7 Harnessing Host Plant Resistance for Major Crop Pests: De-coding In-Built Systems

V. Selvanarayanan, M. Saravanaraman, N. Muthukumaran, and Jobichen Chacko

Abstract

Identification, development, and exploitation of insect-resistant/tolerant cultivars is an economically viable, ecologically safe and farmer-friendly tactic. Developing insect-resistant cultivars was successful in vegetable crops like tomato, brinjal, okra, cauliflower, and potatoes because of their wider gene pool as well as short duration. In contrast, developing insect-resistant/tolerant cultivars of fruit crops, tea, and coffee has been less explored. This warrants for concerted research attempts. Conventional hybridization, mutation breeding, grafting, and other resistance breeding methods are being employed to develop insect-resilient cultivars. Molecular approaches to harness such desirable traits are also attempted and the field success of such cultivars needs to be validated. Transgenic cultivars of these horticultural crops are yet to be popularized due to environmental paradox and consumers' perplexity.

Keywords

Insect resistance · Crops · Mechanisms · Cultivars · Wild lines

7.1 Introduction

Use of insecticides for managing insect pests crops is restricted, since vegetables and fruits are consumed fresh while spices, tea, and coffee are processed as they possess higher export value. Biological control of insect pests is successful only in few crops. At this juncture, identification and exploitation of host plant resistance

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(HPR) in crops is economically viable and safe and can serve as a pivotal platform for integrated pest management (IPM). Though insect-resilient cultivars have been widely developed and exploited in field crops, such as wheat, rice, sorghum, and cotton, comparatively less success has been witnessed with certain horticultural crops. Pest-resistant/tolerant cultivars have been well exploited in vegetables compared to other horticultural crops. The wider gene pool of the vegetable crops offers ample scope for exploration and exploitation. In contrast, lack of greater genetic diversity and temporal requirement for developing insect-resistant/tolerant cultivars are the major impediments in long duration crops, such as tea and coffee. This warrants research efforts to identify and develop resistant cultivars.

Developing insect-tolerant/resistant crop cultivars should be a recurring attempt, because these cultivars may later succumb to the selection pressure by insect pests. In spite of this requisite, concerted research attempts are lacking currently as evidenced by lesser research publications and declining number of entomologists and/or breeders working on developing insect-tolerant/resistant cultivars.

Breeding for insect resistance using conventional hybridization, backcross breeding, or mutation breeding has been found to be promising in vegetable crops (Lal et al. 2004), while vegetative propagation methods such as grafting has been found to be promising in fruit and plantation crops (Sharma et al. 2004). Currently, higher impetus is being paid for employing molecular tools to harness such host plant resistance. The field success of cultivars thus developed needs to be validated. Though insect-resistant, transgenic cotton is popular among Indian farmers, transgenic vegetables and other horticultural crops are yet to surpass the environmental issues and consumers' conundrum.

Transgenic crops provide an option for developing pest-resistant crops. But the effectiveness of transgenic has been reduced by resistance in pests. The number of pest resistant transgenic crops has increased from 3 in 2015 to 16 in 2016. However, there are 17 cases where transgenics have not become susceptible to pests, including the recently introduced transgenic corn with a *Bt* vegetative insecticidal protein (vip). Recessive inheritance of pest resistance and refugees of non-Bt plants have sustained susceptibility of pests to *Bt* crops (Tabashnik and Carriere 2017).

7.2 Vegetables

Among the Solanaceous vegetables, gene pool of tomato, brinjal, and potato are widely explored for identifying or developing insect-resistant or tolerant varieties (Lal et al. 2004). Tolerant varieties are preferred because it involves traits that limit the negative impact of pest damage on yield. Characterizing the defensive traits of plants to repel/deter herbivores or restrict their feeding and understanding the mechanism is important to harness HPR for pest management (Mitchell et al. 2016). Several strategies for enhanced crop resistance to phytophagous pests, viz., plant secondary metabolites, microbiome science are coming to force. Advances in metabolic engineering of plant secondary chemistry offer the promise of specific deterrence to plant feeding insect pests, and applications of these disciplines can be further facilitated by plant breeding and genetic technologies (Douglas 2018).

The wider genetic diversity in the genus *Lycopersicon* which in tandem with advancement in genome mapping of tomato offers greater avenue for resistance breeding programs. Many wild species of *Lycopersicon* such as *Lycopersicon pimpinellifolium* (Jusl.) Mull. (Juvik et al. 1982), *L. hirsutum* Hump. and Bonpl., *L. hirsutum f. glabratum* C.H. Mull. (Kashyap et al. 1990), *L. cheesmanii* (Bordat et al. 1987), and *L. pennellii* (Goffreda et al. 1988) are reported to be resistant to many insects. The cultivated species *L. esculentum* (*Solanum esculentum*) has greater varietal diversity but lacks resistance traits.

Tomato germplasm comprising 321 accessions, including wild species, land races, hybrids, and cultivars (89% cultivated species, *L. esculentum*, 10% wild relative, *L. pimpinellifolium,* and 1% suspected cross of these two) was screened for resistance against *Helicoverpa armigera* Hubner, both under field and glasshouse conditions at Annamalai Nagar, Tamil Nadu, India. The accession Varusanadu Local was found to possess resistance to *H. armigera* (Selvanarayanan 2000). Among the biophysical factors of resistance, density of two non-glandular types (III and V) and three glandular types (I, VI, VII) of trichomes (hairs) on the foliage was found to exert significant positive correlation with insect resistance. Among the biochemical factors, phenols of the foliage and acidity of the fruits exerted a significant negative correlation with larval feeding (Selvanarayanan and Narayanasamy 2006) (Fig. 7.1).

Conventional hybridization of the promising accession, Varusanadu Local with popular cultivars yielded viable hybrids but a wider variation in resistance was observed in the hybrid derivatives with regard to fruit worm, *H. armigera* (Dhakshinamoorthy 2002), serpentine leaf miner, *Liriomyza trifolii* Blan., whitefly, *Bemisia tabaci* Genn., and leaf caterpillar, *Spodoptera litura* Fab. (Muthukumaran 2004). Since segregation of traits in the hybrids was witnessed, backcross breeding of the promising accession, Varusanadu Local with the popular cultivar, PKM 1 was attempted (Manikandan 2012). The first-generation backcross progeny recorded lesser larval population of *H. armigera* and *S. litura* (Fig. 7.2). Similarly, infestation of *L. trifolii* and nymphal population of *B. tabaci* were also less in the parent

