the genotypes, data recorded on 14 quantitative traits from 144 accessions in experiment-I was subjected for D^2 analysis. The results are presented below.

4.5.1 Cluster composition

The genotypes were grouped into 13 well-separated clusters (Fig 2). Cluster I consisted of five accessions of wild okra namely, *A. angulosus*, *A. ficulneus*, *A. moschatus* var. *multiformis*, *A. tetraphyllus* var. *pungens* and *A. tuberculatus* (Table 4.18). Two more wild species *viz.*, *A. moschatus* and *A. tuberosus* were clubbed into cluster II. Another wild species *A. tetraphyllus* was grouped alone in cluster III. Except Susthira, the remaining 11 accessions of *A. caillei* were clubbed into cluster IV. The 124 accessions of *A. esculentus* were distributed in nine clusters (V to XIII).

Cluster number V composed of two landraces namely, Aarumasavendai and Maravendai. Cluster VI accommodated five accessions namely, Anakomban, Salkeerthy, Susthira, EC 17 and NER 7. Cluster VII composed of 12 released okra varieties such as Arka Anamika, Arka Abhay, Aruna, Bio 2, EMS 8-1, MDU 1, Parbhani Kranti, Punjab Padmini, Pusa Makhmali, Sel 2, Varsha Upahar, VRO 06 and nine unimproved germplasm of Indian and exotic origin. Cluster XI was the largest accommodating 29 unimproved germplasm of Indian and exotic origin. Cluster VIII consisted of 18 accessions, cluster IX consisted of 16 accessions, cluster X consisted of 16 accessions, cluster XII consisted of 6 accessions and cluster 13 consisted of 12 accessions of *A. esculentus*.

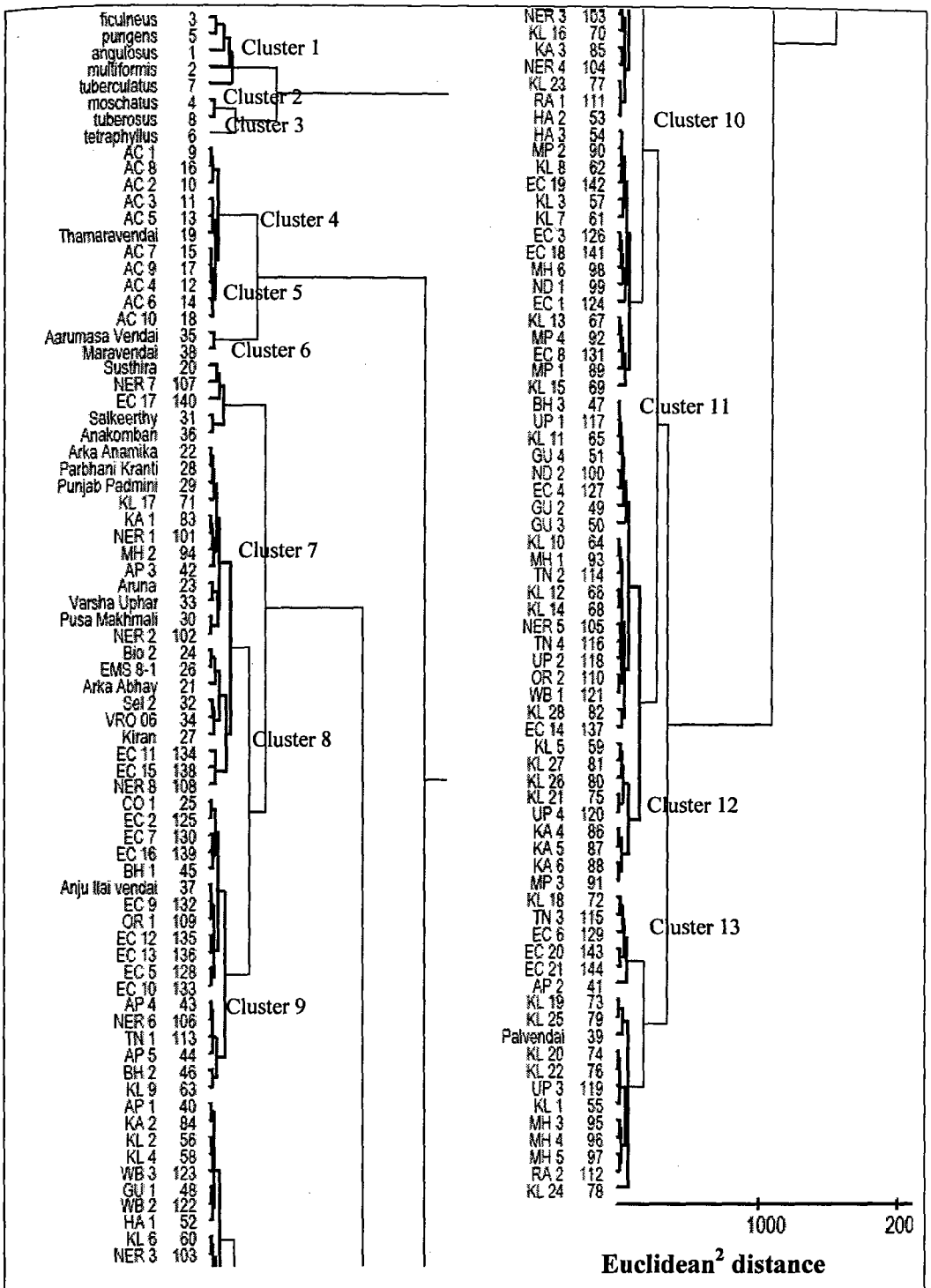


Fig 3 Dendrogram showing similarity and divergence among 144 okra accessions based on 14 quantitative traits

Table 4.18 Cluster composition and geographical origin of genotypes

Cluster No	No. of genotypes	Name of the genotypes	Geographical origin
I	5	*A. angulosus*, *A. ficulneus*, *A. moschatus* var. *multiformis*, *A. tetraphyllus* var. *pungens* and ***A. tuberculatus***	Kerala, Tamil Nadu, Sikkim
II	2	*A. moschatus* and *A. tuberosus*	Kerala
III	1	***A. tetraphyllus***	Kerala
IV	11	AC Nos-1, 2, 3, 4, 5, 6, 7, 8, 9, 10 and Thamaravenda	Kerala West Africa
V	2	Aarumasavendai and Maravendai	Tamil Nadu
VI	5	Anakomban, EC 17, NER 7, Salkeerthy and **Susthira**	Kerala, NE-Region, SE-Asia
VII	21	**Arka Anamika**, Arka Abhay, AP 3, Aruna, Bio 2, EC 11, EC 15, EMS 8-1, KA 1, MH 2, MDU 1, NER 1, NER 2, NER 8, KL 17, Parbhani Kranti, Punjab Padmini, Pusa Makhmali, Sel 2, Varsha Upahar and VRO 06	Karnataka, Maharashtra New Delhi, NE-Region, Tamil Nadu
VIII	18	Anjilaivendai, AP 4, AP 5, BH 1, BH 2, Co-1, EC 2, EC 5, EC 7, EC 16, EC 9, EC 10, EC 12, EC 13, KL 9, NER 6, OR 1 and TN 1	Andhra, Orissa, Tamil Nadu, SE-Asia
IX	16	AP 1, HA 1, HA 2, GU 1, KA 2, KA 3, KL 2, KL 4, KL 6, KL 16, KL 23, NER 3, NER 4, RA 1, WB 2 and WB 3.	Andhra, Haryana, Gujarat, Karnataka, Kerala, Rajasthan, NE-Region, West Bengal
X	16	EC 1, EC 3, EC 8, EC 18, EC 19, HA 3, KL 3, KL 7, KL 8, KL 13, KL 15, MH 6, MP 1, MP 2, MP 4 and ND 1	Haryana, Kerala, Maharashtra, M.P., New Delhi, SE-Asia
XI	29	BH 3, EC 4, EC 14, GU 2, GU 3, GU 4, KA 4, KA 5, KL 5, KA 6, KL 10, KL 11, KL 12, KL 14, KL 21, KL 26, KL 27, KL 28, MH 1, MP 3, NER 5, ND 2, OR 2, TN 2, TN 4, UP 1, UP 2, UP 4 and WB 1,	Bihar, Karnataka, Kerala, Maharashtra, M.P., New Delhi, Orissa, Tamil Nadu, U.P, West Bengal
XII	6	AP 2, EC 6, EC 20, EC 21, KL 18 and TN 3	Andhra, Kerala, Maharashtra, Rajasthan, U.P.
XIII	12	KL 1, KL 19, KL 20, KL 22, KL 24, KL 25, MH 3, MH 4, MH 5, RA 2, Palvenda and UP 3.	Kerala, Maharashtra, Rajasthan, U.P.

Not: Genotypes in bold faces were selected for crossing programme

4.5.2 Cluster mean

The means of 14 quantitative traits for each cluster are given in Table 4.19. Based on cluster mean, the uniqueness of each cluster was identified and the same is presented hereunder.

Cluster I: Characterized by high internode number (29.00) and marketable fruit yield (79.34 per cent)

Cluster II: Registered the highest value for leaf number per plant (38.50 leaves)

Cluster III: Highly resistant to shoot borer (SI=0 per cent). Also recorded the highest value for fruit number (59 fruits per plant) and lowest values for fruit weight (3.80 g /fruit), fruit length (4.07 cm), fruit girth (14.90 mm), shoot infestation (0 %) and marketable fruit yield (42.40 %).

Cluster IV: Showed low Fruit borer infestation (22.82 per cent). Late flowering (55.70 days) but recorded the maximum value for fruit girth (26.83 mm), fruit yield (248.56 g/plant) and marketable fruit yield (76.60 %).

Cluster V: Exhibited prolonged flowering period (43.45 days) and high plant height (196 cm).

Cluster VI: Characterized by high fruit weight (21.01g per fruit), fruit length (24.23 cm) and fruit yield (226.38 g /plant) but susceptible to YVMV.

Cluster VIII: Characterized by early flowering (37.81 days)

Cluster IV: Characterized by dwarf plant stature (71.14 cm), less internode number (13.62 internodes per plant) and leaves (11.63 leaves per plant). Susceptible to shoot borer (SI= 70.89 per cent).

Cluster X: Exhibited short internodal length (4.75 cm).

Cluster XII: Showed short flowering period (18.57 days) and poor fruit yield (8.11 fruits / plant).

Cluster XIII: Characterized by long internodal length (11.56 cm).

Table 4.19 Cluster mean and contribution of characters towards divergence

Cluster No	Dff	Flp	Pht	LNo	IN	IL	FN	FW	FL	FG	FY	SI	FI	MFY %
I	48.73	31.28	152.67	31.47	**29.07**	**4.75**	25.40	4.15	4.11	16.10	**107.01**	8.74	23.89	**79.34**
II	45.17	30.00	154.83	**38.50**	27.00	4.82	41.00	4.72	5.13	20.50	198.62	23.48	47.88	54.57
III	44.67	33.33	172.00	32.67	27.67	8.53	**59.00**	**3.80**	**4.07**	**14.90**	225.07	**0.00**	**55.60**	**42.40**
IV	**55.70**	30.09	128.84	19.88	20.34	7.23	13.75	17.89	11.12	**26.83**	**248.56**	14.70	**22.82**	76.60
V	54.83	**43.45**	**195.75**	21.00	14.32	7.68	14.08	16.33	12.88	22.05	228.37	65.00	29.60	74.00
VI	44.00	31.40	115.83	12.39	14.72	6.97	10.95	**21.01**	**24.23**	18.33	226.38	41.33	23.70	76.97
VII	39.33	27.72	142.02	13.48	15.33	9.49	10.71	14.44	14.40	18.22	157.11	53.65	37.73	66.29
VIII	**37.81**	32.49	109.94	12.56	15.07	9.78	11.04	16.72	12.79	20.84	183.32	52.50	34.11	72.54
IX	41.33	28.89	**71.14**	**11.63**	**13.62**	6.77	9.13	15.43	11.86	18.23	140.10	**70.89**	55.38	55.09
X	42.24	29.59	65.60	12.96	15.10	**4.75**	8.40	18.23	11.81	21.87	155.97	63.54	34.06	75.79
XI	42.67	26.43	87.02	13.65	15.52	6.92	10.78	18.31	15.49	19.85	203.35	54.81	37.26	74.96
XII	53.39	**18.57**	84.29	13.50	14.72	7.00	**8.11**	15.37	12.23	23.94	129.04	46.11	33.43	70.10
XIII	46.39	26.40	91.83	12.39	15.01	**11.56**	8.71	15.87	12.57	20.92	137.21	53.54	52.56	61.32
Contri--bution (%)	**13.68**	**9.01**	**22.42**	**1.48**	**2.51**	**10.06**	**1.18**	**2.29**	**13.11**	**4.94**	**9.21**	**1.62**	**2.67**	**5.81**

Abbreviation: Dff-Days to first flowering, Flp-Flowering period, Pht-Plant height (cm), LNo-Number of leaves/plant, IN-Number of internode, IL-Internode length (cm), FN-Fruit number / plant, FW-Average fruit weight (g), FL-Fruit length (cm), FG-Fruit girth (mm), FY-Fruit yield (g)/ plant, SI-Shoot infestation (%), FI-Fruit infestation (%), MFY-Marketable fruit yield (%).

Values in bold and bold underlined faces refer to the minimum and maximum values, respectively

4.5.3 Contribution of characters to divergence

The most important characters contributing towards divergence (Table 4.19) were plant height (22.42 per cent), days to first flowering (13.68 per cent), fruit length (13.11 per cent), and internodal length (10.06 per cent). These four traits together have contributed 60 per cent of the total diversity. The contribution of other traits to divergence, in their descending order, were fruit yield (9.21 per cent), flowering period (9.01 per cent), marketable fruit yield (5.81 per cent), fruit girth (4.94 per cent), fruit infestation (2.67 per cent), internode number (2.51 per cent), fruit weight (2.29 per cent), leaf number (1.48 per cent) and fruit number (1.18 per cent).

4.5.4 Inter and intra-cluster distances

The maximum intra-cluster distance was 36 in cluster IX (Table 4.20) whereas the maximum was 203 in cluster I followed by cluster VI (108). The range for intra-cluster distances (36-203) was low as compared to the range for inter-cluster distances (62-1774). The group constellation showed that the maximum inter-cluster distance was between cluster III and clusters I to XIII (distance ranged from 1596 to 1774) followed by cluster II and VI (957), cluster II and V (848). Cluster IV that contain genotypes of *A. caillei* showed closest proximity to cluster XII (139) but diverged from cluster VI (258). With respect to divergence among genotypes of *A. esculentus*, the closest proximity was found between cluster IX and XI (62) whereas the maximum distance was observed between cluster X and V (423).

4.5.5. Selection of parents for crossing programme

On the basis of results from first two field experiments and by taking into account the resistance of genotypes to shoot and fruit borer, yield potential and genetic divergence, the following parents were selected for crossing programme to develop a high yielding strain with inbuilt resistance to shoot and fruit borer.

Table 4.20 Inter cluster (upper diagonal values) and intra cluster (diagonal values) distances for 13 clusters in 144 okra accessions

Cluster No	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
I	203	226	737	418	571	678	537	528	534	512	539	534	589
II		50	275	717	848	957	790	795	801	791	812	817	871
III			0	1596	1664	1774	1603	1629	1667	1697	1687	1720	1716
IV				40	225	258	236	175	204	168	181	139	195
V					48	325	326	338	417	423	399	413	418
VI						108	169	166	206	232	158	242	220
VII							73	85	123	175	117	166	138
VIII								46	67	96	72	120	83
IX									36	63	62	98	75
X										53	78	100	115
XI											54	99	87
XII												64	101
XIII													61

Table 4.20a Genotypes selected for crossing programme

#	Parental genotype	Species Status	Cluster No	Remarks
1	*A. tuberculatus*	Wild	I	HR to fruit borer
2	*A. tetraphyllus*	Wild	III	HR to fruit borer
3	*A. caillei* Accn AC 5	Semi-wild	IV	MR to shoot and fruit borer
4	*A. caillei* cv. Susthira	Cultivated	VI	MR to shoot borer
	A. esculentus			
5	Variety Arka Anamika	Cultivated	VII	High yielding
6	Accession No KL 29	Cultivated	VIII	MR to shoot borer
7	Accession No EC 2	Cultivated	VIII	MR to fruit borer
8	Accession No KL 28	Cultivated	XI	High yielding

(HR-refers to highly resistant; MR-moderately resistant)

4.6 TRANSFER OF SHOOT AND FRUIT BORER RESISTANT GENES TO A HIGH YIELDING VARIETY

4.6.1 Hybridization between a high yielding genotype (KL 28 of *A. esculentus*) and a wild species highly resistant to shoot borer (*A. tetraphyllus*)

4.6.1.1 Crossability and nature of F_1 hybrid

The direct and reciprocal crosses between *A. tetraphyllus* and *A. esculentus* genotype KL 28 were successful. The F_1 resulted from direct as well as reciprocal cross resembled its wild parent. The hybrid produced pale yellow large showy flowers in contrast to small and pale white flowers in *A. tetraphyllus*. Style and stigma resembled those of *A. tetraphyllus*. Leaf shape was intermediate between the parents. The F_1 was highly vigourous and heterotic but it possessed more spines on fruits than those found on wild parent. Fruit shape of F_1 was intermediate between parents (Plate 7).

4.6.1.2 Analysis of variance (ANOVA)

Data recorded from the F_1s of cross KL 28 x *A. tetraphyllus* and *A. tetraphyllus* x KL 28 are given in Table 4.21. ANOVA revealed significant

Table 4.21 *Per se* performance and heterosis in the interspecific hybrid *A. esculentus* cv. KL 28 x *A. tetraphyllus*

	Dff♣	Flp♣	Pht	Bran	LNo	IN	IL♣	FN	FW	FL	FG♣	FY	SI %	FI %	MFYg
Direct cross KL 28 x *A. tetraphyllus*															
Mean	43.67	41.00	202.3	6.33	82.00	31.33	8.44	73.67	5.13	6.67	17.55	377.13	0.00	31.24	259.50 (69 %)
RH (d_{ii})			39**	42**	159**	52**		116**	-40**	-26**		87**		-23**	145**
HB(d_i)			21**	-19*	105**	16**		40**	-62**	-51**		82**		1.36	124**
Reciprocal cross															
Mean	46.00	45.67	232.00	5.50	71.95	36.00	8.13	89.33	5.20	6.63	16.77	464.67	0.00	36.66	293.99 (63 %)
RH (d_{ii})			60**	24	127**	75**		162**	39**	-26**		130**		-11*	177**
HB(d_i)			38**	-30**	80**	33**		70**	-61**	-51**		124**		-18**	154**
CD at 5% for d_{ii}			25.01	1.17	5.92	2.34		6.17	0.74	1.64		36.02		5.95	18.21
CD at 5% for d_i			28.88	1.35	683	2.7		7.13	0.85	1.89		36.97		6.87	20.93
Parents															
A. tetraphyllus	49.67	47.67	167.67	7.83	40.00	27.00	8.85	52.62	3.73	4.37	16.43	196.52	6.07	50.79	96.42 (49 %)
KL 28	38.00	37.67	123.00	1.06	23.33	14.17	8.88	15.44	13.44	13.67	19.73	207.77	46.33	50.82	115.89 (55.85)

* P<0.05 and ** P<0.01 Values precedes asterisks were rounded to nearest integer Heterosis over better parent denoted as HB (d_i) and mid parent as RH (d_{ii})

♣ Heterosis was not calculated due to insignificance of parents *versus* F_1 mean square

Table 4.22 ANOVA showing treatment means squares for the cross *A. esculentus* cv. KL 28 x *A. tetraphyllus* (Direct and reciprocal cross)

Source	df	Dff	Flp	Pht	Bran	LNo	INo	IL	FNo	FW	FL	FG	FY	FI	MFY
Replications	2	1.58	3.00	507.00	3.47*	44.14	7.94	0.11	10.16	0.07	0.58	0.16	57.07	67.32*	166.32
Treatments	3	71.77**	61.33*	6597**	25.47**	2242**	264**	0.38	3066**	58.8**	48.84**	6.59	51749**	298.66**	29886**
Hybrids	1	8.17	32.67	1320*	1.04	151*	32.66**	0.14	368**	0.01	0.00	0.93	11493**	44.06	1784**
Parents	1	204.17**	150**	2992**	68.88**	416**	247**	0.00	2073**	141.32**	129.73**	16.30	189.84	0.00	568.61
Hybrids vs Parents	1	3.00	1.33	15480.**	6.50**	6158**	513**	1.00	6759**	35.08**	16.80**	2.53	143565**	851**	87306**
Error	6	3.69	7.00	208.89	0.46	11.69	1.83	0.77	12.73	0.18	0.90	3.23	342.41	11.82	109.71

* P<0.05 and ** P<0.01 Shoot infestation was 0 % hence not analysed

Table 4.23 ANOVA showing treatment means squares for the cross *A. esculentus* cv. Arka Anamika x *A. tuberculatus* (Direct and reciprocal cross)

Source	df	Dff	Flp	Pht	Bran	LNo	IN	IL	FNo	FW	FL	FG	FY	SI	MFY
Replications	2	1.08	3.56	236.71	0.24	84.28**	8.61	1.92	5.19	2.11	3.04	0.05	1104.58	34.33	489.81
Treatments	3	2.44	46.40**	6319**	0.54*	685.66**	100.1**	0.73	239.66**	69.01**	69.78**	26.83**	3984.54	1490**	1411.64
Hybrids	1	6.00	104.16**	2610**	0.48	130.76**	109.0**	0.44	164.53*	0.21	3.62	0.96	1972.54	150.00	1972.54
Parents	1	0.00	22.04	904.78	0.00	46.48*	66.66*	1.74	229.03**	134.42**	205.33**	56.73	8104*	3552**	718.31
Hybrids vs Parents	1	1.33	13.02	15444*	1.14*	1879**	124.54**	0.02	325.41**	72.42**	0.39	22.82**	1876.25	767.99*	1544.06
Error	6	2.19	4.12	166.68	0.10	5.11	6.62	2.04	13.51	1.25	5.47	1.15	1200.13	69.89	1331.79

* P<0.05 and ** P<0.01 Fruit infestation was 0 % hence not analysed

Abbreviation used: Dff-Days to first flowering, Flp-Flowering period, Pht-Plant height (cm), Bran-Number of branches/plant, LNo-Leaf number / plant, IN- Internode number /plant, IL-Internode length (cm), FN-Fruit number / plant, FW-Single fruit weight (g), FL-Fruit length (cm), FG-Fruit girth (mm), FY-Fruit yield (g)/ plant, SI-Shoot infestation, FI – Fruit infestation, MFY-Marketable fruit yield (g)

differences due to parents *versus* crosses for plant height, number of branches per plant, number of leaves per plant, internode number, number of fruits per plant, fruit weight, fruit length and fruit yield (Table 4.22).

4.6.1.3 Response of hybrids to shoot and fruit borer infestation

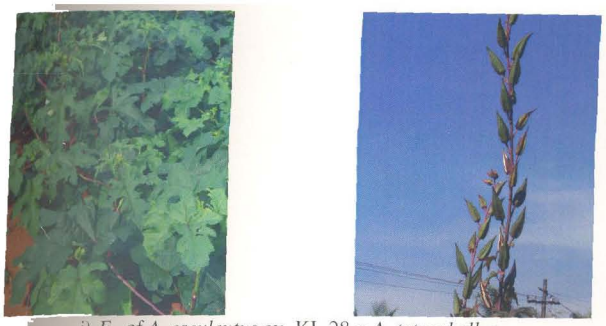
The percentage of shoot damage in the resistant parent *A. tetraphyllus* and the F_1 were zero (Table 4.21). Both of them were exhibiting field resistance to shoot borer whereas fruit damage recorded in the hybrid was 31.24 per cent in the direct F_1s and 36.66 per cent in the reciprocal F_1s.

4.6.1.4 Performance of hybrids for yield and yield attributes

Days to first flowering was 43.67 days in the direct F_1s (KL 28 x *tetraphyllus*) whereas it was 46 days in the reciprocal (Table 4.21). The flowering period lasted for 41 days in the direct cross and 45.67 days in the reciprocal F_1s. Plant height was 202.3 cm in direct cross whereas 232 cm in reciprocal F_1s. The hybrid produced 5.50 to 6.33 branches per plant and 71.95 to 82.00 leaves per plant. The hybrid exhibited prolificacy for fruit number (89.33 fruits per plant in the reciprocal cross or 162 per cent heterobeltiosis) and fruit yield (465.67 g fruits in reciprocal cross or 130 per cent heterobeltiosis). The differences between direct and reciprocal crosses were significant for fruit number (89.33 *vs.* 73.67 fruits per plant) and fruit yield (464.07 *vs.* 377.13 g per plant).

4.6.1.5 Fertility of inter-specific hybrids

Pollen fertility in F_1s ranged from 4.00 to 36.36 per cent (data not shown). Selfing F_1 flowers resulted in pod formation. However, pods did not have seeds. Therefore, sib-mating between F_1 plants was resorted. It resulted in seed bearing pods. However, the seeds were empty and did not have embryo or cotyledons. The direct and reciprocal F_1s was backcrossed with *A. esculentus* genotype KL 28.



i) F_1 of *A. esculentus* cv. KL 28 x *A. tetraphyllus*

ii) F_1 of *A. esculentus* cv. Arka Anamika x *A. tuberculatus*

iii) *esculentus* cv. KL 9 x *A. caillei* cv. AC 5

iv) Arka Anamika x KL 9

Plate 7 Inter and intra-specific okra hybrids synthesized for the present study

Bud pollination in the previous day evening combined with repeated pollination in the next day using pollen from KL 28 resulted in seed bearing pods. However, the seeds did not germinate as it devoid of embryo and cotyledon.

4.6.2 Hybridization between a high yielding genotype (Arka Anamika) and a wild species highly resistant to fruit borer (*A. tuberculatus*)

4.6.2.1 Crossability and nature of F_1 hybrid

Crosses between *A. tuberculatus* x Arka Anamika were rather easy and the crossability index was 52.70 per cent. On the other hand, *A. esculentus* x *A. tuberculatus* crosses showed anomalies like flower shedding, fruit drops and empty pods. The crossability index was 28.33 per cent. Leaves borne at bottom nodes of the F_1 plants were intermediate in shape between parents while those at stem apex resembled that of *A. tuberculatus*. The hybrid showed short trichomes on stem and fruits in contrast to long tubercular trichomes in *A. tuberculatus*. Petals in F_1 were larger than those of *A. tuberculatus*. Petal colour was pale yellow (similar to *A. esculentus*) but stigma was scarlet red (similar to *A. tuberculatus*). Ridges on the fruits of F_1 were prominent resembling to those in Arka Anamika whereas fruit length was shorter (Plate 7) than those of Arka Anamika but longer than those of *A. tuberculatus i.e.* 10.00 cm in direct and 17.57 in reciprocal hybrid (Table 4.24).

4.6.2.2 ANOVA

Data recorded from the F_1 plants of the cross Arka Anamika x *A. tuberculatus* and *A. tuberculatus* x Arka Anamika are given in Table 4.23. The ANOVA revealed significance of treatment mean square for all the traits, except days to first flowering, internodal length and marketable fruit yield (Table 4.23). Significant mean square due to parents *versus* crosses were also observed for plant height, number of branches, leaf number, internode number, fruit number, fruit

Table 4.24 *Per se* performance and heterosis in the interspecific hybrid *A. esculentus* cv. Arka Anamika x *A. tuberculatus*

	Dff♣	Flp	Pht	Bran	LNo	IN	IL♣	FN	FW	FL	FG	FY	SI %	FI %	MFYg
Direct cross Arka Anamika x *A. tuberculatus*															
Mean	39.00	39.00	177.84	2.33	42.25	19.51	9.19	25.67	4.87	10.01	14.87	125.08	6.67	0.00	125.08 (100%)
RH (d_{ii})		-5	40**	16.67	93**	12.58		25	-49**	-10.2	-18**	-25.64	-76*		
HB(d_i)		-9.3	28**	16.67	71**	-5.58		-3.75	-66**	-41*	-0.56	-39*	100		
Reciprocals															
Mean	37.00	47.33	219.56	2.90	51.58	28.04	8.65	36.14	4.50	11.57	15.67	161.34	16.67	0.00	161.34 (100 %)
RH (d_{ii})		15**	73**	45**	136**	62**		76**	-53**	3.74	-13*	-4.09	-40		
HB(d_i)		10*	58**	45**	109**	36**		36**	-68**	-32*	-4.79	-21.29	400		
CD at 5% for d_{ii}		3.51	22.34	0.55	3.91	4.45		6.36	1.94	4.05	1.86	59.94	14.46		
CD at 5% for d_i		4.05	25.79	0.64	4.52	5.14		7.34	2.24	4.67	2.14	69.21	16.70		
Parents															
A. tuberculatus	38.67	43.00	139.23	2.00	24.67	20.67	8.45	26.67	4.87	5.30	14.96	131.47	3.33	0.00	131.47 (100%)
Arka Anamika	38.67	39.17	114.67	2.00	19.10	14.00	9.53	14.31	14.33	17.00	21.11	204.97	52.00	45.89	109.58 (53.85)

* P<0.05 and ** P<0.01 Values precedes asterisks were rounded to nearest integer Heterosis over better parent denoted as HB (d_i) and mid parent as RH (d_{ii})
♣ Heterosis not estimated due to non significance of P vs F_1 Coefficient of YVMV in the direct cross was 18.06 and reciprocal cross was 28.10 and Nil in B_1

weight, fruit girth, and shoot infestation, indicating the presence of heterosis and prepotency of parents involved in this cross.

4.6.2.3 Response of hybrids to shoot and fruit borer infestation

Fruit borer infestation in the parent Arka Anamika was 45.89 per cent (Table 4.24). The F_1 hybrid as well as parent *A. tuberculatus* showed field resistance to fruit borer (Fruit damage was zero per cent). Shoot infestation in the F_1 was 6.67 per cent in the direct F_1s and 16.67 per cent in the reciprocal F_1s.

4.6.2.4 Performance of hybrids for yield and yield attributes

Days to first flowering in the reciprocal F_1 were 37.00 days whereas it was 38.67 days in the parent Arka Anamika. However, the difference was statistically insignificant. Plant height in the reciprocal F_1 was 219.56 cm whereas it was 177.84 cm in the direct cross. The heterobeltiosis was 58 per cent in reciprocal hybrid and 28 per cent in the direct cross (Table 4.24). The number of branches per plant varied from 2.33 in direct cross to 2.90 in reciprocal cross. Reciprocal F_1 exhibited prolificacy for fruit number. It produced 36.14 pods per plant (heterobeltiosis =36 per cent) whereas direct cross produced 25.67 fruits per plant (heterosis was insignificant). Fruit yield in the direct and reciprocal crosses were 125.08 and 161.34 g per plant.

4.6.2.5 Fertility of inter-specific hybrids

Pollen fertility in the hybrids varied from 23.00 per cent to 34.50 per cent. Selfing F_1 flowers produced pods but without seeds or shriveled seeds. When F_1 was backcrossed with Arka Anamika seed bearing pods were formed. However, the seeds were empty (without embryo) and did not germinate.

4.6.3 Hybridization among genotypes moderately resistant to shoot and fruit borer (*i.e.* between *A. esculentus* and *A. caillei*)

The observations recorded in field experiment four *i.e.* evaluation of 6 x 6 full diallel hybrids generated from *A. esculentus* cv. KL 9 (MR to shoot borer), *A. esculentus* cv. EC 2 (MR to fruit borer), *A. caillei* cv. AC 5 and Susthira (MR to shoot or fruit borer) and high yielding cultivars Arka Anamika and KL 28 are presented in Table 4.26.

4.6.3.1 ANOVA

The analysis of variance revealed significant variation among parents, among crosses, parent *vs.* crosses, indicating thereby, potential genetic differences among the parents, their prepotency and possible presence of heterosis in the F_1 for all the characters, except number of branches and leaf number (Table 4.25). Further, variance due to *gca* and *sca* were significant for all the traits. The reciprocal effects (*rca*) were significant for all the traits, except for number of branches, internodal length and shoot infestation.