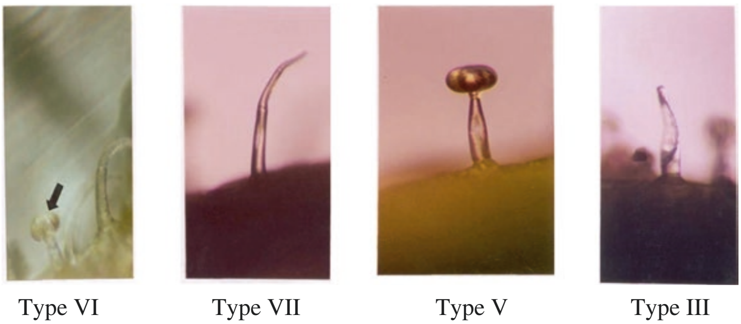


Fig. 7.1 Types of trichomes on tomato accessions

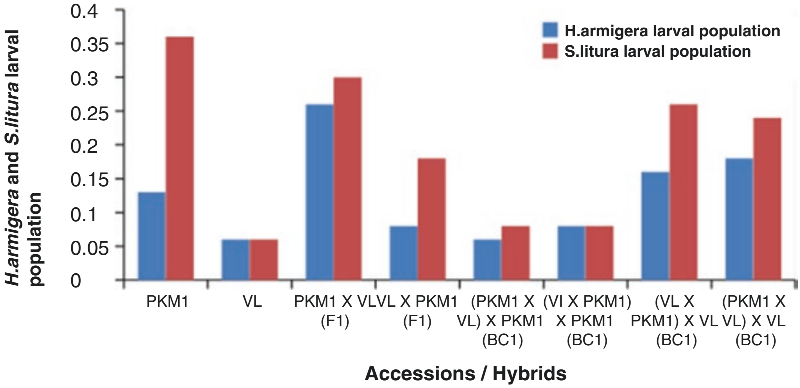


Fig. 7.2 Population of *H. armigera* and *S. litura* on selected tomato accessions and their back-cross progenies

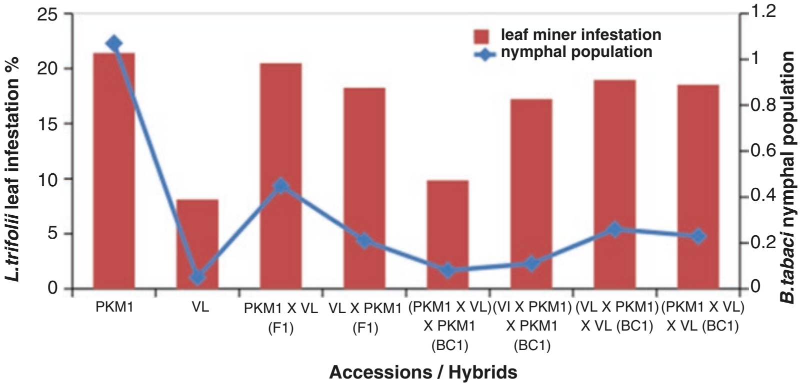


Fig. 7.3 Infestation of *L. trifolii* and population of *B. tabaci* on selected tomato accessions and their backcross progenies

Varusanadu Local and also the backcross progeny (Fig. 7.3). Further studies may help to understand the stabilization of traits over generations (Selvanarayanan 2015).

As an alternative to hybridization, mutation breeding was considered a quick method of resistance breeding, and certain tomato mutants were found promising against *H. armigera*, *S. litura,* and *B. tabaci* (Gopalakrishnan 2010; Selvanarayanan 2015). Tomato Hybrid Kashi Abhimaan (VRTH-101) and the variety Punjab Chhuhara recorded low incidence of fruit borer in the field (Anonymous 2012), while the variety Pusa 120 and Pusa Hybrid 2 were found field-tolerant to root knot nematode (Anonymous 2007).The International *Solanum* Genome project paved way for mapping of the tomato genome and in identifying Quantitative Trait Loci (QTLs) for insect resistance.

7.2.1 Eggplant (Brinjal)

India, being native of brinjal, *Solanum melongena* L., varietal diversity was much explored to identify insect-resistant traits. Long and round-fruited varieties exhibited differential reaction to the fruit borer, *Leucinodes orbonalis* Guen. Among the long-fruited varieties screened, PBR-129-5, Pusa Purple Cluster, SM 17-4, ARU-2C, and Punjab Barsati were found tolerant (Singh et al. 1990). In the round-fruited group, Pusa Purple Round and Punjab Neelam were tolerant (Singh 1991). Antixenosis resistance to the fruit and shoot borer was found highly correlated to tight seed arrangement in the fruit mesocarp (Lal 1991). Cultivars, Pusa Purple Round and Pusa Basant were found to be resistant to shoot and fruit damage by *L. orbonalis* (Ramprasad 1998). SM-17-4 recorded low incidence of fruit borer, and among the biochemical factors analyzed in this cultivar, higher levels of glycoalkaloids, peroxidase, and polyphenol oxidase (catechol oxidase) were considered responsible for resistance (Bajaj et al. 1989). In contrast, the cultivar SM 17-4 was found highly susceptible to the jassid, *Amrasca biguttula* Ishida (Singh et al. 1990). Long-fruited varieties, such as S 188-2, Pusa Purple Long, S 34, S 258, Manjari Gota, and Dorli, were the most promising against *A. biguttula* (Pawar et al. 1987). Among the round-fruited varieties, Annamalai, Arka Round Purple, Arka Navneet, A-61, Gote-2, PBR-91-1, PBR-91-2, Konkan, and Kranti were found tolerant (Singh et al. 1990; Milenovic et al. 2019).

Bemisia tabaci species complex are major pests of cassava in Africa. Whiteflies incur heavy losses in cassava in Africa through vectoring viruses causing mosaic and brown streak disease. The electropenetrography (EPG) technique was used to record feeding of the whitefly by creating an electrical circuit through the insect and plant system. The workers deployed EPG to investigate feeding behavior of *B. tabaci* on cassava, sweet potato, tomato, and cotton (Figs. 7.4 and 7.5).

Resistance to spotted beetle, *Henosepilachna vigintioctopunctata* F. was noticed in the wild species, *Solanum xanthocarpum*, whereas cultivated varieties such as Punjab Moti and DBR-31 were found moderately resistant (Jayalakshmi 1994). Solanine content and total phenols were factors of resistance against whitefly, *Bemisia tabaci* Genn., infesting brinjal (Soundararajan and Baskaran 2001). Varieties viz. Manjari Gota, Arka Shrish, Mahabaleshwar, Pusa Kranti, and Arka Kusumkar were found to be tolerant to aphids, *Aphis gossypii* Glov. (Singh et al. 1990; Patel et al. 1995). Grafting of *S. melongena* on the wild line, *S. torvum* yielded fruit borer tolerance, but desirable yield parameters could not be enhanced (Rahman et al. 2002). Though transgenic brinjal (BT-Brinjal) has been developed in India, its large scale use is pending government approval.