4.6.3.2 Performance of parents

Shoot borer infestation in parents ranged from 12.67 in Susthira to 42.78 per cent in Arka Anamika (Table 4.26). Next to Susthira, parent AC 5 and KL 9 exhibited less damage to shoots (SI=13.67 and 18.21 per cent respectively). They were on par. Fruit borer infestation in parents ranged between 13.22 and 50.82 per cent. Parent EC 2, AC 5 and Susthira had less damage in fruits *i.e.* 13.22, 19.06 and 22.50 per cent respectively. They did not differ from each other. However, the *gca* effect was significant in significant direction for AC 5 alone.

With respect to yield and yield attributes in parents, early flowering was detected in Arka Anamika (37.56 days) and with high and significant *gca* effect in

Table 4.25 Skeleton of ANOVA for 6 x 6 full diallel progenies based on Griffing's method I model I

Source	df	Dff	Flp	Pht	Bran	LNo	IN	IL	FNo	AFW	FL	FG	FY	SI	FI	MFY	YVMV
i) Combined ANOVA for Parents and crosses																	
Rep	2	4.50	7.36	30.12	0.96	7.77	6.99	0.33	8.01	3.36	2.71	2.74	755	8.36	49.3	1680.4	159.54*
Parents	5	175.9**	85.83**	6312**	2.22**	143.9**	40.35**	17.74**	18.14**	11.95**	38.62**	38.94**	8811**	893.7**	714.5**	7103*	116.58**
F_1's	29	85.3**	32.41**	2449**	1.49**	138.9**	44.24**	5.42**	223.2**	17.66**	21.80**	18.61**	43323**	321.6**	329.9**	32491**	196.92**
P *versus* F_1	1	35.5**	59.67**	22673**	0.68	0.30	260.07**	32.60**	451.1**	11.58**	45.77**	23.74**	122895**	459.4**	454.5**	105321**	1805.5**
Error	70	0.63	4.16	56.40	0.47	7.49	12.54	1.88	5.61	3.45	1.47	1.97	101	77.1	78.40	903	61.64
ii) ANOVA for combining ability effects																	
GCA	5	198.0**	48.09**	3449**	1.89**	95.10**	33.26**	7.23**	61.13**	9.17**	14.44**	19.84**	12438**	601**	450.3**	13942**	122.74**
SCA	15	5.79**	9.82**	1109**	0.40**	31.17**	13.82**	2.70**	51.06**	6.32**	7.47**	6.71**	10102**	77**	97.60**	8375**	89.16**
RCA	15	3.52**	5.89**	524.1**	0.19	42.70**	13.85**	1.07	84.44**	3.41**	7.07**	3.52**	17380**	38	54.39*	11045**	49.90**
Error	70	0.21	1.38	18.79	0.16	2.5	4.8	0.63	1.87	1.15	0.49	0.65	33.77	25.69	26.13	301	20.54
iii) Variance components																	
σ^2A		32.08	799.91	395.86	0.25	10.81	3.29	0.77	1.94	0.50	1.20	2.22	443.46	87.55	59.17	971.24	5.97
σ^2D		3.24	4.90	633.03	0.14	16.65	5.24	1.20	28.56	3.00	4.05	3.52	5846.07	30.26	41.50	4688.13	39.84
σ^2r		1.66	2.26	252.67	0.02	20.10	4.53	0.22	41.29	1.13	3.29	1.44	8673.12	6.41	14.13	5372.00	14.68

* P<0.05 and ** P<0.01 σ^2r refers to variance due to reciprocals

Table 4.26 *Per se* performance, *sca* and heterosis in the inter- and intra-specific F_1s

	Shoot infestation (%)			Fruit infestation (%)		
	per se	d_{iii} %	*scal rca*‡	*per se*	d_{iii} %	*scal rca*
Group I Inter varietal *A. esculentus* hybrids						
A A x KL 28	30.67	15.00	-1.64	28.00	-16.97	0.3
A A x KL 9	20.67	-22.50*	7.69	20.48	-40.32	-4.62
A A x EC 2	30.00	12.50	-2.22	21.19	-38.24	6.09
KL 28 x A A	**40.67**	52.50**	5.0	46.92	36.75	9.22*
KL 28 x KL9	31.00	16.25	1.04	44.11	28.55	5.35
KL 28 x EC 2	24.89	-6.66	-0.43	36.40	6.08	-0.63
KL 9 x A A	30.00	12.48	10.11*	33.82	-1.43	-1.29
KL 9 x KL 28	29.67	11.25	-0.67	42.00	22.64	-1.02
KL 9 x EC 2	23.33	-12.50	-0.32	32.48	-5.34	3.94
EC 2 x A A	35.55	33.33*	2.78	**48.66**	41.82*	13.73**
EC 2 x KL 28	36.67	37.50*	5.89	31.96	-6.85	5.74
EC 2 x KL9	30.00	12.50	3.33	33.74	-1.65	0.63
Group I mean	**32.83**			**35.03**		
Group II Inter varietal *A. caillei* hybrids						
AC 5 x Susthira	23.78	-10.84	15.13	29.32	-14.55	8.62
Susthira x AC 5	20.00	-25.01*	-11.89**	13.92	-59.42**	-7.7
Group II mean	**26.89**			**21.62**		
Group III Inter specific hybrids (*A. esculentus* x *A. caillei*)						
A A x AC 5	33.33	-12.52	6.77	15.47	-54.91**	-8.45
A A x Susthira	20.67	-22.50	-2.28	19.05	-44.49*	-8.95
KL 28 x AC 5	**20.33**	-23.77	1.23	16.00	-52.62*	-5.36
KL 28 x Susthira	28.00	4.99	6.98	22.76	-33.65	-7.07
KL 9 x AC 5	**12.67**	-52.49**	7.62	**12.13**	-64.65**	-1.67
KL 9 x Susthira	26.67	0.00	10.84*	32.60	-4.99	1.64
EC 2 x AC 5	40.00	49.98*	12.6	18.98	-44.69*	3.49
EC 2 x Susthira	35.00	31.23*	13.14**	21.40	-37.64	0.16
AC5 x A A	28.33	6.22	7.5	14.81	-56.83**	-8.25
AC 5 x KL 28	20.67	-22.50	8.17	21.53	-37.25	2.64
AC 5 x KL 9	24.67	-7.50	11	13.87	-59.57**	-0.47
AC 5 x EC 2	22.00	-17.51	2.56	19.36	-43.56*	0.19
Susthira x A A	20.00	-25.01	10.68**	15.34	-55.29**	-1.85
Susthira x KL 28	25.00	-6.26	8.46	19.39	-43.49*	-1.69
Susthira x KL 9	30.00	12.49	9.96**	23.65	-31.07	-4.47
Susthira x EC 2	26.67	0.00	5.83	18.00	-47.31*	-1.66
Group III mean	**24.25**			**19.04**		
Group IV Parents						
Arka Anamika	42.78	*gca*	8.71**	47.06	*gca*	4.44*
KL 28	36.33		4.92*	50.82		6.44**
KL 9	18.21		0.7	34.03		4.78**
EC 2	26.11		2.6	13.22		-2.13
AC 5	13.67		-8.33**	19.06		-8.71**
Susthira	12.67		-8.6**	22.50		-4.82*
Group IV mean	**28.30**	**CD 5%**	**5.39**	**31.11**	**CD 5%**	**5.43**
Check : Texico F_1	26.67			34.31		
CD at 5 %	14.33	14.09	9.00/7.64	14.46	14.25	9.08/7.7

* $p<0.05$ and ** $p<0.01$. AA refers to Arka Anamika d_{iii} –Heterosis over Texico hybrid No 46

In a column values in bold and bold underlined faces refer to minimum and maximum values, respectively.

‡ *sca*-refers to specific combining ability effects and *rca* refers to reciprocal effects

(Table Contd...)

Table 4.26 continuation. *Per se* performance, *sca* and heterosis in 6 x 6 diallel progenies

	Days to first flowering			Flowering period		
	per se	d_{iii} %	*sca/ rca*	*per se*	d_{iii} %	*sca/ rca*
Group I Inter varietal *A. esculentus* hybrids						
A A x KL 28	38.00	1.79	-0.31	37.00	6.73	-1.76
A A x KL 9	39.33	5.36**	-1.28**	37.33	7.69	0.10
A A x EC 2	40.67	8.93**	0.55	38.50	11.06*	2.92**
KL 28 x A A	39.67	6.25**	0.83*	35.67	2.88	-0.67
KL 28 x KL9	40.33	8.04**	0.84	35.33	1.92	-2.73*
KL 28 x EC 2	37.33	0.00	-0.83*	33.67	-2.88	0.01
KL 9 x A A	**37.00**	-0.89	-1.17**	37.67	8.65	0.17
KL 9 x KL 28	41.00	9.82**	0.33	32.00	-7.69	-1.67
KL 9 x EC 2	37.33	0.00	-1.47**	34.67	0.00	1.87
EC 2 x A A	39.33	5.36**	-0.67	37.67	8.65	-0.42
EC 2 x KL 28	40.67	8.93**	1.67**	34.67	0.00	0.5
EC 2 x KL9	40.00	7.14**	1.33**	36.00	3.85	0.67
Group I mean	**39.22**			**35.85**		
Group II Inter varietal *A. caillei* hybrids						
AC 5 x Susthira	52.33	40.18**	1.99**	31.33	-9.62*	-2.84*
Susthira x AC 5	**54.33**	45.54**	1.00**	28.00	-19.23**	-1.67
Group II mean	**53.33**			**29.67**		
Group III Inter specific hybrids (*A. esculentus* x *A. caillei*)						
A A x AC 5	45.33	21.43**	0.16	38.33	10.58*	-0.32
A A x Susthira	48.00	28.57**	2.09**	36.50	5.29	-0.01
KL 28 x AC 5	45.00	20.54**	-0.05	**41.67**	20.19**	2.02*
KL 28 x Susthira	47.00	25.89**	1.88**	36.67	5.77	1.88
KL 9 x AC 5	48.00	28.57**	0.48	38.67	11.54**	1.88
KL 9 x Susthira	49.33	32.14**	2.24**	33.67	-2.88	0.07
EC 2 x AC 5	48.00	28.57**	0.14**	33.00	-4.81	1.79
EC 2 x Susthira	50.67	35.71**	1.4**	**27.67**	-20.19**	0.31
AC5 x A A	48.33	29.46**	1.5**	36.67	5.77	-8.3
AC 5 x KL 28	49.00	31.25**	2**	36.00	3.85	-2.83
AC 5 x KL 9	47.67	27.68**	-0.17	37.33	7.69	-0.67
AC 5 x EC 2	47.00	25.89**	-0.5	38.33	10.58*	2.67**
Susthira x A A	51.00	36.61**	1.5**	30.67	-11.54*	-2.92**
Susthira x KL 28	52.33	40.18**	2.67**	32.67	-5.77	-2
Susthira x KL 9	51.33	37.50**	1**	30.67	-11.54**	-1.5
Susthira x EC 2	48.33	29.46**	-1.17**	32.67	-5.77	2.5**
Group III mean	**48.52**			**35.07**		
Group IV Parents						
Arka Anamika	37.56	*gca*	-3.05**	38.39	*gca*	2.20**
KL 28	38.00		-2.67**	37.67		1.20*
KL 9	39.17		-2.37**	34.50		0.50
EC 2	40.33		-2.37**	24.33		-1.73**
AC 5	56.00		4.86**	34.00		0.92**
Susthira	50.44		5.60**	29.28		-3.10**
Group IV mean	**43.58**	**CD 5%**	**0.31**	**33.03**	**CD 5%**	**0.80**
Check: Texico F_1	**37.33**			**34.67**		
CD at 5 %	2.29	1.73	0.81/ 0.69	3.33	3.28	2.09 /1.78

(contd...)

Table 4.26 continuation. *Per se* performance, *sca* and heterosis in 6 x 6 diallel progenies

	Plant height (cm)			Internode number		
	per se	d_{iii} %	*scal rca*	*per se*	d_{iii} %	*scal rca*
Group I Inter varietal *A. esculentus* hybrids						
A A x KL 28	138.83	16.34**	-23.11**	19.83	21.43	-2.95
A A x KL 9	172.50	44.55**	-1.66	21.50	31.63	0.8
A A x EC 2	182.17	52.65**	-1.37	19.17	17.35	-0.08
KL 28 x A A	162.33	36.03**	11.75**	**13.00**	-20.41	-3.42*
KL 28 x KL9	195.33	63.69**	19.56**	19.67	20.41	0.43
KL 28 x EC 2	172.67	44.69**	23.1**	16.33	0.00	1.13
KL 9 x A A	165.83	38.97**	-3.33	20.17	23.47	-0.67
KL 9 x KL 28	183.33	53.63**	-6	19.00	16.33	-0.33
KL 9 x EC 2	161.17	35.06**	18.96**	19.83	21.43	-0.97
EC 2 x A A	123.17	3.21	-29.5**	19.33	18.37	0.08
EC 2 x KL 28	179.50	50.42**	3.42	22.33	36.73*	3
EC 2 x KL9	177.00	48.32**	7.92*	19.83	21.43	0
Group I mean	**167.82**			**19.17**		
Group II Inter varietal *A. caillei* hybrids						
AC 5 x Susthira	130.00	8.94	-20.11**	19.00	16.33	-4.04*
Susthira x AC 5	153.53	28.66**	11.77**	21.33	30.61	1.17
Group II mean	**141.77**			**20.17**		
Group III Inter specific hybrids (*A. esculentus* x *A. caillei*)						
A A x AC 5	215.33	80.45**	18.14**	29.33	79.59**	3.02
A A x Susthira	126.83	6.28	0.24	22.67	38.78*	1.7
KL 28 x AC 5	**227.33**	90.50**	10.19*	**32.67**	100.00**	3.68*
KL 28 x Susthira	168.83	41.48**	19.9**	22.00	34.69	1.91
KL 9 x AC 5	212.53	78.10**	12.57**	25.00	53.06**	0.90
KL 9 x Susthira	163.83	37.29**	0.15	24.00	46.94**	-0.09
EC 2 x AC 5	204.00	70.95**	3.68	27.50	68.37**	0.52
EC 2 x Susthira	151.83	27.23**	16.95**	23.33	42.86*	2.62
AC5 x A A	205.67	72.35**	-4.83	24.33	48.98**	-2.50
AC 5 x KL 28	175.67	47.21**	-25.83**	19.83	21.43	-6.42**
AC 5 x KL 9	189.50	58.80**	-11.52**	23.50	43.88*	-0.75
AC 5 x EC 2	146.67	22.91**	-28.67**	18.83	15.31	-4.33**
Susthira x A A	162.17	35.89**	17.67**	22.50	37.76*	-0.08
Susthira x KL 28	157.40	31.90**	-5.72	21.33	30.61	-0.33
Susthira x KL 9	**117.17**	-1.82	-23.33**	16.67	2.04	-3.67*
Susthira x EC 2	129.17	8.24	-11.33**	21.33	30.61	-1.00
Group III mean	**172.12**			**23.43**		
Group IV Parents						
Arka Anamika	182.50	*gca*	6.42**	18.00	*gca*	-0.16
KL 28	123.00		5.37**	14.17		-1.28
KL 9	117.33		2.51	16.55		-0.62
EC 2	72.00		-14.3**	13.00		-1.33
AC 5	185.50		24.04**	23.17		3.16**
Susthira	96.65		-24.06**	19.17		0.23
Group IV mean	**129.50**	**CD 5%**	**4.61**	**17.34**	**CD 5%**	**2.17**
Check : Texico F_1	119.33			16.33		
CD at 5 %	12.26	12.17	7.20/6.53	5.78	5.70	3.63/3.08

(Contd...)

Table 4.26 continuation. *Per se* performance, *sca* and heterosis in 6 x 6 diallel progenies

	Internode length (cm)			No. of fruits / plant		
	per se	d_{iii} %	*scal rca*	*per se*	d_{iii} %	*scal rca*
Group I Inter varietal *A. esculentus* hybrids						
A A x KL 28	**7.81**	-15.96	-1.37	15.89	-2.69	0.56
A A x KL 9	12.22	31.49*	0.67	18.33	12.25*	2.51*
A A x EC 2	11.05	18.87	0.4	8.00	-51.01**	-3.17**
KL 28 x A A	10.32	11.08	1.26*	8.33	-48.97**	-7.28**
KL 28 x KL9	11.75	26.47*	1.5*	9.50	-41.82**	-7.70**
KL 28 x EC 2	11.13	19.80	1.0	9.33	-42.85**	-0.19
KL 9 x A A	9.82	5.70	-1.2*	11.50	-29.58**	-5.75**
KL 9 x KL 28	**12.30**	32.32**	0.27	**7.50**	-54.07**	-1
KL 9 x EC 2	8.26	-11.15	-0.94	9.67	-40.80**	-0.72
EC 2 x A A	7.96	-14.38	-1.54*	13.13	-19.58	2.57**
EC 2 x KL 28	9.30	0.07	-0.92	14.67	-10.19	2.67*
EC 2 x KL9	8.26	-11.15	0	12.67	-22.43	1.5
Group I mean	**10.01**			**11.54**		0.56
Group II Inter varietal *A. caillei* hybrids						
AC 5 x Susthira	8.02	-13.70	0.56	10.33	-36.72**	-8.2**
Susthira x AC 5	8.47	-8.90	0.22	11.33	-30.60**	0.5
Group II mean	**8.24**			**10.83**		
Group III Inter specific hybrids (*A. esculentus* x *A. caillei*)						
A A x AC 5	8.97	-3.52	-0.14	25.00	53.09**	4.53**
A A x Susthira	8.35	-10.11	-0.31	13.67	-16.31	0.51
KL 28 x AC 5	10.62	14.28	1.03	27.00	65.34**	1.41
KL 28 x Susthira	8.53	-8.18	-0.5	18.50	13.29	6.97**
KL 9 x AC 5	8.71	-6.28	-0.37	**32.67**	100.04**	7.52**
KL 9 x Susthira	9.20	-1.00	-0.01	13.33	-18.35	2.2
EC 2 x AC 5	8.30	-10.69	0.26	23.33	42.89**	4.06**
EC 2 x Susthira	10.44	12.37	1.96**	13.07	-19.98*	3.24
AC5 x A A	9.48	2.01	0.26	15.33	-6.10	-7.33**
AC 5 x KL 28	10.38	11.69	-0.12	9.00	-44.89**	-14**
AC 5 x KL 9	9.46	1.76	0.37	11.94	-26.88**	-13.86**
AC 5 x EC 2	8.51	-8.43	0.11	12.33	-24.47**	-9.00
Susthira x A A	8.32	-10.47	-0.02	14.00	-14.27	0.17
Susthira x KL 28	7.97	-14.28	-0.28	17.00	4.10	0.25
Susthira x KL 9	8.25	-11.19	-0.47	14.00	-14.27	0.33
Susthira x EC 2	8.32	-10.47	-1.06	16.33	0.02	2.63*
Group III mean	**8.99**			**14.63**		
Group IV Parents						
Arka Anamika	11.13	*gca*	0.61	11.67	*gca*	0.67
KL 28	8.88		0.72*	12.44		-0.88
KL 9	9.71		0.70*	9.07		-1.19*
EC 2	5.20		-0.61*	7.67		-2.19**
AC 5	7.06		-0.35	14.17		4.20**
Susthira	5.28		-1.07**	9.15		-0.61
Group IV mean	**7.88**	**CD 5%**	**0.84**	**10.69**	**CD 5%**	**1.45**
Check : Texico F_1	9.29			16.33		
CD at 5 %	2.23	2.21	1.41/1.19	3.86	3.83	2.43

(Contd...)

Table 4.26 continuation. *Per se* performance, *sca* and heterosis in 6 x 6 diallel progenies

	Average fruit weight (g)			Fruit length (cm)		
	per se	d_{iii} %	*scal rca*	*per se*	d_{iii} %	*scal rca*
Group I Inter varietal *A. esculentus* hybrids						
A A x KL 28	13.08	-10.94**	0.55	16.53	13.48**	2.07**
A A x KL 9	**16.13**	9.82**	3.31**	14.15	-2.88	-0.22
A A x EC 2	11.24	-23.49**	1.68	9.50	-34.80**	-0.03
KL 28 x A A	12.17	-17.13**	-0.45	11.02	-24.39**	-0.93
KL 28 x KL9	14.01	-4.66	1.45	13.14	-9.79	-0.11
KL 28 x EC 2	9.87	-32.83**	-0.19	14.67	0.66	-1.09
KL 9 x A A	13.80	-6.04*	-1.16	11.00	-24.50**	-0.46
KL 9 x KL 28	9.83	-33.11**	-2.09*	11.42	-21.62**	2.08**
KL 9 x EC 2	8.76	-40.37**	-1.12	9.67	-33.63**	3.6**
EC 2 x A A	15.49	5.46*	2.12*	10.00	-31.37**	2.28*
EC 2 x KL 28	10.72	-27.01**	0.43	9.67	-33.63**	2.42**
EC 2 x KL9	9.14	-37.76**	0.19	10.06	-30.95**	0
Group I mean	**12.02**			**11.74**		
Group II Inter varietal *A. caillei* hybrids						
AC 5 x Susthira	13.45	-8.44*	2.13	15.33	5.24	-0.62
Susthira x AC 5	14.92	1.60	0.74	13.48	-7.48	0.11
Group II mean	**14.19**			**14.41**		
Group III Inter specific hybrids (*A. esculentus* x *A. caillei*)						
A A x AC 5	10.19	-30.63**	-2.2	15.92	9.24	-2.1**
A A x Susthira	11.56	-21.32**	-1.74	12.52	-14.07	-0.32
KL 28 x AC 5	8.49	-42.22**	-0.47	12.87	-11.69	1.59
KL 28 x Susthira	10.54	-28.26**	0.1	14.90	2.26	-0.32
KL 9 x AC 5	9.68	-34.10**	-2.28*	13.27	-8.95	-0.95
KL 9 x Susthira	9.70	-33.99**	-0.81	15.92	9.24	-0.72
EC 2 x AC 5	8.75	-40.46**	0.24	**9.06**	-37.82**	1.76**
EC 2 x Susthira	12.08	-17.79**	1.55	11.33	-22.24**	1.81*
AC5 x A A	8.73	-40.58**	-0.73	13.45	-7.69	1.22*
AC 5 x KL 28	11.50	-21.72**	1.51	14.98	2.84	2.67**
AC 5 x KL 9	**7.53**	-48.76**	-0.22	13.56	-6.95	0.52
AC 5 x EC 2	11.87	-19.18**	1.56	12.92	-11.35	1.43*
Susthira x A A	12.28	-16.40**	0.36	13.27	-8.95	3.45**
Susthira x KL 28	14.59	-0.66	2.03*	**17.05**	17.02**	1.8**
Susthira x KL 9	12.80	-12.86**	1.55	14.68	0.75	3**
Susthira x EC 2	15.18	3.32	1.55	11.26	-22.72*	1.2*
Group III mean	**11.53**			**13.16**		
Group IV Parents						
Arka Anamika	11.67	*gca*	0.93*	14.83	*gca*	0.98**
KL 28	9.44		-0.26	13.67		0.27
KL 9	9.50		-0.68	11.97		0.65*
EC 2	7.93		-0.65	8.00		-0.61*
AC 5	12.63		-0.68	11.72		-1.94**
Susthira	12.84		1.33**	13.76		0.66*
Group IV mean	**10.67**	**CD 5%**	**1.14**	**12.32**	**CD 5%**	**0.74**
Check : Texico F_1	14.69			14.57		
CD at 5 %	3.03	2.98	1.90/1.62	1.97	1.94	1.24/1.05

(Contd...)

Table 4.26 continuation. *Per se* performance, *sca* and heterosis in 6 x 6 diallel progenies

	Fruit girth (mm)			Fruit yield (g) / plant		
	per se	d_{iii} %	*sca/ rca*	*per se*	d_{iii} %	*sca/ rca*
Group I Inter varietal *A. esculentus* hybrids						
A A x KL 28	23.18	49.44**	1.13	207.89	-13.36*	21.42**
A A x KL 9	22.50	45.02**	0.27	295.71	23.24**	107.5**
A A x EC 2	24.28	56.53**	-0.37	89.92	-62.52**	-29.38**
KL 28 x A A	21.51	38.68**	-0.84	101.45	-57.72**	-128.9**
KL 28 x KL9	20.48	32.02**	1.73*	133.05	-44.55**	-97.4**
KL 28 x EC 2	15.56	0.30	-4.56	92.09	-61.62**	-6.73
KL 9 x A A	19.65	26.67**	-1.42*	158.74	-33.84**	-134.9**
KL 9 x KL 28	22.63	45.90**	1.08	73.70	-69.28**	-35.51**
KL 9 x EC 2	21.86	40.91**	-0.23	84.67	-64.71**	-23.55**
EC 2 x A A	21.94	41.45**	-1.17	203.45	-15.21*	71.36**
EC 2 x KL 28	20.33	31.05**	2.38**	157.26	-34.46**	44.77**
EC 2 x KL9	21.86	40.91**	0	115.81	-51.73**	26.79**
Group I mean	**21.32**			**142.81**		
Group II Inter varietal *A. caillei* hybrids						
AC 5 x Susthira	21.90	41.19**	-1.24	138.98	-42.08**	-79.13**
Susthira x AC 5	25.82	66.42**	1.96**	169.15	-29.50**	20.15**
Group II mean	**23.86**			**154.07**		
Group III Inter specific hybrids (*A. esculentus* x *A. caillei*)						
A A x AC 5	23.93	54.28**	0.91	254.75	6.17	35.71**
A A x Susthira	22.40	44.41**	-0.49	157.97	-34.16*	-25.62**
KL 28 x AC 5	22.39	44.35**	0.71	229.15	-4.50	2.68
KL 28 x Susthira	26.52	70.97**	1.52*	194.95	-18.75**	115.6**
KL 9 x AC 5	23.18	49.40**	0.91	316.21	31.79**	52.96**
KL 9 x Susthira	22.69	46.28**	0.03	129.29	-46.11**	20.47**
EC 2 x AC 5	26.68	71.96**	0.17	204.09	-14.94*	55.46**
EC 2 x Susthira	26.79	72.67**	2.64**	157.80	-34.23**	76.27**
AC5 x A A	25.62	65.17**	0.85	133.83	-44.22**	-118.6**
AC 5 x KL 28	24.83	60.06**	1.22	103.50	-56.86**	-161.7**
AC 5 x KL 9	23.60	52.15**	0.21	89.88	-62.54**	167.6**
AC 5 x EC 2	23.97	54.53**	-1.35*	146.42	-38.98**	-88.88**
Susthira x A A	23.42	50.97**	0.51	171.92	-28.35**	10.12*
Susthira x KL 28	21.39	37.86**	-2.57**	248.07	3.39	51.28**
Susthira x KL 9	21.38	37.82**	-0.66	179.20	-25.31**	37.39**
Susthira x EC 2	27.88	79.72**	0.55	247.90	3.32	75.57**
Group III mean	**24.17**			**168.26**		
Group IV Parents						
Arka Anamika	20.74	*gca*	-0.3	136.11	*gca*	29.78**
KL 28	19.73		-1.27**	117.47		-17.47**
KL 9	16.70		-1.69**	86.20		-28.81**
EC 2	27.11		0.98**	60.82		-38.09**
AC 5	24.08		1.38**	178.97		37.77**
Susthira	22.13		0.91**	117.46		16.83**
Group IV mean	**21.75**	**CD 5%**	0.86	**116.17**	**CD 5%**	6.17
Check : Texico F_1	15.51			239.94		
CD at 5 %	2.29	2.28	1.44/1.22	16.44	16.32	10.3/8.76

(Contd...)

Table 4.26 continuation. *Per se* performance, *sca* and heterosis in 6 x 6 diallel progenies

	Marketable fruit yield (g)			MFY %	Branches	CI % for YVMV
	per se	d_{iii} %	*sca/ rca*			
Group I Inter varietal *A. esculentus* hybrids						
A A x KL 28	148.21	-8.26	18.69	74.31	1.56	0.00
A A x KL 9	195.70	21.13*	70.73**	67.95	1.72	0.00
A A x EC 2	75.24	-53.43**	-42.14*	88.71	0.83	15.86
KL 28 x A A	67.49	-58.23**	-97.0**	72.96	1.17	0.00
KL 28 x KL9	73.62	-54.43**	-78.7**	63.99	**0.39**	0.00
KL 28 x EC 2	73.98	-54.21**	-2.24	87.79	1.33	22.71
KL 9 x A A	110.69	-31.49**	-84.4**	74.89	1.39	13.06
KL 9 x KL 28	**46.23**	-71.39**	-15.95	76.66	0.78	0.00
KL 9 x EC 2	57.32	-64.52**	-23.78	75.73	0.89	14.61
EC 2 x A A	103.78	-35.77**	10.06	54.64	1.33	12.00
EC 2 x KL 28	106.74	-33.93**	19.38	72.53	1.56	19.87
EC 2 x KL9	78.15	-51.63**	16.56	72.75	0.89	12.79
Group I mean	**94.76**			**73.58**	**1.15**	**9.24**
Group II Inter varietal *A. caillei* hybrids						
AC 5 x Susthira	100.92	-37.53**	-85.3**	74.47	1.67	34.18
Susthira x AC 5	146.67	-9.21	32.25*	89.61	2.00	16.37
Group II mean	**123.80**			**82.04**	**1.83**	**25.27**
Group III Inter specific hybrids (*A. esculentus* x *A. caillei*)						
A A x AC 5	221.28	36.97**	60.31**	89.06	2.61	0.00
A A x Susthira	129.81	-19.65	1.41	86.44	2.30	24.31
KL 28 x AC 5	190.37	17.83	7.72	85.38	3.17	0.00
KL 28 x Susthira	154.25	-4.52	104.9**	82.85	2.72	17.73
KL 9 x AC 5	**265.87**	64.56**	57.8*	86.48	2.83	0.00
KL 9 x Susthira	88.79	-45.04**	10.94	**73.72**	1.83	16.44
EC 2 x AC 5	166.72	3.20	38.6*	84.99	2.44	27.67
EC 2 x Susthira	126.84	-21.49*	70.25**	84.94	2.28	26.83
AC5 x A A	117.86	-27.05*	-102**	92.63	2.33	0.00
AC 5 x KL 28	81.22	-49.73**	-137.**	87.96	2.00	0.00
AC 5 x KL 9	77.72	-51.90**	-138.7*	89.20	1.67	0.00
AC 5 x EC 2	116.60	-27.83**	-76.3**	84.86	1.94	30.21
Susthira x A A	145.44	-9.98	12.29	88.81	1.89	24.30
Susthira x KL 28	206.73	27.96	49.73**	86.63	1.83	21.16
Susthira x KL 9	144.50	-10.56	45.64**	84.86	1.94	**35.24**
Susthira x EC 2	212.45	31.50**	72.46**	88.53	**3.17**	31.30
Group III mean	**139.61**			**86.40**	**2.31**	**15.94**
Group IV Parents						
Arka Anamika	73.27		9.79	55.98	2.00	0.00
KL 28	65.60		-23.1*	55.69	1.06	0.00
KL 9	58.99		-32.7**	70.05	1.00	0.00
EC 2	52.10		-30.2**	90.78	2.50	12.89
AC 5	146.95		50.18**	83.59	3.17	0.00
Susthira	93.31		26.06**	82.61	2.45	10.33
Group IV mean	**81.70**		**18.44**	**73.12**	**2.03**	**3.87**
Check: Texico F_1	161.56			**71.66**	**1.00**	**0.00**
CD at 5 %	49.09	48.36	30.8/26.2	14.32	NS	12.82

* $p<0.05$ and ** $p<0.01$. AA refers to Arka Anamika d_{iii} –Heterosis over Texico hybrid No 46
In a column values in bold and bold underlined faces refer to minimum and maximum values, respectively.

negative direction (-3.05) (Table 4.26). The flowering period lasted from 24.33 days in EC 2 to 38.39 days in Arka Anamika. The *gca* effects of this trait were high and significant for Arka Anamika (2.20). The parent AC 5 registered the high mean for plant height (185.50 cm) and its *gca* effect was significant. Number of internode ranged from 13 in parent EC 2 to 23.17 in AC 5. The *gca* effect of this trait was significant (3.16) for AC 5 alone. Internodal length was shortest (5.28 cm) in Susthira. Its *gca* effect were significant in desirable direction (-1.07). Number of fruits per plant varied from 7.67 in EC 2 to in 14.17 in AC 5. The *gca* effects were significant (4.20) in desirable direction for AC 5 alone. Fruit yield per plant ranged between 660.82 g in EC 2 and 178.97 g in AC 5. Next to AC 5, Arka Anamika (136.11g fruits per plant) and Susthira (117.46 g fruits per plant) manifested high fruit yield with significant *gca* effects. Parent AC 5 also excelled for marketable fruit yield by recording146.95 g fruits per plant. Parents Arka Anamika, KL 28, KL 9 and AC 5 showed field resistance to YVMV (CI=0 %).

4.6.3.3 Crossability between *A. esculentus* x *A. caillei* and nature of F_1 hybrids

The 30 F_1s of 6 x 6 diallel mating are sorted into three groups *viz.,* i) *A. esculentus* x *A. esculentus* crosses (12 hybrids), ii) *A. caillei* x *A. caillei* crosses (2 hybrids) and iii) *A. esculentus* x *A. caillei* crosses (16 hybrids). Their mean, *sca* effects and standard heterosis for 14 traits are presented in Table 4.26. Comparison of hybrids in the three groups revealed that intra-specific hybrids of *A. esculentus* flowered earlier (39.22 days) than intra-specific hybrids of *A. caillei* (53.33 days), exhibiting long flowering period (35.85 days), tall plant stature (167.82 cm), high internode number (19.17), long but thin fruit (fruit length=11.74 cm; fruit girth=21.32 mm) than the intra-specific hybrids of *A. caillei* (29.67 days). On the other hand, the inter-specific hybrids exhibited high fruit number (14.63 fruits per plant), high fruit yield (168.26 g per plant), low shoot damage (24.25 per cent) and low fruit damage (9.04 per cent) than intra-specific hybrids of *A. esculentus*.

Since the 6 x 6 diallel involves genotypes belonging to two species namely, *A. esculentus* and *A. caillei*, the crossability between these species needs mention here. Crosses between *A. esculentus* and *A. caillei* resulted in pods with germinable seeds in both direct as well as reciprocal crossing. Fruit shapes in the *A. esculentus* x *A. caillei* hybrid appeared intermediate between parents. However, the hybrid resembled to that of *A. caillei* for leaf size, leaf veins and stem thickness. The hybrid showed lobed leaves resembling to that of *A. esculentus.* The number of epicalyx segments in the direct and reciprocal F_1's was between 5 and 10 *i.e.* intermediate between those in parents but shape of the epicalyx was triangular *i.e.* similar to that of *A. caillei.* Pollen fertility in the hybrid was 21.73 per cent.

4.6.3.4 Response of F_1 hybrids to shoot and fruit borer infestation

Percentage of shoot infestation in the 30 F_1s ranged from 12.67 to 40.67 per cent (Table 4.26). Among the 16 intra-specific hybrids of *A. esculentus,* Arka Anamika x KL 9 showed the least shoot borer infestation (20.67 per cent) while the cross combination KL 9 x AC 5 showed the least shoot damage (12.67 per cent) among the 12 inter-specific crosses between *A. esculentus* x *A. caillei.* Shoot infestation in the intra-specific hybrids of *A. caillei* was 20 per cent in Susthira x AC 5 and 23.78 per cent in Susthira x AC 5. The standard heterosis over check (Texico hybrid No 46) and *sca* effects of the last two crosses were not only significant but also in negative direction, which is desirable for this trait.

Percentage fruit infestation in the hybrids was between 12.13 and 48.66 per cent (Table 4.26). The interspecific hybrid KL 9 x AC 5 and intra-specific hybrids Arka Anamika x KL 9 and Arka Anamika x EC 2 exhibited the lowest fruit damage *i.e.*12.13, 20.48 and 21.19 per cent respectively in their respective hybrid groups. The standard heterosis of these hybrids were -64.65 and -40.32 per cent, respectively. However, their *sca* effects were insignificant.

4.6.3.5 Performance of F_1 hybrids for yield and yield attributes

4.6.3.5.1 Days to first flowering

The intra-specific hybrids of *A. esculentus* flowered earlier (39.22 days) than *A. esculentus* x *A. caillei* hybrids (48.52 days) and intra-specific hybrids within *A. caillei* (53.33 days). The *sca* effects were significant and negative for two cross combinations namely, Arka Anamika x KL 9 (-1.28) and KL 9 x EC 2 (-1.47). However, hybrids manifesting significant negative heterosis over standard hybrid (Texico hybrid no 46) could not be discernible.

4.6.3.5.2 Flowering period

Flowering period ranged from 27.67 days in EC 2 x Susthira to 41.67 days in KL 28 x AC 5 (Table 4.26). Standard heterosis was positive and significant for Arka Anamika x EC 2 (11.06 per cent), KL 28 x AC 5 (20.19 per cent), KL 9 x AC 5 (11.54 per cent), Arka Anamika x AC 5 and AC 5 x EC 2 (10.58 per cent). The *sca* effects were significant in the above crosses except Arka Anamika x AC 5 and KL 9 x AC 5

4.6.3.5.3 Plant height

The average height 16 inter-specific hybrids of *A. esculentus* x *A. caillei* was 172.12 cm whereas the average plant height was 167.82 cm in 12 intra-specific hybrids of *A. esculentus* and 141.77 cm in two intra-specific hybrids of *A. caillei* (Table 4.26). Cross combination KL 28 x AC 5 was the tallest (227.33 cm) followed by Arka Anamika x AC 5 (215.33 cm), KL 9 x AC 5 (212.53 cm). The standard heterosis in the above hybrids was 90.50, 80.45 and 78.10 per cent respectively and their *sca* effects were significant. Reciprocal effects were significant for two crosses *viz.*, Susthira x AC 5 (mean=153.53 cm) and Susthira x Arka Anamika (mean= 162.17 cm).

4.6.3.5.4 Internodal number

Number of internodes on main stem varied between 13 (KL 28 x Arka Anamika) to 32.67 (KL 28 x AC 5) (Table 4.26). The *sca* effects were significant in KL 28 x AC 5. This hybrid manifested 100 per cent standard heterosis.

4.6.3.5.5 Length of internode

The shortest internode (7.81 cm) was observed in the hybrid Anamika x KL 28 (direct cross) whereas the longest (12.30 cm) in the hybrid KL 9 x KL 28 (reciprocal cross) (Table 4.26). No hybrid was found superior to check

4.6.3.5.6 Number of fruits per plant

Number of fruits per plant in the hybrids ranged from 7.50 to 32.67 (Table 4.26). The inter-specific hybrid KL 9 x AC 5 recorded 32.67 fruits per plant followed by KL 28 x AC 5 (27 fruits per plant) and Arka Anamika x AC 5 (25 fruits per plant). Among intra-specific hybrids of *A. esculentus,* cross Arka Anamika x KL 9 manifested significant standard heterosis (12.25 per cent). The *sca* effects were positively significant in the above crosses, except KL 28 x AC 5.

4.6.3.5.7 Average fruit weight

Weight of single fruit varied between 7.53 g in AC 5 x KL 9 and 16.13 g in Arka Anamika x KL 9 (Table 4.26). The standard heterosis in the cross Arka Anamika x KL 9 was 9.82 per cent and the *sca* effects were positive and significant (3.31).

4.6.3.5.8 Fruit length

Shortest fruit length was observed in EC 2 X AC 5 whereas the lengthy one (17.05 cm) in Susthira x KL 28 (Table 4.26). The latter was a reciprocal cross and manifested 17.02 per cent standard heterosis. The reciprocal effect (*rca*) was

positive and significant (1.8). The intra-specific hybrid of *A. esculentus*, Arka Anamika x KL 28 also showed high *per se* for fruit length (16.5 cm) with significant *sca* effects and high standard heterosis (13.48 per cent).

4.6.3.5.9 Fruit girth

Fruit girth was thin (15.56 mm) in the cross KL 28 x EC 2 to 27.88 mm whereas thick (27.88 mm) in the cross Susthira x EC 2 (Table 4.26).

4.6.3.5.10 Fruit yield

The range of fruit yield in 30 hybrids was from 73.70 g to 316.21 g per plant (Table 4.26). The mean fruit yield in 16 inter-specific crosses of *A. esculentus* x *A. caillei* was 168.26 g per plant whereas it was 142.81 g per plant in 12 intra-specific crosses of *A. esculentus*. The inter-specific hybrid KL 9 x AC 5 registered higher fruit yield *i.e.* 316.21 g per plant followed by inter-varietal cross Arka Anamika x KL 9 (295.71 g/plant). The standard heterosis of cross KL 9 x AC 5 and Arka Anamika x KL 9 were 31.79 and 23.24 per cent respectively. Their *sca* effects were positive and significant. Reciprocal effect was significant in Susthira x KL 28 and Susthira x EC 2 which recorded 248.07 and 274.90 g fruits per plant.

4.6.3.5.11 Marketable fruit yield

Marketable fruit yield ranged from 46.23 to 265.87 g per plant (Table 4.26). The hybrids which manifested significant positive heterosis for this trait, in their descending order, were KL 9 x AC 5 (m = 265.87 g; d_{iii} = 65.56 %), Arka Anamika x AC 5 (m = 36.97 g; d_{iii} = 60.31 %), and Arka Anamika x KL 9 (m = 195.70 g; d_{iii} = 21.13 %). The reciprocal effects were positive and significant for Susthira x EC 2 which recorded 212.45 g fruits per plant and 31.50 % standard heterosis.

4.6.3.5.12 YVMV

The co-efficient of infection for YVMV ranged from 0 to 35.24 per cent (Table 4.26). Eleven hybrids namely, Arka Anamika x KL 28, Arka Anamika x KL 9, KL 28 x Arka Anamika, KL 28 x KL 9, KL 9 x KL 28, Arka Anamika x AC 5, KL 28 x AC 5, KL 9 x AC 5, AC 5 x Arka Anamika, AC5 x KL 28, AC 5 x KL 9 manifested field resistance to YVMV (Co-efficient of infection= 0 per cent).

4.7 SELECTION OF CROSS COMBINATIONS FOR FURTHER STUDIES

Considering resistance to shoot infestation, fruit infestation and YVMV on one side and yield attributes (*per se*, heterosis) and combining ability (*sca*) on the other side, the following two cross combinations were selected for further studies.

1. Intra-specific cross of *A. esculentus*: **Arka Anamika x KL 9:** This cross combination showed high fruit number, high yield, field resistance to YVMV, early flowering, moderate degree of resistance to shoot and fruit borer and high marketable fruit yield (Plate 7). Its parent KL 9 was moderately resistant to shoot borer and Arka Anamika showed field resistance to YVMV.

2. Inter-specific hybrid ***A. esculentus*** **cv. KL 9 x** ***A. caillei*** **cv. AC 5:** This cross combination manifested prolificity for fruit number vis-à-vis fruit yield, moderate degree of resistance to both shoot and fruit borer (Plate 7). Both the parents of this cross were moderately resistant to shoot borer

4.8 GENERATION MEAN ANALYSIS

The two promising crosses mentioned above were advanced to F_2 and BC_1 to isolate high yielding segregants showing inbuilt resistance to shoot and fruit borer. To elucidate the nature of gene action for shoot and fruit borer resistance, generation mean analysis was carried out using the data recorded from P_1, P_2, F_1, F_2, B_1 and B_2 generations of the above two cross combinations.

4.8.1 Generation mean analysis in the cross Arka Anamika x KL 9

The *per se* performance of P_1, P_2, F_1, F_2, B_1 and B_2 of inter-varietal cross (of *A. esculentus*) Arka Anamika x KL 9 for 15 quantitative traits are presented in Table 4.27. The results of scaling test are presented in Table 4.28 and the estimates of gene effects [m, d, h, i, j, l] are given in Tables 4.29. Salient results are highlighted below.

4.8.1.1 Shoot infestation

***Per se* performance:** Shoot borer infestation in moderately resistant parent (KL 9) was 28.55 per cent (Table 4.27), whereas in susceptible parent (Arka Anamika) shoot infestation was 41.97 per cent. Shoot borer damage in the F_1 was 23.33 per cent. The mean shoot infestation in the segregating generation *i.e.* F_2, B_1 and B_2 were on par with each other as well as with that of resistant parent.

Scaling test: Scales A, B and D were significant, indicating the presence of epistasis (Table 4.28).

Gene effects: Since epistasis were present, six parameters [m,d,h,i,j,l] were estimated (Table 4.29). The estimates specifying additive effects [d=4], additive x additive interaction effects [i=6.93] and additive x dominance effects [j=-2.71] were significant. When significant main effects [d=4] were compared with significant interaction effects [i + j = 4.2] it appears that both main effects and interaction effects were of equally importance. Since the probability for χ^2 test was found below 0.05, joint scaling test was performed with square root transformed values. The resulting χ^2 value was significant for digenic interaction model. The estimates of variance components in F_2 revealed that non-additive variance component was not only low but in negative direction (σ^2D=-10.02). The heritability in narrow sense was 33.2 per cent (Table 4.30). The degree of

Table 4.27 Performance of six generation materials of inter-varietal cross (of *A. esculentus*) Arka Anamika x. KL 9 for various quantitative traits

	P_1	P_2	F_1	F_2	B_1	B_2	CD 5 %	d_i %	ID %
% shoot infestation	41.97	28.55	23.33	25.27	29.00	23.33	5.00	-22.9**	-9.07
% fruit infestation	42.06	39.50	32.19	37.89	39.43	33.31	3.64	-18.49	-17.69
Days to first flowering	43.00	38.00	37.67	39.33	42.33	38.00	1.96	0.86	-11.50
Flowering period	44.00	40.67	49.33	44.00	46.67	42.67	2.48	21.31**	10.81
Plant height (cm)	112.33	131.0	154.67	129.33	115.00	135.7	8.77	18.06**	16.38
Branches / plant	1.67	1.00	1.67	1.90	1.33	1.67	NS		
Internode / plant	15.33	16.00	19.00	16.83	15.33	17.33	NS		
Internode length (cm)	7.49	8.68	8.61	8.81	7.93	7.97	NS		
Fruits / plant	13.33	14.33	20.67	19.00	17.67	18.33	3.04	44.18**	8.06
Average fruit weight (g)	14.00	14.53	15.47	13.17	14.43	14.75	NS		
Fruit length (cm)	14.02	13.40	13.47	12.87	13.47	13.61	NS		
Fruit girth (mm)	16.14	17.78	16.81	16.50	16.42	16.40	NS		
Fruit yield / plant (g)	187.00	208.7	293.4	273.16	264.17	275.0	42.83	40.61**	6.89
CI for YVMV (%)	0.00	0.00	0.00	9.33	8.19	0.0	-		
Marketable fruit yield in g and (%)	111.22 (59%)	134.12 (65%)	202.33 (69%)	172.36 (63 %)	163.73 (62%)	184.96 (67%)	32.78	50.85**	14.81

P1 =Arka Anamika and P2 = KL 9.

d_i refers to heterobeltiosis (F_1 -BP) / F_1 ; ID refers to inbreeding depression effects ($F_1 - F_2$)/ F_1

Table 4.28 Scaling test to detect the presence epistasis in the cross *A. esculentus* cv. Arka Anamika x *A. esculentus* cv. KL 9

Traits	Scale A	Scale B	Scale C	Scale D
Shoot infestation (%)	3.69**	9.12**	5.88	-3.47*
Fruit infestation (%)	4.60**	-5.61**	5.61**	3.31**
Days to first flowering	4.00	0.33	11.00	3.67
Flowering period	0	-2.67	-7.33	2.33
Plant height	-37**	-14.3**	-35.3**	8.00**
Number of fruits /plant	0.66	1.67**	7.00**	2.33**
Fruit yield / plant	47.2**	47.92**	109.1**	7.16
Marketable fruit yield (%)	13.9**	33.45**	39.43**	-3.97

* and ** refers to significant at 5 % and 1 % respectively

Table 4.29 Estimates of gene effects based on six generation means in the inter varietal cross *A. esculentus* cv. Arka Anamika x *A. esculentus* cv. KL 9

	m	d	h	i	j	l	Type †	χ^2
%SI	35.26** (5.91℗)	4.00** (0.57)	4.00 (0.81)	6.93*	-2.71** (-0.44)	-19.75 (-1.03)	Higher order interaction	9.36**
%FI	37.89** (6.57℗)	6.38** (0.09)	-15.2** (-9.22)	-6.62** (-0.21)	5.10** (0.86)	7.63*	Higher order interaction	7.98**
DFF	37.16**	2.50**	-2.91				ADM	4.56^{NS}
Flp	37.67**	1.66**	13.66				ADM	4.29^{NS}
Pht	129.33*	-20.6**	17.00**	-16.0**	-11.3**	67.33**	Di-C	12.3^{NS}
FN	19.00**	-1.00**	2.17**	-4.67**	-0.50	2.33	Di-C	2.70^{NS}
FY	273.1**	-10.83*	80.91**	-14.32	-0.33	-80.86**	Di-D	0.35^{NS}
MFY g	172.3**	-21.2**	87.61**	7.97	-9.76	-55.3**	Di-D	0.21^{NS}

* and ** refers to significant at 5 % and 1 % respectively

℗ Estimates of joint scaling test using square root transformation.

† ADM=Additive dominance model; Di-Digenic non-allelic interaction model; C-complementary epistasis.

Abbreviation used: DFF-Days to first flowering, Flp- Effective flowering period, Pht-Plant height (cm), FN-Fruits / plant, FY-Fruit yield / plant (g), SI-Shoot infestation (%), FI-Fruit infestation (%), MFY-Marketable fruit yield in (g).

dominance was partial towards resistant parent as indicated by $(H/D)^{-5}$ ratio (-0.76), which is desirable for this character.

Table 4.30 Estimates of additive variance (σ^2A), dominance variance (σ^2D), dominance degree $(H/D)^{-5}$ and heritability in narrow sense (h^2_{NS}) and broad sense (h^2_{BS}) for shoot and fruit infestation

Traits	σ^2A	σ^2D	$(H/D)^{-5}$	h^2_{BS}	h^2_{NS}
Shoot infestation	21.08	-10.02	-0.76	0.910	0.332
Fruit infestation	29.52	-11.79	-0.69	0.703	0.549

4.8.1.2 Fruit infestation

Fruit borer infestation among six generation materials varied from 32.19 to 42.06 per cent. The F_1 manifested 21 per cent relative heterosis in desirable direction (-) but the value was insignificant. Infestation in the F_2 and backcross progenies (B_1 and B_2) falls within their parental values *i.e.* 32 to 39 per cent. The genes interact as evident from the significance of scales A, B, C and D.

The estimates of m, d, h, i, j and l were significant indicating the importance of additive as well as non-additive gene effects. The additive effects were positive [d=6.38] whereas the additive x additive interaction effects were negative [i=-6.62]. Both were of equal strength. Similarly, the dominance effect was negative [h=-15.21] while the dominance x dominance interaction was positive [l = 7.63]. Internal cancellation of positive and negative effects may likely to take place that would ultimately results in low heterosis. Joint scaling test performed using percentage shoot infestation as well square root transformed values indicated significant χ^2 value. Partitioning of variance components in F_2 revealed that additive and non-additive components were in opposite direction. The heritability in narrow sense was 54.9 per cent. The degree of dominance was partial towards resistant parent (-0.69).

4.8.1.3 Days to first flowering

Although, the F_1 flowered earlier (37.67 days) it did not differ from parent KL 9 (38 days). The estimate of scales A, B, C, D were non-significant *i.e.* epistasis was absent. Since epistasis was absent, the values [m], [d] and [h] alone were estimated. The additive effects were positive and highly significant [d=2.50] while the dominance effects [h=-2.91] were insignificant.

4.8.1.4 Flowering period

Duration of flowering varied from 42.67 days to 49.33 days. The F_1 manifested 16.53 per cent heterobeltiosis (m= 49.43 days) and F_2 showed 10.81 per cent inbreeding depression. The estimates of scales A, B, C and D were insignificant suggesting absence of inter-allelic interaction. The additive effect was highly significant [d=1.66] whereas the dominance effect was high (h=13.66) but non-significant.

4.8.1.5 Plant height

Plant height in parent Arka Anamika and backcross B_1 were 112.33 cm and 115.67 cm respectively. Both were on par. The hybrid exhibited 18.06 per cent heterosis over better parent, KL 9. Scaling test was significant for all the scales hence epistasis was assumed to be present. For the interacting crosses, six parameter model was adopted. The non-additive effects [h+l=84.33] were larger than additive effects [d+i=-36.66]. The sign of [h] and [l] were in the same direction (+) and hence the interaction is complementary epistasis.

4.8.1.6 Number of fruits per plant

The F_1 recorded the maximum value for this trait (20.67 fruits per plant) vis-à-vis 83.72 per cent heterobeltiosis. The mean number of fruits in the F_2

population was 19 per plant equivalent to 16.45 per cent inbreeding depression. Number of fruits per plant in the back cross progenies were 17.67 in B_1 and 18.33 in B_2. Scales B, C and D were significant. The additive effects and additive x additive interaction effects [d + i= -5.67] were in almost equal magnitude as that of dominance, dominance x dominance effects [h+l=4.50]. Therefore, both additive and dominance effects were important for this character. The interaction was of complementary epistasis as [h] and [l] are in same direction.

4.8.1.7 Fruit yield

Yield per plant in F_1, B_1 and F_2 were 293 g, 275 g, 273 g and were on par (Table 4.27). The heterosis in F_1 over better parent (KL 9) was 40.61 per cent and inbreeding depression in F_2 was only 6.89 per cent. Scaling test showed presence of epistasis (Table 4.28). The estimates of dominance effect [h=80.91] and dominance x dominance interaction effects [l=-80.86] were of equal strength but in opposite direction (Table 4.29) probably due to negative dominance at some loci. Hence the interaction was duplicate epistasis.

4.8.1.8 Marketable fruit yield

The F_1 recorded 202.33 g marketable yield per plant followed by B_1 (184.96 g per plant). Both were on par. Scaling test indicated the presence of epistasis. Non-additive effects were greater [h=87.61; l=-55.32] than additive effects [d=-21; i=7.97]. The interaction was duplicate epistasis since [l] was negative and [h] was positive.

4.8.1.9 YVMV

The parents, F_1 and B_2 showed field resistance to YVMV. The co-efficient of infection was 0 per cent.

4.8.2 Genetic analysis in the cross *A. esculentus* cv. KL 9 x *A. caillei* cv. AC 5

Data recorded from field experiment five were subjected for generation mean analysis. The *per se* performance of six generation materials *i.e.* P_1, P_2, F_1, F_2, B_1 and B_2 of the interspecific cross KL 9 (*A. esculentus*) x AC 5 (*A. caillei*) for 15 traits are presented in Table 4.31. The results of scaling test are presented in Table 4.32 and the estimates of gene effects [m, d, h, i, j, l] are given in Table 4.33. Salient results are presented below.

4.8.2.1 Shoot infestation

Shoot infestation in parent AC 5 was 21.14 per cent, whereas it was 28.55 per cent in moderately resistant parent KL 9 (Table 4.31). The hybrid showed 27.67 per cent shoot damage and was on par with parent KL 9. Percentage of shoot borer infestation in the segregating generation *viz.*, F_2, B_1 and B_2 ranged between 26.67 and 30.20 per cent. The scales A, B and C were significant indicating the presence of inter-allelic interaction (Table 4.32). Therefore, six parameter model was tried at first. The joint scaling test performed using original scale (per cent SI) and square root transformed value indicated significance of χ^2 (Table 4.33) hence, the digenic non-allelic model was assumed to be inadequate. Partitioning of F_2 variance indicated that additive variance was greater than dominance variance (Table 4.34). The heritability in narrow sense was 66.4 per cent. The degree of dominance was positive and greater than unity (1.12).

Table 4.34 Estimates of variance components, dominance degree and heritability for shoot and fruit infestation

Traits	σ^2A	σ^2D	$(H/D)^{.5}$	h^2_{BS}	h^2_{NS}
Shoot infestation	41.17	-18.14	1.12	0.91	0.664
Fruit infestation	9.38	-3.93	-1.95	0.51	0.199

Table 4.31 Performance of six generation materials of inter-specific cross *A. esculentus* cv. KL 9 x *A. caillei* cv. AC 5 for various quantitative traits

	P_1	P_2	F_1	F_2	B_1	B_2	CD 5 %	d_i %	ID %
% shoot infestation	28.55	21.14	27.67	30.20	27.33	26.67	6.00	-3.08	-9.16
% fruit infestation	39.50	22.03	26.60	29.33	28.86	26.67	7.58	20.76	-10.27
Days to first flowering	38.00	57.67	43.33	44.33	40.00	43.33	1.93	14.03**	-2.30
Flowering period	40.67	45.33	49.33	46.33	44.00	44.67	5.30	8.82	6.08
Plant height (cm)	131.00	129.3	225.00	188.33	169.33	155.7	20.53	71.76**	16.30
Branches / plant	1.00	2.67	2.33	1.67	1.00	2.00	0.72	-12.50	28.57
Internode / plant	16.00	20.00	28.00	24.00	17.67	24.00	3.38	40.00**	14.28
Internode length (cm)	8.68	4.98	7.94	7.31	7.56	5.78	1.69	-8.41	7.90
Fruits / plant	14.33	17.33	33.00	18.33	17.33	22.00	3.95	90.38**	44.44
Average fruit weight (g)	14.53	13.83	12.24	13.00	14.25	13.35	NS		
Fruit length (cm)	13.40	10.67	13.73	12.32	13.70	12.30	NS		
Fruit girth (mm)	17.78	22.02	22.29	20.74	20.15	22.48	NS		
Fruit yield / plant (g)	208.67	240.7	403.09	239.33	245.50	293.5	60.89	67.49**	40.62
CI for YVMV (%)	0.00	0.00	0.00	27.05	0.00	0.00	8.46	48.74	-11.62
Marketable fruit yield in g and (%)	134.12 (66%)	192.90 (80 %)	306.19 (76%)	186.07 (72%)	177.24 (73%)	230.51 (74%)	56.45	58.42**	39.23

P1 = *A. esculentus* cv. KL 9 and P 2 = *A. caillei* cv. AC 5
d_i refers to heterobeltiosis while ID refers to inbreeding depression

Table 4.32 Scaling test to detect the presence epistasis in the cross *A. esculentus* cv. KL 9 x *A. caillei* cv. AC 5

Traits	Scale A	Scale B	Scale C	Scale D
Shoot infestation (%)	-1.57**	4.55**	15.78**	6.40**
Fruit infestation (%)	-8.33**	4.71**	2.61	3.14*
Days to first flowering	1.33	-14.3**	-5.00	5.33**
Flowering period	-2.00	-5.33	0.66	4.00
Plant height	-17.3**	-43.0**	43.00**	51.67**
Number of fruits /plant	-12.7**	-6.33**	-2433**	-2.67**
Fruit yield / plant	-120**	-56.6**	-298**	-60.3**
Marketable fruit yield (%)	-85.8**	-38.4**	-195**	-35.6**

* and ** refers to significant at 5 % and 1 % respectively

Table 4.33 Estimates of gene effects based on six generation means in the inter-specific cross family *A. esculentus* cv. KL 9 x *A. caillei* cv. AC 5

	m	d	h	i	j	l	Type†	χ^2
%SI	30.20** (5.42ℙ)	0.67** (0.37)	-9.98** (-0.16)	-12.8** (-0.46)	-3.04** (-0.58)	9.82	Higher order interaction	6.60**
%FI	29.33** (5.47ℙ)	2.19** (0.81)	-10.4** (-0.33)	-6.28*	-6.54** (-1.13)	9.95*	Di-D	3.78 NS
DFI	44.33**	-3.33**	-15.1**	-10.66*	6.50**	26.33*	Di-D	3.81 NS
Flp	51.00**	-2.33**	-17.0**				ADM	1.39 NS
Pht	188.3**	13.67**	-8.50	-103**	12.83**	163**	Di-D	1.59 NS
FN	18.33** (23.19♠)	-4.67** (-1.47)	22.50**	5.33** (-7.39)	-3.16 (8.86)	13.6** (19.7)	Higher order interaction	5.79 **
FY	35.26** (5.91♠)	4.00** (0.57)	4.00 (0.81)	6.93*	-2.71** (-0.44)	-19.75 (-1.03)	Higher order interaction	1.54 NS
MFYg	186.0** (210.8♠)	-53.2** (-29.03)	213.7**	71.24** (-47.90)	-23.69 (83.09)	-160** (265.65)	Higher order interaction	2.71 NS

ℙ Estimates of joint scaling test using square root transformation. ♠ Joint scaling test using log transformation

† ADM=Additive dominance model; Di-Digenic non-allelic interaction model; C-complementary epistasis.

Abbreviation used: DFF-Days to first flowering, Flp- Effective flowering period, Pht-Plant height (cm), FN-Fruits / plant, FY-Fruit yield / plant (g), SI-Shoot infestation (%), FI-Fruit infestation (%), MFY-Marketable fruit yield in (g).

4.8.2.2 Fruit infestation

Fruit borer infestation was low in parent AC 5 (22.03 per cent). Infestation in F_1, F_2 B_1 and B_2 ranged between 26.67 per cent and 30 per cent. They were on par with each other as well as with AC 5. Scales A, B and D were significant, thereby suggesting the presence of inter allelic interaction of all kinds. Additive effects were positive but low [d = 2.19] while additive x additive interaction effects were greater but negative [i =-6.28]. Similarly dominance effects were negative [h=-10.44] while dominance x dominance interaction effects was positive [l= 9.95]. The interaction happened to be duplicate epistasis.

4.8.2.3 Days to first flowering

A. esculentus parent KL 9 flowered earlier (38 days) than *A. caillei* parent AC 5 (58 days). The derivatives from these parents *i.e.* F_1, F_2, B_1 and B_2 flowered between 40 and 44 days. The hybrid did not manifest heterobeltiosis in desirable direction for this trait. Scales B and D were significant hence epistasis is present. Both additive (d=-3.33) and additive x additive effects (i=-10.66) were significant.

4.8.2.4 Flowering period

The mean of F_1 (49.33 days) and F_2 (46.33 days) did not differ for this trait. Scaling test indicated absence of epistasis hence, three parameter model was adopted. The estimate of [h] was greater than [d].

4.8.2.5 Plant height

The F_1 manifested 72 per cent heterosis over better parent. Hybrid vigour acquired in F_1 (*i.e.*225 cm) lost in F_2 (mean=188 cm; inbreeding depression=16.30 per cent) and further reduction in height could be observed in the backcross progenies (169 to 188 cm). The scales A, B, C and D were significant hence

epistasis was assumed to be present. Non-additive effects [h+l=155.17] were greater than additive effects [d+i=89.66].

4.8.2.6 Number of fruits per plant

The F_1 hybrids showed prolificity for fruit number (33 fruits per plant). The heterobeltiosis was 90.38 per cent. F_2 produced 18.33 fruits per plant *i.e.* the vigour gained in F_1 was lost in the second filial generation to 44 per cent. Scaling test indicated presence of inter-allelic interaction. But the joint scaling test indicated the inadequacy of digenic epistasis model.

4.8.2.7 Fruit yield

The F_1 manifested high heterosis (67.49 per cent) for fruit yield (403.09 g per plant). The heterotic vigour expressed in the F_1 lost in the F_2 as evident from 40.62 per cent inbreeding depression. Fruit yield in F_2 (239.33 g) and B_2 (293.50 g) were on par. Back cross progenies B1 *i.e.* (KL 9 x AC5) x KL 9 also recorded as high as 245.5 g fruits per plant. Scales A, B, C, D were significant. The estimates of [h] and [l] showed opposite sign hence it was a duplicate epistasis. Joint scaling test performed using original values as well as log transformed values indicated the inadequacy of digenic non-allelic interaction model to explain the variation for yield.

4.8.2.8 Marketable fruit yield

Marketable fruit yield ranged between 134 g per plant in parent KL 9 and 306.19 g per plant in the F_1. Next to F_1, fruit yield was high in B_2 (230.51 g/plant). Joint scaling test indicated significance of χ^2 value hence the digenic non-allelic interaction model was seems to be inadequate.