7.2.2 Potato

Next to tomato, potato, *Solanum tuberosum* L., has wider genetic diversity. In India, extensive breeding efforts have culminated in the identification or development of potato cultivars resistant to diseases than insect pests. Of the many varieties released

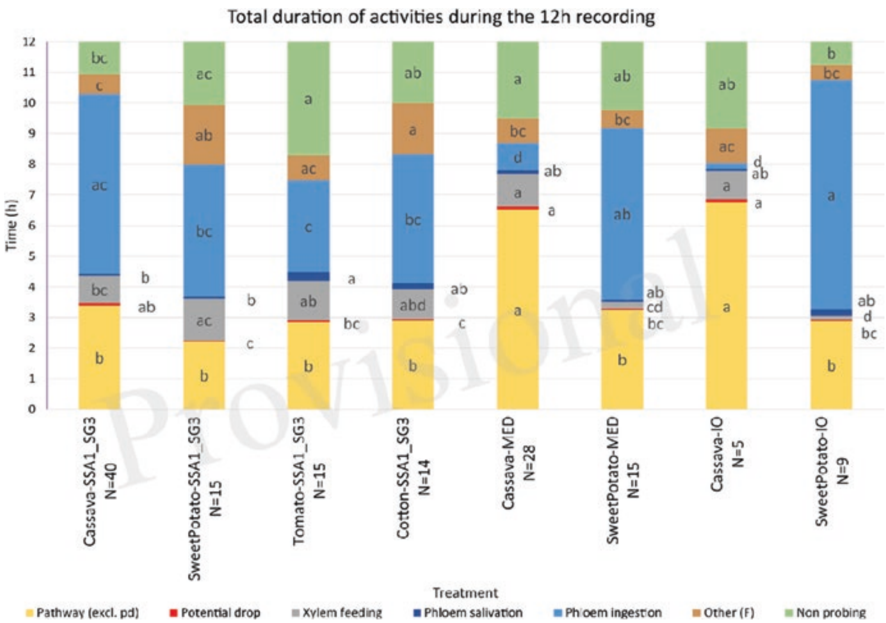
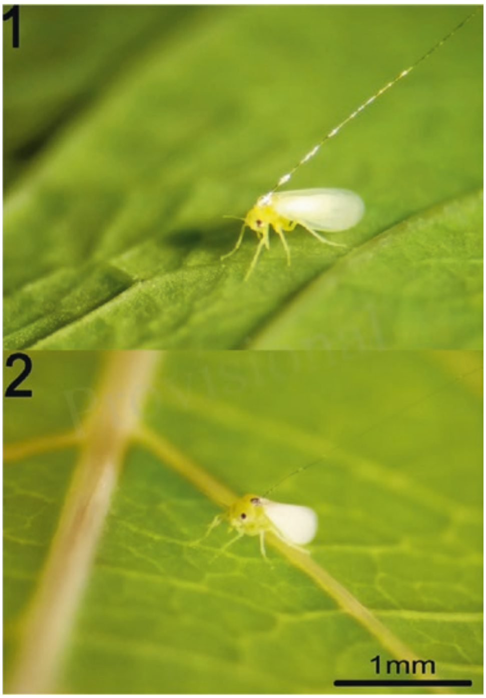


Fig. 7.4 Total duration of activities during the 12th recording. (Source: Milenovic et al. 2019)

Fig. 7.5 Comparative visual observation of whiteflies tethered to different wires. (Source: Milenovic et al. 2019)



by Central Potato Research Institute, Shimla, only three cultivars namely Kufri Anand, Kufri Muthu, Kufri Suryaare tolerant to leafhoppers, *Empoasca* spp. (CPRI 2015). Shakti was reported to be the least susceptible to aphid, whitefly, and cutworms, while Kufri Jyoti was less susceptible to leafhopper (Singh et al. 1990).

In the United States and other countries, scope of wild potato lines in conferring insect resistance has been widely explored. Glandular trichomes on the foliage of the wild potato, *S. neocardenasii*, adversely affect the feeding behavior of the green peach aphid, *Myzus persicae* (Sulzer), and the leafminer, *L. trifolii* (Burgess), by delaying the amount of time required to begin feeding (LaPointe and Tingey 1986). Upon removing the pubescence from foliage, an increase in feeding by *Empoasca fabae* Harris was observed (Tingey and Laubengayer 1986).

7.2.3 Okra

Among the Malvaceous vegetables, okra or ladies finger (*Abelmoschus esculentus* (L.) Moench) is popular in India. The shoot and fruit borer, *Earias vittella* Fab. is the most dreaded pest. Contradictory views have been reported regarding the insect tolerance in few cultivars. Okra cultivars Pusa Sawani and Pusa A-4 were recorded to be tolerant to shoot and fruit borer, *Earias* spp. (Anonymous 2007), whereas Bhat et al. (2007) reported that Pusa Sawani was susceptible to *Earias* spp. Mandal et al. (2006) and Rahman et al. (2012) inferred that Arka Anamika is less preferred, whereas Sharma and Jat (2009) refuted this statement.

Balakrishnan et al. (2011) crossed the cultivated species of okra, *A. esculentus* with the semi-domesticated West African species, *Abelmoschus caillei* (A. Chev.) and reported that the F1 hybrid of the cross Sel 2 × Ac 5 as promising in terms of yield and resistance to shoot and fruit borer. On exploring the factors of resistance, hair density on the okra fruits was found to exert positive correlation with resistance to shoot and fruit borer (Kumbhar et al. 1991).

Considering the above, 38 okra accessions were screened for resistance to *E. vittella* at Annamalai Nagar, Tamil Nadu, India, wherein five accessions, namely Salem Local, Anu, Pappapatti Local, Karina, and Ankur were found to record lesser infestation. The variety Arka Anamika was highly susceptible. On exploring the factors of resistance operating in these accessions, density and length of trichomes and also phenol content in Salem Local was found to exert a significant influence on resistance (Karthik 2015).

7.2.4 Cruciferous Vegetables

Diamondback moth, *Plutella xylostella* (L.) is the serious insect pest-infesting major cruciferous vegetables. Though a wider varietal diversity exists with regard to these crops, insect resistance traits are rare in the cultivars. Among the cauliflower varieties screened by Lal et al. (1997), none was found resistant but varieties Early Winter, Adam's White Heads, and RSK-1301 were moderately resistant. Ganesan and Narayanasamy (2000) screened 40 accessions of cauliflower and found none to be resistant to *P. xylostella*. Among the cabbage cultivars, Pride of India and Pusa Drum Head were reported to be highly resistant to *P. xylostella* (Nathu et al. 2000).

In some cruciferous crops, wax blooms on the leaves were found to deter feeding of the cabbage flea beetle, *Phyllotreta albionica* (LeConte) (Anstey and Moore 1954; Stoner 1990). In contrast, certain cruciferous crops devoid of wax bloom with a glossy, reflective green appearance were also found to influence resistance level to pests, probably due to other biochemical factors of resistance. Glossy-leafed kale and Brussels Sprouts recorded lesser feeding by the cabbage aphid, *Brevicoryne brassicae* (L), and the cabbage whitefly, *Aleurodes brassicae* (Walker) than waxy-leaved cultivars (Thompson 1963). The glossy genotypes cause antixenosis reactions in larvae of the diamondback moth (Eigenbrode et al. 1991). In addition to leaf waxes, the foliar toughness of several cruciferous crops also adversely affects the feeding behavior of mustard beetles, *Phaedon cochleariae* Fab (Tanton 1962).

Plant resistance to aphids may found several tissues, as epidermis, mesophyll, and phloem. But not all of them have influence on feeding preference of aphids. Electrically recorded feeding behavior of cabbage aphids were combined with choice tests and microscopic observations. Physical features were important for aphids feeding preference on the four cultivars of oilseed rape (Figs. 7.6 and 7.7) (Hao et al. 2019).

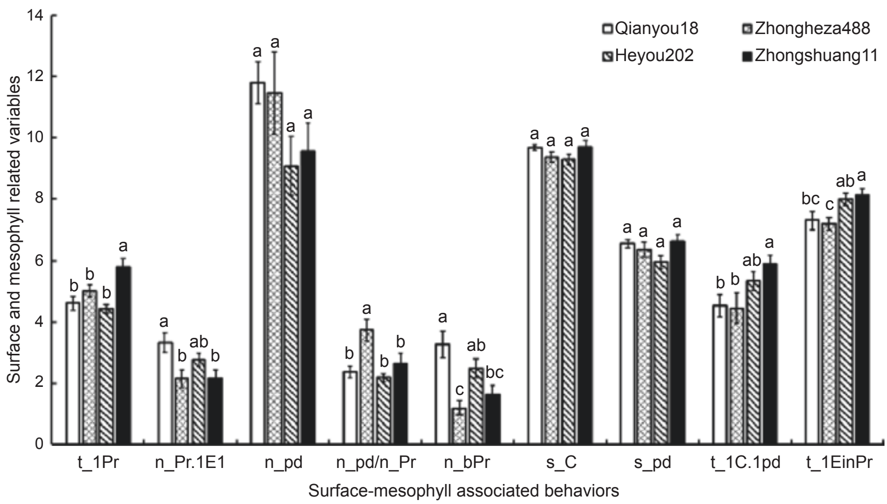


Fig. 7.6 The electropenetrography (EPG) variables of the *B. brassicae* stylet pathway before reaching the phloem tissue of the host plants. Bars represent standard error (SE). The data were compared using the analysis of variance (ANOVA) followed by the unrestricted least significant difference (LSD) after the square-root transformation for frequency variables and natural log transformation for time variables. The level for significance was set to $P < 0.05$. Different lowercase letters on the columns indicated the significant differences among the four cultivars. (Source: Hao et al. 2019)

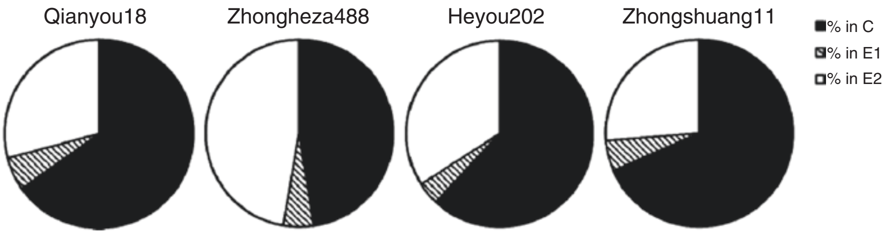


Fig. 7.7 The percentages of different activities in relation to the complete probing of B. brassicae on oilseed rape during 6-h electropenetrography (EPG) experiments. The % in C represents the percentage of probing spent in the pathway; the % in E1 represents the percentage of probing spent in salivation; the % in E2 represents the percentage of probing spent in sap ingestion. (Source: Hao et al. 2019)

7.2.5 Cucurbitaceous Vegetables

Reports on host plant resistance to insects in cucurbits have been earlier reviewed by Dhillon and Wehner (1991). Pumpkin beetles, fruit fly, and pumpkin caterpillars are the serious insect pests in India. Among the cucurbits, bitter gourd was the least preferred by the pumpkin beetle, *Aulacophora foveicollis* (Lucas) (Kalyanasundaram 1998). Of the various *Cucumis* subsp., *Cucumis melo* cv. Gumuk, *C. melo* cv. Kosa, *C. melo* var. *callosus*, *C. melo* Cv. Chibbar, and *C. melo* var. *agrestis* were highly resistant to *A. foveicollis* (Janakiraman 1980). The wild type, *C. callosus* was recorded resistant to the fruit fly, *Dacus cucurbitae* also (Chelliah 1969). The content of cucurbitacin and toughness of the fruit rind are the possible resistant factors.

Variety PKM 1 of ribbed gourd was found tolerant to pumpkin beetle and fruit fly (TNAU 2014) while the variety Kashi Surbhi (IVAG-03) of ash gourd, *Benincasa hispida* (Thunb.) Cogn. was reported to be tolerant to leaf miner (Anonymous 2012).

7.3 Fruit Crops

In few centers in India, investigations to explore and exploit insect resistance in fruit crops have been attempted and those works have been well reviewed by Batra et al. (1993), Batra and Sharma (1993), and Sharma et al. (2004). Beyond screening of varieties of major fruit crops for insect tolerance/resistance, only isolated attempts were made to develop new varieties using vegetative propagation methods like grafting or budding.

7.3.1 Mango

Fruitfly, *Bactrocera dorsalis* (Hendel) is a serious pest on mango in India. Varieties namely Langra and EC-95862 were found resistant, whereas Banganapalli, Alphonso, and Totapuri were susceptible (Jayanthi and Verghese 2008). Phenol content in the peel and pulp was found to exert a positive correlation with fruit fly resistance (Verghese et al. 2012).

Most of the available mango varieties were found susceptible to mango hoppers, *Idioscopus nitidulus* (Walker), another key pest on mango. Among 392 accessions field screened, only 32 were found less preferred by visual grading of damage and hopper population. But it was suggested to validate this observation by challenging these accessions with hoppers (Devi et al. 2013). Among the mango varieties, Baneshan, Bangalora, Chinnarasam, and Khader were found resistant to hoppers (Nachiappan 1982). Contents of potassium and phenols in these varieties had a positive correlation with hopper resistance (Nachiappan and Bhaskaran 1983).

Varieties Bangalora and Neelum were found highly susceptible to the mango nut weevil, *Sternochetus mangiferae* (Fabricius) and skin toughness and age of the fruit were reported to be the factors contributing to susceptibility (Sundara Babu 1969). Bagle and Prasad (1984) reported the least infestation in Langra as against the highest in Jahangir and Alphonso.

7.3.2 Banana

Banana, a popular fruit in India, has wider genetic diversity. Insect resistance in the banana clones has been consistently evaluated in India. Upon evaluating 17 banana accessions for resistance against banana stem weevil, *Odoiporous longicollis* Oliver, Srinivasa Reddy et al. (2015) inferred that the accession Sugandhalu (AAB type) was the least susceptible. Thippaiah et al. (2013) observed that Rasabale was the least susceptible variety to pseudostem weevil. Anitha (2004) recorded intermediate level of infestation on the clones of Palayankodan and Poovan. Furthermore, biophysical factors such as stem girth and plant height were found to have no relation with infestation by the weevil (Srinivasa Reddy et al. 2015; Padmanaban et al. 2001). Varieties Vennon, Klue Teparod, and Peyan were found free of *Thrips florum* Schmutz (Mohanasundaram and Shivakumar 1972). Varieties resistant to the lacewing bug, *Stephanitis typicus* (Distant) were Jurmony, Thatillakuman, Malakali, Krishna Vazhai, and Kali (Mohanasundaram 1987).