4.8.2.9 YVMV

The interspecific hybrids and B_1 showed field resistance to YVMV. The co-efficient of infection was 0 per cent. The F_2 progenies had 27.05 per cent co-efficient of infection.

4.9 HOST PLANT RESISTANCE IN OKRA TO SHOOT AND FRUIT BORER

4.9.1 Multiple choice tests to assess oviposition preference for wild and cultivated okra

Data on number of eggs laid on the shoots, buds, fruits of wild and cultivated okra and number of larvae penetrated into shoots, buds and fruits are presented in Table 4.35. Out of the 10 *Abelmoschus* species tested, *A. tetraphyllus* recorded the minimum number of eggs on shoots (2.00) followed by *A. tuberculatus* (2.33) and *A. tetraphyllus* var. *pungens* (4.33). Similar trend was noticed for the number of larval penetration into the shoots with *A. tetraphyllus* (1.00), *A. tetraphyllus* var. *pungens* (2.00) and *A. ficulneus* (2.33) recording the least value. The number of larvae penetrated into the shoots of *A. tetraphyllus* was two egg per plant, although it received 4.33 eggs per plant. Shoot borer susceptible species *A. esculentus* and *A. moschatus* recorded 12.33 and 9.67 eggs, respectively which were greater than 3.67 eggs recorded in *A. caillei* shoot.

Earias vittella did not prefer the buds and fruits of *A. tuberculatus* for oviposition since no eggs was observed on them. The number of eggs recorded on the buds of *A. caillei*, *A. tetraphyllus* var. *pungens* and *A. ficulneus* were 2.67, 2.33 and 1.33 egg, respectively. Only one larva was found inside the buds of *A. ficulneus* and two each in *A. caillei* and *A. tetraphyllus* var. *pungens*. The remaining species including the cultivated okra received relatively more number of eggs (4.67 to 9.67 eggs per three buds) on buds.

Table 4.35 Number of eggs laid and number of larvae of *E. vittella* penetrated in shoots, buds and fruits of 10 *Abelmoschus* taxa in the multiple choice test

#	Species	Shoots		Buds		Fruits	
		No of eggs in top 15 cm shoot apex	No of larvae entered into shoot	No of eggs on 3 buds	No of larvae entered	No of eggs laid on 3 fruits	No of larvae entered in 3 fruits
1	*A. angulosus*	6.33^{c}	3.67^{ab}	5.67^{cd}	4.67^{c}	10.00^{bc}	4.67^{c}
2	*A. caillei*	3.67^{de}	2.67^{cd}	2.67^{f}	2.00^{e}	6.33^{cd}	3.33
3	*A. esculentus*	12.00^{a}	3.33^{bc}	7.33^{bc}	5.67^{ab}	15.67^{a}	8.33^{a}
4	*A. ficulneus*	3.33^{de}	2.33^{d}	1.33^{fg}	1.00	9.00^{bc}	3.67^{d}
5	*A. moschatus*	9.67^{b}	4.33^{a}	9.67^{ab}	5.00^{bc}	9.33^{bc}	6.00^{b}
6	*A. moschatus* var. *multiformis*	6.33^{c}	4.00^{ab}	11.33^{a}	6.00^{a}	9.67^{bc}	6.67^{b}
7	*A. tetraphyllus*	2.00^{e}	1.00^{e}	4.67^{efg}	3.33^{d}	11.33^{b}	7.67^{a}
8	*A. tetraphyllus* var. *pungens*	4.33^{d}	2.00^{d}	2.33^{f}	2.00^{e}	4.00^{d}	1.67
9	*A. tuberculatus*	3.33^{de}	2.67^{cd}	0.00^{g}	0.00^{g}	0.00^{e}	0.00^{f}
10	*A. tuberosus*	7.67^{c}	3.67^{ab}	8.33^{b}	4.67^{c}	10.00^{bc}	4.67^{c}
Mean		5.87	2.97	5.33	3.43	8.53	4.67
CD at 5 %		1.40	0.87	2.35	0.85	3.43	0.91

Mean in a column followed by same alphabet do not differ significantly at P=0.05 by DMRT

Earias vittella exhibited high preference to the fruits of cultivated okra. As many as 15.67 eggs were recorded on three fruits. The number of larvae bored the fruits were also high in *A. esculentus* (8.33 larvae per three fruits) followed by *A. tetraphyllus* (7.67 larvae per three fruits). On the other hand, *A. tuberculatus* exhibited antixenosis for oviposition to fruit borer as no egg was observed on the fruits. *A. tetraphyllus* var. *pungens* recorded the least number of eggs and larvae on fruits (4.00 and 1.67 respectively) followed by *A. caillei* (6.33 and 3.33 respectively).

4.9.2 No choice test to assess the presence of antibiosis factors

Data on the effects of feeding resistant shoots and fruits on the post embryonic development of *E. vittella* are presented in Table 4.36. When the larvae feed on *A. esculentus* shoots (susceptible species), larval period lasted for 11 days and the life cycle was completed in 24 days. On the other hand, the larval period extended up to 14.33 days and life cycle to 27.33 days when they were reared in *A. tetraphyllus* shoots (resistant species). When resistant shoots were fed, significant reduction in pupation percentage, adult emergence and fecundity rate were observed. Larval mortality was 65 per cent in resistant shoots, whereas in susceptible shoot it was 44.33 per cent. Growth indices such as larval growth index (2.45) and total developmental growth index (2.16) were low in resistant shoots than those in susceptible shoots (5.10 and 3.49 respectively).

When the larvae fed on *A. esculentus* fruits (susceptible species), larval period lasted for 13 days, whereas in *A. tuberculatus* fruits (resistant species) it was 15 days. However, the two species did not differ for adult longevity (3-4.67 days) and fecundity rate (141-197 eggs / female). Significant differences for larval mortality and larval growth index (LGI) was recorded when larvae reared in resistant and susceptible species. Larval growth index was relatively low in *A. tuberculatus* (3.53) due to prolonged larval period and low pupation percentage. The total developmental growth index was insignificant between the species due to their insignificant differences in adult emergence.

Table 4.36 Effect of feeding shoots and fruits of resistant and susceptible okra on the post embryonic development of *E. vittella* in a single choice test

Parameters	Rearing on shoots of			Rearing on fruits of		
	A. esculentus	*A. tetraphyllus*	*t-test*	*A. esculentus*	*A. tuberculatus*	*t-test*
Larval period (days)	11.00 ±1.73	14.33 ±1.53	S	13.00 ±1.00	15.00 ±1.53	S
Larval mortality (%)	44.33 ±5.51	65.00 ±3.61	S	36.33 ±2.52	41.33 ±4.53	S
Pupal period (days)	10.00 ±1.00	9.67 ±1.85	NS	9.33 ±1.53	10.67 ±1.16	NS
Pupation (%)	55.67 ±5.51	35.00 ±3.61	S	63.67 ±2.52	58.67 ±1.53	NS
Adult emergence (%)	83.67 ±5.03	59.00 ±5.57	S	89.67 ±4.00	86.67 ±6.08	NS
Adult longevity (days)	5.00 ±1.00	3.33 ±0.57	NS	4.67 ±0.58	3.00 ±1.00	NS
Fecundity rate per female	197.67 ±26.00	43.67 ±9.29	S	167.33 ±29.32	141.00 ±44.57	NS
Egg period (days)	3.00 ±0.00	3.33 ±0.57	NS	3.00 ±0.00	3.00 ±0.00	NS
Total development period (days)	24.00 ±2.65	27.33 ±0.58	S	25.33 ±5.33	28.67 ±0.33	S
Larval growth index	5.10 ±0.46	2.45 ±0.22	S	4.91 ±0.29	3.53 ±0.26	S
Total developmental growth index	3.82 ±0.23	2.16 ±0.18	S	3.56 ±0.39	3.05 ±0.08	NS

S= Significant at 5 %; NS=Non significant

Given values are mean± standard deviations

Larval Growth Index (LGI)= Pupation (%) divided by larval period

Total Developmental Growth Index TDGI=Adult emergence (%) divided by total development period

4.10 SYMPTOMS OF RESISTANCE

During the course of study, it was observed that some of the genotypes respond to the fruit borer attack by way of triggering hypersensitive reactions. The outcome of which was manifested as detailed below.

4.10.1 External symptom: Hypersensitive eruption

When neonate larvae of *E. vittella* bite a tender okra fruit, the upper epidermal cells at the point of bite respond to the infestation and produced small eruption or bulging that becomes hardened in due course (Plate 8b). Larval penetration through these points could hardly take place. It was a kind of hypersensitive response against fruit infestation. The larvae have to make several attempts before entering into mesocarp and in the process some neonate larvae lose their energy and perish since they did not get enough food. The symptom was recorded in *A. caillei* genotype AC 5 and in *A. tuberculatus*. Bulging on the infested buds was also observed.

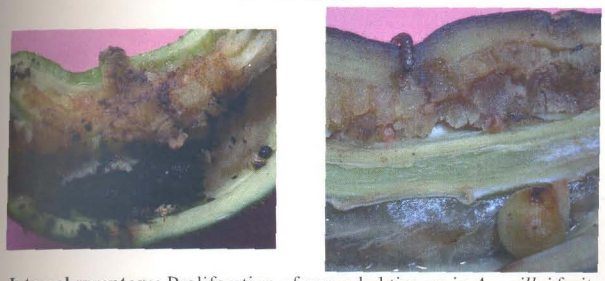
4.10.2 Internal symptom: Proliferation of wounded tissues

In the case of external symptom, the symptoms appeared before the larval entry into fruits. On the other hand, the internal symptoms appeared after larval entry into fruits. The cells of the inner epidermis and placenta respond to the infestation by producing abnormal cell growth (proliferation) resembling an *in vitro* calli in the mesocarp and endocarp region (Plate 8b). The proliferated cells arrest further movement of larvae inside the fruits and damage to the seeds. The seeds located farthest away from the point of attack remain un-infested. The proliferated tissues were greenish white. On exposure to air turn brownish and shrinks. This symptom was observed in *A. caillei* cv. Susthira, *A. esculentus* genotype KL 9, *A. tuberculatus* and in the F_1 cross of Arka Anamika x KL9.

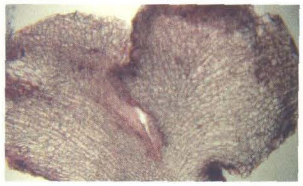
Shoot infestation Bud infestation Fruit infestation

Plate 8a. Kind of damage inflicted by shoot and fruit borer

External symptom: Hypersensitive eruption on the fruits of *A tuberculatus* and *A. caillei*



Internal symptom: Proliferation of wounded tissues in *A. caillei* fruit



Anatomy of proliferated fruit tissues (L.S.)

Plate 8b. Symptoms of resistance in okra in response to fruit borer attack

4.11 PHYSICAL BASIS OF RESISTANCE

4.11.1 Trichome *versus* ovipositional preference

To have a correlated study between trichome *versus* resistance, microscopic examination of trichome type, length, density on shoot, bud and fruits of wild and cultivated okra was undertaken. The data are in presented in Table 4.37.

Shoot trichome length was the shortest (0.42 mm) in *A. tetraphyllus* followed by *A. ficulneus* (0.45 mm), *A. angulosus* (0.48 mm) and *A. caillei* (0.54 mm) (Table 4.37). Shoot trichome length was longest in *A. moschatus* var. *multiformis* (2.03 mm). Length of trichome present on buds was shortest in *A. caillei* (0.46 mm) and *A. tuberosus* (0.51 mm) whereas longest in *A. tetraphyllus* var. *pungens* (2.12 mm). With regard to length of trichome on fruits, *A. moschatus* var. *multiformis* and *A. angulosus* showed lengthy trichomes (3.47 and 3.27 mm respectively).

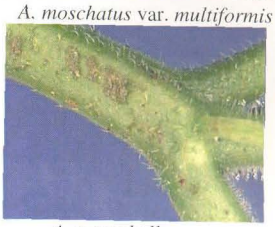
As regard to density of trichome on shoots, the minimum value was registered in *A. esculentus* (3.67 per 5 mm^2) and *A. caillei* (4.00 per 5 mm^2) whereas the maximum value was registered in *A. tuberosus* (58 per 5 mm^2) (Table 4.37). Density of trichome on the shoots of *A. angulosus* was also high (43.67 per 5 mm^2). Density of trichome on buds of *A. tuberosus* was high (58.33 per 5 mm^2) followed by *A. ficulneus* (36.67 per 5 mm^2), *A. moschatus* (34.67 per 5 mm^2) and *A. moschatus* var. *multiformis* (34.33 per 5 mm^2). The latter three species were on par. Density of trichome on fruits was low in *A. tuberculatus* (6 per 5 mm^2) and *A. moschatus* (9 per 5 mm^2) whereas high in *A. tuberosus* (36.33 per 5 mm^2) and *A. ficulneus* (34.67 per 5 mm^2).

Correlation co-efficient between trichome length and density *versus* number of eggs laid on the shoots in a multiple choice test revealed non-significant correlation co-efficient (r) among the pairs compared, except shoot hair length

A. angulosus

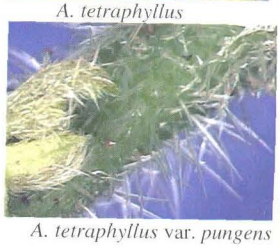
A. moschatus var. *multiformis*

A. caillei



A. tetraphyllus

A. esculentus



A. tetraphyllus var. *pungens*

A. ficulneus

A. tuberculatus

A. moschatus

A. tuberosus

Plate 9 Variability for shoot trichomes in *Abelmoschus* species

A. angulosus

A. moschatus var. *multiformis*

A. caillei

A. tetraphyllus

A. esculentus

A. tetraphyllus var. *pungens*

A. ficulneus

A. tuberculatus

A. moschatus

A. tuberosus

Plate 10 Variability for fruit trichomes in *Abelmoschus* species

Table 4.37 Trichome length and density on shoots, buds and fruits of cultivated and wild *Abelmoschus* species

	Species	Trichome length (mm)			Trichome density (in 5 mm^2)		
		Shoots	Buds	Fruits	Shoots	Buds	Fruits
1	*A. angulosus*	0.48^{de} ±0.13	0.81^{cde} ±0.15	3.27^{a} ±0.53	43.67^{b} ±5.51	14.33^{c} ±2.89	15.67^{cd} ±1.53
2	*A. caillei*	0.54^{de} ±0.05	0.46^{f} ±0.06	0.81^{c} ±0.04	4.00^{f} ±1.00	16.00^{c} ±2.65	18.33^{c} ±0.58
3	*A. esculentus*	1.03^{cd} ±0.56	0.84^{cd} ±0.11	0.85^{c} ±0.06	3.67^{f} ±1.53	18.00^{c} ±2.00	23.33^{b} ±2.08
4	*A. ficulneus*	0.45^{e} ±0.09	0.69^{def} ±0.04	0.85^{c} ±0.08	6.33^{ef} ±2.08	36.67^{b} ±4.04	34.67^{a} ±3.21
5	*A. moschatus*	1.67^{ab} ±0.47	0.97^{bc} ±0.10	1.53^{b} ±0.15	9.67^{def} ±1.53	34.67^{b} ±4.93	9.00^{e} ±1.00
6	*A. moschatus* var. *multiformis*	2.03^{a} ±0.24	1.12^{b} ±0.24	3.47^{a} ±0.16	29.67^{c} ±2.08	34.33^{b} ±10.60	13.33^{d} ±2.31
7	*A. tetraphyllus*	0.42^{e} ±0.04	0.59^{def} ±0.17	1.46^{b} ±0.07	12.33^{def} ±7.09	15.33^{c} ±4.93	23.33^{b} ±1.15
8	*A. tetraphyllus* var. *pungens*	1.30^{bc} ±0.29	2.12^{a} ±0.27	1.88^{b} ±0.19	18.00^{d} ±6.08	15.33^{c} ±4.62	18.67^{c} ±0.58
9	*A. tuberculatus*	0.92^{cde} ±0.47	0.57^{ef} ±0.07	1.56^{b} ±0.19	14.33^{de} ±4.04	25.67^{bc} ±4.16	6.00^{e} ±00
10	*A. tuberosus*	1.12^{c} ±0.08	0.51^{f} ±0.03	1.54^{b} ±0.41	58.00^{a} ±9.00	58.33^{a} ±19.35	36.33^{a} ±3.79
Mean		**1.00**	**0.87**	**1.72**	**19.97**	**26.87**	**19.87**
CD at 5 %		0.55	0.24	0.41	8.53	13.79	3.55

Given values are mean ± standard deviations
Mean in the same column followed by same alphabet do not differ significantly at P=0.05 by DMRT

versus number of eggs laid on shoots (Table 4.38) for which the 'r' was positively significant. The correlation co-efficient between trichome density and oviposition on buds or fruits were also insignificant.

Table 4.38 Correlation between trichome on okra and oviposition by *E. vittella*

No. of eggs laid on	Trichome length in			Trichome density in		
	Shoots	Buds	Fruits	Shoots	Buds	Fruits
Shoots	0.79**			0.31		
Buds		0.04			0.39	
Fruits			-0.02			0.45
Significance of 'r'	S	NS	NS	NS	NS	NS

(Correlation co-efficient were based on values in Table 4.37 and 4.35)

4.11.2 Trichome *versus* infestation

The correlation co-efficient between trichome length and density in ten *Abelmoschus* species *versus* shoot and fruit borer infestation in these species revealed insignificant values (r) among the pairs compared (Table 4.39).

Table 4.39 Correlation between trichome in okra and infestation by *E. vittella*

Infestation in	Trichome length in		Trichome density in	
	Shoots	Fruits	Shoots	Fruits
Shoots	0.38		-0.01	
Fruits		0.20		0.27
Significance of 'r'	NS	NS	NS	NS

(Correlation were based on values in Table 4.37 and mean of Tables 4.8 to 4.10)

4.12 BIOCHEMICAL BASIS OF RESISTANCE

4.12.1 Moisture content *versus* ovipositional preference and infestation

Moisture content in 10 *Abelmoschus* species varied from 73.04 to 90.20 per cent in shoot and from 76.87 to 90.94 per cent in fruits (Table 4.40). Shoot moisture content was low in *A. angulosus* (73.04 per cent) and *A. moschatus* var.

Table 4.40 Estimates of moisture content, pH and mucilage in the resistant and susceptible *Abelmoschus* species

#	Species	Moisture content (%)		pH of the extract		Mucilage (%)	
		Shoots	Fruits	Shoots	Fruits	Shoots	Fruits
1	*A. angulosus*	73.04^{b}	77.14	6.1^{bcd}	6.2	3.39^{c}	4.64^{ab}
2	*A. caillei*	86.72^{a}	90.94	5.8^{d}	6.2	2.69^{c}	4.16^{ab}
3	*A. esculentus*	89.74^{a}	88.74	6.1^{bcd}	6.3	4.29^{c}	6.19^{a}
4	*A. ficulneus*	79.00^{ab}	84.00	6.2^{abc}	6.4	7.52^{ab}	1.89^{b}
5	*A. moschatus*	88.56^{a}	89.72	6.7^{a}	6.1	3.07^{c}	4.94^{ab}
6	*A. multiformis*	74.42^{b}	79.48	6.1^{bcd}	6.5	4.57^{bc}	6.70^{a}
7	*A. tetraphyllus*	87.08^{a}	82.27	5.9^{bcd}	6.2	2.95^{c}	3.78^{ab}
8	*A. pungens*	86.75^{a}	88.77	6.1^{bcd}	6.1	3.83^{c}	5.50^{ab}
9	*A. tuberculatus*	82.96^{ab}	76.87	5.9^{cd}	6.5	4.99^{abc}	5.09^{ab}
10	*A. tuberosus*	90.20^{a}	87.60	6.0^{bcd}	6.2	8.50^{a}	6.70^{a}
Mean		85.05	85.38	6.14	6.26	4.71	4.99
CD at 5 %		10.85	NS	0.45	NS	2.96	3.57

NS-Non significant at P=0.05

Mean in the same column followed by same alphabet did not differ significantly at P=0.05 by DMRT

For want of space *A. moschatus* var. *multiformis* written as *A. multiformis* and *A. tetraphyllus* var. *pungens* as *A. pungens*

multiformis (74.42 per cent). They were on par. With respect to moisture content in fruits, the mean moisture content did not differ between species. The correlation co-efficient between moisture content in shoots and fruits with the number of larval penetration in shoots and fruits and also with per cent infestation were insignificant (Table 4.41).

Table 4.41 Correlation between pH, moisture content and mucilage content with number of larval entry in fruits and percentage of infestation

Phytochemicals	No. of larvae entered into		Infestation (%) in	
	Shoots	Fruits	Shoots	Fruits
Moisture content in shoots or fruits	-0.20	0.36	0.29	0.40
pH in shoots or fruits	0.44	-0.20	0.23	-0.30
Mucilage content in shoots or fruits	0.07	0.46	0.06	0.45
Significance of correlation co-efficient	NS	NS	NS	NS

(Correlations were based on data in Table 4.35 *versus* 4.40; 4.35 *versus* 4.8 to 4.10)

4.12.2 pH *versus* ovipositional preference and infestation

Shoot extracts were more acidic than the fruit extracts (Table 4.40). The mean pH of shoot extracts was 6.14 and for fruit extracts it was 6.26. The lowest value for shoot pH (5.8) was recorded in *A. caillei* followed by *A. tetraphyllus* and *A. tuberculatus* (pH=5.9). These species were resistant to shoot borer. On the other hand, shoot borer susceptible species like *A. esculentus* and *A. moschatus* has significantly higher pH (6.5 to 6.7). But correlation co-efficient between shoot pH and shoot infestation was insignificant. Regarding pH of fruit extract, the species resistant to fruit borer like *A. tuberculatus* had high pH (6.5) similar to those in susceptible species like *A. multiformis* and *A. ficulneus* and correlation co-efficient between shoot pH and fruit infestation were insignificant (Table 4.41)

4.12.3 Mucilage *versus* ovipositional preference and infestation

Mucilage were present in the shoots as well as fruits of wild and cultivated species (Table 4.40). It was high in *A. tuberosus* shoot (8.50 per cent). Resistant species like *A. tetraphyllus* and *A. caillei* had low mucilage (2.95 and 2.69 per

Table 4.42 Content of some selected phytochemicals in the shoots of resistant and susceptible *Abelmoschus* species

#	Species	Resistant class	Phenol (µg/g)	Tannin (µg/g)	Gossypol (µg/g)
1	*A. tetraphyllus*	HR	132.8[a]	87.02[a]	8.79[a]
2	*A. caillei*	MR	140.0[a]	76.31[b]	7.23
4	*A. esculentus*	HS	69.55[b]	70.00[b]	6.29[c]
CD at 5 %			12.50	8.16	1.03

Table 4.43 Contents of some selected phytochemicals in the fruits of resistant and susceptible *Abelmoschus* species

#	Species	Resistant class	Phenol (µg/g)	Tannin (µg/g)	Gossypol (µg/g)
1	*A. tuberculatus*	HR	48.3[c]	733.6[a]	6.30[c]
2	*A. caillei*				
a	Healthy fruits	MR	265.2[a]	630.3[b]	8.11[a]
b	Proliferated fresh tissue from infested fruits	Induced or hypersensitive	119.0[b]	572.0[c]	1.21[d]
3	*A. esculentus*	HS	99.0[b]	701.2[a]	7.71[b]
CD at 5 %			31.82	48.20	1.03

Note: Weight expressed in oven dry weight basis
Mean in the same column followed by same alphabet do not differ significantly at P=0.05 by DMRT
HR-Highly resistant; FR-Moderately resistant; HS-Highly susceptible

cent respectively) but statistically they were on par with susceptible species like *A. angulosus* (3.39 per cent), *A. esculentus* (4.29 per cent), *A. moschatus* (3.07 per cent), and *A. tetraphyllus* var. *pungens* (3.83 per cent). *Abelmoschus ficulneus* had very low mucilage (1.89 per cent) in fruits. Whereas *A. tuberosus* had high mucilage in fruit (6.7 per cent) and was on par with *A. moschatus* var. *multiformis* (6.70 per cent) and *A. esculentus* (6.19 per cent). The correlation co-efficient between mucilage content and infestation was not significant (Table 4.41).

4.12.4 Phenol

Phenol in the shoots of highly resistant *A. tetraphyllus* (132.8 µg per gram) and moderately resistant *A. caillei* (140 µg per gram) were significantly higher than susceptible species *A. esculentus* (69.55 µg per gram) (Table 4.42). Phenol in the fruits of resistant species *A. tuberculatus* was 48.3 µg per gram while it was significantly high (99.0 µg) in susceptible species *A. esculentus* (Table 4.43). Moderately resistant healthy fruits of *A. caillei* recorded the highest phenol (265.2 µg per gram) while the proliferated fruit tissues of *A. caillei* formed after fruit borer infestation had low phenol (119 µg per gram).

4.12.5 Tannin content

Tannin content was significantly higher (87.02 µg per gram) in highly resistant *A. tetraphyllus* shoots than in moderately resistant *A. caillei* (76.31 µg per gram) and susceptible *A. esculentus* shoots (70 µg per gram) (Table 4.42). Fruit borer susceptible species *i.e. A. esculentus* and resistant species *A. tuberculatus* recorded 701 and 733.6 µg per gram of tannin in fruit and were on par (Table 4.43). Tannin content was low (572 µg per gram) in the proliferated fruit tissues of *A. caillei.*

4.12.6 Gossypol content

Gossypol was present in the shoot and fruits of okra and the content ranged from 1.21 to 8.82 µg per gram of dry tissues (Table 4.42 and 4.43). Shoots of *A.*

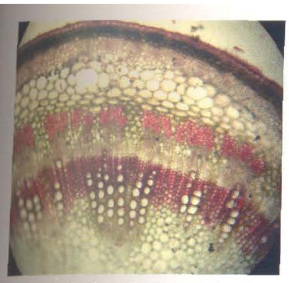
tetraphyllus recorded the highest value for gossypol content (8.79 µg per gram) in shoots and this was significantly higher than the susceptible species *A. esculentus* (6.29 µg per gram). The reverse trend was noticed in the fruits with susceptible species *A. esculentus* recording relatively higher gossypol (7.71 µg per gram) than the resistant species *A. tuberculatus* (6.30 µg per gram). The proliferated *A. caillei* fruit tissue had low gossypol (1.21 µg per gram) content.

4.13 ANATOMICAL BASIS OF RESISTANCE

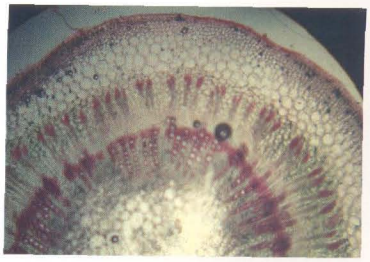
Anatomical differences observed in 30 days old shoots and seven days old fruits of resistant and susceptible species are shown in Plate 11 and in Table 4.44 and 4.45.

Table 4.44 Shoot anatomical differences between resistant and susceptible species

Cells /Tissues	**Resistant species (*A. tetraphyllus*)**	**Susceptible species (*A. esculentus*)**
Epidermis	Larger epidermal cells, highly lignified with thick cuticle	Smaller epidermal cells without cutinisation
Hypodermis	Three to four cell layers deep	Two to three cells deep
Collenchyma	Smaller cells but compactly arranged and 5 cells deeper	Relatively large cell but only 3 to 4 cells deep
Cortical parenchyma	Compactly arranged, less deeper (3-4 cells), embedded few relatively large lysigenous mucilage cavity	More deeper than *tetraphyllus* (5 cells deep); mucilage cavity could not be distinguished
Vascular tissues	Closely packed xylem strands, separated by sclerenchymatous cells	Less number of vascular bundles.
Pith	Compactly arranged parenchymatous cell	Less compact

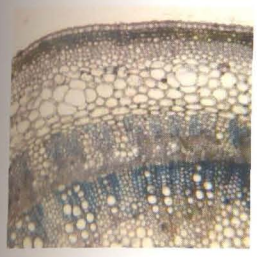


A. tetraphyllus (Resistant shoot)



A. esculentus (susceptible shoot)

i) Shoot anatomical differences between resistant and susceptible species

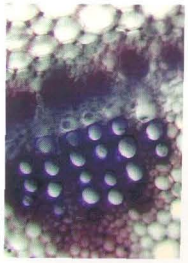


A. tetraphyllus (Resistant shoot)

A. esculentus (susceptible shoot)

ii) Histo-chemical staining for phenol: Greenish blue indicates phenolic compounds

A. tetraphyllus (Resistant shoot)



A. esculentus (susceptible shoot)

iii) Staining for pectic acid / tannin/ lignin: Greenish blue indicates tannin or lignin whereas red colour indicates pectic acid

Plate 11 Anatomical and histochemical differences between resistant and susceptible okra shoots.

Table 4.45 Fruit anatomical differences between resistant and susceptible species

Cells / Tissues	Resistant species (*A. tuberculatus*)	Susceptible species (*A. esculentus*)
Trichomes	Rough, rigid or needle like trichomes, highly suberised or lignified but present in low density	Velvety or soft and short hairs present in high density
Ridge Vascular bundle	Wider and larger	Narrow
Mucilage cavity	Less	More

4.14 HISTO-CHEMICAL BASIS OF RESISTANCE

4.14.1 Histochemical differences between resistant and susceptible shoot

Histochemical differences observed in 30 days old shoots of resistant (*A. tetraphyllus*) and susceptible species (*A. esculentus*) are given below.

4.14.1.1 Phenolic compounds

When a fresh hand cut section of resistant and susceptible stem was stained with toluidine blue in strong acidic medium, xylem and pericycle appeared greenish blue indicating the presence of phenolic compounds in them (Plate 11). Pericycle in the shoots of resistant species (*A. tetraphyllus*) stained deeply (score 3) and ray cells surrounding xylem was stained feebly (score 1), suggesting high phenol. On the other hand, the intensity of staining was less (score 1to 2) in susceptible shoots (*A. esculentus*).

4.14.1.2 Pectic acid, tannin and lignin

Resistant species possessed high lignin and tannin (stained greenish blue) in collenchyma, pericycle and xylem whereas susceptible shoot showed pectic acid in collenchyma and pericycle (stained red) (Plate 11).

Table 4.46 Histochemical difference between resistant and susceptible shoots for pectic acid, tannin and lignin

Cells / Tissue	*A. esculentus* (Susceptible)	*A. tetraphyllus* (Resistant)
Collenchyma	Red (2)	Blue (1)
Pericycle	Red (2)	Greenish blue (2)
Xylem	Violet blue (3)	Greenish blue (2)

4.14.1.3 Cellulose

Staining with Toluidine blue indicated distribution of cellulose in all the tissues or cells. The pericycle and xylem of *A. tetraphyllus* showed cellulose mixed with other compounds (stained greenish blue) and in high concentration (score 3), while *A. esculentus* had pure cellulose in these cells (stained blue) and also in less amount as evident from feeble staining. The ray cells in *A. tetraphyllus* stained blue which was not so in *esculentus* (Table 4.47).

Table 4.47 Histochemical difference between resistant and susceptible shoots for cellulose

Cells / Tissue	*A. esculentus* (Susceptible)	*A. tetraphyllus* (Resistant)
Collenchyma	Blue (2)	Blue (3)
Pericycle	Blue (3)	Greenish blue (3)
Xylem	Greenish blue (2)	Greenish blue (3)
Rays	-	Blue (3)

4.14.1.4 Starch / Cutin / Suberin / Mucilage

Staining fresh hand cut section with iodine-chloral-potassium iodide turned epidermis into yellow colour due to cutinisation. Staining was deep in resistant species, while A. *esculentus* did not absorb stain. However, the species under study did not differ for starch, mucilage, and suberin. In both species, endodermis stained blue due to presence of starch. Xylem elements stained brown indicating their lignification. Collenchyma cells stained violet due to mucilage.

4.14.2 Histochemical differences between resistant and susceptible fruits

Histochemical differences observed in seven days old fruits between resistant (*A. tuberculatus*) and susceptible species (*A. esculentus*) are given below.