7.3.3 Citrus

In India, citrus species diversity is vast and offers ample scope for resistance screening. Among the insects infesting citrus, leaf miner, *Phyllocnistis citrella* Stainton is a key pest. Batra et al. (1970) screened 24 species/cultivars of citrus and found that Rough Lemon, citronella (*Poncirus trifoliata* x *Citrus parodist*), Carrizo, and Troyer citrange were free from leaf miner infestation. Citrus whitefly, *Dialeurodes citri* (Ashmead) also causes considerable damage to citrus plantations. Different citrus groups such as sweet orange (*Citrus sinensis* Osbeck), mandarin (*C. reticulata* Blanco), grapefruit and pomelo (*C. paradisi* Macf and *C. grandis* Osbeck), and citranges exhibited varying degrees of infestation by whitefly (Sharma et al. 2004). With regard to citrus psyllid, *Diaphorina citri* Kuwayama, none of the screened cultivars were completely resistant but cultivars Cleopatra and Rubidoux were commercially resistant (Batra et al. 1970).

7.3.4 Grapevine

Berry thrips, *Scirtothrips dorsalis* Hood is one of the key pests of grapes and none of the varieties screened were devoid of scab formation by the berry thrips (Thirumurthi et al. 1972).Similarly, of the 140 cultivars screened for resistance to jassid, *Arboridia vinifera* (Sohi and Sandhu), none was free from attack (Batra et al. 1982). Grapevine cultivars Bangalore Blue and Bhokri were reported to be resistant to the defoliating beetle, *Adoretus duvanceli* Blanchard (Chakrabarty et al. 1970). Cultivars Bhokri and Golden Queen were least preferred by the flea beetle, *Scelodonta strigicollis* (Mots.) (Rao et al. 1992).

7.3.5 Cashew

Among the insect pests infesting cashew, the tea mosquito bug, *Helopeltis antonii* Sign. causes severe loss. Mass culturing method for *H. antonii* and varietal screening protocols in cashew were standardized; all the screened accessions were found susceptible (Sundararaju 1999). Cashew stem and root borer, *Plocaederus ferrugineus* L. is another pest, and the available cashew germplasm was found susceptible (Sundararaju 2010).

7.3.6 Apple (*Malus domestica* Borkh)

The maiden work on plant resistance against insect pests was initiated in apple by Lindley (1831), wherein the cultivars Winter Majestin and Siberian BitterSweet were reported resistant to wooly aphid, *Eriosoma lanigerum* (Hausmann) (Smith 2005). Since this maiden work, varieties possessing insect resistance were rarely developed in India. Variety Golden Delicious was found to record less infestation by *E. lanigerum* (Adlakha and Hameed 1972). Variety Shalimar Apple–1 was found field resistant to green aphid, *Aphis pomi* (DeGeer) and red spider mite, *Panonychus ulmi* (Koch) (Anonymous 2012).

7.4 Plantation Crops

7.4.1 Coffee

Although around 100 species are available in the genus *Coffea*, Coffee breeding is largely restricted to the two species, *C. arabica* (Arabica coffee) and *C. canephora* (Robusta coffee). Of these, Arabica coffee is highly preferred by consumers. To date, there is no reported source of resistance to coffee berry borer (*Hypothenemus hampei* Ferrari) in *C. arabica* and *C. robusta*. Among the other species, *C. abeokuta* and *C. excelsa* were found consistently resistant to berry borer (Samuel et al. 2013) in terms of less infestation and least preference for feeding and oviposition. They exhibited ovipositional and feeding deterrence due to relatively high phenol and tannin content, less reducing sugars and also lower enzyme activity such as peroxidase and phenylalanine ammonia lyase (Irulandi et al. 2007). Robusta coffee is generally resistant to white stem borer (*Xylotrechus quadripes* Chev.) but the interspecific robusta-arabica hybrids are susceptible (Mishra and Slater 2012). Since it was difficult to incorporate desirable traits in these two species using conventional breeding, molecular tools are employed (Noir et al. 2003). Transgenic Coffee plants carrying *Bacillus thuringiensis cry1Ac* gene have been produced in other countries (Leroy et al. 2000).

7.4.2 Tea

Key insect pests such as shot-hole borer, tea mosquito bug, and mites cause severe yield loss in tea. Attempts to exploit the host plant resistance in tea clones against these pests have been done in China and Sri Lanka. Amongst the 28 tea cultivars screened for infestation by tea mosquito bug (*Helopeltis theivora* Waterhouse), no clone was immune, while TV4, TV11, TV28, TV29, and ST449 were less susceptible (Roy et al. 2009). In Sri Lanka, 74 accessions of cultivated and unadapted tea genotypes were evaluated in the field for Shot hole borer, *Xyleborus fornicatus* Eichh. resistance based on number of galleries. Only three accessions, DG 7, DG 39, and DG 66 were found to have higher resistance than TRI 2023, among the adapted gene pool (Walgama et al. 2008).

7.4.3 Spices

A select list of popular cultivars of important spice crops field tolerant or resistant to pests is furnished in Table 7.1.

Resistance evaluation and breeding attempts are being carried out consistently under the All India Coordinated Research Project on Spices, which culminates in identification and exploitation of accessions with desirable traits. At Indian Institute of Spices Research (IISR), incorporation of pollu beetle, *Longitarsus nigripennis* Mots. resistance through interspecific hybridization involving *Piper attenuatum* and *P. barberi* with *P. nigrum* has been achieved (Sasikumar et al. 1999). Later, four accessions of cultivated black pepper, viz., accession nos. 816 (Neyyantinkara mundi), 841 (Velayuthakaniyakadan), 1084 (Cheppukula mundi), and 1114 (Kumbachola) were found relatively resistant to pollu beetle (Krishnamoorthy and Parthasarathy 2011) (Table 7.1).