4.14.2.1 Phenolic compounds

Susceptible fruits did not absorb stain. However, vascular bundles of resistant fruits stained greenish blue indicating presence of phenol (Plate 12).

4.14.2.2. Pectic acids, tannin and lignin

Except trichome in *A. tuberculatus,* which stained greenish blue (due to lignin), other cells of resistant as well as susceptible fruits did not absorb stain, probably due to low pectic acid, lignin or tannin in the fruits.

4.14.2.3 Reducing substances

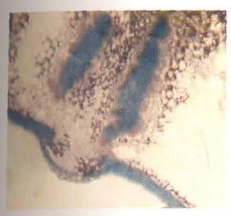
Cells in the upper epidermis, ground tissues, trapezium, septum and seeds turned metallic copper brown when Fehling's solutions were added and then warmed gently indicating presence of reducing substances in both species (Plate 12). However, the staining intensity on the upper epidermis was higher in *A. tuberculatus* than in *A. esculentus.*

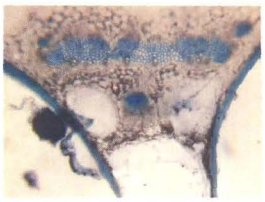
4.14.2.4 Starch / Cutin / Suberin

Dorsal vascular bundles embedded in the ground tissues stained brown indicating lignifications in both species. Inner epidermis stained bluish purple due to starch. Trichomes in *A. tuberculatus* stained yellow due to cutinisation (Plate 12) whereas in cultivated okra trichome remains unstained.

A. tuberculatus (Resistant species) ***A. esculentus*** (susceptible species)

i) **Staining to detect cutin in fruits**: In Zn-Chloral-KI test *A. tuberculatus* trichomes were stained yellow due to presence of cutin.





ii) **Staining for phenol in *A. tuberculatus* fruits**: Vascular bundles located near trapezium and placenta stained greenish blue indicating presence of phenolic compounds

a)

b)

iii) **Staining for reducing substances in *A. tuberculatus* fruits**: a) Upper epidermis of fruit epicarp stained metallic brown due to presence of reducing substances. b) In the field grown plants of *A. tuberculatus* ants were attracted to the petals and fruits due to presence of reducing substabces. Presence of ants reduces shoot and fruit borer damage.

Plate 12 Localisation for selected biochemical in the fruit samples of fruit borer resistant species (*A. tuberculatus*)

4.15 HISTOCHEMICAL ANALYSIS IN THE PROLIFERATED FRUIT TISSUES OF *A. CAILLEI*

Anatomical and histochemical investigations in the proliferated fruit tissues of *A. caillei* revealed that the cells were elongated, meristematic, parenchymatous and radially arranged (Plate 8b). Few cells on the periphery of callus stained blue (score 2) when 0.05 per cent toluidine blue added on the hand cut fresh section for 10-60 seconds indicating presence of lignin or tannin. When the tissue was tested for the presence of lignin one or two layers of sub-marginal (periphery) cells stained red (score 1). The cells did not absorb stain when tested for the presence of phenolic compounds. Cells in the periphery of tissues stained yellow in iodine-potassium iodide-chloral hydrate stain mixture indicating presence of cutin or suberin. Inner cells stained violet purple indicating the presence of starch.

DISCUSSION

5. DISCUSSION

Plants and insects have co-existed as a balanced natural equilibrium since antiquity. Crop intensification for higher yields led to disturbance of the balance between the host and insects, leading to insect outbreaks and serious crop losses. To overcome the pest problems in modern crop production systems, synthetic pesticides were introduced after Second World War (Panda and Khush, 1995). The dependence on synthetic pesticides for pest control increased with the availability of inexpensive broad spectrum insecticides. After two decades, the adverse effects of excessive and indiscriminate use of pesticides on the soil, plant and animal health became evident (Metcalf, 1980). To minimize the dependence on synthetic pesticides, an ecological approach for pest management popularly called integrated pest management (IPM) was developed (Smith, 1989). A resistant crop variety provides the basic foundation for IPM. Resistant variety could be useful either as complete control or as a part of IPM with insecticides, cultural practices and biological control (Panda *et al.* 1971). In crops like rice, wheat, maize, peas etc insect resistant varieties have been developed successfully through conventional breeding programmes.

In India, okra (also known as Bhendi or Lady's Finger) is grown in an area of three lakh hectare (NHB, 2005). All the present day cultivars are susceptible to shoot and fruit borer (*E. vittella*). The yield loss due to this pest ranged from 50.77 to 67.7 per cent, equivalent to 2.7 to 7.0 t / ha (Rawat and Sahu, 1973; Krishnaiah *et al.*, 1976; Dhamdhere *et al.*, 1984). Hence, shoot and fruit borer infestation is treated as an important production problem in okra (Sidhu, 1998). Moreover, okra fruits are harvested at five to seven day interval. Therefore, application of synthetic pesticide particularly at reproductive stage is not advisable due to residual problems on fruits (Kole *et al.*, 2002). Thus, fruit borer resistant varieties are highly preferred and if made available it would certainly compliment the IPM programme. Hence, it becomes imperative to develop a resistant variety against this pest. The present study is an attempt in this endeavour.

5.1 Germplasm utilized for the study

The success of any breeding programme often depends on the availability of right kind of germplasm in sufficient numbers. Every effort was made in this study to assemble as many as diverse germplasm from different geographical region. The bulk of the germplasm of have been obtained from India's National Gene Bank (NBPGR, New Delhi). Besides, the author has undertaken exploration trips to Kerala, Tamil Nadu, North Eastern States to collect landraces and wild *Abelmoschus* species. Thus, in all 144 okra accessions have been assembled before the commencement of breeding programme. The materials include eight wild species, one semi-wild or partially domesticated and one cultivated species.

From the exploration trips, it was observed that the occurrence of some wild species were restricted certain specific ecological niches. For instance, *A. angulosus* was found in The Nilgiri hills (Tamil Nadu) and Sabarimala hills (Kerala) at an altitude of 800 to 1000 m above msl. Similarly, *A. tetraphyllus* var. *pungens* was found only in the high hills of Sikkim Himalayas. *Abelmoschus ficulneus* was collected from Ariyalur district of Tamil Nadu where the soil is slightly alkaline and it did not germinate in the acidic soils of Kerala, hence warranted soil amelioration with lime for its germination (in the experimental Farm of KAU). Another wild species *i.e. A. tuberculatus* obtained from Maharashtra and Uttar Pradesh exhibited its full growth if soils were treated with lime. The exploration also revealed that *A. tuberosus*, a tuberising species and *A. moschatus* var. *multiformis* an ornamental species could be located only in the Trichur district of Kerala.

Regarding *A. caillei*, out of 12 accessions eight have obtained from West Africa and two from Kerala and another two from Sikkim. In West Africa, this species was growing in wild and cultivated only by certain tribal (Hamon and Yapo, 1985 and Hamon and Charrier, 2001). *Abelmoschus caillei* is a perennial species. In Kerala and in Sikkim it is grown in the homestead but not as a

commercial crop. Despite its partial domestication, this species still retain few wild or undesirable traits like photosensitivity, spininess on fruits, unattractive fruit shape and colour, slimy secretion on fruits etc. Hence, it is often treated as a semi-wild. The present study revealed that some of the undesirable traits mentioned above had significance in imparting resistance against *E. vittella*. Regarding cultivated species (*A. esculentus*), large number of germplasm lines collected was of unimproved ones (105 accessions) originated from South Asian countries like India, Bangladesh, Sri Lanka and Nepal where the problems of *E. vittella* persist. Nineteen released okra varieties were also included in this study to see their response against *E. vittella*.

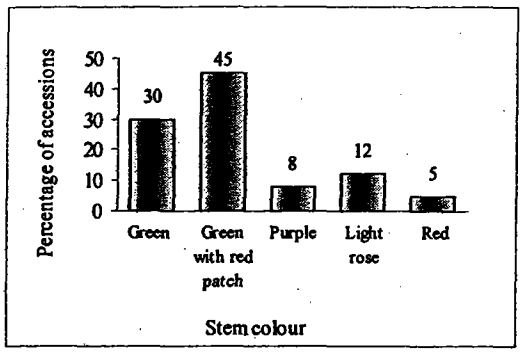
The landraces collected by the author also deserves mention. Each landrace had name signifying their marker trait hence the farmers distinguish them easily by the attributes it possesses. Their photographs are given in Plate 1. For example, the landrace 'Anjilai vendai' from Tamil Nadu put forth flowers as soon as it attain five leaf stage, hence named by farmers as 'Anjilai' (means five leaves in Tamil) 'vendai' (means okra). The landrace 'Aarumasa vendai' is a photosensitive and flower after three or four months and then yield for another two or three months, hence the name 'Aarumasa (means six month in Tamil) 'Vendai' (okra). Another landrace, 'Maravendai' is a prolific bearer and grow like a tree, hence called 'Mara' (means tree in Tami) 'Vendai' (Plate 1). 'Pal venda' was a landrace from Kerala. It bears white fruits, hence named by farmers as 'Pal' (means milk) and 'Venda' (means okra in Malayalam). Another landrace from Kerala is 'Anakomban'. It bears slightly curved fruits looks like the tusks of an elephant, hence called 'Ana' (means elephant in Malayalam) and 'komban' (means tusk bearer).

5.2a Variability in the germplasm for qualitative traits

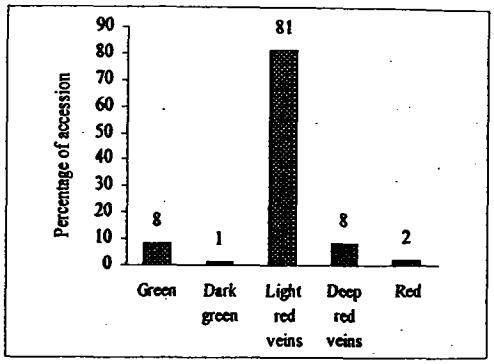
It is not only the assembly of right kind of germplasm is important but also equally important is to characterize the variability in the germplasm for important

traits (Chheda and Fatokun, 1982). This will help to understand the magnitude of variability in a particular crop as well as expose the value of germplasm to the breeders. Hence, the extent of variability in the germplasm for qualitative traits was assessed on the basis of descriptor state (*e.g.* green, dark green, red etc.) for a character (*e.g.* fruit colour) and number of genotypes belonging to each descriptor state. The results showed the existence of high variability for leaf shape, fruit shape, pigmentation on stem, fruit and petal, pubescence of stem and fruits, position of fruits on main stem and fruit ridges. There were 25 different fruit shapes (Plate 5). Intra-specific variability for fruit shape in *A. esculentus* and *A. caillei* was high as evident from 13 and 10 varying fruit shapes respectively in each species. The germplasm exhibited 15 different leaf types (Plate 4). Each type differs for lobing pattern, serration on leaf margin and shape of leaf tip. Five lobed leaves with medium to deep lobing were predominant (74 per cent) in the materials studied. In *A. caillei,* leaves were soft and coriaceous (thick and leathery) and hence used as a leafy vegetable in West Africa (Hamon and Charrier, 1983). The results agree with those of Jawili and Rasco (1990) who reported high variability for leaf shape in common okra.

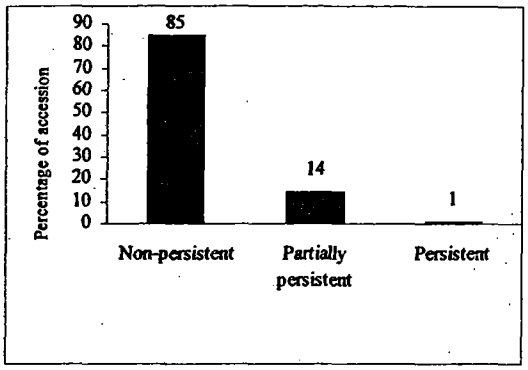
With regard to pigmentation on plant parts, the accessions spread across six to eight descriptor states of fruit colour, petal colour, stem colour and leaf colour indicating presence of high variability for these traits (Fig 4). Accessions bearing green stem and green stem with red patches represented 75 per cent of the genotypes studied (Plate 5). A traditional cultivar Aarumasavendai, indigenous germplasm such as KL 20, MH 3, 4 & 5, ND 2 and RA 2, exotic germplasm such as EC- 2, 6, 12 and a wild species *A. tetraphyllus* had purple stem. *Abelmoschus ficulneus, A. moschatus*, AC 1, AC 9, BH 1, KA 4, KL 1, 11, 12, 23, Maravendai, MH 1 & 6, NER 5, NER 7, Palvenda, Thamaravenda, TN 2 showed rose pigmentation on stem whereas AC 5, AP 2, Aruna, CO-1, EC 10, EC 21 and KL 22 had intense rose pigmentation on stem with deep red leaf veins. Three genotypes *viz.,* Aruna, CO-1 and KL 22 displayed purple pigmentation on stem, petiole, flower and fruits. Petiole colour ranged from green to purple (Fig. 4).



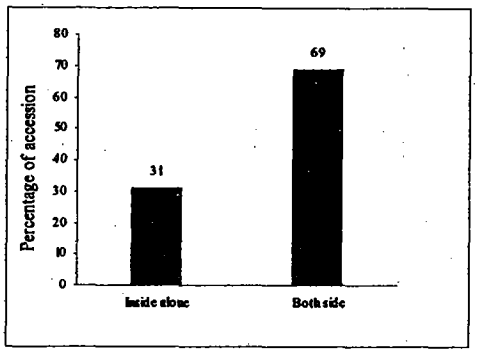
i. Stem colour



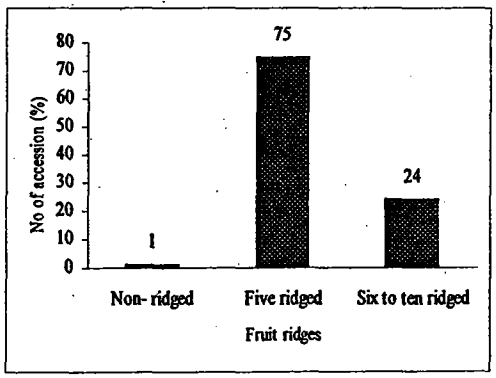
ii. Leaf colour



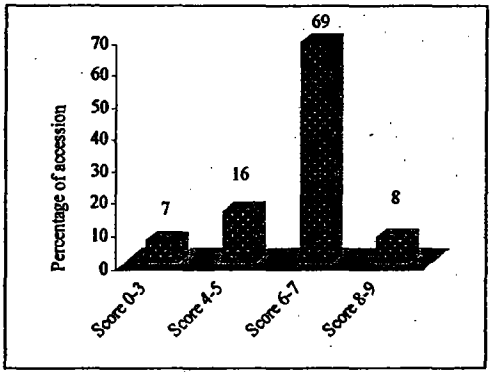
iii. Persistence of epicalyx segment



iv. Presence of spot on petal



v. No. of ridges on fruits



vi. Fruit quality score

Fig. 4 Variability for selected qualitative characters in 144 okra accessions

Leaf lamina colour varied from green to red with various grades of green-red mix. *A. tetraphyllus* and *A. tetraphyllus* var. *pungens* had dark green leaves whereas the remaining 142 accessions exhibited light green leaves. *A. moschatus*, Aruna, Co-1 and all the *A. caillei* accessions except AC 1 and AC 10 had deep red leaf veins. Accessions EC 1, KL 26, MP 1 and UP1 were non-pigmented. Previous reports by Girenko and Pugachev (1983) and Ariyo (1993) indicated the existence of high variation for stem colour, fruit colour and fruit shape in *A. esculentus* and *A. caillei*.

Petal colour varied from white to red (Plate 4). Inter-specific variation exists for petal colour between *Abelmoschus* species but intra-specific variation exists only in *A. esculentus*. In *A. esculentus* petal colour was of two types *viz.*, either yellowish white (in 83 % accessions) or yellowish white with red veins (in Aruna, Co-1, AP-2 and KL-22). The guinien okra *A. caillei* had cream yellow petal while *A. tetraphyllus* and *A. tuberculatus* had pale white petal. Stigma in *A. tuberculatus* was scarlet red and spot inside a petal was brown in contrast to purple in other species. *A. ficulneus* had white petals whereas *A. moschatus* var. *multiformis* produced red petals with outwardly curved margin adding to its aesthetic value. Sulphur yellow petals were observed in *A. angulosus*, *A. moschatus*, *A. tetraphyllus* var. *pungens* and *A. tuberosus*. Fruit colour varied from pale white to pink. Intra-specific variation was high in *A. esculentus* followed by *A. caillei* due to the allogamous nature of the species (Hamon and Koechlin, 1991). The traditional cultivar Palvenda bore pale white fruits (hence known as palvenda in Malayalam). Aruna, Co-1 and EC 21 had red fruits. Fruit colour of the remaining accessions ranged from pale white to red.

Epicalyx shape and number is an important taxonomic key in the genus *Abelmoschus* for distinguishing species (Waalkes, 1966). Intra-specific variability was absent for epicalyx shape (Plate 4). However, it varied among species as shown in Table 5.1. Persistence of epicalyx was appears to a rare trait and it was observed only in *A. angulosus* and *A. tetraphyllus* var. *pungens*. Epicalyx segments in *A. caillei* were partially persistent (Fig 4). The study indicated the

partially persistent triangular epicalyces makes *A. caillei* less preferred by *E. vittella* for oviposition on flower buds as evident from less number of eggs laid on it (Table 4.35).

Table 5.1 Epicalyx shape and number in wild and cultivated okra

Species	Epicalyx shape	Epicalyx No	Most common number
A. esculentus	Linear	6 - 10	8
A. ficulneus	Lanceolate	4 -7	6
A. moschatus & *A. tuberosus*	Linear	8-12	10
A.moschatus var. *multiformis*	Linear	6 - 8	7
A. tetraphyllus	Triangular	4	4
A. tuberculatus	Linear	8 - 10	9
A. angulosus	Triangular, wavy, free	3 - 4	4
A. caillei	Triangular, free	5 -7	6
A. tetraphyllus var. *pungens*	Triangular, adnaate	4	4

The genus *Abelmoschus* displayed greater variation in trichome morphology, density and length of trichomes in vegetative and fruiting parts of the plant (Plate 9 and 10). The trichomes are non-glandular and could be divided into, i) single hair either unicellular or multi-cellular and ii) stellar hairs originating from a tuft of several cells fused at their base giving rise to unicellular trichomes. The distribution of trichomes was not uniform in the plant. For example *A. caillei, A. ficulneus* and *A. tetraphyllus* had less hairy stem but had rather rough and coarse hairs on fruits. Though some genotypes of *A. caillei* such as Thamaravenda and Susthira are cultivated, presence of slightly rough trichomes on the fruits of AC Nos. 3, 4, 6 and 7 discourages their commercial cultivation. In *A. moschatus*, stem is densely covered with long hairs but it has less hairy fruits. The density, rigidity and sharpness of trichomes on fruits varied from species to species (Table 5.2). The observation revealed that in fruit borer resistant species like *A. caillei, A.*

tetraphyllus var. *pungens* and *A. tuberculatus* the trichomes were rather rough and coarse as compared to soft trichomes present in the susceptible species

Table 5.2 Trichome type in resistant and susceptible species

Species	Resistant category	Trichome type
A. esculentus	S	Tomentose (Soft, short, dense)
A. moschatus var. *multiformis*	S	Villous (Soft, long & dense)
A. moschatus *A. tetraphyllus* *A. tuberosus*	S	Hirsute (Rather rough & coarse)
A. ficulneus	S	Scabrous (Feeling rough, swollen at base)
A. caillei	MR	Pilose (Needle like, dense)
A. tetraphyllus var. *pungens*	HR	Strigose (Short, stiff, swollen at base)
A. tuberculatus	HR	Hispid (Rigid and bristle)

(S-susceptible; MR-Moderately resistant; HR-highly resistant)

Intra-specific variation for fruit shape and fruit ridges was high in *A. esculentus* and *A. caillei*. There were 13 fruit types in *A. esculentus* and 10 fruit types in *A. caillei* (Plate 5). They also exhibit an array of variation for number of ridges on fruit ranging from non-ridged fruits in *A. caillei* accession AC 2 to multi-ridged fruits with constriction at middle in *A. esculentus* accessions KL 9, KL 14, KL 15, MP 4, MH 1, MH 5, MH 6, EC 2 and MH 3. Five ridged fruits were the most common type (found in 74 per cent of the germplasm) followed by multi-ridged fruits (24 per cent). Three accessions namely, AC 7, UP 1 and UP 2 appeared distinct from other for having fruits with non-ridged base and ridged apex (Fig 4 and Plate 6a). With regard to fruit tip, acute fruit apex was more prevalent among *A. esculentus,* whereas obtuse rostrum was common in the wild species. Both types were common in *A. caillei* (Plate 4). Hamon and Charrier (1983), Bisht *et al.* (1995) and Ariyo (1993) while studying the genetic diversity observed greater variation for fruit shape in *A. caillei* and *A. esculentus* accessions collected from India, Bangladesh, Nepal, Sri Lanka and Africa.

Intra-specific variation for fruit position on main stem could not see in *A. esculentus*. All the 124 accessions produced upright or erect fruits. However, accessions in *A. caillei* displayed variation for this trait. Out of 12 accessions, orientation of fruits on main stem was horizontal in AC 7, pendent in AC 6 and upright in remaining 10 accessions (Plate 4). Martin (1982 a) also observed similar variation for this trait in *A. caillei* accessions collected from Ghana and Ivory Coast. In *A. ficulneus* and *A. tetraphyllus,* fruits were aligned one side on the main stem. In the case of *A. moschatus* species *i.e. A. moschatus, A. moschatus* var. *multiformis* and *A. tuberosus* fruits possessed long pedicel. If the position of petiole or fruits oriented right angle to main stem, plucking of fruits would be made easy without injury to the stem.

Fruit quality assessed on the basis of fruit colour, tenderness, surface texture etc. revealed the presence of high variability ranging from non-palatable prickly fruits in wild species to non-spiny and quality fruits in cultivated species (Fig 4). In wild species fruits were not at all palatable due to the presence of spines whereas the accessions belonging to *A. caillei* produced palatable fruits but of low quality due to unattractive shape, presence of trichomes, viscous smears on fruit surface etc. *A. caillei* variety Susthira was distinct from other accessions. Its fruit shape resembled common okra and was free from spines (fruit quality scores was six). Presence of trichome though an undesirable trait from the consumer point of views it is an important factor in deciding oviposition preference by *Earias vittella* as pointed out by Saini and Singh (1999). Barring four spiny genotypes (KL 19, KL 23, MH 1 and EC 2) other accessions of *A. esculentus* produced medium to good quality fruits. Eleven accessions of *A. esculentus* such as OR 2, WB 1, EC 5, Bio 2, Salkeerthy, KL 2, KL 26, KL 28, MP 1, MP 3 and NER 7 had good quality fruits. They can be used as donors for improving fruit quality. Similar results were reported by Nizar *et al.* (2004).

Microscopic examination of seed surface architecture revealed the presence of inter-specific variation for seed shape and seed surface texture (Plate 6b). Seed

shape of *A. caillei, A. esculentus, A. ficulneus, A. tetraphyllus* and *A. tuberculatus* were globose to ovoid. The last three species had hairy seeds and hence concentric markings on the testa were invisible. *A. caillei* had globular seeds with clear concentric markings on testa. Shape of seed was oblong in *A. esculentus* except NER 7 and NER 8 with globular seeds. *A. angulosus* had villous hairs on testa and its seed shape was intermediate between globular and reniform. Seeds of *A. moschatus* species *i.e. A. moschatus, A. moschatus* var. *multiformis* and *A. tuberosus* were reniform, glabrous with prominent hilum and concentric rings on testa. *A. tuberculatus* produced hairy seeds. Its hilum shape resembled the standard petal of legume flower with broad apex and narrow base. Seeds of *A. pungens* were similar to those of *A. angulosus* with less hair and concentric rings on testa feebly visible. Since trichome on seeds shed during the process of seed extraction and storage which causes allergic to some person non-hairy seeds as in *A. caillei* is generally preferred.

The results furnished above on the pattern of variation for qualitative traits would be of great importance to both germplasm collectors and to breeders. Since most of the qualitative characters like trichome, fruit shape, fruit ridges, leaf colour, epicalyx shape, branching pattern etc. are directly or indirectly related to fruit quality, productivity and resistance to biotic and abiotic stresses an understanding on the magnitude of variability for these traits would certainly helps the breeder to select potential parental lines for productive as well as protective breeding programmes in line with consumer preference. The information on seed surface architect would help to the taxonomist to assess the similarity and divergence of *Abelmoschus* species.

5.2b Variability for quantitative traits

Simple measures like range, genotypic co-efficient of variability (GCV) and phenotypic co-efficient of variability (PCV) will provide an insight into the extent of variability present in a germplasm for quantitative traits (Sharma, 1998). The

variability for days to first flowering, flowering period and fruit girth was low (Fig.5) in the materials studied as evident from low GCV (< 15 per cent). The genotypes included in the study exhibited medium variability (GCV=15 to 30 per cent) for internode number, average fruit weight, fruit length and marketable fruit yield and high variability (GCV > 30 per cent) for plant height, number of branches per plant, number of leaves per plant, length of internode, number of fruits per plant, fruit yield per plant, shoot borer infestation, fruit borer infestation and incidence of YVMV. The high GCV gives an indication that there was justifiable variability among the genotypes with respect to these characters and therefore offer scope for improvement through selection. Similar observations were made by Majumder *et al.* (1974) and Dhall *et al.* (2003).

This finding also agrees with that of Kirtisingh *et al.*(1974) and Dhall *et al.* (2003) who reported medium GCV for fruit yield, leaf number, branches and low GCV for days to flowering. The narrow difference between the values of GCV and PCV for characters like days to first flowering, flowering duration, internode number, internodal length and fruit length indicated the limited role of environment in the expression of these traits. Hence, it is expected that heritability of these traits would be high. In such a situation, simple phenotypic selection would be rewarding for improving these components traits. However, the phenotypic expression of branches per plant, leaf number, incidence of YVMV, shoot borer infestation and fruit borer infestation were influenced largely by environmental factors as evident form wide differences between GCV and PCV. Recombination breeding would be rewarding to improve these traits.

5.3 Performance of genotypes for yield and yield attributes

The study revealed that accessions of *A. esculentus* flowered 12 to 13 days earlier than that of *A. caillei* (55.31 days). The two early flowering *A. esculentus* genotypes AP5 (31.67 days) and EC 16 (32 days) can be used as donors for earliness.

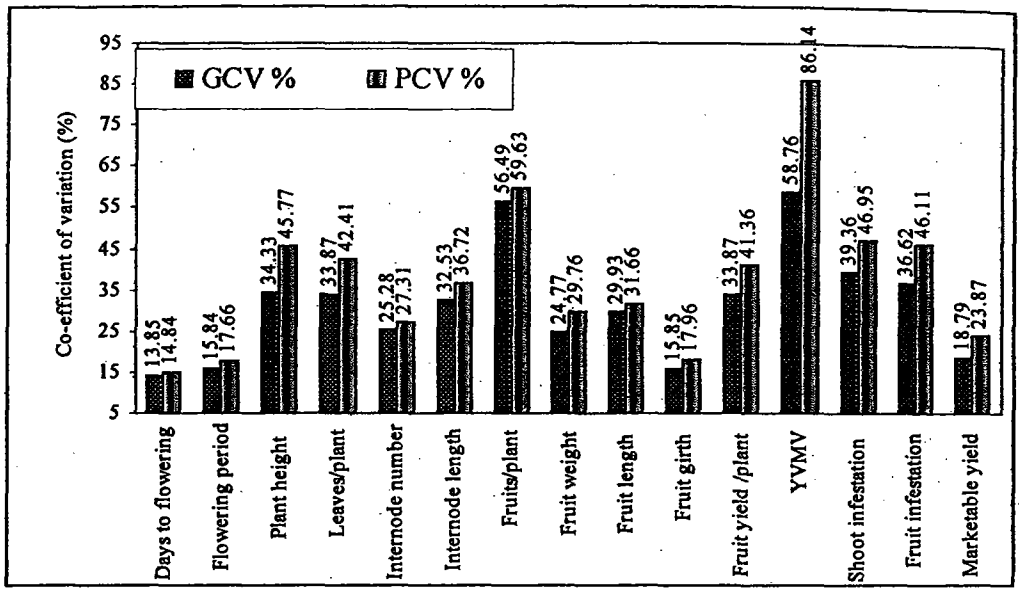


Fig. 5 Genotypic and phenotypic coefficient of variation for quantitative traits

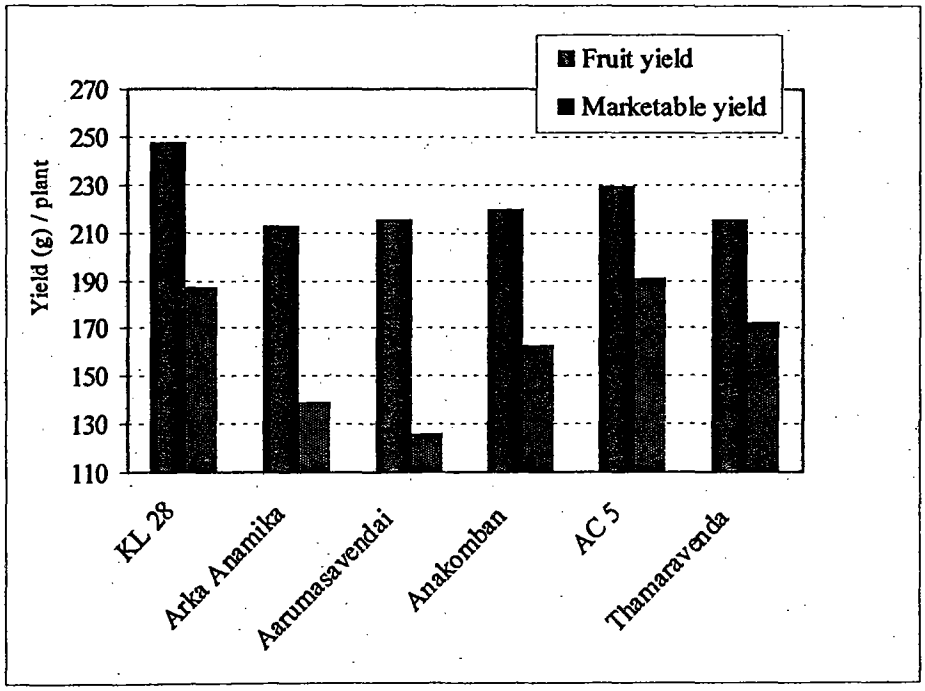


Fig. 6 Fruit yield and marketable fruit yield in selected genotypes

The landraces Maravendai and Aarumasavendai were distinct from others. They displayed prolonged flowering period (more than 40 days) but found to be late flowering (52-57 days). *A. caillei* accession AC 4 and wild species *A. angulosus* and *A. ficulneus* exhibited photosensitivity. They remained in vegetative phase under long day (June to August). According to Ariyo (1993) cultivation of *A. caillei* in West Africa is limited to four months, from September to December, due to its photosensitivity. In view of these, it is advisable to grow Maravendai, Aarumasavendai and AC 4 during short day period (September to December).

Plant height and number of branches per plant are important yield contributing characters in okra (Vijay and Manohar, 1990). The tallest genotype (170.32 cm) in the cultivated species was Maravendai (*i.e.* tree okra) followed by Aarumasavendai. However, both were moderately susceptible to YVMV. In okra, as only one fruit is borne in a leaf axil, low internodal length and high internode number are desirable for increasing the number of fruits per plant (Singh and Singh, 1979). Landraces like Maravendai and Arumarasavendai displayed high internode number, while KL 21 and Susthira displayed shortest internodal length hence these genotypes could be useful for productive breeding.

Among wilds species, *A. moschatus* var. *multiformis* was very short (41.33 cm height). It produced few primary branches. Each primary branch produced secondary and tertiary branches. The profuse branching habit is highly desirable as it positively correlated to number of flowers per plant. This species also displayed long flowering phase (41.33 days). Every alternative day, an attractive red flower was borne. This species is worthy for ornamental gardening.

A. esculentus accessions KL 26, Anakomban, Salkeerthy and NER 7 produced long fruits. In general, *A. caillei* fruits were thicker than that of *A. esculentus*. Average fruit weight was high in Salkeerthy (20.6 g), NER 4 (19.7 g) and UP 1 (19.6 g).

Abelmoschus esculentus accession KL 28 and Arka Anamika and *A. caillei* accessions AC 5 were ranked top for fruit yield as well as marketable fruit yield (Fig 6). *A. esculentus* such as Arka Anamika, KL 9 and KL 28 showed field resistance to YVMV. *A. caillei* accessions AC 2, AC 5, AC 8, AC 9 and Thamaravenda and wild species *A. angulosus*, *A. moschatus* var. *multiformis* and *A. tetraphyllus* var. *pungens* were also showed field resistance to YVMV. Bora *et al.* (1992) also reported that Arka Anamika was field resistant to YVMV and Chheda and Fatokun (1982) and Kousalya *et al.* (2006) reported that *A. caillei* was highly resistant to YVMV. However, previous report on resistance in *A. angulosus*, *A. moschatus* var. *multiformis* and *A. tetraphyllus* var. *pungens* to YVMV have not observed and possibly this is the first report on resistance in these wild species.

5.4 Screening genotypes for resistance to shoot and fruit borer

Kashyap and Kalloo (1983) and Sharma (2004) suggested that while conducting a germplasm screening programme against insect pest, the released varieties, landraces, national and world collections have to be screened in addition to wild species of that particular crop. Accordingly, 14 commercial varieties, five traditional cultivars, 84 indigenous germplasm, 21 exotic germplasm, 12 accessions of semi-wild species (*A. caillei*) and eight wild species were included in this study so as to select a highly resistant genotype to *E. vittella*. The above germplasm were obtained from major okra growing countries where *E. vittella* is a major pest. These germplasm have not been tested previously except Punjab Padmini, Arka Anamika, Co-1, Parbhani Kranti and Sel-2. With regard to wild species, a comprehensive screening was not conducted earlier using all the wild species at a given location, concentrating simultaneously on two parameters namely resistance to shoot borer and resistance to fruit borer. In view of this, all the wild species were included in this study. The results of the present study are discussed hereunder.

5.4.1 Resistance in cultivated species

The nineteen cultivated varieties tested in the present study were susceptible to shoot and fruit borer. Previous workers like Mahadevan and Dhandapani (1985), Gupta (1988), Vyas and Patel (1991), Srinivasa and Sugeetha (2001), Neeraja *et al.* (2004) reported the susceptibility of variety Co-1, Parbhani Kranti, Pusa Makhmali, Varsha Upahar and Arka Anamika to fruit borer. The study revealed that genotype KL 9 was moderately resistant to shoot borer and genotype EC 2 to fruit borer (Fig 6). The resistance in these genotypes was further confirmed in the second year trial. Although these two moderately resistant accessions were not specifically bred for resistance to *Earias*, the presence of resistance in these accessions suggests that it can be transferred to a high yielding variety. Such a practical approach was suggested earlier by Nawale and Sonone (1977) to transfer resistant gene from a moderately resistant okra line AE 22. The same was adopted in the present study.

5.4.2 Resistance in semi-wild species

Among the accessions of *A. caillei,* AC 5 was found moderately resistant to shoot and fruit borer and Susthira was moderately resistant to shoot borer alone (Fig.7). The finding that *A. caillei* is moderately resistant to fruit borer is in conformity with Kashyap and Verma (1983) who recorded 11 per cent fruit infestation in *A. manihot* var. *Ghana* but for shoot infestation no previous report could be seen. The level of resistance in AC 5 suggests that it can be used as a moderately resistant donor for shoot as well as fruit borer.

5.4.3 Resistance in wild okra

The wild species, in general, showed more resistance to shoot and fruit borer except *A. moschatus* and *A. moschatus* var. *multiformis*. It was found that *A. tuberculatus* was highly resistant to fruit borer but moderately resistant to shoot borer. Pal *et al.* (1952) stated that *A. tuberculatus* was 'almost immune' to *E. insulana* but it was not clearly mentioned whether it is for shoot infestation or for

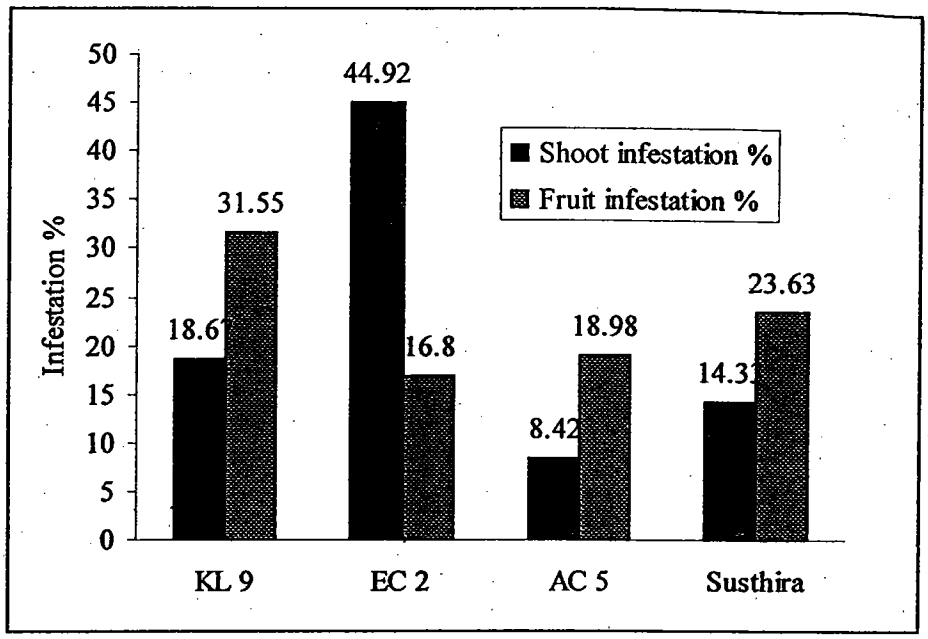


Fig 7 Shoot and Fruit infestation in selected genotypes

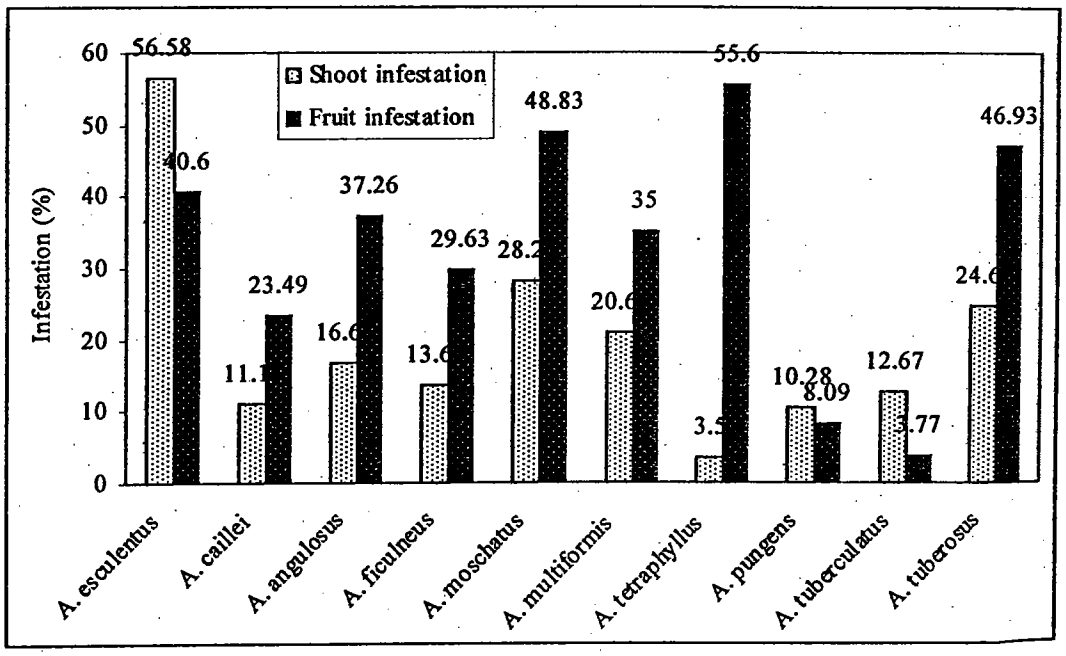


Fig. 8 Shoot and Fruit infestation: species wise comparison

fruit infestation. Bisht *et al.* (1997) reported *A. tuberculatus* as 'least infested' for fruit borer. In the present study *A. tetraphyllus* was found highly resistant to shoot borer. However, it was susceptible to fruit borer. Raut and Sonone (1979) reported that this species was resistant to shoot borer. The high altitude species *A. tetraphyllus* var. *pungens* was highly resistant to fruit borer, moderately resistant to shoot borer and free from YVMV. This is the first report on the resistance of the species to *E. vittella* and YVMV.

5.4.4 Species-wise comparison of resistance

The genus *Abelmoschus* which includes one cultivated (*A. esculentus*), one partially domesticated (*A. caillei*) and eight wild species exhibited varying response to shoot and fruit borer infestation (Fig 8). The mean shoot infestation in 122 accessions of *A. esculentus* was 56.58 per cent which was relatively higher than its mean fruit infestation (40.60 per cent). On the other hand, shoot and fruit infestation (SI=11.11 and FI=23.49 per cent) in 12 accessions of *A. caillei* was less than corresponding values in *A. esculentus*. This showed that *A. caillei* is relatively more resistant to shoot and fruit borer than *A. esculentus*. Further, the percentage shoot infestation in *A. caillei* was less than the percentage fruit damage suggesting that *A. caillei* was relatively more resistant to shoot infestation than fruit borer.

The study also revealed differential response of genotypes to shoot infestation and fruit infestation even though the pest which attacks the shoots and fruits is one and the same *i.e. E. vittella.* For instance, the wild species, *A. tetraphyllus* was highly resistant to shoot borer (SI=3.5 per cent) but highly susceptible to fruit borer (FI=55.60 per cent) (Fig 8). Similarly, *Abelmoschus ficulneus* was moderately resistant to shoot borer (SI=16.67 per cent) but susceptible to fruit borer (FI=29.63 per cent). The species *A. tuberculatus* was highly resistant to fruit borer (FI=3.37 per cent) but recorded 12.67 per cent shoot infestation. This necessitated expression of resistance separately for shoot borer as well as fruit borer. Further, the differential response of genotypes to shoot and

fruit infestation would result in undesirable consequences while selecting a donor for resistance. For instance, if one select *A. tetraphyllus* as donor for shoot borer resistance, its susceptibility to fruit borer would also gets dragged unintentionally. No previous report regarding the differential response of *A. tetraphyllus* and *A. tuberculatus* to shoot and fruit infestation have observed. Since the factors imparting resistance to *E. vittella* includes biophysical, biochemical and histochemical factors (see section 5.11). The distribution (presence or absence) and the magnitude (quantity) of the resistant imparting factors in shoots and fruits are not uniform and this would be a possible reason for this phenomenon.

From the study, the relative degree of resistance in ten *Abelmoschus* taxa to shoot borer could be represented as: *A. tetraphyllus >A. ficulneus>A. tetraphyllus* var. *pungens>A. tuberculatus>A. caillei>A. angulosus>A. moschatus>A. moschatus* var. *multiformis>A. tuberosus >A. esculentus.* For fruit borer the order of resistance were *A. tuberculatus>A. tetraphyllus* var. *pungens >A. caillei>A. ficulneus>A. tuberosus>A. angulosus>A. moschatus* var. *multiformis>A. moschatus> A. tuberculatus> A. esculentus.*

5.5 Correlated response

The correlation studies have indicated that there was a negative association between number of internodes, number of leaves per plant, number of fruits per plant and plant height with shoot borer infestation and positive association between days to first flowering and shoot borer infestation. Therefore, it can be concluded that by selecting genotypes having early flowering, enhanced plant height, high internode number, high leaf number per plant and short fruit length there will be reduction in shoot borer infestation. Moreover, shoot borer infestation showed negative association with marketable fruit weight and both shoot borer and fruit borer infestation were interrelated. Therefore, if shoot borer infestation reduced fruit borer infestation would also be minimized. Further, by selecting genotypes with higher marketable fruit yield both shoot borer and fruit

borer infestation could be minimized. With regard to fruit girth, it was positively correlated with yield and negatively correlated with fruit infestation. Yield is an ultimate the breeder. Therefore, by selecting genotypes having high fruit girth or thick fruits (in addition to high fruit number and fruit length) fruit yield can be enhanced and at the same time fruit borer infestation would be minimized. Thus, selection based on these correlated traits will be a step towards the development of resistant or tolerant genotypes. The study agree with Malik *et al.* (1986) who observed correlation between shoot borer infestations in brinjal with fruit thickness and Deo *et al.* (1996) who suggested selection based on plant height to improve the yield in okra.

5.6 Genetic divergence among genotypes and its implication

The wealth of any germplasm collection is measured in terms of its genetic diversity it contains. Further, selection of parents for the breeding depends on the existence of genetic diversity and its assessment is very much helpful in improving the quantitative traits. Multivariate analysis has been used by many workers to classify variation pattern in okra germplasm (Chheda and Fatokun, 1982; Mishra *et al.*, 1996). The inter- and intra-cluster distances are an index of genetic diversity among the genotypes. The 144 genotypes were grouped into 13 clusters based on 14 quantitative traits. The wide range of inter-cluster distances indicated the existence of greater genetic divergence in the materials studied (Fig 9). The intra-cluster distances indicated that the genotypes within each cluster were less divergent except those in cluster No I (consisted of wild species) and VI (consisted of *A. caillei* and *A. esculentus*). Genotypes from different geographical regions assorted into the same cluster suggesting that there is no parallelism between genetic diversity and geographical diversity. Patil *et al.* (1996) reported similar results based on similar studies in okra. Forces of differentiation at inter-cluster level are assessed by the percentage contribution of individual traits towards divergence. The most important characters contributing towards divergence were plant height, days to first flowering, fruit length and length of

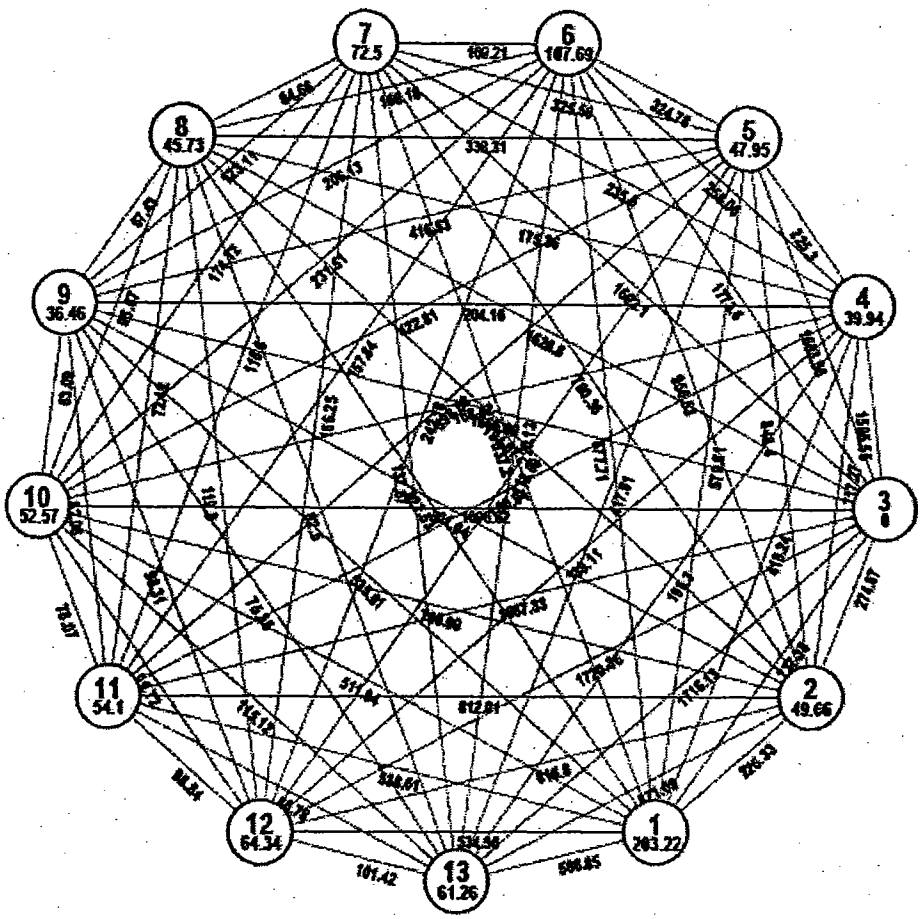
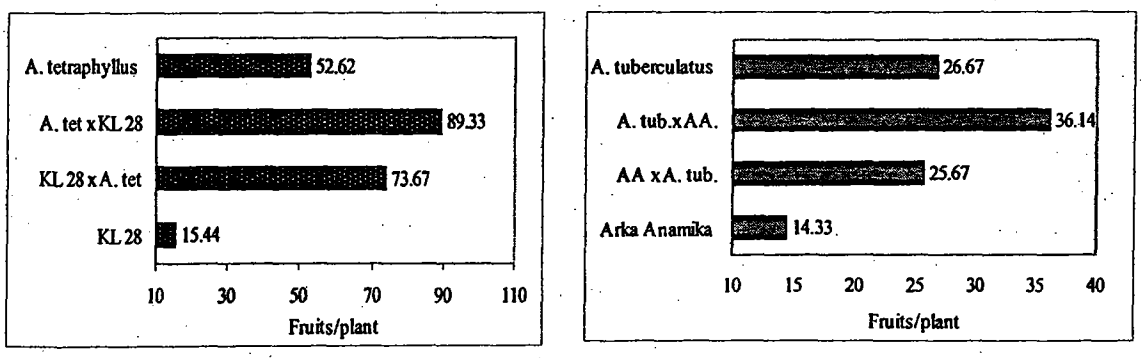


Fig. 9 Diagram showing inter-intra cluster distances -Not to the scale



i. *A. esculentus* x *A. tetraphyllus* ii *A. esculentus* x *A. tuberculatus*

Fig 10 Number of fruits per plant in the interspecific hybrids

internode. These four traits together contributed 60 per cent of the total diversity. Partap *et al.* (1980) and Mishra *et al.*(1996) also observed contribution of fruit length and fruit yield towards divergence.

It has been well established that more the genetic diversity of genotype for crossing, the greater would be the chance of obtaining heterotic hybrids and broad spectrum of genetic variability in the segregating generations (Arunachalam, 1981). However, when crosses are to be made at inter-specific level or between wild and cultivated species it would be desirable to choose parents showing less divergence due to crossability barrier as well as the expression of sterility in the F_1. In the present study, a wild species highly resistant to shoot borer *i.e. A. tetraphyllus* was sorted into a cluster III. High yielding genotypes were grouped in cluster V (landraces) and cluster VII (commercial varieties). The inter-cluster distances revealed shortest distance between cluster III and cluster VII. Therefore, crossing among the genotypes from cluster III and VII would bring heterotic crosses with less crossability barrier or sterility in the resulting F_1.

The genotypes of *A. caillei* were grouped in cluster IV. They showed moderate degree of resistance to shoot and fruit borer. The inter cluster distance between cluster IV (*A. caillei*) and cluster III (*A. tetraphyllus*) was the highest followed by cluster IV and cluster VI (*A. esculentus*). Crossing among genotypes between these clusters though would result in high heterotic hybrid but the hybrids may show sterility due to higher inter-cluster distance. Therefore, from the practical point of view, genotypes from clusters having the shortest inter-cluster distance are considered worthwhile. Accordingly, it is suggested to go for hybridization between genotypes in cluster IV (*A. caillei*) and cluster XII (*A. esculentus*). The inter-cluster distance between the two was the shortest. As regard to inter-varietal hybridization in *A. esculentus,* crossing between cluster V (landraces) and IX (unimproved germplasm) is suggested to realize heterotic effects since the inter cluster distances were high.

5.7 Transfer of shoot and fruit borer resistance from wild species to cultivated okra

Wild relatives form an important gene pool, from which source materials for insect resistance have been widely used. In the present study, the inter-specific hybrid *A. esculentus* (KL 28) x *A. tetraphyllus* was highly resistant shoot borer infestation. Its parent *A. tetraphyllus* was also highly resistant to shoot borer but *A. esculentus* was susceptible. Resistance to shoot borer in F_1 was thus found to be dominant over susceptibility. Similarly, the inter-specific hybrid *A. esculentus* (Arka Anamika) x *A. tuberculatus* was highly resistant to fruit borer. Its parent *A. tuberculatus* was highly resistant to fruit borer but *A. esculentus* was susceptible. The resistance to fruit borer in the F_1 was thus dominant over susceptibility. In both crosses, resistance was governed by major gene. Panda and Khush (1995) reported that resistance in rice to BPH (*Nilaparvatha lugens*) was controlled by major genes.

The inter-specific hybrids between *A. esculentus* and *A. tetraphyllus*, *A. esculentus* and *A. tuberculatus* exhibited prolificacy for fruit number (Fig 10) particularly when the wild species used as female parent. It resulted in high heterosis for fruit yield due to cytoplasmic influence. However, the breeding programme to transfer resistant genes (through conventional breeding method) from *A. tetraphyllus* and *A. tuberculatus* to *A. esculentus* could not be continued beyond F_1 due to sterility in the inter-specific hybrids. The possible reasons for the sterility in the inter-specific F_1 are differences in the chromosome number of parents and meiotic irregularities as also reported by Madhusoodanan and Nazeer (1986) and Fatokun (1987) in the inter-specific cross *A. esculentus* x *A. caillei.* While attempting to transfer YVMV resistance from *A. tetraphyllus* to *A. esculentus,* Hamon and Yapo (1986) and Nerkar and Jambhale (1985) observed the occurrence of hybrid sterility. Therefore, in future, innovative technique like *in vitro* embryo culture as reported in *A. esculentus* x *A. moschatus* cross by Gadwal *et al.* (1968) may be taken up to overcome the sterility barriers.

5.8 Transfer of resistant gene from a moderately resistant source

Resistance to shoot and fruit borer (moderate resistance) was also found in *A. caillei* genotypes AC 5 and Susthira and *A. esculentus* genotypes KL 9 and EC 2. Previous workers like Dhillon and Sharma (1982), Martin (1982 a), Jambhale and Nerkar (1983) Sharma and Sharma (1984) had used this species as donors for YVMV resistance. The present study is an attempt to transfer its shoot and fruit borer resistance to cultivated okra. Crosses between *A. esculentus* and *A. caillei* was successful in either direction as also reported by Dhillon and Sharma (1982) and Hamon and Yapo (1986) although Chacko *et al.* (1998) and Kousalya *et al.* (2006) reported failure of *A. esculentus* x *A. caillei* crossing.

5.8.1 Gene action for shoot and fruit borer resistance

The estimate of *GCA* variance and genetic parameters (σ^2A and σ^2D) in the diallel analysis would indicate whether gene action is additive or non-additive. Combining ability analysis for the 6 x 6 full diallel cross revealed that the resistance was a polygenic trait and involved preponderance of additive gene action for shoot borer resistance and both additive and non-additive gene action for fruit borer resistance and these traits. These traits could be improved through breeding programmes like biparental mating followed by recurrent selection which capitalize both additive and non-additive variances.

5.8.2 Gene action for yield and yield attributes

Combining ability analysis indicated the importance of both additive and non-additive genetic variances for fruit girth. Hence, this trait could be improved through biparental mating followed by recurrent selection as reported earlier by Chavadhal and Malkhandale (1994). For days to first flowering and flowering period the *gca* variances were high, signifying the importance of additive gene effects for these characters. Consequently, it is suggested that these traits could be improved through selection rather than heterosis breeding (Jawili and Rasco, 1990).

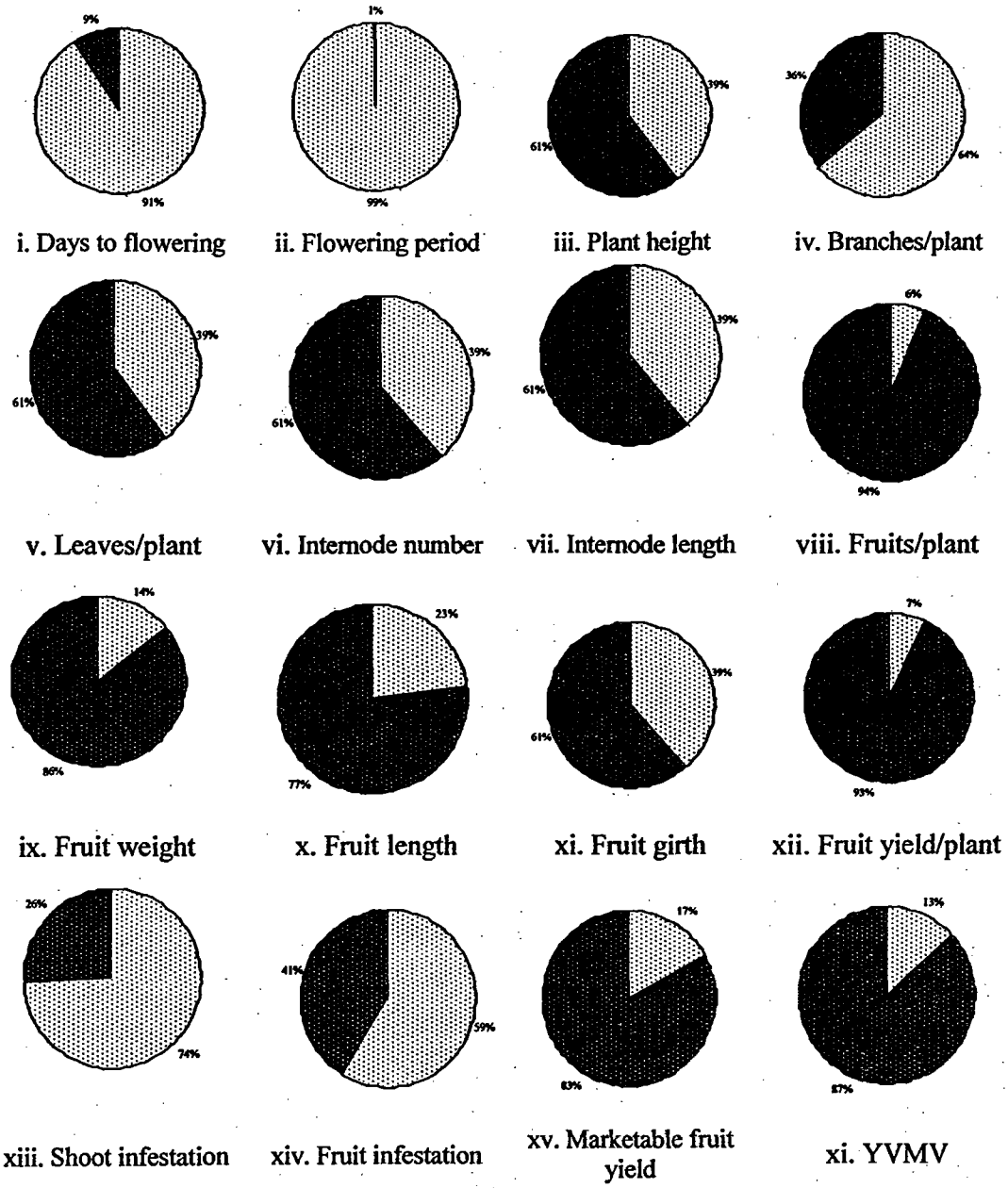


Fig.11 Proportion of additive and non-additive variance for quantitative traits

On the other hand, non-additive gene effects were higher for plant height, length of internode, fruits per plant, fruit weight, fruit length, fruit yield and co-efficient of infection for YVMV (Fig.11). Therefore, yield could be enhanced through the improvement of these component traits through recombination or heterosis breeding. Similar projection were made earlier by Sivakumar *et al.* (1995), Partap and Dhankar (1980) and Rani and Arora (2003a).

5.8.3 General combining ability effects of parents

When large numbers of crosses are made, a few crosses may show superiority for yield and yield contributing traits over their parents. The parents of such heterotic crosses are said to be good general combiners. The *gca* is a measure of additive genetic variance (Sprague and Tatum, 1942). On the basis of direction and magnitude of *gca* effects, it was found that Arka Anamika was a good general combiner for days to first flowering, flowering period, fruit length and YVMV resistance. *A. caillei* accession AC 5 was a good general combiner for plant height, internode number, fruits per plant, fruit yield, shoot and fruit borer resistance and marketable fruit yield (Fig. 11). The variety Susthira was a good general combiner for internodal length and shoot borer resistance.

5.8.4 Specific combining ability effects and heterosis in hybrids

In monogenic model like Griffing's approach the *sca* effects signify the role of non-additive gene action particularly the dominance deviation. Therefore, the hybrid performance will be highlighted with reference to *sca* along with *per se* and standard heterosis (over check hybrid Texico hybrid No.46).

5.8.4.1 Reaction of hybrids for shoot and fruit infestation

The F_1 hybrids of inter-specific cross KL 9 x AC 5 and the intra-specific cross Arka Anamika x KL 9 exhibited moderate degree of resistance to shoot borer (Fig.12). Intra-specific crosses of *A. esculentus* involving KL 9 (selected as resistant donor for shoot borer) such as KL 9 x Arka Anamika, KL 9 x EC 2, EC 2

x KL 9 were moderately resistant to shoot borer. Parent KL 9 when crossed with any moderately resistant genotypes of *A. caillei,* the resultant hybrids showed moderate degree of resistance to shoot borer as evident from cross combinations like KL 9 x AC 5, KL 9 x Susthira, AC 5 x KL 9, Susthira x KL 9. However, the *sca* and reciprocal effects in the above hybrids (except Arka Anamika x Susthira and EC 2 x AC 5) were insignificant. The results implies that i) resistance expressed by KL 9 to shoot borer are heritable and controlled by polygene and ii) additive gene effects might be predominant than non-additive effects.

Intra-specific crosses of *A. caillei* and inter-specific crosses of *A. esculentus* and *A. caillei* showed less fruit infestation (mean FI=21.62 per cent and 19.04 per cent respectively) than the intra-specific crosses of *A. esculentus* (FI=35.03 per cent). The inter-specific cross KL 9 x AC 5 and the intra-specific cross Arka Anamika x KL 9 and Arka Anamika x EC 2 ranked first for low fruit infestation in their respective hybrid groups ((Fig. 12). However, no cross combinations exhibited significant *sca* in desirable (-) direction.

5.8.4.2 Performance of hybrids for yield and yield attributes

Cross combinations KL 9 x Arka Anamika and KL 9 x EC 2 flowered earlier (37 to 38 days). Their *sca* effects were negatively significant and hence considered as good specific combiner for this trait. For flowering period, although five hybrids namely, Arka Anamika x EC 2 (d_{iii}=11.05 per cent), Arka Anamika x AC 5 KL 9 x AC 5, KL 28 x AC 5 and AC 5 x EC 2 registered high standard heterosis vis-à-vis high *per se* the *sca* effects were significant and positive in Arka Anamika x EC 2 alone. High^{+} x high^{-} *gca* effects resulted in high *sca* in this cross.

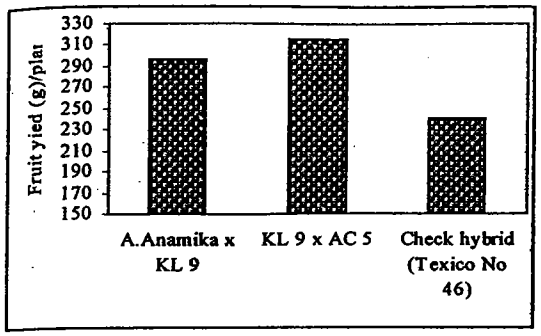
Although 25 hybrids recorded significant standard heterosis for plant height, it was remarkably high in inter-specific crosses like KL 28 x AC 5, Arka Anamika x AC 5 and KL 9 x AC 5. Their *sca* effects were also positively significant and hence they could be considered as best specific combiners for improving plant height. Barring KL 9 x AC 5, other combinations had parents with H^{+} x H^{+} *gca.*

The cross combination KL 28 x AC 5 manifested high *sca* effects and heterosis for internode number while Arka Anamika x KL 28 could be considered as good specific combiner for improving internodal length.