Conventional breeding approaches to develop insect-resistant/tolerant cultivars were successful only in a few crops. The duration required to develop such cultivars in tandem with the quick break down of resistance due to biotype development is the major impediment. This warrants a realistic cooperation between breeders and entomologists. Segregation of the desirable traits in the offspring, difficulty in exploiting the desirable traits in wild lines, and masking quantitatively inherited

Table 7.1 List of popular spice cultivars with insect tolerance/resistance

Crop	Name of the variety/cultivar/clone	Report on resistance
Cardamom	Mudigere 1	Moderately tolerant to thrips, hairy caterpillar, and white grubs
	ICRI 4 (TDK4)	Tolerant to capsule borer
	PV2; IISR Kodagu Suvasini (CCS-1); IISR Vijetha (NKE-12)	Tolerant to thrips, capsule borer
	IISR Avinash (RR-1)	Tolerant to capsule borer
Pepper	Pournami	Tolerant to root knot nematode, *M. incognita*[a]
Ginger	Sonali	Resistant to scale insect[a]
	IISR Mahima	Resistant to root knot nematode, *M. incognita* and *M. javanica* pathotype 1
Turmeric	BSR.2	Resistant to rhizome scales
	Krishna and Sugandham	Moderately resistant to rhizome scales
	Suroma	Field tolerant to rhizome scales
	Suranjana (TCP-2)	Resistant to rhizome scales and moderately resistant to shoot borer
Coriander	Rajendra Swathi	Field tolerant to aphids
	Sadhana	Field tolerant to white fly, mites, and aphids
	Swathi	Field tolerant to white fly
	Azad Dhania-1	Tolerant to aphids

Source: AICRPS (2015)
[a]Anonymous (2007)

resistant traits by environmental effects are the constraints in conventional resistance breeding programs (Selvanarayanan 2011). Crop resistance can be improved by synergistic and additive action of insecticides. For example, significant synergistic interactions were found between aphid-resistant soybean isolines and lambda cyhalothrin in 2015 (Hanson and Koch 2018).

Conventional breeding attempts should be supplemented by molecular studies. For identifying the promising genotypes, marker aided (= assisted) selection (MAS) may be attempted. Further the genes responsible for desirable traits may be located by identifying Quantitative Trait Loci. Novel techniques such as Embryo rescue or exploiting somaclonal variation using tissue culture may envisage development of promising genotypes. Systems biology approach integrating all "omics" studies is gaining prominence, and such advancement in functional genomics and proteomics may aid in rapid development of new crop cultivars (Selvanarayanan 2015).

References

Adlakha RL, Hameed SF (1972) Wooly apple aphid, *Eriosoma lanigerum* (Hausmann) in Kullu valley. Pesticides 6:13–21

AICRPS (2015) Varieties released, All India Coordinated Research Project on Spices, Indian Institute of Spices Research. http://www.aicrps.res.in/index.php/download-it/varieties-released. Accessed 5 Oct 2017

Anitha N (2004) Clonal susceptibility and age preference of banana pseudostem weevil, *Odoiporus longicollis* Olivier. Insect Environ 10(1):32–34

Anonymous (2007) Report of the working group on horticulture. In: Plantation crops and organic farming for the XI five year plan period (2007– 2012). Government of India, Planning Commission, New Delhi, p 420

Anonymous (2012) Report of the 19th meeting of Central Sub-Committee on Crop Standards, Notification and Release of Varieties for Horticulture Crops, New Delhi, p 68

Anstey TH, Moore JF (1954) Inheritance of glossy foliage and cream petals in green sprouting broccoli. J Hered 45:39–41

Bagle BG, Prasad VG (1984) Varietal incidence and control of stone weevil, *Sternochetus mangiferae* Fabricius. Indian J Entomol 46:389–392

Bajaj KL, Singh D, Kaur G (1989) Biochemical basis of relative field resistance of eggplant (*Solanum melongena*) to the shoot and fruit borer (*Leucinodes orbonalis* Guen.). Vegetable Science 16(2):145–149

Balakrishnan D, Sreenivasan E, Radhakrishnan VV (2011) Fruit and shoot borer (*Earias vitella* Fab.) resistance in okra (*Abelmoschus esculentus* (L.) Moench). Asian J Biosci 6(2):194–197

Batra RC, Sharma DR (1993) Current status of insect resistance in fruit crops. In: Dhaliwal GS, Dilawari VK (eds) Advances in host plant resistance to insects. Kalyani Publishers, New Delhi, pp 327–358

Batra RC, Uppal DK, Sohi BS (1970) Indexing the genetic stock of different species of citrus against leaf miner and citrus psylla. Indian J Horticult 27:76–79

Batra RC, Brar SS, Singh SN, Rehala AS (1982) Note on incidence of grape jassid on different cultivars of grapes. Indian J Horticult 39:144–145

Batra RC, Sandhu GS, Sharma DR (1993) Host plant resistance to insect pests. In: Chadha KL, Pareek OP (eds) Advances in horticulture, vol 3: Fruit crops: part 3. Malhotra Publishing House, New Delhi, pp 1649–1660

Bhat OK, Bhagat KC, Gupta A, Vijay KK (2007) Screening of okra genotypes against *Amrasca biguttula biguttula* (Ishida) and *Earias vitella*. Environ Ecol 25(2):434–439

Bordat D, Laterrot H, Renand M, Morethi A (1987) Phenomena of *Lycopersicon cheesmanii* Riley resistance to *Liriomyza trifolii* (burgess) and *L. sativae* Blanchard (Diptera: Agromyzidae). Agronom Trop 42:43–46

Chakrabarty DP, Ghose GC, Das PK, Dhua SP (1970) Studies on the relative susceptibility of different varieties of grape to *Adoretus duvanceli* blanch. Technology 7(3):184–185

Chelliah S (1969) *Cucumis callosus* (Rottl.) (Sync. Krigonus Roxb.): a source of resistance to the fruit fly, *Dacus cucurbitae* Coquillett. Annamalai Univ Agric Res Annu 1:189–191

CPRI (2015) Potato varieties. Central Potato Research Institute, Shimla. http://cpriernetin/other_activity/Potato_varietiespdf. Accessed 5 Oct 2015

Devi TS, Verghese A, Dinesh MR, Vasugi C, Jayanthi PK (2013) Germplasm evaluation of mango for preference of the mango hopper, *Idioscopus nitidulus* (Walker) (Hemiptera: Cicadellidae): the first step in understanding the host plant resistance. Pest Manage Hortic Ecosyst 19(1):10–16

Dhakshinamoorthy G (2002) Studies on resistance of tomato against fruit borer, *Helicoverpa armigera* (Hubner). M.Sc. (Agri.) dissertation, Annamalai University, India, p 110

Dhillon NPS, Wehner TC (1991) Host-plant resistance to insects in cucurbits—germplasm resources, genetics and breeding. Int J Pest Manage 37(4):421–428

Douglas AE (2018) Strategies for enhanced crop resistance to insect pests. Annu Rev Plant Biol 69:637–660

Eigenbrode SD, Stoner KA, Shelton AM, Kain WC (1991) Characteristics of glossy leaf waxes associated with resistance to diamondback moth (Lepidoptera: Plutellidae) in *Brassica oleracea*. J Econ Entomol 84(5):1609–1618

Ganesan K, Narayanasamy P (2000) Field resistance of different cultivars of cauliflower against diamondback moth *Plutella xylostella* (L.). Madras Agric J 87(7–9):526–528

Goffreda JC, Mutschler MA, Tingey WM (1988) Feeding behavior of potato aphid affected by glandular trichomes of the wild tomato. Entomol Exp Appl 48(2):101–107