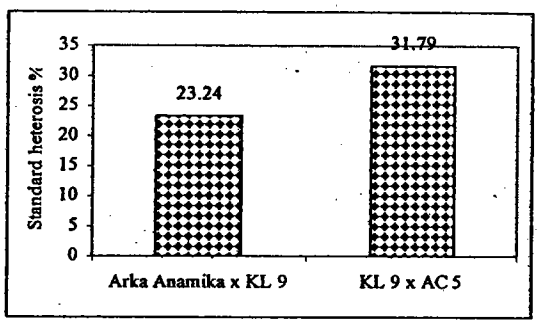
Number of fruits per plant varied from 7.50 to 32.67. Inter-specific hybrids manifested high *per se* vis-à-vis high heterosis this trait. The top ranking cross was KL 9 x AC 5 (32.67 fruits/plant; 100 per cent heterosis). Among 12 intra-specific crosses of *A. esculentus*, Arka Anamika x KL 9 alone manifested high *per se* (18.33 fruits / plant) and high standard heterosis (d_{iii}= 12.25 per cent) over Texico hybrid No 46.

Fruit yield per plant varied from 73.70 g to 316.21 g. However, only five hybrids registered high fruit yield vis-à-vis standard heterosis than check hybrid recording 239 g fruits/ plant. They were, KL 9 x AC 5 (507.90 g/plant; d_{iii}=31.79 per cent), Arka Anamika x KL 9, Arka Anamika x AC 5, Susthira x KL 28 and Susthira x EC 2 (247.90 g/plant). A perusal of *sca* and reciprocal effects in the above heterotic hybrids revealed that *sca* effects were significant for all the crosses, which indicates that fruit yield is governed predominantly by non-additive gene action. When these best heterotic crosses viewed in relation to the *gca* effects of their parents, high *sca* or *per se* was apparent not only in H^+ x H^+ combination (Arka Anamika x AC 5) but also in H^- x H^+ combinations (KL 28 x Arka Anamika; KL 28 x AC 5) or H^+ x H^- combinations (Arka Anamika x KL 9 and AC 5 x EC 2). Therefore, in practice, at least one of the parents for heterosis breeding should be a high general combiner for fruit yield.

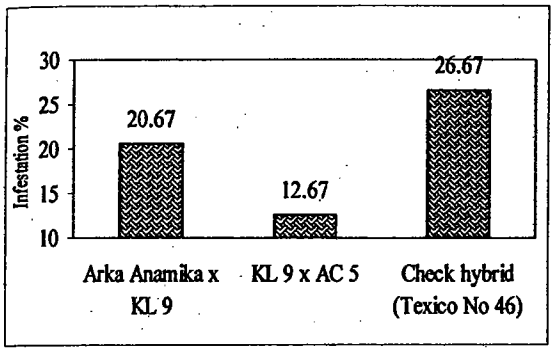
Two hybrids manifested significant *sca* and high marketable fruit yield over and above the check hybrid. They were KL 9 x AC 5 with 265.87 g and Arka Anamika x KL 9 with 195.70 g marketable fruit yield. They showed field resistance to YVMV. These two can be considered as good specific combiner for improving marketable fruit yield.



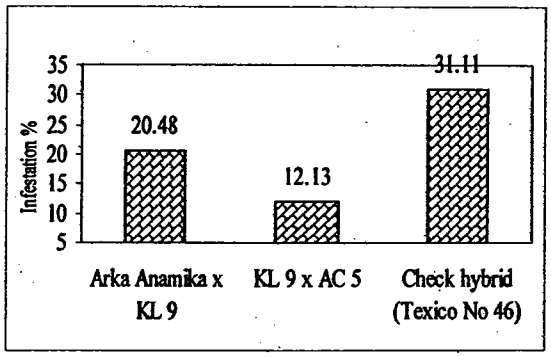
a. Fruit yield/plant



b. Standard heterosis



c. Shoot infestation



d. Fruit infestation

Fig 12 Performance of two promising F_1s for yield and resistance to *E. vittella*

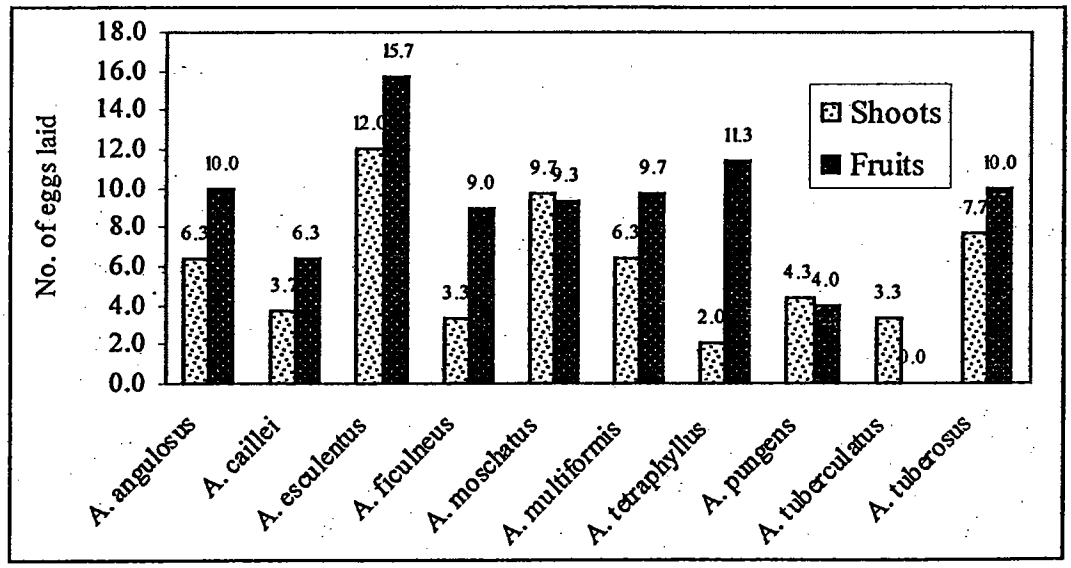


Fig 13. Oviposition preference of *Earias vittella* for the shoots and fruits of wild and cultivated okra

Thus, by considering resistance to shoot and fruit borer on one side and yield attributes and combining ability on the other side, an intra-specific cross of *A. esculentus i.e.* Arka Anamika x KL 9 and an inter-specific hybrid of *A. esculentus* x *A. caillei i.e.* KL 9 x AC 5 can be projected (Fig. 12) as worthy for exploitation either as varieties or as F_1 hybrids.

5.8.5 Reciprocal differences

The ANOVA revealed the significance of reciprocal effects for all the traits under study except for number of branches, length of internode and shoot infestation. Therefore, while choosing crosses in addition to *sca*, importance may be given to reciprocal difference as well. In case of fruit yield per plant, considering the magnitude and direction of reciprocal effects, reciprocal difference was important for Susthira x EC 2 and KL 28 x Susthira. Hence, it is presumed that Susthira and KL 28 will give better progenies only when they are deployed as ovule parent but not as pollen parent. Similarly for fruit length, the cross KL 28 x Susthira and for internodal length KL 9 x KL 28 excelled well. Therefore, these differences should also be taken into account while making crosses.

5.9 Generation mean analysis

The generation mean analysis subdivides the genetic differences between parents and assists the breeder in deciding on a strategy to combine or transfer desired trait.

***5.9.1 Gene action for shoot and fruit borer resistance in the cross* Arka Anamika x KL 9**

The results indicated that additive-dominance and digenic non-allelic interaction model were inadequate to explain the variation for shoot and fruit resistance in terms of components of mean. Therefore, it is presumed that still a

higher order of gene interaction such as trigenic interaction or linkage relationship along with modifying genes may be involved in shoot and fruit borer resistance. Ghai *et al.* (1990) observed similar results for pod borer resistance in okra.

5.9.2 Gene action for yield and yield attributes in the intra-specific cross family Arka Anamika x KL 9

Information on the genetic architecture of yield and yield components is essential for proper selection of parents and breeding methodology. Therefore, it is important to identify and estimate the nature of gene action along with epistasis, so that the fixable components could be exploited by using a suitable breeding technique. The non-allelic interaction (epistasis) was absent for days to first flowering and flowering period in the cross Arka Anamika x KL 9. The additive variance was high for days to first flowering whereas the dominance variance was high for flowering period. Therefore, a breeding programme which effectively capitalizes additive gene effects and at the same time maintain certain degree of heterozygosity would be useful for improving these traits. Similar result was reported by Randhawa (1989).

On the other hand, epistasis was observed for plant height, fruit number, fruit yield and marketable fruit yield and the digenic non-allelic interaction model was found adequate to explain the variation in these traits. The interactions were complementary for plant height and fruit number but duplicate epistasis was observed for fruit yield. In duplicate epistasis, due to negative dominance in some locus, mutual cancellation of positive and negative effects may take place and in such situation additive effects would be important in deciding the net effects. Hence, heterosis breeding is not desirable but it would be possible to isolate segregants as good as that of F_1 in the subsequent filial generations.

5.9.3 Mean performance of F_1, F_2, B_1 and B_2 of the cross Arka Anamika x KL 9

The F_1 hybrid recorded 293.4 g fruit yield per plant. The yield of segregating material B_2 was on par with F_1. The segregating generation B_2 showed

field resistance to YVMV and recorded relatively low shoot damage (23.33 per cent). High yielding segregants resistant to YVMV and shoot infestation were isolated from B_2. These materials on further improvement would result in a high yielding variety resistant to YVMV and moderately resistant to shoot borer since one of its parent (KL 9) was resistant to YVMV and moderately resistant to shoot borer.

5.9.4 Gene action for shoot and fruit borer resistance in the cross KL 9 x AC 5

Resistance to fruit borer in the inter-specific cross KL 9 x AC 5 was governed by digenic duplicate epistasis whereas for resistance to shoot borer in the same cross digenic non-allelic interaction model was found inadequate. Hence a still higher order of gene interaction such as trigenic interaction or linkage intricacies along with modifier complex may be involved in the expression of resistance.

5.9.5 Gene action for yield and yield attributes in the cross KL 9 x AC 5

Inter-allelic interaction (epistasis) was discernible for all the traits except for flowering period in this inter-specific cross. Duplicate epistasis was observed for days to first flowering and plant height. Hence, it would be desirable to go for recombination breeding to isolate useful segregants. Arumugam and Muthukrishnan (1979) were also observed duplicate epistasis. Additive gene action was predominant for days to first flowering. For flowering period preponderance of dominance effect was observed. For fruit number, fruit yield and marketable fruit yield digenic non-allelic model was found inadequate. Since yield is a complex multiplicative character one of the possible reason for the inadequacy of digenic model would be the presence of higher order of gene interactions like trigenic non-allelic interaction etc.

5.9.6 Mean performance of F_1, F_2, B_1 and B_2 of the cross KL 9 x AC 5

Being an inter-specific hybrid, the F_1 manifested high fruit number (33 fruits per plant) and fruit yield (403 g per plant). The heterobeltiosis was 90.38 and

67.49 per cent respectively for fruit number and fruit yield. The hybrid was moderately resistant to shoot and fruit borer and showed field resistance to YVMV. However, for commercial exploitation, its fruit quality was not appealing. Secondly, pollen fertility in this inter-specific cross was low which resulted in poor seed set or fruit with less seeds and hence its taste was not good. Thirdly, tender fruits had slimy secretions which caused irritation while harvesting. Hence, exploitation of heterosis in inter-specific hybrid may not be a meaningful proposition although its yield and gene action are favourable for heterosis breeding.

Keeping the drawbacks in mind high yielding fertile segregants resistant to YVMV and showing moderate resistance to shoot and fruit borer were isolated from B_1 progenies. These materials if forwarded or backcrossed with KL 9 will regain its fertility and would result in a high yielding variety resistant to YVMV and moderately resistant to shoot and fruit borer since both of its parent are resistant to YVMV and shoot borer.

5.10 The type and mechanisms of resistance in okra to shoot and fruit borer

Painter (1951) recognised three types of resistance *viz.*, non-preference, antibiosis and tolerance. Non-preference or antixenosis denotes the response of insect to the characteristics of plants, which made unattractive to the insect for oviposition, food and shelter. Antixenosis involves various morphological or biochemical features of host plants. Antibiosis refers to the adverse effects on the insect's normal life when a resistant host is plants used for food. Death of first instar larvae, abnormal growth rate, failure to pupate and adults to emerge from pupae, decreased fertility, fecundity and longevity etc. are the manifestation of antibiosis.

The multiple choice test indicated the existence of antixenosis for oviposition by *E. vittella* in the shoots of *A. tetraphyllus* and *A. ficulneus* and fruits of *A. tuberculatus* and *A. tetraphyllus* var. *pungens* (Fig. 13). The order of

preference of 10 *Abelmoschus* species by *E. vittella* for oviposition in the shoots could be arranged as *A. esculentus*> *A. moschatus*> *A. angulosus*>*A. tuberosus*>*A. moschatus* var. *multiformis*>*A. caillei*>*A. tetraphyllus* var. *pungens*>*A. ficulneus*> *A. tuberculatus*> *A. tetraphyllus.* Oviposition preference by *E. vittella* for the fruits of 10 *Abelmoschus* species could be arranged as *A. esculentus*>*A. tetraphyllus*>*A. moschatus* var. *multiformis*>*A. moschatus*>*A. angulosus*>*A. tuberosus*> *A. ficulneus*>*A. caillei*>*A. tuberculatus.*

The results also showed that some factors residing on the shoot epidermis in *A. tetraphyllus* var. *pungens* and *A. ficulneus* might be responsible for its resistance to shoot borer because few larvae had penetrated into shoots even though they received more eggs on shoots. Satpute *et al.* (2002) also reported that *A. esculentus* fruits were more preferred by *E. vittella* for oviposition than cotton bolls.

The results of single choice test revealed the suitability of *A. esculentus* shoots as larval food and adverse effect of feeding *A. tetraphyllus* shoots on the growth and development of *E. vittella.* The values for larval growth index and total developmental growth index were significantly less in *A. tetraphyllus* shoots hence there are possibility for the presence of antibiosis factor but in very low scale. The present finding agrees with Ambegaonkar and Bilapate (1984) who reported that larval period was shortest in okra fruits and longest on cotton flowers. Singh (1987) observed poor survival of *E. vittella* larvae and prolonged developmental period in shoot and fruit borer tolerant okra genotypes.

In the single choice test it was observed that the *E. vittella* larvae did not bore intact fruits of *A. tuberculatus*. Larval mortality was 41.33 per cent. Hence, cut fruits were provided. Such specific form of food requirement was not compulsory when *A. esculentus* fruits were fed, thereby suggesting that some factors on the fruit epicarp might be responsible for deterrence (or non-preference) to the larvae than antibiosis factor as a whole if at all present. This species had prickly hairs on fruits which might have deterred the larvae.

5.11 Basis of resistance

5.11.1 Biophysical basis of resistance

Srinivasan and Narayanswamy (1961) reported that red bhendi genotypes offered moderate degree of resistance to *Earias* and colour related resistance in okra to *E. vittella* does not exist. In the present study, 22 red bhendi accessions of both indigenous and exotic origin were tested against *E. vittella.* The mean shoot and fruit infestation in these accessions was above 30 per cent *i.e.* they did not offer resistance although they were red. This finding supported the opinion of Mehta and Saxena (1970) and Kishore *et al.* (1983) that plant colour may not contribute resistance to *E. vittella* as it oviposited in the darkness. Despite the existence of 15 different leaf types and three distinct epicalyx shapes in the germplasm screened none could be attributed of having antixenosis to *E. vittella,* whereas in cotton long pedicel, frego bract and okra leaf type offered resistance to *Earias* spp (Lingappa and Ramani, 1983). However, the study revealed that partially persistent (up to seven days after pollination) triangular epicalyx as found in *A. caillei* were less preferred by *E. vittella* than persistent triangular epicalyx or non-persistent linear epicalyx.

5.11. 2 Hairiness versus resistance

The relationship between hairiness and oviposition preference has been studied by previous workers like Mote (1982) and Kumbhar *et al.* (1991). Their studies were focused on intra-specific comparison where the variability is limited as compared to inter-specific variation, which was the focus in this study. In the present study trichome length and density on fruits could not be correlated with either ovipositional preference or with fruit infestation percentage. *Earias vittella* preferred long hairy shoots for oviposition to short hairy shoots as correlation co-efficient was significant (r=0.79). But once eggs are deposited on a shoot, then presence or absence of hair may not cause adverse effects on larval development as evident from number of larvae found on the test plants. The correlation co-

efficient between shoot infestation *versus* trichome length and density on shoots were insignificant. Hence, presence of trichomes on shoots alone may not offer resistance to *Earias* but it may increase or decrease the level of resistance in combination with other factors. This observation is deviating from those Singh and Chaudhary (1989) and Singh and Taneja (1991) who reported that density and length of trichome on host plant decides oviposition preference of *E. vittella* but corroborate with that of Gupta and Yadav (1978) who opined that the texture of fruit surface cannot be taken as the sole factor for determining resistance.

A perusal of trichome type on the fruits of *A. tuberculatus* and *A. tetraphyllus* var. *pungens* (both highly resistant to fruit borer) revealed that trichome density was less in *A. tuberculatus* fruits than in *A. tetraphyllus* var. *pungens*. The above species were on par with *A. moschatus* (a susceptible species) for trichome length. But orientation and sharpness of the trichome differs in each species. In the resistant species (*A. tuberculatus*) the type of trichomes was hispid (rigid and bristle) and oriented perpendicular to fruit axis while in *A. moschatus* it was soft and oblique (Table 5.2). Therefore, it appears that trichome length or density alone could not contribute for resistance in *A. tuberculatus* to fruit borer but it is the rigidity and sharpness of the trichome imparts resistant to fruit borer.

5.11.3 Biochemical basis of resistance

Singh (1987) reported positive correlation between moisture content in okra fruits and survival of *E. vittella* larvae in okra. Sharma and Agarwal (1984) reported positive correlation between moisture content in cotton shoot and *E. vittella* infestation. The results of the present study indicated that this factor could hardly be responsible for discrimination by *E. vittella* because most of the resistant and susceptible *Abelmoschus* species were on-par for fruit moisture content and correlation between shoot and fruit moisture content with larval penetration and infestation percentage was insignificant. This finding is in confirmation with that of Mehta and Saxena (1970).

Regarding pH, the indication was that lower the pH of shoot lower would be the infestation on shoot as evident from the pH of *A. tetraphyllus* and *A. caillei.* However, the correlation co-efficient between shoot infestation and shoot pH was non-significant. Therefore, a generalization on the influence of pH on infestation could not be drawn. However, low pH in the shoots of *A. tetraphyllus* and *A. caillei* might be one among the resistance contributing factor. Singh (1988) observed low pH in the leaves of jassid susceptible okra variety. The results also indicated that fruit pH had no association with fruit infestation.

With regard to mucilage in shoots and fruits, the differences in shoot and fruit mucilage content between resistant and susceptible species and its correlation co-efficient with infestation were insignificant to draw any meaningful conclusion as resistance factors.

Phenolic compounds were known to impart resistance to *Earias* in cotton (Sharma and Agarwal, 1984). Resistant shoots of *A. tetraphyllus* and *A. caillei* had high phenol than those in susceptible shoots. Confirmatory evidence have come from histo-chemical studies. Presence of phenolic compounds in the pericycle in *A. tetraphyllus* have contributed to its higher phenol. But the same trend could not discernible in resistant fruits of *A. tuberculatus.* Nevertheless, *A. caillei* fruit had very high phenol on fruits. Therefore, resistance to fruit borer in *A. tuberculatus* could not be attributed to phenol content. But it was uncertain whether it had any role in resistance in *A. caillei.* Previous report by Arumugam and Muthukrishnan (1979) confirm that *A. caillei* had higher phenol than *A. esculentus.*

Tannin reacts with digestive enzymes and other proteins in insect, thereby reducing the nutritive value of the ingested foods. They may also act as feeding inhibitors. This antibiotic compound was higher in the shoots of *A. tetraphyllus.* Confirmatory evidences have come from histo-chemical studies. Pericycle and xylem tissue of *A. tetraphyllus* stained greenish blue in chloral hydrate-toluidine blue staining. This finding is in line with that of Sharma *et al.* (1982) who reported high tannin in the cotton genotype resistant to *Earias* but deviated from

Singh (1987) who reported that tannin content in okra fruits did not exceed 0.49 per cent, which may not be sufficient enough to induce complete antibiosis.

The polyphenolic compound gossypol is another insect growth inhibitor. Its content on the shoot and fruit samples of *Abelmoschus* species was very low (0.001 to 0.087 per cent). The presence of relatively high gossypol content in the shoots of *A. tetraphyllus* than those in the susceptible shoots could be considered as one of the factors for resistance but it has no role in imparting resistance in *A. tuberculatus* against fruit borer. Previous studies on the role of gossypol content with resistance in okra to *E. vittella* are lacking. However, Sharma and Agarwal (1984) reported that presence of gossypol (>0.50 per cent) in resistant cotton genotypes had inhibited the growth of *E. vittella.*

5.11.4 Anatomical and histo-chemical basis of resistance

5.11.4.1 Shoot anatomy versus resistance

The epidermal layer of *A. tetraphyllus* and its various modifications like hairs were found to be capable of exerting antixenosis to *E. vittella* along with other structural and chemical components. This species had highly cutinized larger epidermal cells, thick hypodermal and collenchyma layers with compactly arranged ground tissues as compared to susceptible shoots (*A. esculentus*). The number of vascular bundles was relatively high with interspersed sclerenchymatous layers which were absent in susceptible species. The presence of cutin on the shoot epidermis has been confirmed through cytochemical studies using iodine-chloral-potassium iodide stain. The cells stained yellow. Cutins are extra cellular substances, forming major component of plant cuticle. Being esterified with fatty acid it behaves like lipid. Cutin also imparts resistance to *Earias* through the structural defence. The above structural arrangement might have obstructed the entry of larvae into the shoots. Panda *et al.* (1971) reported the presence of compact vascular bundles with lignified cells in the brinjal cultivars resistant to shoot and fruit borer (*Leucinodes orbonalis*).

5.11.4.2 Fruit anatomy versus resistance

Presence of rough, long, highly, lignified trichomes, dry epidermal cells, compactly arranged deep hypodermal and mesocarp cells with wider and larger ridge vascular bundles in *A. tuberculatus* fruits might be the contributing factors for its resistance to fruit borer. Presence of lignin as well as cutin on the trichome was confirmed through histo-chemical studies. Presence of phenol in the fruits of *A. tuberculatus* was detected in the vascular bundles located adjacent to trapezium and placenta. High staining intensity for reducing substances in the upper epidermis of fruit epicarp in *A. tuberculatus* might be one of the reasons for attracting more ants. Ants also had a significant role in reducing shoot and fruit infestation in this particular species as their presence or movement either deter the oviposition by moth or eat away the eggs of *E. vittella*

5.12 Symptoms of resistance or Hypersensitive reaction against infestation

When neonate larvae of *E. vittella* bite a tender okra fruit, a series of hypersensitive response has been triggered in the host plants, the outcome of which was manifested in the form of rusty eruption or bulging on the fruit surface (Plate 8b). Larval penetration through these points could hardly take place. The resistant genotypes also produced *calli* like growth inside the affected fruits. The proliferated cells arrest further movement of larvae inside the fruits and damage to the seed was minimum. In the case of external symptom, the symptoms appeared before the larval entry into fruits. On the other hand, the internal symptoms appeared after larval entry into fruits. In order to ascertain the significance of abnormal cell proliferation anatomical and histochemical investigation were carried out. The results indicated that the proliferated tissue was made up of elongated parenchymatous cells, with very low gossypol, phenol and tannin. The cells had low reducing substances, free from mucilage. Though, the exact chemical components responsible for its induction could not be deduced but it is assumed that it may be a oxidizing compounds since on exposure to air, the proliferated cells turn brownish and shrinks. Further, the cells in the *calli* were

meristematic with thin cell wall, it is also suspected that auxin like phyto-hormones may be involved in its induction. This requires further studies. Such hypersensitive response was exhibited by *A. caillei* cv. AC 5 and Susthira, *A. esculentus* cv. KL 9 and the wild species *A. tuberculatus*. This is the first of its kind and no earlier report was available in okra. However, the symptoms was similar to 'proliferation' in cotton boll resistant to boll weevil (Hinds, 1962), 'hypersensitive resistance' in mustard against cabbage worm (Saphiro and DeVay, 1987). This kind of induced resistance may be of great significance in okra as it reduces infestation and seed damage but cannot be taken as a breeding character because the symptoms were not observed in all the infested fruits.

Thus, the results unfold a number of factors that are associated with shoot and fruit borer resistance in okra. These factors may act either individually or in combinations.

5.13 Future line of work

The present study revealed that wild species *A. tetraphyllus*, *A. tetraphyllus* var. *pungens* and *A. tuberculatus* are potential donors for shoot and fruit borer resistance. The high altitude species *A. tetraphyllus* var. *pungens* is also immune to yellow vein mosaic virus. It is possible to transfer the shoot and fruit borer resistant gene from *A. tetraphyllus* and *A. tuberculatus* to cultivated okra till first filial generation through conventional hybridization. The process of backcrossing could not be continued due to hybrid sterility in the F_1 plants. Since sterility is the major bottleneck in the process of gene transfer, attempt may be made to overcome the post-zygotic barriers through embryo culture or genetic engineering. When this is done it will open major avenues for further research. Secondly, two promising segregating materials were isolated from the cross Arka Anamika x KL 9 and KL 9 x AC 5. These segregants were fertile, high yielding, moderately resistant to shoot borer and field resistant to YVMV. The materials have to be advanced further to isolate high yielding strain with moderate resistance to shoot and fruit borer and YVMV. Its moderate resistance if managed with the other IPM practices such as use of botanical or biological then the cost of control and insecticide residue problems would be minimized.

SUMMARY

6 SUMMARY

The salient findings of the study are summarized below.

1. In order to identify a better resistant source in okra against the shoot and fruit borer (*Earias vittella*) as much as **144** geographically diverse **germplasm** spreading over 10 *Abelmoschus* taxa **were assembled** through exploration as well as supply from ICAR and SAUs.

2. The magnitude of **variability** in these germplasm was high for **qualitative traits** like fruit shape, leaf shape, fruit quality, petal colour, epicalyx shape, pigmentation on stem, petiole, leaf and petal, fruit colour, fruit position on main stem, pubescence on stem and fruits, epicalyx number and fruit ridges.

3. The extent of **variability** in the germplasm was **low** for **quantitative traits** like days to first flowering, flowering period and fruit girth; **medium** for internode number, average fruit weight, fruit length and marketable fruit yield and **high** variability for plant height, number of branches per plant, number of leaves per plant, length of internode, number of fruits per plant, fruit yield per plant, shoot borer infestation, fruit borer infestation and incidence of YVMV.

4. The D^2 analysis reveled that the **genetic divergence** in the germplasm lines were **high.** Traits like plant height, days to first flowering, fruit length and internodal length have contributed maximum variability towards genetic divergence. The genotypes were sorted into **13 clusters.** Genotypes **resistant to shoot and fruit borer** were found in **Cluster I, III and IV.** Hybridization between genotypes in cluster IV (*A. caillei*) and cluster XII (*A. esculentus*) is suggested **to combine high yield with shoot and fruit borer resistance.** Crossing between cluster V (landraces) and IX (unimproved germplasm) is also suggested to realize heterotic effects for fruit yield.

5. **Correlation** studies indicated that by selecting genotypes having early flowering, enhanced plant height, high internode number, high leaf number per plant and short fruit length, it would be possible to reduce shoot borer infestation. **If shoot borer infestation reduced, fruit borer infestation would also be minimized.** By selecting genotypes for higher marketable fruit yield both shoot borer and fruit borer infestation could be minimized. By selecting genotypes with thick fruits, high fruit number and fruit length fruit yield can be enhanced and at the same time fruit borer infestation can be minimized.

6. Genotypes **AP 5** and **EC 16** have **flowered early** (32 days). Landraces like Maravendai and Arumarasavendai had high internode number. KL 21 and Susthira displayed shortest internodal length. Anakomban, Salkeerthy, KL 26, and NER 7 had long fruits. Accessions OR 2, WB 1, EC 5, Bio 2, Salkeerthy, KL 2, KL 26, KL 28, MP 1, MP 3 and NER 7 had **high quality fruits.** These genotypes can be used in the breeding programmes to improve the respective traits.

7. The wild species *Abelmoschus moschatus* var. *multiformis* has **aesthetic value,** hence worthy to be promoted for ornamental **gardening.**

8. *A. esculentus* genotypes Arka Anamika and KL 28 and *A. caillei* genotype AC 5 recorded **high marketable fruit yield**

9. *A. esculentus* genotypes Arka Anamika, KL 9 and KL 28 and *A. caillei* genotypes AC 2, AC 5, AC 8, AC 9 and Thamaravenda and wild species *A. angulosus*, *A. moschatus* var. *multiformis* and *A. tetraphyllus* var. *pungens* showed **field resistance to YVMV.**

10. The study exposes **differential response of a genotype** to shoot as well as fruit infestation even though the pest that inflict shoot and fruit damages are one and the same.

11. The wild species *A. tetraphyllus* was highly resistant to shoot borer and *A. ficulneus* was moderately resistant to shoot borer.

12. The wild species *A. tuberculatus* and *A. tetraphyllus* var. *pungens* were **highly resistant to fruit borer and moderately resistant to shoot borer.**

13. *A. caillei* genotype AC 5 was **moderately resistance to shoot borer as well as fruit borer,** whereas variety Susthira showed moderate resistance to shoot borer alone.

14. *A. esculentus* genotype **KL 9** showed **moderate degree of resistance** to **shoot borer and EC 2** showed moderate degree of resistance to **fruit borer.**

15. The genotype AC 5, Susthira and *A. tuberculatus* exhibited **hypersensitive response** against fruit borer infestation. Fruit borer infested fruits exhibited **resistance symptoms** like bulging on the bud and fruit surface, hardening of tissues and proliferation of wounded tissues.

16. **Hybridization** were effected between *A. tetraphyllus* and *A. esculentus* genotype KL 28 and *A. tuberculatus* and *A. esculentus* cv. Arka Anamika with a view to **transfer resistance genes from wild species** to high yielding varieties. The inter-specific hybrid *A. tetraphyllus* x KL 28 was highly resistant to shoot borer. Hybrid of cross *A. tuberculatus* x Arka Anamika was highly resistant to fruit borer. In both cases **resistance was dominant over susceptibility and controlled by major gene.** The process of gene transfer could not be continued beyond F_1 through conventional hybridization due to sterility in the F_1 plants.

17. To combine high yield and fruit borer resistance, **hybridization** were also effected in **6 x 6 full diallel** fashion involving *A. esculentus* genotypes KL 9, EC 2, KL 28, Arka Anamika and *A. caillei* genotypes AC 5 and Susthira. It was possible to obtain F_2 and BC_1 despite partial sterility in the F_1. The **inter-specific hybrids were heterotic** for fruit yield and manifested moderate resistance to shoot and fruit borer. Shoot borer resistance was governed by additive gene action. Both **additive and non-additive gene action** were involved in **fruit borer resistance. Fruit yield** in okra was governed by **non-additive gene** action

18. Parent AC 5 was **good general combiner** for fruit number, fruit yield, shoot and fruit borer resistance, whereas Susthira was good general combiner for shoot borer resistance. Arka Anamika was good general combiner for earliness, flowering period, plant height, fruit length and fruit yield.

19. Two F_1 hybrids *viz.*, **KL 9 x Arka Anamika** and **KL 9 x AC 5** excelled for **fruit yield.** Their average fruit yield were **294 g and 455 g per plant** respectively. They showed moderate resistance to shoot borer and YVMV. These crosses were advanced to F_2 and backcross

20. **Generation mean analysis** for shoot and fruit borer resistance in the inter-varietal cross KL 9 x Arka Anamika revealed that **shoot borer resistance** and **fruit borer resistance** were **not an outcome of simple additive dominance or digenic non-allelic interaction** model but more **complexities like higher order interaction was involved.** The gene action was duplicate epistasis for fruit yield and complementary epistasis for plant height and fruit number.

21. In the **inter-specific cross** KL 9 x AC 5, **duplicate epistasis** govern the inheritance of **fruit borer resistance.** The digenic non-allelic interaction model was found inadequate to explain the inheritance of shoot borer resistance, fruit number, fruit yield and marketable fruit yield.

22. The **type and mechanism of resistance in okra** to shoot and fruit borer were also investigated. Shoots of *A. tetraphyllus* and fruits of *A. tuberculatus* and *A. tetraphyllus* var. *pungens* exhibited **antixenosis for oviposition** to *Earias vittella.* Larval growth index and total development growth index was low when *E. vittella* reared on *A. tetraphyllus* shoots.

23. **Biophysical factors** like pigmentation on various parts of okra plants, epicalyx shape and fruit shape did **not relate to resistance.** *Earias vittella* **did not prefer** or less prefer for **oviposition on the buds** of *A. caillei,* whose **epicalyx shape was triangular and partially persistent** on the fruit but **prefer shoots having long hairs.** Length and density of trichome on the

fruits had insignificant correlation with oviposition preference as well as with percentage of infestation in fruits. But **if the trichomes are rigid, sharp and perpendicular to fruit axis it imparts antixenosis for oviposition.** Moisture content, mucilage content in shoots and fruits and pH of shoot and fruit extracts had no correlation with oviposition preference or with percentage of shoot and fruit infestation.

24. With regard to **biochemical factors,** presence of **high phenol content, tannin content and gossypol** content in the shoots of *A. tetraphyllus* **imparts resistance** to *E. vittella.*

25. **Anatomical and histochemical studies** have indicated that resistant shoots of ***A. tetraphyllus*** were characterized by **cutinized epidermis,** larger epidermal cells, thick hypodermal and collenchyma layers compactly arranged ground tissues and vascular bundles. The factors imparting resistance in ***A. tuberculatus*** to fruit borer were **rigid and sharp trichomes,** compactly arranged deep hypodermal and mesocarp cells with wider and larger ridge vascular bundles. Tannin content was also high in the fruits of *A. tuberculatus.* **Reducing substances** present in the upper epidermis of fruit epicarp had attracted **ants, which also played a role in reducing shoot and fruit borer infestation.**

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* Originals not seen

APPENDICES

Appendix I

Table 1. Details of artificial filed release of test insect (*E. vittella*) and population load in the infector rows (Salkeerthy)

Field Experiment No.	Date of sowing	Date on which moth were released in the field	No. of ♀ moths released	% Shoot infestation in infector variety (Salkeerthy)	% Fruit infestation in infector variety (Salkeerthy)
1	10 November 2002	Nov. first week	28	80.00	48.67
		Nov.fourth week & Dec. fourth week	41		
2	16 March 2003	March fourth week	12		
4	06 October 2005	Oct. last week	18	70.00	40.26
		Dec. first week	25		
5	23 January 2006	Feb. second week	16	60.33	33.33
		March third week	13		

Appendix II

Table 2 Characterization data for 124 accessions of *A. esculentus* for 21 qualitative characters

#	Accession No.	GH	SP	SC	LS	LC	Pe C	EN	ES	EP	PC	PS	F Po	FC	FS	FT	FR	F Pu	FQ	S Sh	S Su	SR
I	**Varieties**																					
1	Arka Abhay	1	1	2	5	3	2	3	1	1	3	2	1	3	2	1	2	1	7	3	2	2
2	Arka Anamika	1	1	2	5	3	2	3	1	1	3	2	1	3	1	1	2	1	7	3	2	2
3	Aruna	1	1	5	5	5	3	3	1	1	6	2	1	5	1	1	2	1	7	3	2	2
4	Bio-2	1	1	2	7	3	2	3	1	1	3	2	1	3	1	1	2	1	8	3	2	2
5	CO-1	1	1	5	5	5	3	3	1	1	6	2	1	5	2	1	2	1	6	3	2	2
6	EMS 8-1	1	1	2	5	3	2	3	1	1	3	2	1	2	1	1	2	1	7	3	2	2
7	MDU-1	1	1	2	5	3	2	3	1	1	3	2	1	3	1	1	2	1	7	3	2	2
8	Parbhani Kranti	1	1	2	5	3	2	3	1	1	3	2	1	2	1	1	2	1	7	3	2	2
9	Punjab Padmini	1	1	2	5	3	2	3	1	1	3	2	1	2	1	1	2	1	7	3	2	2
10	Pusa Makhmali	1	1	2	5	1	2	3	1	1	3	2	1	2	2	1	2	1	7	3	2	2
11	Salkeerthy	1	1	1	4	3	1	3	1	1	3	2	1	1	1	1	2	1	8	3	2	2
12	Sel-2	1	1	2	5	3	2	3	1	1	3	2	1	3	1	1	2	1	7	3	2	2
13	Varsha Upahar	1	1	2	5	3	2	3	1	1	3	2	1	3	2	1	2	1	7	3	2	2
14	VRO-06	1	1	2	5	3	2	3	1	1	3	2	1	3	1	1	2	1	7	3	2	2
II	**Landraces**																					
1	Aarumasavendai	1	1	3	4	3	1	3	1	1	3	2	1	3	1	1	2	1	6	3	2	2
2	Anakomban	1	1	1	4	3	1	3	1	1	3	2	1	1	2	1	2	1	7	3	2	2
3	Anjilaivendai	1	1	2	5	3	2	3	1	1	3	2	1	3	1	1	2	1	7	3	2	2
4	Maravendai	1	1	4	4	3	4	3	1	1	3	2	1	7	6	2	3	2	6	3	2	2
5	Palvenda	1	1	4	4	3	4	3	1	1	3	2	1	1	5	1	3	1	6	3	2	2

Abbreviation: GH-Growth habit, SP-Stem pubescence, SC-Stem colour, LS-Leaf shape, PeC-Petiole colour, EN-Epicalyx number, ES-Epicalyx shape, EP-Epicalyx persistence, PC- Petal colour, PS-Petal spot, FPo-Fruit position, FC-Fruit colour, FS-Fruit shape, FT-Fruit tip, FR-Fruit ridges, FPu- Fruit pubescence, FQ-Fruit quality score, SSh-Seed shape, SSu-Seed surface, SR-Concentric rings on seed

NB: For details of descriptor code refers to section 3.4.1

Appendix II

Table 2 continuation .....Characterization data for 124 accessions of *A. esculentus*

SNo	Accession No	GH	SP	SC	LS	LC	Pe C	EN	ES	EP	PC	PS	F Po	FC	FS	FT	FR	F Pu	FQ	S Sh	S Su	SR
III	**Indigenous germplasm**																					
1	AP 1	1	2	2	4	3	2	3	1	1	3	2	1	6	2	1	2	1	6	3	2	2
2	AP 2	1	1	5	6	3	3	3	1	1	6	2	1	2	2	1	2	1	7	3	2	2
3	AP 3	1	2	2	5	3	2	3	1	1	3	2	1	2	2	1	2	1	6	3	2	2
4	AP 4	1	1	2	5	3	2	3	1	1	3	2	1	3	2	1	2	1	7	3	2	2
5	AP 5	1	2	1	5	3	2	3	1	1	3	2	1	2	1	1	2	1	6	3	2	2
6	BH 1	1	1	4	4	3	4	3	1	1	3	2	1	6	4	1	2	1	6	3	2	2
7	BH 2	1	1	2	5	3	2	3	1	1	3	2	1	2	4	2	2	2	7	3	2	2
8	BH 3	1	1	1	4	3	1	3	1	1	3	1	1	1	2	1	2	1	7	3	2	2
9	GU 1	1	2	2	5	3	2	3	1	1	3	2	1	2	2	1	2	1	7	3	2	2
10	GU 2	1	1	1	4	3	1	3	1	1	3	1	1	1	2	1	2	1	7	3	2	2
11	GU 3	1	1	1	5	3	1	3	1	2	3	1	1	1	2	1	2	1	7	3	2	2
12	GU 4	1	1	1	4	3	1	3	1	1	3	1	1	1	2	1	2	1	7	3	2	2
13	HA 1	1	2	2	4	3	2	3	1	1	3	2	1	2	2	1	2	1	7	3	2	2
14	HA 2	1	1	1	4	3	1	3	1	1	3	1	1	1	2	1	2	1	6	3	2	2
15	HA 3	1	1	2	4	3	1	3	1	1	3	2	1	2	1	1	2	2	7	3	2	2
16	KL 1	1	2	4	5	3	4	3	1	1	3	2	1	2	2	1	2	1	7	3	2	2
17	KL 2	1	1	2	5	3	2	3	1	1	3	2	1	2	2	1	2	1	8	3	2	2
18	KL 3	1	1	2	5	3	2	3	1	1	3	2	1	3	4	1	2	1	6	3	2	2
19	KL 4	1	3	2	1	3	2	3	1	2	3	2	1	6	2	1	2	3	5	3	2	2
20	KL 5	1	1	1	4	3	2	3	1	1	3	2	1	1	2	1	2	1	7	3	2	2
21	KL 6	1	2	2	4	3	2	3	1	1	3	2	1	3	1	1	2	1	7	3	2	2
22	KL 7	1	1	1	4	3	2	3	1	1	3	2	1	2	5	1	2	1	7	3	2	2
23	KL 8	1	1	2	4	3	2	3	1	1	3	2	1	2	13	2	3	1	5	3	2	2
24	KL 9	1	2	2	5	3	1	3	1	1	3	2	1	2	7	1	3	1	7	3	2	2

(Table contd...)

Appendix II

Table 2 continuation .....Characterization data for 124 accessions of *A. esculentus*

SNo	Accession No	GH	SP	SC	LS	LC	Pe C	EN	ES	EP	PC	PS	F Po	FC	FS	FT	FR	F Pu	FQ	S Sh	S Su	SR
25	KL 10	1	1	1	8	3	4	3	1	1	3	2	1	4	1	1	2	1	6	3	2	2
26	KL 11	1	1	4	2	3	4	3	1	1	3	2	1	4	6	1	3	1	7	3	2	2
27	KL 12	1	1	4	4	3	4	3	1	1	3	2	1	4	6	1	3	1	7	3	2	2
28	KL 13	1	1	1	4	3	2	3	1	1	3	2	1	2	6	2	3	1	7	3	2	2
29	KL 14	1	1	2	5	3	2	3	1	1	3	2	1	2	7	1	3	1	7	3	2	2
30	KL 15	1	1	1	4	3	2	3	1	1	3	2	1	3	7	1	3	1	7	3	2	2
31	KL 16	1	1	2	5	3	2	3	1	1	3	2	1	2	5	1	2	1	7	3	2	2
32	KL 17	1	1	1	4	3	1	3	1	1	3	1	1	1	2	1	2	1	7	3	2	2
33	KL 18	1	1	2	4	3	2	3	1	1	3	2	1	3	6	2	3	1	6	3	2	2
34	KL 19	1	1	2	4	3	2	3	1	1	3	2	1	2	14	2	3	1	4	3	2	2
35	KL 20	1	1	3	4	3	4	3	1	1	3	2	1	6	2	1	2	1	7	3	2	2
36	KL 21	1	1	2	5	3	2	3	1	1	3	2	1	4	1	1	2	1	6	3	2	2
37	KL 22	1	1	5	4	3	3	3	1	1	6	2	1	6	1	1	2	1	7	3	2	2
38	KL 23	1	1	4	4	3	4	3	1	1	3	1	1	1	1	1	2	2	4	3	2	2
39	KL 24	1	1	1	4	3	1	3	1	1	3	1	1	2	2	1	2	1	7	3	2	2
40	KL 25	1	1	2	4	3	1	3	1	1	3	2	1	2	5	2	2	1	6	3	2	2
41	KL 26	1	1	1	4	1	1	3	1	1	3	1	1	1	2	1	2	1	8	3	2	2
42	KL 27	1	2	1	4	3	2	3	1	1	3	1	1	2	2	1	2	1	6	3	2	2
43	KL 28	1	1	1	4	3	1	3	1	1	3	1	1	1	2	1	2	1	8	3	2	2
44	KA 1	1	1	1	4	1	1	3	1	1	3	1	1	4	1	1	2	1	6	3	2	2
45	KA 2	1	1	1	7	3	2	3	1	1	3	2	1	2	2	1	2	1	6	3	2	2
46	KA 3	1	1	2	4	3	2	3	1	1	3	2	1	1	1	1	2	1	7	3	2	2
47	KA 4	1	1	4	4	3	4	3	1	1	3	1	1	2	1	1	2	1	7	3	2	2
48	KA 5	1	1	1	2	1	1	3	1	1	3	1	1	1	5	1	3	1	6	3	2	2
49	KA 6	1	1	2	4	3	2	3	1	1	3	2	1	2	2	1	2	1	7	3	2	2
50	MP 1	1	1	1	4	1	1	3	1	1	3	1	1	3	6	1	3	1	8	3	2	2

(Table contd...)

Appendix II

Table 2 continuation .....Characterization data for 124 accessions of *A. esculentus*

S.No	Accession No	GH	SP	SC	LS	LC	PeC	EN	ES	EP	PC	PS	F Po	FC	FS	FT	FR	F Pu	FQ	S Sh	S Su	SR
51	MP 2	1	1	1	5	3	2	3	1	1	3	2	1	1	1	1	2	1	7	3	2	2
52	MP 3	1	2	2	4	3	2	3	1	1	3	2	1	1	2	1	2	1	8	3	2	2
53	MP 4	1	1	1	4	3	2	3	1	1	3	2	1	3	7	1	3	2	7	3	2	2
54	MH 1	1	3	4	4	3	4	3	1	1	3	2	1	4	7	1	2	3	4	3	2	2
55	MH 2	1	1	1	4	3	2	3	1	1	3	2	1	3	1	1	2	1	7	3	2	2
56	MH 3	1	1	3	2	3	3	3	1	1	3	1	1	4	2	1	2	2	5	3	2	2
57	MH 4	1	2	3	4	3	4	3	1	1	3	2	1	7	6	1	3	1	5	3	2	2
58	MH 5	1	2	3	4	3	4	3	1	1	3	2	1	7	7	1	3	1	6	3	2	2
59	MH 6	1	2	4	4	3	4	3	1	1	3	2	1	7	7	1	3	1	6	3	2	2
60	ND 1	1	1	1	4	3	2	3	1	1	3	2	1	4	6	2	3	2	5	3	2	2
61	ND 2	1	1	3	7	3	2	3	1	1	3	1	1	6	2	1	2	1	6	3	2	2
62	NER 1	1	1	1	5	3	2	3	1	1	3	2	1	2	6	1	3	1	7	3	2	2
63	NER 2	1	1	2	5	3	2	3	1	1	3	2	1	2	1	1	2	1	7	3	2	2
64	NER 3	1	2	2	5	3	2	3	1	1	3	2	1	2	4	1	2	1	7	3	2	2
65	NER 4	1	2	2	4	3	2	3	1	1	3	2	1	2	2	1	2	1	7	3	2	2
66	NER 5	1	1	4	4	3	4	3	1	1	3	2	1	2	6	2	3	1	7	3	2	2
67	NER 6	1	1	2	5	3	2	3	1	1	3	2	1	2	2	1	2	1	7	3	2	2
68	NER 7	1	1	4	5	3	2	3	1	1	3	2	1	3	2	1	2	1	8	1	2	2
69	NER 8	1	1	1	5	3	2	3	1	1	3	2	1	2	1	1	2	1	6	1	2	2
70	OR 1	1	1	2	7	3	2	3	1	1	3	2	1	2	6	2	3	1	5	3	2	2
71	OR 2	1	2	2	4	3	1	3	1	1	3	2	1	2	1	1	2	1	9	3	2	2
72	RA 1	1	1	2	5	3	2	3	1	1	3	2	1	3	6	1	2	1	7	3	2	2
73	RA 2	1	2	3	4	3	4	3	1	1	3	2	1	1	14	2	2	1	5	3	2	2
74	TN 1	1	2	2	7	3	2	3	1	1	3	2	1	2	1	1	2	1	7	3	2	2
75	TN 2	1	1	4	4	3	4	3	1	1	3	2	1	4	6	1	3	1	6	3	2	2
76	TN 3	1	1	1	1	3	1	3	1	1	3	1	1	1	1	1	2	2	6	3	2	2
77	TN 4	1	1	2	4	3	2	3	1	1	3	2	1	1	6	1	2	1	7	3	2	2

Appendix II

Table 2 continuation .....Characterization data for 124 accessions of *A. esculentus*

SNo	Accession No	GH	SP	SC	LS	LC	PeC	EN	ES	EP	PC	PS	FPo	FC	FS	FT	FR	FPu	FQ	SSh	SSu	SR
78	UP 1	1	1	1	4	1	1	3	1	1	3	1	1	4	3	1	2	1	6	3	2	2
79	UP 2	1	1	2	7	3	2	3	1	1	3	2	1	4	12	1	1	1	7	3	2	2
80	UP 3	1	2	2	5	3	2	3	1	1	3	2	1	2	2	1	2	1	7	3	2	2
81	UP 4	1	1	2	5	3	2	3	1	1	3	2	1	2	2	1	2	1	6	3	2	2
82	WB 1	1	1	2	4	3	2	3	1	2	3	2	1	2	1	1	2	1	9	3	2	2
83	WB 2	1	1	2	5	3	2	3	1	1	3	2	1	2	2	1	2	1	7	3	2	2
84	WB 3	1	2	2	4	3	2	3	1	1	3	2	1	2	1	1	2	1	7	3	2	2
IV	**Exotic germlasm**																					
1	EC 1	1	1	1	2	1	1	3	1	1	3	1	1	3	6	1	2	1	5	3	2	2
2	EC 2	1	2	3	4	3	4	3	1	1	3	2	1	7	16	2	3	1	4	3	2	2
3	EC 3	1	1	2	5	3	2	3	1	1	3	2	1	3	7	1	3	1	7	3	2	2
4	EC 4	1	1	1	4	3	2	3	1	1	3	2	1	1	2	2	2	1	6	3	2	2
5	EC 5	1	2	2	4	3	2	3	1	1	3	2	1	3	6	2	3	1	9	3	2	2
6	EC 6	1	1	3	4	3	3	3	1	1	3	2	1	2	7	1	3	1	7	3	2	2
7	EC 7	1	2	2	5	3	2	3	1	1	3	2	1	3	4	2	2	1	6	3	2	2
8	EC 8	1	1	1	4	3	2	3	1	1	3	2	1	2	2	1	2	1	7	3	2	2
9	EC 9	1	1	2	4	3	2	3	1	1	3	1	1	3	5	1	3	1	7	3	2	2
10	EC 10	1	1	5	4	3	3	3	1	2	3	1	1	6	1	2	2	1	6	3	2	2
11	EC 11	1	1	2	5	3	2	3	1	2	3	1	1	2	1	1	2	1	7	3	2	2
12	EC 12	1	3	3	1	3	3	3	1	1	3	2	1	6	2	1	2	3	5	3	2	2
13	EC 13	1	1	2	5	3	2	3	1	1	3	2	1	3	2	2	2	1	7	3	2	2
14	EC 14	1	1	1	2	3	4	3	1	1	3	1	1	1	2	1	2	1	7	3	2	2
15	EC 15	1	2	2	4	3	2	3	1	1	3	2	1	2	1	1	2	2	7	3	2	2
16	EC 16	1	1	2	4	3	2	3	1	2	3	2	1	2	2	1	2	1	7	3	2	2
17	EC 17	1	1	1	1	3	2	3	1	1	3	2	1	2	1	1	2	2	7	3	2	2
18	EC 18	1	1	2	4	3	4	3	1	1	3	2	1	3	5	1	3	1	7	3	2	2
19	EC 19	1	1	2	5	3	2	3	1	1	3	2	1	2	6	1	3	1	7	3	2	2
20	EC 20	1	1	2	2	3	2	3	1	1	3	2	1	3	11	1	2	2	5	3	2	2
21	EC 21	1	1	5	4	3	3	3	1	1	3	2	1	5	17	1	2	1	5	3	2	2

Table 3 Characterization data for 12 accessions of *A. caillei* for 21 qualitative characters

#	Accession No	GH	SP	SC	LS	LC	PeC	EN	ES	EP	PC	PS	FPo	FC	FS	FT	FR	FPu	FQ	SSh	SSu	SR
1	AC 1	1	1	4	3	3	4	2	3	2	1	1	1	6	5	1	3	1	4	1	1	1
2	AC 2	1	2	2	3	4	2	2	3	2	1	1	1	2	10	2	1	2	4	1	1	1
3	AC 3	1	3	1	3	4	2	2	3	2	1	1	1	6	9	2	2	3	3	1	1	1
4	AC 4	1	1	1	3	4	1	2	3	2	1	1	1	2	18	1	2	3	3	1	1	1
5	AC 5	1	1	5	3	4	4	2	3	2	1	1	1	6	16	2	2	1	5	1	1	1
6	AC 6	1	1	1	1	4	2	2	3	2	1	1	3	3	8	1	2	3	4	1	1	1
7	AC 7	1	3	1	6	4	3	2	3	2	1	1	2	3	12	1	3	3	4	1	1	1
8	AC 8	1	1	1	3	4	4	2	3	2	1	1	1	3	16	2	2	1	4	1	1	1
9	AC 9	1	1	4	3	4	4	2	3	2	1	1	1	6	6	2	3	3	5	1	1	1
10	AC 10	1	1	2	8	5	2	2	3	1	1	1	1	2	15	1	3	2	6	3	2	2
11	Thamaravenda	1	1	4	3	4	2	2	3	2	1	1	1	6	6	1	3	1	5	1	1	1
12	Susthira	1	2	2	4	4	2	2	3	2	1	1	1	2	1	1	2	1	6	3	2	2

Table 4 Characterization data for eight wild *Abelmoschus* taxa for 21 qualitative characters

#	Species	GH	SP	SC	LS	LC	PeC	EN	ES	EP	PC	PS	FPo	FC	FS	FT	FR	FPu	FQ	SSh	SSu	SR
1	*A. angulosus*	1	2	1	14	1	2	1	4	3	2	1	1	1	21	2	2	3	2	2	3	2
2	*A. ficulneus*	3	1	4	10	1	2	2	2	1	5	1	4	2	25	2	2	3	1	1	3	1
3	*A. moschatus*	1	3	4	11	4	2	3	1	2	2	1	2	1	19	2	2	3	2	2	1	1
4	*A. m* var. *multiformis*	1	3	2	12	1	2	3	1	2	7	1	1	1	20	2	2	3	2	2	1	1
5	*A. tetraphyllus*	2	2	3	13	2	2	1	3	1	4	1	4	6	22	2	2	3	1	1	3	2
6	*A.t.* var. *pungens*	1	3	2	9	2	2	1	5	3	2	1	1	2	23	2	2	3	1	2	2	1
7	*A. tuberculatus*	1	3	1	15	1	2	4	1	1	4	1	1	2	24	1	2	3	2	1	3	2
8	*A. tuberosus*	1	3	1	12	1	1	3	1	2	2	1	1	1	20	2	2	3	1	2	1	1

Appendix III

Table 6 Skeleton of ANOVA showing treatment mean squares and coefficient of variation (CV %) for 15 quantitative characters recorded in experiment 1

#	Traits	Species	*A. esculentus*			*A .caillei*	Wild species
			Variety	Indigenous germplasm	Exotic lines		
		df	**18**	**83**	**20**	**11**	**7**
1	Days to first flowering		82.50** (3.77)	67.55** (5.48)	833.65** (4.24)	33.84** (6.60)	159.81** (5.48)
2	Flowering period		102.35** (4.64)	54.61** (6.16)	83.95** (5.78)	29.95** (5.58)	65.40** (7.13)
3	Plant height (cm)		3327.96** (10.26)	2067.60** (10.83)	1323.24** (10.25)	1403.70** (7.13)	4496.89** (7.35)
4	Number of leaves per plant		43.28** (19.09)	22.25** (17.77)	36.56** (20.98)	42.77** (14.75)	124.33** (8.33)
5	Number of internode per plant		11.93** (11.63)	14.69** (9.88)	19.49** (10.15)	55.73** (10.63)	108.52** (8.12)
6	Internodal length (cm)		15.26** (17.23)	22.19** (14.31)	26.42** (13.69)	4.09** (14.90)	14.51** (17.01)
7	Number of fruits per plant		17.82** (13.09)	25.14** (20.87)	20.36** (19.29)	16.44** (19.37)	506.66** (14.35)
8	Average fruit weight (g)		23.40** (11.51)	38.08** (17.75)	20.31** (18.43)	18.44** (8.28)	2.95** (5.15)
9	Fruit length (cm)		74.98** (8.05)	26.27** (10.93)	24.40** (8.80)	23.11** (12.50)	4.39** (4.31)
10	Fruit girth (mm)		17.96** (6.22)	19.46** (8.12)	41.76** (8.78)	45.94** (11.00)	22.11** (5.89)
11	Fruit yield per plant (g)		5830.70** (14.61)	12080.16** (25.18)	10193.75** (21.93)	8942.38** (13.58)	14579.37** (18.01)
12	CI for YVMV		10.66** (19.77)	6.79** (27.20)	3.77** (17.89)	NS	Not analysed
13	Shoot infestation (%)♣		3.32** (13.50)	3.73** (20.84)	4.55** (17.06)	2.37** (5.18)	8.50**. (12.75)
14	Fruit infestation (%)♣		228.80** (16.04)	206.27** (18.50)	89.52** (17.75)	45.21** (7.99)	484.89** (4.11)
15	Marketable fruit yield (%) ♣		260.96** (8.44)	315.66** (15.54)	106.10** (8.78)	37.17** (3.91)	487.75** (2.89)

*, ** refers to significant at 5 and 1 per cent respectively

♣= Analysis was done using angular transformed values

Values in parenthesis refers to coefficient of variation in percentage based on EMS

BREEDING FOR RESISTANCE TO SHOOT AND FRUIT BORER (*Earias vittella* Fab.) IN OKRA (*Abelmoschus esculentus* (L.) Moench)

R. KARUPPAIYAN

ABSTRACT OF THE THESIS

Submitted in partial fulfilment of the
requirement for the degree of

Doctor of Philosophy in Agriculture

Faculty of Agriculture
Kerala Agricultural University, Thrissur

2006

Department of Plant Breeding and Genetics
COLLEGE OF HORTICULTURE
VELLANIKKARA, THRISSUR - 680 656
KERALA, INDIA

ABSTRACT

Realizing the need to identify a resistant source in okra (*Abelmoschus esculentus* (L.) Moench) against the shoot and fruit borer (*Earias vittella* Fab.) 144 geographically diverse germplasm lines spreading over 10 *Abelmoschus* taxa were assembled through exploration and from ICAR and SAUs. A filed study was undertaken during 2002-03 at the College of Horticulture, KAU, Vellanikkara utilizing the 144 okra genotypes. The germplasm exhibited high variability for qualitative traits like fruit shape, leaf shape, fruit quality, petal colour, epicalyx shape, pigmentation on stem, petiole, leaf and petal, fruit colour, fruit position on main stem, pubescence on stem and fruits, epicalyx number and fruit ridges. Medium to high variability was observed for quantitative traits like number of internodes, single fruit weight, fruit length, marketable fruit yield, plant height, number of branches, number of leaves, internodal length, number of fruits, fruit yield, shoot and fruit borer infestation and incidence of YVMV.

High genetic divergence was observed among the genotypes. Characters like plant height, days to first flowering, fruit length and internodal length have contributed maximum towards genetic divergence. The genotypes were grouped into 13 clusters. To combine high yield with shoot and fruit borer resistance, hybridization was suggested between genotypes in cluster IV (*A. caillei*) and cluster XII (*A. esculentus*). Hybridization between cluster V (landraces) and IX (unimproved germplasm) was also suggested to realize heterosis for fruit yield.

Genotypic correlation co-efficient revealed that genotype showing early flowering, enhanced plant height, high internode number, high leaf number per plant and short fruit length were less prone to shoot borer infestation. If shoot borer infestation is less, fruit borer infestation would be minimized, since they were correlated positively. Fruit infestation showed negative correlation with marketable fruit yield, hence by selecting genotype having higher marketable fruit yield, both shoot borer infestation and fruit borer infestation could be minimized.

Two accessions *viz.*, AP 5 (IC 33087[*]) and EC 16 (EC 169500) flowered early. The landrace Maravendai ranked first for plant height and fruit girth while Aarumarasavendai displayed prolonged flowering period and high internode number. Accession KL 21 (IC 282257) and Susthira had short internodal length. Long fruits were observed in Anakomban, KL 26 (IC 140907) and NER 7. Two accessions *viz.*, OR 2 (IC 99746) and WB 1 (IC 52305 B) ranked top for fruit quality.

The high yielding genotypes of *A. esculentus* were KL 28 (IC 140934 and Arka Anamika and of *A. caillei* was EC 305760 (228.62 g per plant). Arka Anamika, KL 9 (IC 45818) and KL 28 (IC 140934) and West African okra lines AC 5 (EC 305760) and Thamaravenda and wild species *A. angulosus*, *A. moschatus* var. *multiformis* and *A. tetraphyllus* var. *pungens* showed field resistance to YVMV.

The genotype responded differently to shoot infestation and fruit infestation although the pest that inflicts shoot and fruit damage was one and the same. *Abelmoschus tetraphyllus* was highly resistant shoot borer and *A. ficulneus* was moderately resistant to shoot borer. *Abelmoschus tuberculatus* and *A. tetraphyllus* var. *pungens* were highly resistant to fruit borer and moderately resistant to shoot borer. Among *A. caillei* genotypes, AC 5 (EC 305760) was moderately resistant to shoot and fruit borer while Susthira was moderately resistant to shoot borer alone. *A. esculentus* genotype KL 9 (IC 45818) of was moderately resistant to shoot borer and EC 2 (EC 329365) was moderately resistant to fruit borer. Hypersensitive response to fruit borer infestation was noticed in AC 5 (EC 305760), Susthira and *A. tuberculatus*.

The inter-specific hybrids of *A. tetraphyllus x A. esculentus* accession KL 28 (IC 140934) and *A. tuberculatus* x *A. esculentus* cv. Arka Anamika were highly

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[*] The IC and EC number given within parenthesis refers to national accession number assigned by NBPGR

resistant to fruit borer. In both cases, resistance was found dominant over susceptibility and controlled by major genes.

A 6 x 6 full diallel analysis involving *A. esculentus* and *A. caillei* genotypes revealed preponderance of additive gene action for shoot borer resistance, days to first flowering and flowering period. Non-additive gene action were observed for plant height, internode length, fruits per plant, fruit weight, fruit length and fruit yield. Both additive and non-additive gene action were important for fruit borer resistance. The cross Arka Anamika x KL 9 (IC 45818) and KL 9 (IC 45818) x AC 5 (EC 305760) produced high marketable fruit yield.

Generation mean analysis in the cross Arka Anamika x KL 9 (IC 45818) revealed that shoot and fruit borer resistance involved more complex higher order gene interactions. In the cross KL 9 (IC 45818) x AC 5 (EC 305760), duplicate epistasis govern the inheritance of fruit borer resistance.

Multiple choice test revealed that shoots of *A. tetraphyllus* and fruits of *A. tuberculatus* and *A. tetraphyllus* var. *pungens* exhibited antixenosis for oviposition to *Earias vittella*. Larval growth index and total development growth index was low when *E. vittella* reared on *A. tetraphyllus* shoots. *Earias vittella* prefer shoots having long hairs for oviposition. Length and density of trichomes on the fruits had insignificant correlation with oviposition preference as well as with infestation in fruits. But the rigidity and sharpness of trichome offer resistance to fruit borer. Presence of high phenol content, tannin content and gossypol content in the shoots of *A. tetraphyllus* also impart resistance to *E. vittella*.

Anatomical and histochemical studies revealed that resistant shoots of *A. tetraphyllus* were characterized by cutinized epidermal layer, larger epidermal cells, thick hypodermal and collenchyma layers compactly arranged ground tissues and vascular bundles. Similarly, the factors imparting resistance to fruit borer in *A. tuberculatus* were rigid and sharp trichomes, compactly arranged hypodermal and mesocarp cells with wider and larger vascular bundles.