Gopalakrishnan R (2010) Induced mutagenesis in selected tomato accessions for resistance against fruitworm, *Helicoverpa armigera* (Hubner) and whitefly, *Bemisia tabaci* Genn. Ph.D. Dissertation, Annamalai University, India, p 214

Hanson AA, Koch RL (2018) Interactions of host-plant resistance and foliar insecticides for soybean aphid management. Crop Prot 112:232–238

Hao Z-P, Zhan H-X, Wang Y-l, Hou S-m (2019) How cabbage aphids *Brevicoryne brassicae* (L.) make a choice to feed on *Brassica napus* cultivars. Insects 10(75):1–11

Irulandi S, Kumar PKV, Rajendran R (2007) Possible biochemical basis for resistance in coffee species and cultivars against the coffee berry borer. J Coffee Res 35(1/2):41–51

Janakiraman R (1980) Evaluation of certain forms of Cucumis for resistance against melon beetle, *Raphidopalpa (Aulacophora) foveicollis* Lucas. M.Sc. (Agri.) dissertation, Annamalai University, India, p 138

Jayalakshmi T (1994) Evaluation of certain varieties of brinjal against the spotted leaf beetle, *Henosepilachna vigintioctopunctata* F. (Coccinellidae: Coleoptera). M.Sc. (Agri.) dissertation, Annamalai University, India, p 95

Jayanthi PD, Verghese A (2008) Studies on differential susceptibility of selected polyembryonic varieties of mango to oriental fruit fly, *Bactrocera dorsalis* (Hendel). Pest Manage Hortic Ecosyst 14(1):20–29

Juvik JA, Berlinger MJ, Ben-David T, Rudich J (1982) Resistance among accessions of the genera *Lycopersicon* and *Solanum* to four of the main insect pests of tomato in Israel. Phytoparasitica 10(3):145–156

Kalyanasundaram A (1998) Seasonal incidence, biology, host preference and management of pumpkin beetle, *Aplacophora foveicollis* (Lucas). M.Sc. (Agri.) dissertation, Annamalai University, India, p 88

Karthik R (2015) Studies on resistance of bhendi accessions against shoot and fruit borer, *Earias vittella* fab. M.Sc. (Agri.) dissertation, Annamalai University, India, p 92

Kashyap RK, Banerjee MK, Verma AN (1990) Survival and development of fruit borer, *Heliothis armigera* (Hübner), (Lepidoptera: Noctuidae) on *Lycopersicon* spp. Int J Trop Insect Sci 11(6):877–881

Krishnamoorthy B, Parthasarathy VA (2011) Improvement of black pepper. In: Hemming D (ed) Plant sciences reviews, CAB International, London, pp 37–48

Kumbhar TT, Kokate AS, Dumbre AD (1991) Studies on the varietal resistance in okra, *Abelmoschus esculentus* L. (Moench) to shoot and fruit borer, *Earias* spp. Maharashtra J Hortic 5(2):78–82

Lal OP (1991) Varietal resistance in the eggplant, *Solanum melongena* against the shoot and fruit borer, *Leucinodes orbonalis* Guen. (Lepidoptera: Pyralidae). Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz 98(4):405–410

Lal OP, Singh R, Sharma SR, Srivastava YN, Lal SK, Rao K (1997) Field resistance in cauliflower germplasm to diamondback moth, *Plutella xylostella* L. under Delhi condition. In: Symposium on integrated pest management for sustainable crop production, 2-4 Dec 1997. Indian Agricultural Research Institute, New Delhi, pp 41–42

Lal OP, Sinha SR, Srivastava YN (2004) Perspectives of host plant resistance in vegetable crops. In: Dhaliwal GS, Singh R (eds) Host plant resistance to insects: concepts and applications. Panima Publishing, New Delhi, pp 399–438

Lapointe SL, Tingey WM (1986) Glandular trichomes of *Solanum neocardenasii* confer resistance to green peach aphid (Homoptera: Aphididae). J Econ Entomol 79(5):1264–1268

Leroy T, Henry AM, Royer M, Altosaar I, Frutos R, Duris D, Philippe R (2000) Genetically modified coffee plants expressing the *Bacillus thuringiensis cry1Ac* gene for resistance to leaf miner. Plant Cell Rep 19(4):382–385

Lindley G (1831) A guide to the orchard and kitchen garden. Longman, Rees, Orme, Brown and Green, London, p 597

Mandal SK, Sah SB, Gupta SC (2006) Screening of okra cultivars against *Earias vitella*. Ann Plant Protect Sci 14(2):471–472

Manikandan KR (2012) Evaluation of resistance in certain *Lycopersicon* hybrids to selected insect pests. M.Sc. (Agri.) dissertation, Annamalai University, India, p 103

Milenovic M, Wosula E, Rapisarda C, Legg JP (2019) Impact of host plant species and whitefly species on feeding behavior of *Bemisia tabaci*. Front Plant Sci 10:1. https://doi.org/10.3389/fpls.2019.00001

Mishra MK, Slater A (2012) Recent advances in the genetic transformation of coffee. Biotechnol Res Int 2012:1–17

Mitchell C, Brennan RM, Graham J, Karley AJ (2016) Plant defense against herbivorous pests: exploiting resistance and tolerance traits for sustainable crop protection. Front Plant Sci 7:1132

Mohanasundaram M (1987) Varietal susceptibility of banana to the lacewing bug, *Stephanitis typicus* distant (Tingidae: Hemiptera). Madras Agric J 74:465–468

Mohanasundaram M, Shivakumar CV (1972) Varietal susceptibility of banana to the banana thrips (*Thrips florum* Schm). Madras Agric J 60:24–25

Muthukumaran N (2004) Resistance of *Lycopersicon* accessions and their hybrid derivatives against certain insect pests. M.Sc. (Agri.) dissertation, Annamalai University, India, p 94

Nachiappan RM (1982) Studies on certain aspects of natural incidence of mango leaf hoppers (Cicadellidae: Homoptera) on different varieties of mango and their control with chemical insecticides. Ph.D. dissertation, Annamalai University, Tamil Nadu, p 183

Nachiappan RM, Bhaskaran R (1983) Biochemical constitution of inflorescence of certain varieties of mango in relation to mango leafhoppers. South Indian Hortic 31:160–165

Nathu R, Raju SVS, Singh HN (2000) Varietal resistance of different cabbage varieties/entries against *Plutella xylostella* under field conditions. Indian J Entomol 62(2):175–180

Noir S, Anthony F, Bertrand B, Combes MC, Lashermes P (2003) Identification of a major gene (Mex-1) from *Coffea canephora* conferring resistance to *Meloidogyne exigua* in *Coffea arabica*. Plant Pathol 52(1):97–103

Padmanaban B, Sundararaju P, Velayudhan KC, Sathiamoorthy S (2001) Evaluation of *Musa* germplasm against banana weevil borers. InfoMusa 10(1):26–28

Patel MM, Patel CB, Patel MB (1995) Screening of brinjal varieties against insect pests. Gujarat Agric Univ Res J 20:98–102

Pawar DB, Mote UN, Kale PN, Ajri DS (1987) Promising resistant sources for jassid and fruit borer in brinjal. Current Research Report, Mahatma Phule Agricultural University, vol 3, pp 81–87

Rahman MS, Alam MZ, Haq M, Sultana N, Islam KS (2002) Effect of some integrated pest management (IPM) packages against brinjal shoot and fruit borer and its consequence on yield. OnLine J Biol Sci (Pakistan) 2(7):489–491

Rahman MM, Uddin MM, Shahjahan M (2012) Varietal preference of okra shoot and fruit borer (*Earias vittella*) among different okra varieties. Bangladesh J Environ Sci 22:146–149

Ramprasad KV (1998) Screening of brinjal germplasm for resistance against shoot and fruit borer, *Leucinodes orbonalis* Guen. (Lepidoptera: Pyralidae). M.Sc. (Agri.) dissertation, Annamalai University, India, p 83

Rao RV, Lakshminarayan K, Subbaratnam GV (1992) Preference of flea beetle adults to certain grapevine varieties. Indian J Entomol 54(1):104

Reddy DS, Madhumathi C, Naveena H, Chowdary LR (2015) Field evaluation of Musa germplasm for resistance against banana stem weevil, *Odoiporus longicollis* (Oliver) (Curculionidae: Coleoptera) in Kadapa district of Andhra Pradesh. J Appl Nat Sci 7(1):1–4

Roy S, Mukhopadhyay A, Gurusubramanian G (2009) Varietal preference and feeding behavior of tea mosquito bug (*Helopeltis theivora* Waterhouse) on tea plants (*Camellia sinensis*). Acad J Entomol 2:01–09

Samuel SD, Norman TSJ, Kumar PKV, Irulandi S (2013) Field tolerance/resistance in selected coffee genotypes/selections to coffee berry borer, *Hypothenemus hampei* (Ferrari) in Pulney Hills, Tamil Nadu. J Coffee Res 41(1/2):87–91

Sasikumar B, Chempakam B, George JK, Remashree AB, Devasahayam S, Dhamayanthi KPM, Peter KV (1999) Characterization of two interspecific hybrids of Piper. J Hortic Sci Biotechnol 74(1):125–131

Selvanarayanan V (2000) Host plant resistance in tomato against fruit borer, *Helicoverpa armigera* (Huebner). Ph.D. dissertation, Annamalai University, India, p 251

Selvanarayanan V (2011) Research on insect resistance in tomato: present trends and future thrusts, pp: 365–371. In: Ambrose DP (ed) Insect pest management, a current scenario. Entomology Research Unit, St. Xavier's College, Palayamkottai, p 594

Selvanarayanan V (2015) Redesigning research on crop resistance to insects: experiences with tomato. In: Chakravarthy AK (ed) New horizons in insect science: towards sustainable pest management. Springer, India, pp 293–306

Selvanarayanan V, Narayanasamy P (2006) Factors of resistance in tomato accessions against the fruit worm, *Helicoverpa armigera* (Hubner). Crop Prot 25:1075–1079

Sharma R, Jat BL (2009) Screening of okra varieties for resistance against shoot and fruit borer, Earias spp. Indian J Plant Protect 37(1/2):178–180

Sharma DR, Batra RC, Gill HS, Arora PK (2004) Advances in fruit crop resistance against insect pests. In: Dhaliwal GS, Singh R (eds) Host plant resistance to insects: concepts and applications. Panima Publishing Corporation, New Delhi, pp 439–491

Singh D (1991) Pests of solanaceous vegetables, pp: SIV:1–25. In: Group discussion of entomologists working in coordinated project on horticultural crops, 28, 29 Jan 1991. Central Institute of Horticulture for Northern Plains, Lucknow

Singh D, Gill HS, Sharma BR (1990) Project directorate of vegetable research, review work on screening germplasm against insect pests resistance (1979–1989). In: XII vegetable workshop, Solan, 4–7 June 1990

Smith CM (2005) Plant resistance to arthropods: molecular and conventional approaches. Springer, The Netherlands, p 423

Soundararajan R, Baskaran P (2001) Mechanisms of resistance in brinjal (*Solanum melongena* L.) to whitefly (*Bemisia tabaci* gen.). Madras Agric J 88:657–659

Stoner KA (1990) Glossy leaf wax and plant resistance to insects in *Brassica oleracea* under natural infestation. Environ Entomol 19(3):730–739

Sundara Babu PC (1969) Studies on the varietal incidence of mango nut weevil, *Sternochetus mangiferae*. South Indian Hortic 17:34–40

Sundararaju D (1999) Screening of cashew accessions to tea mosquito bug, *Helopeltis antonii* sign. (Heteroptera: Miridae). Cashew 13(4):20–26

Sundararaju D (2010) Resistance in cashew germplasm to major insect pests. In: Abstracts of the national workshop on paradigm shifts in research on crop resistance to pests, 4–5 March 2010. Annamalai University, India, pp 17–21

Tabashnik EB, Carriere Y (2017) Surge in insect resistance to transgenic crops and prospects for sustainability. Nat Biotechnol 35:926–935

Tanton MT (1962) The effect of leaf "toughness" on the feeding of larvae of the mustard beetle *Phaedon cochleariae* fab. Entomol Exp Appl 5(1):74–78

Thippaiah M, Kumar CA, Shivaraju C, Chakravarthy AK (2013) Incidence of banana Pseudostem weevil, *Odoiporus longicollis* (Olivier) in South Karnataka. Pest Manage Hortic Ecosyst 16(1):50–53

Thirumurthi S, Ali KA, Subramanium (1972) A note on varietal resistance of grapevine to berry thrips, *Scirtothrips dorsalis* Hood. South Indian Hortic 20:92–93

Thompson KF (1963) Resistance to the cabbage aphid, (*Brevicoryne brassicae*) in Brassica plants. Nature 198(4876):209

Tingey WM, Laubengayer JE (1986) Glandular trichomes of a resistant hybrid potato alter feeding behavior of the potato leafhopper (Homoptera: Cicadellidae). J Econ Entomol 79(5):1230–1234

TNAU (2014) Varieties of vegetable crops. Tamil Nadu Agricultural University, Coimbatore, India. http://agritech.tnau.ac.in/horticulture/horti_TNAU_varieties_vegetablecrops.html. Accessed 5 Oct 2017

Verghese A, Soumya CB, Shivashankar S, Manivannan S, Krishnamurthy SV (2012) Phenolics as chemical barriers to female fruit fly, *Bactrocera dorsalis* (Hendel) in mango. Curr Sci 103:563–566

Walgama RS, Gunasekare MTK, Jayathilake MM, Kottawa Arachchi JD, Liyanage DD (2008) Evaluation of tea (*Camellia sinensis* L.) germplasm for host-plant resistance to shot-hole borer, *Xyleborus fornicatus* Eichh (Coleoptera: Scolytidae). Sri Lanka J Tea Sci 73:29–38